CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Saving Energy Through Use of Biofiltration for Advanced Primary Treatment of Wastewater

May 2023 | CEC-500-2023-019

PREPARED BY:

Primary Authors:
Onder Caliskaner, Ph.D., P.E.
Lilly Imani
Julia Lund, P.E.

Kennedy Jenks
10850 Gold Center Drive, Suite 350
Rancho Cordova, CA 95670
916-858-2700
http://www.kennedyjenks.com

Contract Number: EPC-15-088

PREPARED FOR:
California Energy Commission

Kevin Mori
Project Manager

Virginia Lew
Office Manager
ENERGY EFFICIENCY RESEARCH OFFICE

Jonah Steinbuck, Ph.D.
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

The authors thank the following agencies and persons for their participation and aid throughout this project:

- California Energy Commission
- Linda County Water District (Olivehurst, California)
- Prof. Emeritus George Tchobanoglous / University of California at Davis (Davis, California)
- WesTech Engineering, Inc. (Salt Lake City, Utah)
- BASE Energy, Inc. (San Francisco, California)
- Process Wastewater Technologies, LLC (Rosedale, Maryland)

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Saving Energy Through Use of Biofiltration for Advanced Primary Treatment of Wastewater is the final report for Contract EPC 15-088 conducted by Kennedy Jenks. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's research website (www.energy.ca.gov/research/).

ABSTRACT

Water and wastewater treatment account for substantial energy consumption, statewide and across the country. Conventional wastewater primary treatment uses clarification for solids removal and activated sludge treatment for secondary treatment to remove organics. Biofiltration is an emerging advanced primary-treatment technology that more efficiently and economically removes particulate and soluble material than the conventional primary method of clarification that removes only particulate material. In a biofiltration system, particulate material is removed mainly through filtering, and soluble organic material is removed by using microorganisms to capture and biologically degrade the pollutants. Biofiltration generates energy savings by removing more organic load (when compared with conventional primary treatment), which in turn reduces aeration electricity consumption in the downstream biological treatment and increases digester gas energy production from the diverted organic material. Additional benefits include reduced capital costs and a smaller physical footprint requirement for primary treatment.

Energy savings from biofiltration were demonstrated and quantified at a demonstration-scale biofiltration system at the Linda County Water District Wastewater Treatment Plant, north of Sacramento, California, from July 2018 through March 2020. Throughout the study, the biofilter performed at high levels of total suspended solids, biochemical oxygen demand, and chemical oxygen demand removal. Analysis of 40 sample sets showed total suspended solids, biochemical oxygen demand, and chemical oxygen demand removal rates of 70, 52, and 50 percent, respectively. Biological removal also increased with biofilm development on the filter media. Results showed soluble biochemical oxygen demand and soluble chemical oxygen demand removals of 22 and 25 percent, respectively. The biofilter's total suspended solids, biochemical oxygen demand, and chemical oxygen demand removal performance was approximately 30 to 50 percent higher than with primary clarification. This report evaluates the feasibility of biofiltration as an advanced primary treatment technology based on treatment performance, hydraulic performance, energy consumption, and performance simulation results.

Keywords: wastewater treatment, primary filtration, biofiltration, raw wastewater filtration, carbon diversion, advanced primary treatment, aeration energy decrease, digester gas production increase

Please use the following citation for this report:

Caliskaner, Onder, Lilly Imani, and Julia Lund (Kennedy Jenks). 2020. *Biofiltration as an Advanced Primary Treatment Method to Achieve Substantial Energy Savings*. California Energy Commission. Publication Number: CEC-500-2023-019.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

Wastewater treatment in the United States consumes a considerable amount of energy consuming between 3 to 4 percent of energy use in the country. According to the U. S. Environmental Protection Agency, typical energy use at wastewater treatment plants ranges between 1,600 to 3,300 kilowatt-hours per million gallons of flow treated. A wastewater treatment plant typically contains up to four treatment levels: preliminary, primary, secondary, and tertiary. The preliminary stage removes large debris and coarse particles with mechanical screens and/or grit-removal systems. Primary treatment (clarification) removes settleable solids and floating material. Secondary treatment removes organics using a biological process such as an activated-sludge process. The tertiary stage, or advanced treatment, provides additional treatment and disinfection that meets specific regulatory requirements or effluent (waste) standards. In addition to treating liquid streams, many wastewater treatment plants also produce biogas, a renewable energy source, from removed solids in a process known as anaerobic digestion.

Secondary treatment is typically the most energy-intensive portion of the treatment process, consuming between 30 to 60 percent of energy use at most plants. Aeration of the activated sludge process accounts for most of that energy use. This project explored primary biofiltration, in which particulate material is removed mainly through filtering and soluble organic material is removed by using microorganisms to capture and biologically disintegrate the organic pollutants. The biofiltration of raw wastewater after preliminary treatment, was evaluated as a replacement for conventional primary clarification treatment in assessing potential full-scale energy savings.

Filtration is commonly used at wastewater treatment plants for removing finer particles in tertiary treatment but has not yet been fully implemented for primary solids removal. There is growing interest in filtration as an emerging advanced primary-treatment technology.

Previous Work

In a 2012 project sponsored by the CEC (PIR 11-018), various filtration technologies were evaluated for primary effluent filtration where effluent leaving the primary clarifier was filtered to remove additional suspended solids before secondary treatment. Filtration in this step improved primary effluent quality and reduced aeration energy demand in the secondary activated-sludge process, creating energy and capital savings.

Motivated by the success of primary effluent filtration, the pile cloth disc filtration system used in project PIR 11-018 was modified for primary treatment application in a 2015 project sponsored by the CEC (EPC 14-076). Primary filtration, the filtration of raw wastewater after preliminary treatment, was evaluated as a viable replacement for conventional primary clarification treatment to assess potential energy savings. The project developed the first full-scale primary filtration system at a United States wastewater treatment plant in addition to two other demonstration-scale filtration systems. The primary filtration units used pile cloth disc filtration technology, where wastewater was filtered outside-in filter discs containing cloth media with a nominal pore size of 5 micrometers (μm). All three systems reported stable operation and performance of their primary filtration processes. Results from the project demonstrated that primary filtration is a technically viable and commercially attractive approach for replacing conventional primary treatment and achieving significant electrical energy savings.

Primary Biofiltration

In California, adopting primary biofiltration technology could potentially reap energy-saving benefits similar to those from previous primary effluent and primary filtration projects.

Biofiltration is an emerging technology for improving removal of particulate and soluble material from wastewater. Removing more organic material during primary treatment can increase the secondary biological treatment capacity and energy production from the biogas produced during anaerobic digestion of diverted organic material. This project's biofiltration unit was a compressible media filter. The treatment performance of the compressible media filter was similar to that of the pile cloth disc filtration, which had already been extensively tested for primary filtration. The key difference was the additional removal of soluble organic matter through biofiltration. In this project, the feasibility of primary biofiltration was evaluated for treatment and hydraulic performance, as well as for projected energy savings and the downstream secondary treatment benefits of a full-scale system.

Project Purpose

This project demonstrated that wastewater treatment plants can economically reduce their energy costs by adopting primary biofiltration systems. The research team accomplished this on several fronts.

- Installing and demonstrating a biofiltration system at an existing wastewater treatment plant.
- Quantifying energy saved from aeration in the activated-sludge process.
- Quantifying energy saved (from mixing) reduced activated-sludge volumes.
- Quantifying energy savings from increased digester-gas production.
- Calculating overall capital and energy savings from increased secondary-treatment capacity.
- Demonstrating biofiltration removal efficiencies for total suspended solids, volatile suspended solids, and total particulate and soluble biochemical oxygen demand.

- Developing operational, maintenance, and design criteria for full-scale installations (for example, biofiltration hydraulic, and solids loading rates).
- Establishing a third-party measurement and verification process.
- Implementing a targeted marketing and technology transfer plan to engage a wider audience in the wastewater treatment industry.

Research and development of biofiltration is also important for California's wastewater treatment facilities since its efficiencies could reduce customer wastewater fees. If adopted across California, wastewater energy savings, combined with increased renewable biogas production, could reduce electric utility costs associated with wastewater treatment plant operations.

Approach and Results

A demonstration-scale biofiltration system was installed at the Linda County Water District Wastewater Treatment Plant in Olivehurst, which is 38 miles north of Sacramento, California. The biofilter operated intermittently between July 2018 and April 2019 and has operated continuously since May 2019. The system uses a solids-handling system to thicken reject streams from the filter and direct concentrated solids to the plant's anaerobic digester for biogas production.

The biofiltration unit used in this project was a FlexFilter, supplied by WesTech Engineering, Inc. This unit was selected because of its performance in the California Energy Commission's 2012 primary effluent filtration project (PIR 11-018). Treatment performance of the biofiltration system at Linda County Water District Wastewater Treatment Plant further advanced this performance and demonstrated the technology's success in a primary filtration application. From May 2019 to March 2020, the biofilter performed at high levels for total suspended solids, biochemical oxygen demand, and chemical-oxygen demand removal, regardless of influent-loading-rate variations. Analyses of 40 sample sets showed total suspended solids, biochemical oxygen demand, and chemical oxygen demand removal rates of 70 percent, 52 percent, and 50 percent, respectively. During operational periods, biofiltration also consistently removed soluble material from biofilm development on the filter media. Results showed soluble biochemical oxygen demand and soluble chemical oxygen demand removal rates of 22 percent and 25 percent, respectively. The observed removal efficiencies are notably higher compared to conventional primary treatment especially for biochemical-oxygen demand, chemical oxygen demand, soluble biochemical oxygen demand, and soluble chemical oxygen demand. Both removal and hydraulic performances were, however, negatively affected by operational problems specific to the demonstration-scale system. A key operational challenge was that the demonstration system's operational headloss development ranged between 3 and 3.5 ft, which resulted in short filter run times (e.g., as short as 20-30 minutes depending on the influent loadings).

The negative impacts are summarized below.

- Short filter run times typically result in reduced average removal efficiencies (especially for depth filters), low hydraulic loading rates, high backwash reject water ratios, and low solids concentration in backwash reject water.
- Reduced total suspended solids and volatile suspended solids removal efficiencies due to short run times result in lower gas production in the anaerobic digester (i.e., compared to biofiltration technology's potential). Gas production is more impacted by the volatile suspended solids removal efficiency than soluble biochemical oxygen demand removal efficiency (e.g., primary sludge has higher unit methane production potential compared to the biofilm sludge). Higher particulate (i.e., total suspended solids and volatile suspended solids) removal efficiencies are expected as ripening and auto-filtration mechanisms would become more effective with longer filter run times. It is possible to increase the average total suspended solids and volatile suspended solids removal efficiencies to 80-85 percent from the observed removal efficiency of 70 percent. Longer filter run times would also promote more stable biofilm growth which can potentially increase the soluble biochemical oxygen demand and soluble chemical oxygen demand removal efficiencies. Potential increase in removal efficiencies (especially for soluble biochemical oxygen demand and soluble chemical oxygen demand) would need to be further evaluated with a modified or upgraded demonstration unit.
- Reduced biochemical oxygen demand and soluble biochemical oxygen demand removal efficiencies also result in less aeration power savings in downstream secondary treatment (i.e., compared to biofiltration technology's potential).
- Low hydraulic loading rates decrease the hydraulic capacity of the biofiltration system which increases its footprint requirement.
- High backwash reject water ratios and low backwash reject water solids concentrations increase the size/capacity of the thickening system (required upstream of anaerobic digesters).

Field testing of operational parameters focused primarily on meeting target removal rates while reducing the biofilter's backwash reject water ratio (the ratio of daily volume used for backwash to daily filtered volume produced), which is used to evaluate the efficiency and feasibility of emerging advanced primary-treatment technologies. For an advanced primary-treatment technology to be feasible, a backwash reject ratio of less than 15 to 20 percent is optimal. For the biofilter, key drivers of the backwash reject ratio included the influent hydraulic loading rate, the backwash hydraulic loading rate, filtration run time, the backwash run time, and the headloss development rate. A primary focus of the study was the impact of hydraulic loading rate on reject ratios. In previous CEC demonstrations, the biofilter's performance for primary effluent filtration contributed to the initial target hydraulic loading rate of 5 gallons per minute per square foot (gpm/ft^2) and the average daily flow of 0.14 million gallons per day. Various influent hydraulic loading rates and backwash hydraulic loading rates were evaluated to determine their impact on the system's hydraulic efficiency. It appears that feasible influent hydraulic loading rate and backwash hydraulic loading rate are 2.8–3.3 gpm/ft^2 and 3.5–4.1 gpm/ft^2, respectively, to maintain the hydraulic efficiency of the biofiltration system. Further research is needed to determine the optimum hydraulic loading rate and backwash hydraulic loading rate required to maintain stable biological removal, or biofilm stability.

The following design and operational changes are deemed necessary to ensure biofiltration technology is a commercially attractive advanced primary treatment alternative. Biofiltration system design should be modified to allow 7 to 8 ft of operational headloss development (i.e., as opposed to 3 to 3.5 ft). This operational head increase by approximately 2.5 times is expected to double the average hydraulic loading rate, resulting in a significant reduction in backwash reject water ratio, increase in backwash reject water solids concentration, and reduction in footprint of both the biofiltration and the thickening systems. Both capital and operational costs of the biofiltration system would be lowered with this design change making the biofiltration technology more commercially attractive.

Biofiltration provided substantial energy savings for the secondary activated-sludge process, as quantified by computer process simulations and a third-party measurement and verification (measurement & verification) study. Wastewater process simulations estimated various downstream impacts of demonstration-scale primary biofiltration. The simulations evaluated potential reductions in secondary treatment aeration, mixing-energy requirements, and increases in digester biogas production, a renewable resource. Influent wastewater characteristics and type of secondary treatment process together played important roles in assessing specific benefits from the biofiltration technology. Results from treatment-process simulations of three different waste water treatment plants (including Linda County Water District Wastewater Treatment Plant) showed that primary biofiltration reduced secondary treatment aeration energy by 15 to 20 percent (by diverting biochemical oxygen demand from the secondary process to the digester), increased digester gas production by 10 to 30 percent (by diverting additional amounts of volatile suspended solids and chemical oxygen demand to anaerobic digestion), and increased secondary-process treatment capacity by 5 to 30 percent (by decreasing total suspended solids upstream of the secondary treatment process).

A third-party study determined potential energy savings from a full-scale primary biofiltration system when compared with conventional primary clarification. Energy savings from the biofiltration system accrued primarily from reducing wastewater biochemical oxygen demand loading before entering the aeration basins, lowering aeration requirements, and reducing blower air flow and its energy consumption. The measurement and verification study showed average blower energy reductions of 20 to 30 percent for secondary treatment. Results from the two studies differ since the

BioWin simulations used more conservative assumptions and normal operational conditions while the measurement and verification study used actual field data that included operational start-up problems.

This project accomplished the overall objective of installing and operating the first biofiltration system in a primary filtration setting. Biofiltration shows great promise as an alternative to conventional primary treatments. Additional testing is required, however, before establishing complete design criteria for full-scale biofiltration installations.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

The advanced primary-treatment concept, including biofiltration, received early support from its potential users—from the manufacturers, engineers, academia, and utilities that recognized its notable benefits. In California alone, biofiltration could be installed at some 300 municipal wastewater treatment plants, with a total statewide capacity of more than 4,000 million gallons per day. The biofiltration technology could similarly benefit industrial wastewater treatment operations.

Biofiltration's operational and treatment results from this demonstration project will enable municipalities to accurately evaluate the suitability of the technology for their own facilities. Quantification of energy savings at the demonstration sites will provide additional incentives for wastewater treatment plants to choose biofiltration for advanced primary treatments.

In addition to its future implementation at wastewater treatment plants, this project contributes substantial research value to governmental agencies, academia, and industry manufacturers. The research results, technical reports, operational and design criteria, and modeling studies generated by this project will also augment the overall body of knowledge about biofiltration technology.

To promote project research to the industry and the public, from 2018 through early 2020, the project team delivered presentations at regional and national conferences, and at meetings with wastewater agencies. Continued conference presentations are planned through 2021.

The biofiltration system demonstrated in this project was concluded to be promising for the wastewater treatment industry because of the high primary treatment performance levels observed during the project. Project's PI, Dr. Caliskaner, and the system manufacturer, WesTech Inc., are currently pursuing opportunities to advance this technology to make it more commercially attractive and technically feasible as an advanced primary treatment system. The biofiltration system, without modifications, is a cost-effective primary treatment system (compared to standard primary treatment) for new wastewater treatment plants or wastewater treatment plant expansion projects; notably, for wastewater treatment plants with space limitations and higher unit electricity costs. However, the biofiltration system design should be modified to make it more commercially attractive compared to other advanced primary treatment systems and for replacing or augmenting existing conventional primary treatment systems. Based on the project results, the following major modifications and upgrades are proposed for the biofiltration system to achieve longer filter run times and to increase hydraulic filtration rates. The biofiltration system design would be changed to allow 7 to 8 feet of operational headloss (i.e., as opposed to 3-3.5 ft of operational headloss observed during this demonstration project). This operational head increase by approximately 2.5 times is expected to double the average hydraulic load rate, resulting in significant reduction in the backwash reject water ratio, increase in backwash reject water solids concentration, reduction in footprint, and increase in treatment performance and capacity. Both capital and operational costs of biofiltration system would be lowered with this design change making the biofiltration technology more commercially attractive. The added costs for the recommended design changes are anticipated to be small compared to the capital, energy, and operational cost benefits they will provide from smaller systems, increased removal efficiencies, increased run times, decreased backwash reject water ratios, and reduced thickener operations.

Benefits to California

Energy savings from this project directly support California's ambitious mandated goals to reduce the fossil-fuel emissions that contribute to greenhouse gas air pollution. Municipal wastewater treatment plants statewide are, therefore, increasingly motivated to reduce their energy consumption and ultimately achieve net-zero energy use. As briefly described here, biofiltration offers a viable alternative that decreases energy consumption for wastewater treatment and increases energy recovery from greater biogas production.

Californians would benefit from broad implementation of biofiltration systems at wastewater treatment plants in several ways.

- Reduced Wastewater Utility Fees: Lower capital and operational costs for wastewater treatment plants could be passed along to utility customers through reduced wastewater fees.
- Reduced Electric Utility Fees: Reduced wastewater energy use coupled with increased biogas production and use could decrease electric utility costs for wastewater treatment plants.
- Reduced greenhouse gas emissions: Increased diversion of organics to the anaerobic digester for biogas production and electricity generation would reduce emissions of greenhouse gases generated from wastewater treatment.

CHAPTER 1: Introduction

Background

Secondary biological wastewater treatment processes aerate wastewater and are energy intensive, typically accounting for 40 to 60 percent of total electricity consumption at a wastewater treatment plant (WWTP). Removing greater amounts of organic material before this aerated activated sludge process provides the breakthrough opportunity to reduce electric energy use, though as yet this biofiltration technology has not been implemented full-scale at WWTPs. Biofiltration remains an emerging technology for removing total organic load of soluble and particulate material.

Biofiltration is an advanced primary treatment that would reduce the energy required for secondary treatment, increase energy production in the anaerobic digester from the diverted organic material, increase existing secondary biological treatment capacity, and delay the need to expand secondary biological treatment basins. Compared with conventional primary treatment, biofiltration could potentially decrease electricity consumption for aeration by 15 to 20 percent, increase gas production (biogas) by 10 to 30 percent, and increase secondary biological treatment capacity by 5 to 30 percent.

Overall Project Objectives

This demonstration project had several overall objectives, including to:

- Install and demonstrate a biofiltration system at an existing WWTP.
- Quantify the reduction in electrical energy required for aeration in the activated sludge process.
- Quantify the reduction in electrical energy required for mixing due to the reduced activated sludge volume.
- Quantify the electrical savings from increased digester gas production.
- Determine overall capital and electrical energy savings from increased secondary treatment capacity.
- Demonstrate biofiltration removal efficiencies for total suspended solids (TSS), volatile suspended solids (VSS), and total, particulate, and soluble biochemical oxygen demand (BOD).
- Develop operational, maintenance, and design criteria for full-scale installations (for example, biofiltration hydraulic and solids loading rates).
- Conduct a third-party measurement and verification (M&V) process.
- Develop and implement a structured marketing and technology transfer plan to reach a wider audience in the wastewater-treatment industry.

Project Overview

This project demonstrated that biofiltration is a technically viable and commercially attractive technology to substantially reduce WWTP energy consumption (and its cost). Compressible media filtration technology used in this project to achieve biofiltration has to date been applied only to wastewater tertiary treatment and the use of biofiltration in primary treatment is only emerging; for this project biofiltration was more broadly implemented for primary treatment. This project quantified energy-use reductions in a biofiltration demonstration system developed and operated at the Linda County Water District WWTP north of Sacramento, California. This project provides the performance data required to accurately evaluate potential benefits from sustained, full-scale validation testing, encompassing the quantification of energy savings, organic solids removal efficiencies, operation and maintenance, design criteria, independent monitoring and verification, and technology transfer.

CHAPTER 2: Project Approach

System Description

A demonstration-scale biofiltration unit was installed at Linda County Water District Wastewater Treatment Plant (LCWD WWTP) from January to May 2018. The system operated intermittently between July 2018 and April 2019 and has operated continuously since May 2019.

Overview of Linda County Water District Wastewater Treatment Plant

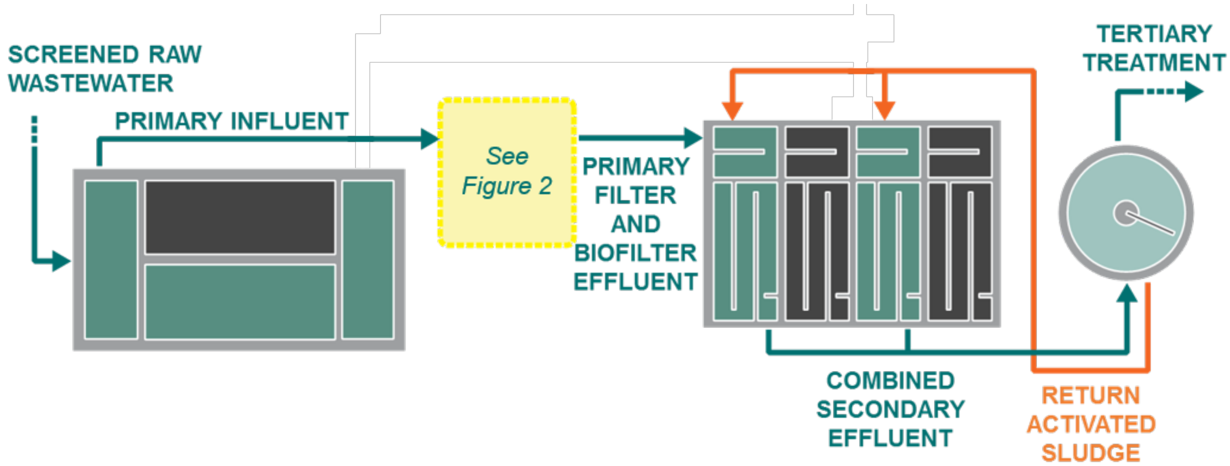
The LCWD WWTP is located near Marysville in Yuba County, which is north of Sacramento, California. It is a tertiary treatment facility consisting of two rectangular primary clarifiers, four activated-sludge basins (ASBs), two circular secondary clarifiers, six compressible-media tertiary filters, two chlorine-contact basins, and two digesters. The liquid process was upgraded in 2011, and the solids-handling process was upgraded in 2016. The WWTP has a capacity of 5-million gallons per day (MGD) and operates at an average daily flow (ADF) of between 2.5 and 2.8 MGD.

Process Flow

Raw wastewater to the LCWD WWTP is collected in the headworks and screened before primary treatment. Under ADF conditions, the plant typically operates one of the two primary clarifiers. Primary effluent is collected in the primary clarifier effluent channel and discharged to two operational activated-sludge basins.

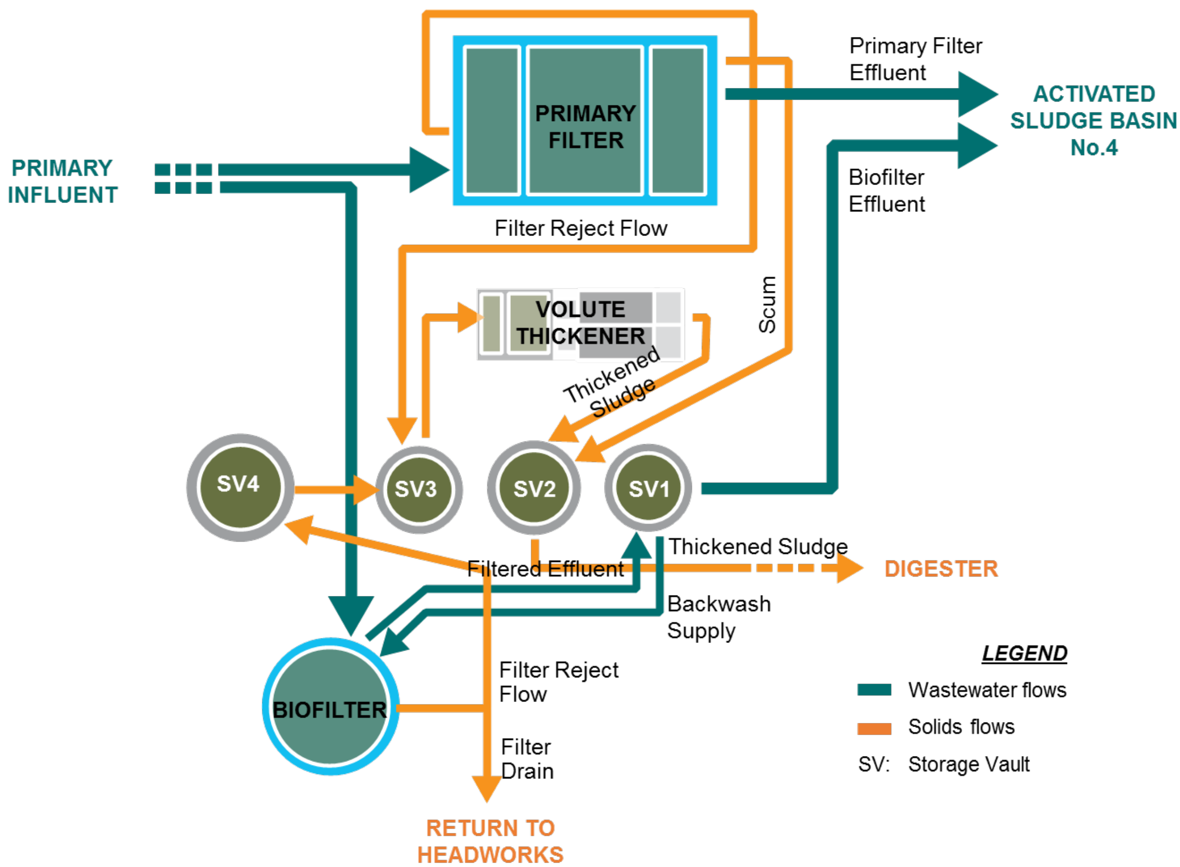
The biofiltration demonstration system at the LCWD WWTP is tied into another primary filtration demonstration that uses a pile cloth depth filter (PCDF). In 2017, the PCDF system was rated for an average design capacity of 1.5 MGD and installed at the LCWD WWTP as part of the Raw Wastewater Filtration Project funded by the California Energy Commission (EPC-14-076). The overall flow diagram and the specific process flow of the two demonstration systems are shown in Figure 1 and Figure 2, respectively.

Figure 1: Process Flow Diagram for Biofiltration and Primary Filtration Demonstrations at Linda County Water District Wastewater Treatment Plant



Process Flow Diagram for Biofiltration and Primary Filtration Demonstrations at LCWD WWTP.
Source: Kennedy Jenks

Figure 2: Process Flow Diagram for the Demonstration System's Liquids and Solids Streams



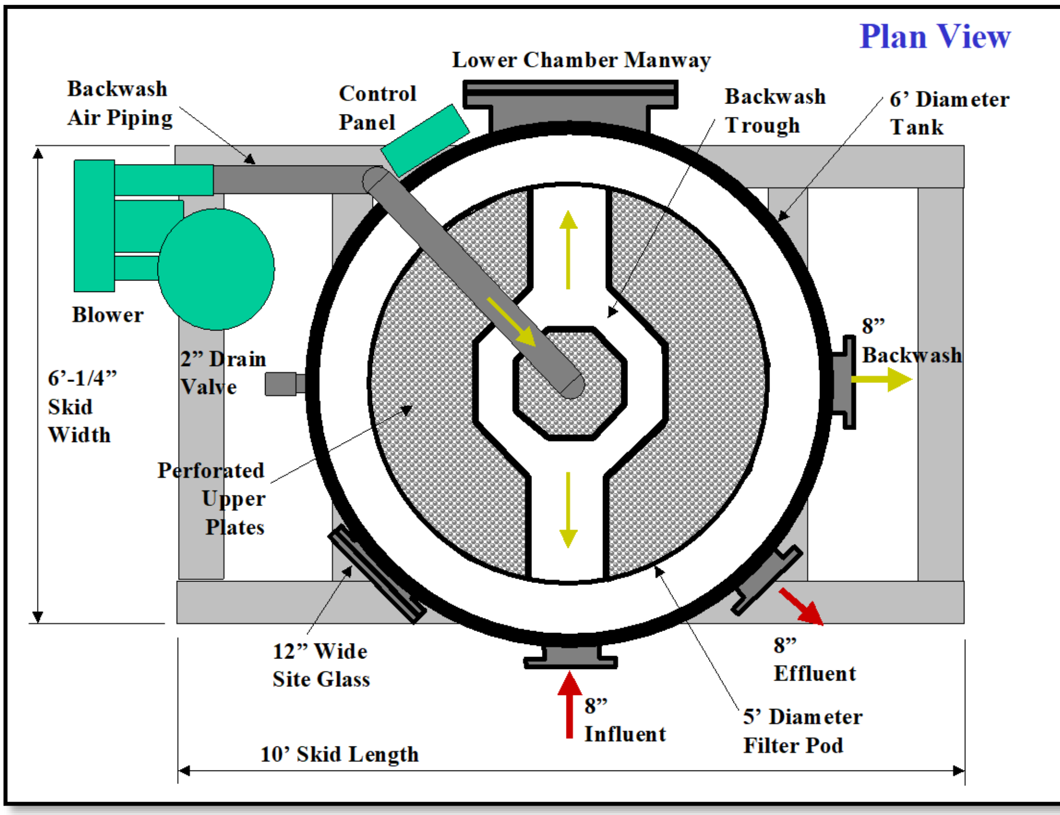
Process Flow Diagram for the Demonstration System's Liquids and Solids Streams.
Source: Kennedy Jenks

Biofiltration System Components

FlexFilter

The biofiltration unit used in this project was a compressible media filter (CMF), also known as FlexFilter, supplied by WesTech Engineering, Inc. The installation at the LCWD WWTP featured a cylindrical tank with an air blower, a control panel, and a power panel, with overall skid dimensions of 150 in.(L) x 92 in.(W) x 142 in.(H). Plan and section views of the skid are shown in Figure 3 and Figure 4, respectively. The 5-foot-diameter filtration had a total filtration area of 19.6 ft^2. The chamber was filled with compressible fiber balls, shown in Figure 5.

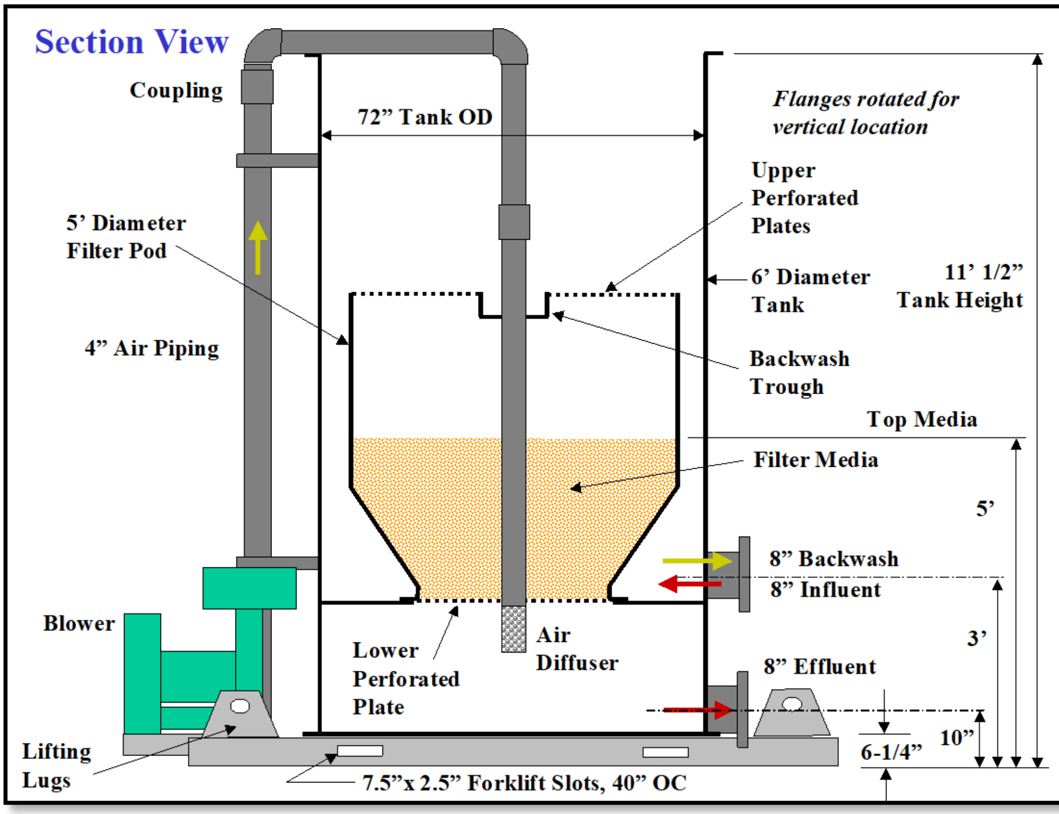
Figure 3: Plan View of Biofiltration Demonstration Skid



Plan View of Biofiltration Demonstration Skid.

Source: WesTech Engineering, Inc.

Figure 4: Section View of Biofiltration Demonstration Skid



Section View of Biofiltration Demonstration Skid.

Source: WesTech Engineering, Inc.

Figure 5: Compressible Media Filter Balls in FlexFilter

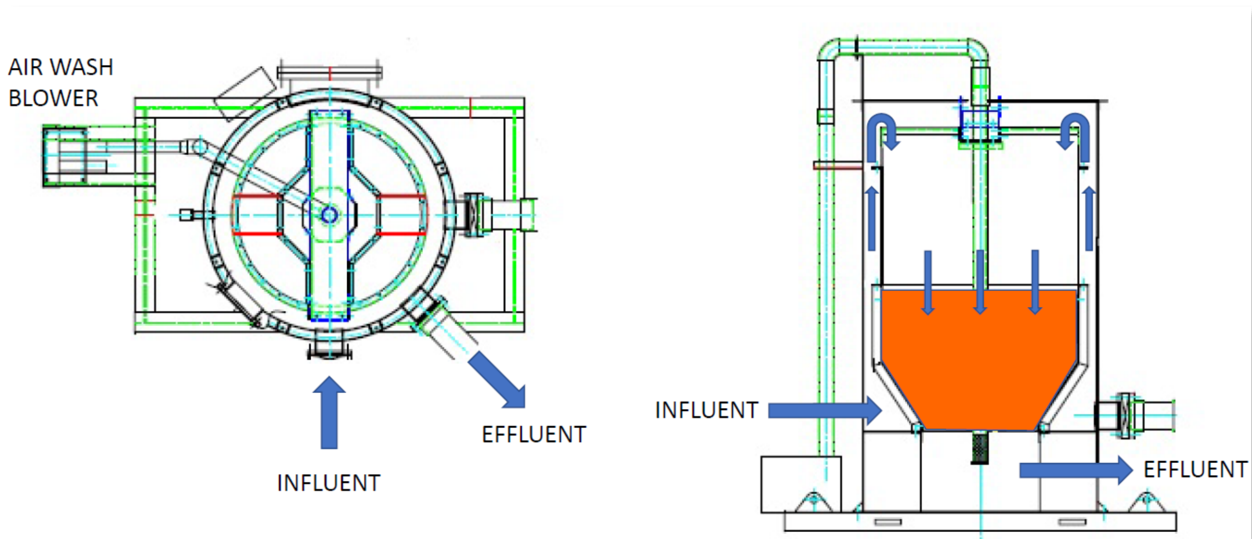
Compressible Media Filter Balls in FlexFilter.

Source: WesTech Engineering, Inc.

The FlexFilter filter cycle consists of two operational modes: filtration and backwash. The FlexFilter system is a gravity system that requires no moving parts in the flow stream aside from open/close valves and a low-head blower for cleaning during backwash cycles. The biofilter system's operational cycles appear in Figure 6 and Figure 7.

During filtration, the influent liquid applies a hydrostatic force to an engineered bladder, causing a bed of individual balls of fiber media to compress before the flow enters the bed from the top. This tapered compression creates densely compressed media at the bottom that graduates to an expanded bed with loose media in the upper zone. As the liquid flows down through the media, larger particles become trapped in the upper portions of the filter. As the liquid works its way down through the media, smaller pores near the bottom of the filter capture the smaller particles. This high-porosity gradient allows more effective use of the entire media bed, resulting in higher filtration performance.

Figure 6: FlexFilter Filtration Cycle Diagram

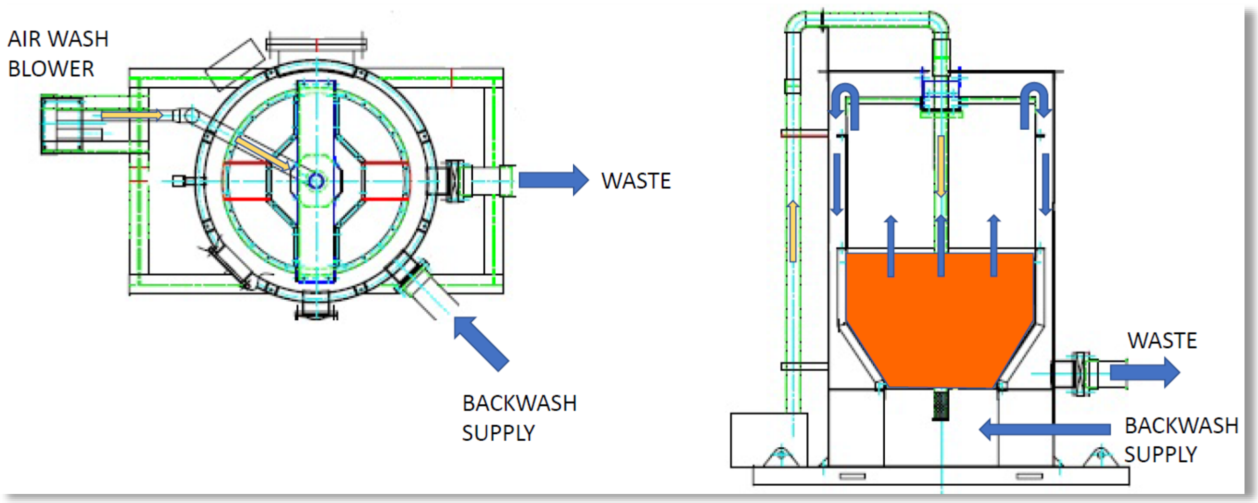


FlexFilter Filtration Cycle Diagram.

Source: WesTech Engineering, Inc.

As the filter bed becomes plugged up, the water level increases and signals the need for a backwash. For the backwash, the feed to the filter cell is stopped, allowing the media to decompress. The air scour is then initiated along with a small amount of backwash water. The cleaning process uses low-head air (4 to 6 psi) to circulate and agitate the media during cleaning, and simultaneously lifts the spent backwash to waste. Filtered effluent is pumped back into the filter from Storage Vault No. 1 as backwash supply water. Due to the volume limitation of the storage vault, filtered effluent from the PCDF demonstration supplements the backwash water supply during a backwash cycle. The chlorine addition system pumps chlorine from a bucket into the backwash supply pipe to control microbial growth; it is set to operate during the last 10 to 15 minutes of the backwash. Backwash reject water (BRW) from the filter is discharged to Storage Vault No. 4. Automated logic controls provide automatic backwashing based on either head or time. Once the backwash is complete, the filter cell returns to service.

Figure 7: FlexFilter Backwash Cycle Diagram



FlexFilter Backwash Cycle Diagram.

Source: WesTech Engineering, Inc.

Influent Source to the Biofilter

Influent to the biofilter is drawn from the primary clarifier influent channel. At start-up, the submersible influent pump was installed in the primary clarifier-influent channel. The pump was set to operate at a constant pump-speed set point. Flow rate to the filter was adjusted according to the test protocol and monitored by an influent flow meter.

Discharges from the Biofilter

The types of discharge from the FlexFilter and their respective discharge locations are summarized in Table 1.

Table 1: Biofilter Discharge Locations

Type of Filter Discharge	Discharge Location
Filtered effluent	Storage Vault No. 1 (to ASB No. 4 for secondary treatment or returned to FlexFilter as backwash supply water)
Filter drain (at initiation of backwash)	Return to headworks
Backwash reject water	Storage Vault No. 4 (to solids thickener)
Filter drain (at conclusion of backwash)	Return to headworks

Biofilter Discharge Locations.

Source: Kennedy Jenks

Storage Vault No. 1

Storage Vault No. 1 at the LCWD WWTP was used as a filter-effluent holding tank for this biofiltration demonstration project. An automated 3-way valve directed flows between the FlexFilter, Storage Vault No. 1, and the ASB splitter box. Two submersible pumps were installed in this manhole and programmed based on both filter operation mode and float switches.

During filtration, biofilter effluent was discharged to Storage Vault No. 1 then pumped by Pump No. 2 to the ASB splitter box, based on float level. If the level reached the top float switch, Pump No. 1 also cycled on to additionally pump from Storage Vault No. 1 to the ASB.

During backwash, filtered effluent in the storage vault was pumped by Pump No. 1 back into the FlexFilter tank as backwash supply water (provided that the storage vault level did not drop below a certain float switch). A portion of the PCDF filter effluent was also diverted by a manually operated valve to Storage Vault No. 1 to supplement the quantity of backwash supply water required by the FlexFilter during a single backwash cycle.

Storage Vault No. 1 overflowed to the plant headworks; there was no valve on that pipeline.

Storage Vault No. 4

Storage Vault No. 4 was constructed for this project to collect filter BRW discharged by the filter during the backwash cycle at the end of air-scour cleaning. Storage Vault No. 4 was equipped with a submersible pump that operated on float switches.

The biofiltration demonstration project used parts of the existing solids handling system installed earlier for the PCDF demonstration. FlexFilter BRW was pumped from Storage Vault No. 4 to Storage Vault No. 3, which was used to hold BRW and filter sludge from the primary filter. The blended filter reject flow from the two demonstration filters was thickened by the Volute Thickener (Process Wastewater Technologies LLC), a dewatering press thickener. The thickener included a flash mixing tank, a flocculation tank, and two dewatering drums. Filter reject flow was pumped from Storage Vault No. 3 to the flash mixing tank and dosed with an acrylamide-based polymer. The mixture was then gently mixed in the flocculation tank to facilitate floc formation. The flocculated mixture was processed by the dewatering drums, each with a design capacity of 150 gallons per minute (gpm). Each drum was composed of a screw encased by a series of alternating moving and fixed rings. The automated thickener can produce a wide range of adjustable solids output; for this project the thickener was operated to achieve the target output of 2 to 12 percent solids.

Sampling and Monitoring Equipment

Project operations included equipment for continuous monitoring as well as for both grab and composite samples analyzed by a third-party laboratory. In addition to constituent monitoring, third-party energy verification was conducted to evaluate energy savings for this emerging technology.

The biofiltration demonstration system was equipped with inline turbidimeters (Solitax sc, HACH) in the FlexFilter influent chamber and effluent pipe, as well as in the primary clarifier influent channel, from which the source water for primary filtration testing was drawn. Sampling taps were installed on the filter influent and effluent pipes to simplify sample collection. Automated samplers were set up to collect composite samples of filter influent and effluent.

A diagram of all sampler and sensor locations is shown in Figure 8.

Figure 8: Diagram of the Biofiltration System Sampler and Sensor Locations

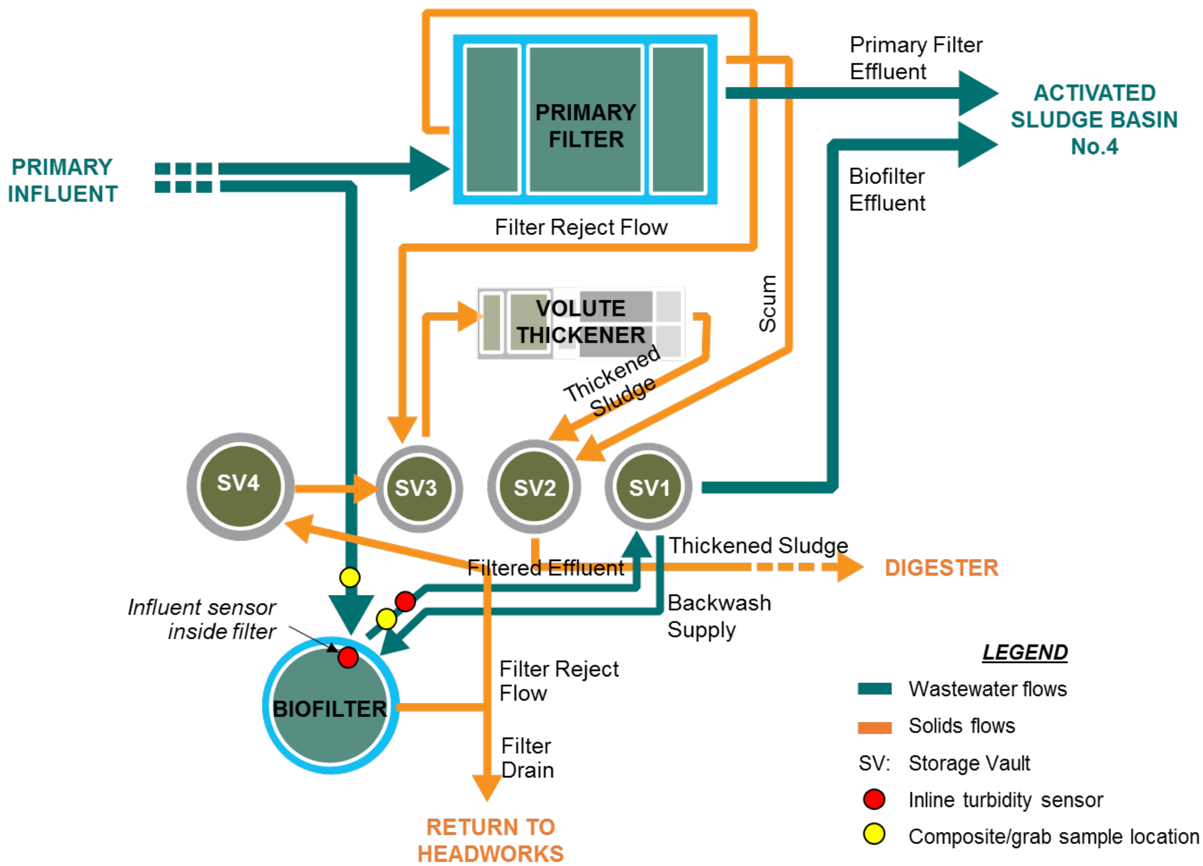


Diagram of the biofiltration system sampler and sensor locations.

Source: Kennedy Jenks

Field Analysis Equipment

Field performance monitoring equipment for the biofiltration system included HACH Solitax sensors for real-time turbidity readings of both biofilter influent and biofilter effluent.

Lab Analysis Equipment

Lab analysis was essential for performance evaluation and to verify and calibrate continuous monitoring equipment. Most of the lab analysis was conducted through a third-party lab for composite and grab samples. On-site lab analysis was also conducted for expedited performance evaluation and verification of continuous monitoring equipment.

LCWD operators also assisted with the lab analysis of TSS for grab samples taken during operation of the biofiltration system. The on-site lab analysis enabled quick reactions and adjustments of the demonstration system through spot checks for specific constituents.

The project used one ISCO Avalanche portable composite sampler for the biofilter influent and one HACH Sigma SD900 composite sampler for the biofilter effluent. Composite samples were taken weekly over 24 hours and shipped to a third-party lab. The samples were tested for TSS, turbidity, particulate and soluble BOD, and other constituents in the sampling protocol.

Installation of Demonstration-Scale System

Installation of the demonstration system was between January and May 2018. Start-up was carried out during June 2018, with a few additional programming changes in July 2018. A timeline of completed activities appears in Table 2.

Table 2: Installation and Start-up Timeline

Date	Activity
1/26/18	Pouring of concrete pad for demonstration skid
1/29/18	Pre-construction meeting at the LCWD WWTP
1/31/18 – 3/27/18	Revision of demonstration system design
2/13/18	Delivery of the biofilter skid to site
3/29/18 – 5/10/18	Installation of piping, Storage Vault No. 4, and electrical connections
5/29/18 – 6/1/18	Set up and testing of instruments and controls
6/11/18 – 6/15/18	Loading of biofilter media and additional testing
6/25/18 – 6/27/18	Wet testing
716/18 – 7/20/18	Completion of programming and alarm set-up

Installation and Start-up Timeline.

Source: Kennedy Jenks

A photograph of the trenching and laying of influent pipe during the construction period is shown in Figure 9. Photographs of the completed biofilter skid with connections and Storage Vault No. 4 are shown in Figure 10 and Figure 11, respectively.

Figure 9: Construction of Biofiltration Demonstration System

Construction of Biofiltration Demonstration System.

Source: Kennedy Jenks

Figure 10: Biofiltration Skid with Completed Piping Connections

Biofiltration Skid with Completed Piping Connections.

Source: Kennedy Jenks

Figure 11: Newly Constructed Storage Vault No. 4

Newly Constructed Storage Vault No. 4.

Source: Kennedy Jenks

Operation and Maintenance

Standard Operating Procedures

The target-peak test flow rate for the primary filtration demonstration system is 100 gpm, as determined by biofilter performance results in a previous study of primary effluent filtration (Caliskaner et al. 2015). The start of filter operation requires manual adjustment of filter influent valve and pump output to stabilize flow at the target flow rate.

Standard operation of the biofilter includes:

- Filtration of up to 100 gpm.
- Thickening of up to 25 gpm of BRW.
- Pumping of up to 5 gpm of thickened, blended backwash to the digester.

Equipment

The biofilter is operated by a human-machine interface (HMI) panel, as shown in Figure 12. This panel has dials to manually open and close valves, although the biofilter is not operated manually under normal operating conditions.

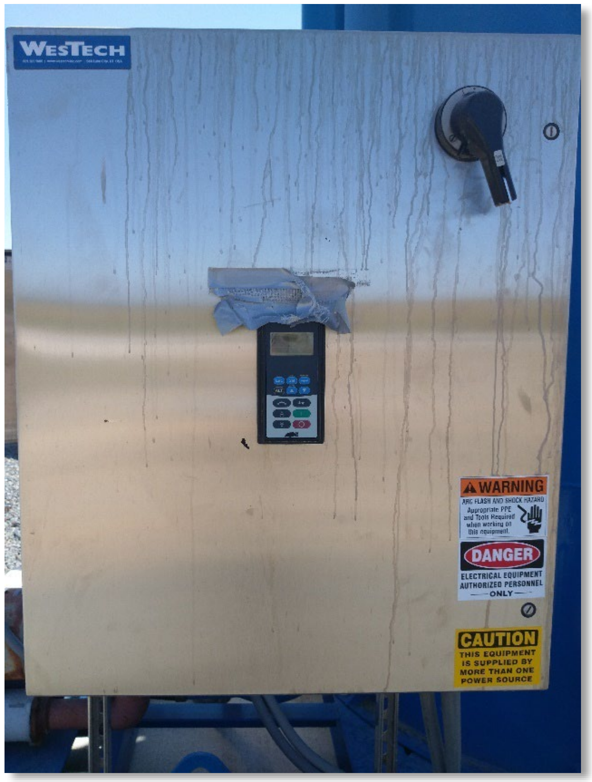
igure 12: Biofilter Human-Machine Interface

Biofilter Human-Machine Interface.

Source: Kennedy Jenks

The biofilter influent pump variable frequency drive (VFD) and all pump circuit breakers and fuses are located inside another panel, shown in Figure 13.

Figure 13: Variable Frequency Drive Panel



VFD Panel.

Source: Kennedy Jenks

Other equipment includes a(n):

- Influent pinch valve.
- Influent flowmeter (downstream of pinch valve; reads to the HMI).
- Backwash supply flow meter (online from Storage Vault 1)

Daily Operational/Testing Checklist

Field staff used the following daily checklist for operating the biofiltration system when the filter was online:

- HMI is checked to confirm that the filter is still online, and for any alarms.
- Flow rate on HMI is checked to make sure it does not deviate too much from the target set point.
- Influent pump variable frequency drive (VFD) is checked for faults.
- Turbidimeters are checked to confirm that filter influent and effluent are in the “normal range” on SC200. Typically, influent turbidity is between 50 and 300

nephelometric turbidity units (NTU) and effluent turbidity is between 20 and 100 NTU. Turbidity sensors are cleaned if necessary by wiping the sensor window with Windex and a paper towel.

- Pump in Storage Vault No.4 is checked to confirm it is operating when float switch is tripped.
- Chlorine dosing pump is checked to confirm it is working during backwash.

Starting the Biofilter

- The manual valve on the line discharging primary filtration effluent to Storage Vault No. 1 was opened. The valve can be opened to about halfway (45°). This valve must be opened to supplement backwash supply water used by the biofilter.
- If HMI screen is off, power was turned on at the main disconnect switch located in the top right-hand corner of the panel.
- On HMI, the "Enable" button was clicked on both the "Filter Control" and "System Control" tabs. (Note: The tabs on the biofilter HMI have a circular flow, where there is more than one way to access a tab. Both "Filter Control" and "System Control" can be accessed from "System Overview," as well as from other locations.)
- Flow reading was checked to confirm it had reached the targeted flow rate.

Setting the Influent Flow

Influent flow to the biofilter was controlled via a constant pump speed on VFD and a pinch valve. Target flow rate for the primary filtration demonstration with biofilter was 100 gpm during the first phase of continuous operation and reduced in subsequent phases. Flow should be ideally maintained close to the target flow rate to achieve optimal hydraulic performance.

The following steps (either one or both) were taken to make flow adjustments:

- The wheel on the pinch valve on the filter influent line was turned to either decrease or increase the valve opening.
- The influent pump speed was adjusted by pressing the up-and-down arrow on the VFD display outside the panel.

Troubleshooting Influent Pump

If the influent flow gets too low, the pump VFD will fault. The following steps were taken to troubleshoot the influent pump using the pump VFD, which is located on the biofilter panel facing west.

1. On the PowerFlex inside the panel, either the green or the red button was pressed to clear the fault.

2. On the pump VFD, the pump reference speed was reset using the up-and-down arrows.
3. On the filter HMI, one of the following steps was taken:
    - If filter showed a low-flow alarm in "Overview," the large text box that reads "Low flow" was clicked to reset the alarm.
    - If the filter was not in alarm condition, it could have been drawing sufficient flow through siphoning. The influent pump could be reset by taking the filter offline, waiting 1-2 minutes, then putting it back on line.

Troubleshooting Storage Vault 4 Pump

1. The circular dial next to the VFD should point to 12 o'clock.
2. The fuses at the top left were checked for red lights, which indicate that the fuses are out. The biofilter manufacturer WesTech was then contacted for fuse replacement. There are two spare 15A fuses in the panel; other fuses have to be purchased.

Regular Maintenance Activities

Regular maintenance activities included manually adjusting flow rates, cleaning in-line turbidimeters, and refilling the bucket of chlorine used during backwash.

Field Log

The field log is shown in Table 3. Regular field activities included sampling and maintenance on the system.

Table 3: Field Log

Date	Tasks Completed
7/24/18	Biofilter was operated.
8/8/18	Biofilter was operated.
8/8/18-8/10/18	Wet testing.
8/15/18	Biofilter was operated.
8/22/18	Biofilter was operated.
9/3/18-9/7/18	WesTech engineer was on-site for operations and system improvements.
9/19/18	Biofilter was operated.
9/28/18	Biofilter was operated.
10/2/18-10/6/18	WesTech engineer was on-site for operations and system improvements.
10/17/18	Biofilter was operated.
10/30/18	Biofilter emergency shutdown alarms were tested.
11/12/18	Biofilter was operated.

Date	Tasks Completed
11/19/18	Biofilter was operated.
11/21/18	Biofilter was operated.
12/5/18	Biofilter was operated.
12/9/18-12/11/18	WesTech engineer was on-site for operations and system improvements.
12/19/18	Biofilter was operated.
1/10/19	Biofilter was operated.
1/17/19	Biofilter was operated.
1/30/19	Biofilter was operated.
2/20/19	Biofilter was operated.
2/27/19	Biofilter was operated.
3/6/18	Biofilter was operated.
3/13/19	Biofilter was operated.
3/19/19	Power to biofilter VFD panel cut off. Panel had to be restarted. Biofilter effluent turbidimeter was installed.
3/20/19	Biofilter influent turbidimeter was replaced. Biofilter was operated.
4/10/19	Biofilter was turned on at 8:30 and left to run overnight.
4/11/19	Storage Vault No. 4 pump stopped running. Biofilter was shut off.
4/24/19	WesTech technician was on-site. Fuses were replaced for Storage Vault No. 4 pump. Biofilter was operated.
4/27/19	Installed new SIM card in turbidimeter.
4/29/19	Biofilter was started at 8:30 am.
5/1/19	Storage Vault No. 4 pump tripped out and surge protection breaker had to be reset. Biofilter influent sampler was installed.
5/3/19	Biofilter influent turbidimeter was fixed. Influent pump VFD faulted and had to be reset. Storage Vault No. 4 pump tripped out again. Biofilter was shut off.
5/8/19	Biofilter was operated.
5/9/19	Biofilter was operated.
5/10/19	Biofilter began operating continuously. Biofilter effluent sampler was installed but there was a problem with connecting the sampler arm. Biofilter was started in the morning and left running continuously.

Date	Tasks Completed
5/20/19	The Biofilter continued to run at 100 gpm but fluctuations in influent flow rate were observed. WesTech on site to troubleshoot Storage Vault No. 4 pump and data logger issues. Increased the circuit breaker trip point for Storage Vault No. 4 pump to 10 amps. Purchased a new USB drive and tested both collection points. Identified "USB 1" slot as the only USB port that works for data logging (USB previously in "USB 2" slot). Collected composite sample of the influent and grab sample of the effluent.
5/29/19	The Biofilter continued to run at 100 gpm but fluctuations in influent flow rate were observed. No problems with the Storage Vault No. 4 pump. Downloaded data from the USB drive and requested the processing program from WesTech. Cleaned Biofilter influent turbidimeter. Observed solids build up on the filter media due to sodium hypochlorite dosing pump out of operation. Collected composite sample of the influent and grab sample of the effluent.
5/31/19	Identified a connection issue with the effluent autosampler's sampling arm. Removed the arm and adjusted the sampling program to only one bottle.
6/5/19	The Biofilter continued to run at 100 gpm but fluctuations in influent flow rate were observed. No Storage Vault No. 4 pump issues. Collected first set of composite samples of both the influent and effluent. Observed that Biofilter was in frequent backwashing mode.
6/24/19	WesTech on site to troubleshoot the chlorine dosing system and influent flow fluctuations. Identified a suction leak in dosing pump which caused the unit to dose unreliably. Adjusted and secured Storage Vault No. 4 discharge valve handle in position to prevent it from being fully closed or fully open (fully open valve will cause the pump to trip the circuit breaker). Adjusted supplemental backwash flow to Storage Vault No. 1 to provide sufficient flow for backwash cycles (it was observed that the backwash supply flow stops regularly).
6/25/19	Performed a sodium hypochlorite clean in place on filter media.
7/23/19	Performed a sodium hypochlorite clean in place on filter media.
7/24/19	Performed a tergazyme clean in place on filter media.
7/25/19	Influent turbidity sensor moved to the influent weir to measure turbidity of raw wastewater prior to entering the filtration chamber. Relocation of the sensor helped improve reliability of measurements and reduce scatter. WesTech technician helped resolve issues with flow data logging.
8/22 - 8/23/19	Biofilter taken offline for replacement of a bolt on the filtration bladder
8/26/19	Installation of an 8" RAS pipeline to supply RAS to designated primary filter activated sludge basin.
8/28/19	No influent flow to Biofilter due to low influent flow alarm
9/17/19	No influent flow to Biofilter due to low influent flow alarm
10/9 - 10/14/19	No influent flow to Biofilter due to low influent flow alarm
10/29/19	No influent flow to Biofilter due to low influent flow alarm

Date	Tasks Completed
10/31/19	Biofilter taken offline to modify Storage Vault No. 1 effluent piping
11/5/19	No influent flow to Biofilter due to low influent flow alarm
11/9 - 11/11/19	No influent flow to Biofilter due to low influent flow alarm
11/19 - 11/20/19	Biofilter taken offline to install influent pump standpipe
11/21/19	Biofilter taken offline due to LCWD draining of sludge beds
11/25/19	LCWD draining of sludge beds, Biofilter was not taken offline
11/27-11/30/19	Power outages due to LCWD testing generators, no influent flow to Biofilter due to low influent flow alarm (Biofilter influent pump resets to default 0 Hz setting after power outage). Biofilter brought back online 12/1/19
12/14/19	“Filter 1 Backwash (BW) Supply Fail to Close” alarm due to low BW flow rate setting (<60 gpm)
12/17/19	Changed BW control to “Level Initiated” only
12/22/19	“Filter 1 BW Supply Fail to Close” alarm due to low BW flow rate setting (<60 gpm)
12/23–12/24/19	LCWD digester supernatant process return to headworks
12/27/19	LCWD draining of sludge beds, Biofilter was not taken offline
1/6/20	No influent flow to Biofilter due to low influent flow alarm
1/21/20	Biofilter influent flow 0 gpm (on VFD). HMI displayed “????” likely due to power outage (reset influent pump to 0 Hz)
1/25/20	“Filter 1 BW Supply Fail to Close” alarm due to low BW flow rate setting (<60 gpm)
1/28/20	No influent flow to Biofilter due to low influent flow alarm
2/4/20	Biofilter influent flow 0 gpm (on VFD). HMI displayed “????” likely due to power outage (reset influent pump to 0 Hz)
2/6/20	Power outages due to LCWD testing generators, resulted in Biofilter 0 gpm and “????” during morning hours.
2/6/20	“Filter 1 BW Supply Fail to Close” alarm due to low BW flow rate setting (<60 gpm)
2/7/20	Removed and cleaned turbidity sensors
2/9/20	“Filter 1 BW Supply Fail to Close” alarm due to low BW flow rate setting (<60 gpm)
2/18/20	WesTech on site: adjusted BW supply valve to higher BW flow rate (~80 gpm) to resolve “Filter 1 BW Supply Fail to Close” alarm, performed a tergazyme clean in place on filter media
2/18/20	WesTech identified a leak in the for replacement of a bolt on the filtration bladder

Date	Tasks Completed
2/20–2/21/20	Tested effluent standpipe bypass for one filtration run each day (operated Biofilter in manual and set up valves to route effluent to storage vault 4 instead of through the effluent pipe)
3/3/20	Placed sodium hypochlorite dosing pump offline to test impact on soluble removal
3/9/20	No influent flow to Biofilter due to low influent flow alarm
3/11/20	No influent flow to Biofilter due to low influent flow alarm
3/12/20	Placed sodium hypochlorite dosing pump back online but reduced flow rate by 20% (since backwash flow rate was reduced by 20% from original set point)

Field Log of Biofilter Operation, July 2018–March 2020.

Source: Kennedy Jenks

Summary of Issues and Resolutions

Various issues arose during the biofilter's operation; the corrective actions taken are summarized in Table 4. Many of the issues experienced with biofilter operation in this demonstration project could be mitigated in future permanent installations by applying lessons learned, testing equipment more thoroughly before operation, and including more redundancy, flexibility, and automation in design and installation (which would be more typical for a commercial full-scale system). A summary of key issues and resolutions during continuous overnight operation of the biofilter included:

1. Adjusting the influent flw rate by manually changing the pump speed on VFD.
    - Specific to the demonstration unit, an actuated valve is recommended for a full-scale installation to maintain the targeted influent-flow rate.
2. Adjusting the influent-flow rate by manually increasing or decreasing the pinch valve on the filter-influent line (prior to standpipe installation).
    - A standpipe (specific to the demonstration unit and recommended for a full-scale installation), if elevation differences create siphoning conditions in the influent pipeline.
3. Clearing faults occurring on the influent pump VFD.
    - Specific to the demonstration unit, panel covers are recommended for a full-scale installation to prevent overheating of electrical components, including VFDs.
4. Clearing the "Low Influent Flow" alarm to restore influent flow to the biofilter.
    - Alarm placed biofilter in a "soft shutdown" mode in which no filtration could occur, but backwashes would continue according to the time-based setpoint (every 90 minutes).

- Specific to the demonstration unit; supervisory control and data acquisition (SCADA) is recommended for a full-scale installation to reset alarm remotely.

5. Clearing “Filter 1 Backwash Supply Fail to Close” to bring the biofilter back online
    - Alarm placed biofilter in shutdown mode in which no filtration or backwash would occur.
    - Specific to the demonstration unit; SCADA is recommended for a full-scale installation to reset alarm remotely.
6. Clearing the HMI fault when power outages occur to bring the biofilter back online.
    - Fault placed biofilter in a “soft shutdown” mode in which no filtration could occur, but backwashes would continue according to the time-based set point.
    - Specific to the demonstration unit, SCADA recommended for a full-scale installation to reset the fault remotely.
    - Coding adjustment recommended to reset influent pump speed to the setpoint prior to power outage (instead of 0 Hz) to prevent the “Low Influent Flow” alarm from occurring.
7. Adjusting the backwash flow rate by manually increasing or decreasing the limit switch on the backwash supply valve.
    - Specific to the demonstration unit, an actuated valve is recommended for a full-scale installation to maintain the targeted backwash flow rate.

Table 4: Summary of Issues and Resolutions

Date	Incident/Issue or O&M Change	Corrective Action	Considerations for Future Full-Scale System	Estimated Probability of Occurrence in Future Full-Scale Systems Scale (0-3)*
9/3/18–9/7/18	Backwash Timeout Alarm disabled filter operation.	Issue was traced to a blower timer setting and resolved.	Programming logic needs to be tested to prevent similar issue.	0
10/30/18–10/31/18	O&M Change: Implementation of automatic shutdown control. Alarm communication between the biofilter and the CEC panel are required for overnight operation of the biofilter. The biofilter is programmed to automatically shut down based on a normally-closed alarm signal from the CEC panel for any of the following conditions: • Primary filter is offline, for any reason • Storage Vault No. 2 Level High or Float Initiated • Storage Vault No. 3 Level High or Float Initiated	The emergency shutdown of the biofilter was tested in 10/2018 and again in 1/2019. The biofilter flow cut off within 30 seconds of the primary filter alarming. When the primary filter alarm signal was removed, the biofilter returned online in 5 seconds. When the biofilter alarms for any reason, signal is transmitted to the CEC dial-out system. Testing performed on 10/2018 confirmed signal was received at the CEC panel when biofilter shuts off under alarm condition.	Programming logic needs to be included in biofilter design to prevent damage to the unit and integrated systems.	0
1/10/19–4/27/19	Influent and effluent turbidity data loss: Turbidity data have not been downloaded due to a broken SIM card.	SIM card replaced by KJ field staff on April 27, 2019.	Loss of data can occur due to the use of broken memory drives. Sensors need to be integrated with the HMI (or SCADA if applicable) to prevent large gaps in data from occurring.	1

Date	Incident/Issue or O&M Change	Corrective Action	Considerations for Future Full-Scale System	Estimated Probability of Occurrence in Future Full-Scale Systems Scale (0-3)*
1/10/19–6/24/19	Hydraulic data loss: Flow data were not collected due to USB damage and setup issues.	WesTech replaced and reconfigured USB on June 24, 2019.	Data loss can occur. A SCADA system is needed to provide redundancy for recording data and help prevent the loss of data.	1
5/10/19–6/30/19	Power issue at Storage Vault No. 4: The submersible pump in Storage Vault No. 4 continued to trip out. The fuses (FU113) went out on 4/11. WesTech technician replaced them with two spare 15A fuses from the panel on 4/24. The pump ran after the fuse replacement, but repeatedly tripped out the surge protector during the next week. Run time before tripping has been decreasing. An identical spare pump was tested at the outlet on 5/3 and it too tripped out after 20 min. The pump trips the breaker after running for about 3 min. Breaker is reset manually to resume operation.	WesTech technicians scheduled a site visit to troubleshoot July 2019. Technician recommended to adjust the breaker trip point to 9.5.	Problem could occur with pumps in the system. Settings need to be adjusted based on performance.	1
5/10/19–5/29/19	Challenges with biofilter effluent sampling: Problem connecting HACH sampling arm. Possible corrosion with the threading on the connection.	Sampling arm was replaced but continued to malfunction. It was ultimately removed on 5/29. Without a distribution arm, 24-hour composite samples are collected in a single bottle instead of 8 bottles. If sampling strategy changes to diurnal collection, distribution arm will need to be fixed and reinstalled.	Issue can be prevented or addressed with regular maintenance.	0

Date	Incident/Issue or O&M Change	Corrective Action	Considerations for Future Full-Scale System	Estimated Probability of Occurrence in Future Full-Scale Systems Scale (0-3)*
7/24–8/29/2019	Bladder seal issue: Short filtration run times observed (Biofilter frequently in backwash mode). WesTech identified a bolt missing on the upper bladder seal during 7/24/2019 site visit. Bolt was determined to have loosened over time and fallen into the filter. The missing bolt caused a localized bladder seal issue and excessive amounts of raw water leaking from outside the bladder into the filter compartment. Leakage did not allow for the bladder to compress properly.	WesTech fixed bladder seal issue during 8/28-8/29 site visit.	Problem could occur with blower in the system due to high agitation on the filter media and bladder. Settings need to be adjusted based on performance. Filtration run times should be monitored regularly to identify changes in performance that are not due to influent loading.	1
09/2019	Chlorine dosing pump issue: Chlorine dosing pump was found to not operate during backwash (chlorine level did not change after multiple days of operation). Polypropylene tubing showed signs of breaking.	Peristaltic pump and tubing were replaced on 9/10. Tubing was placed inside an irrigation hose to shield from the sun.	Problem could occur with pumps and polypropylene tubing in the system. Need to regularly check if the peristaltic pump runs during backwash and that no leaks are present in the tubing.	1
Ongoing	Unsteady influent flow rate control: High variability of feed flow has been observed. Influent feed pump is operated based on set speed and pinch valve position Influent flow rate is variable due to the gravity flow condition and solids accumulation at the manual pinch control valve. Additionally, the primary clarifier influent channel (where the influent feed pump is located) is aerated. When the facility makes changes to air flow in the primary clarifier influent channel, the influent flow rate fluctuates significantly.	Adjustments to VFD speed and opening the pinch valve to help release accumulated solids helps to obtain target setpoint. On 11/19, a standpipe was installed on the influent pump's pipeline to break siphoning conditions and eliminate gravity flow. This allowed for the influent flow rate to be driven solely by the VFD setting instead of by gravity flow and the VFD setting. Fluctuations in influent flow rate continue to be observed due to	An actuated valve is needed for effective hydraulic performance.	0

Date	Incident/Issue or O&M Change	Corrective Action	Considerations for Future Full-Scale System	Estimated Probability of Occurrence in Future Full-Scale Systems Scale (0-3)*
		facility's changes to aeration in the primary clarifier influent channel. Adjustments to VFD speed are made to obtain target influent flow.		
Ongoing	Unsteady backwash flow rate control: High variability of backwash feed flow has been observed. At setpoints between 60-80 gpm, backwash flow rate was often difficult to stabilize as the valve operated in a further closed position than manufacturer recommended (causing more back pressure from the backwash supply pump). Alarm conditions would occur as the backwash supply valve failed to trigger closed, causing the biofilter to shut down.	Manual adjustments were made to the backwash supply valve when KJ personnel were on site to obtain backwash flow rates close to the target setpoint.	An actuated valve is needed for effective hydraulic performance.	0

*** Scale for estimated probability: 0 = not likely because the problem was specific to the demonstration unit; 1 = somewhat likely, 2 = likely, 3 = very likely.**

Source: Kennedy Jenks

CHAPTER 3: Project Results

The biofilter demonstration system performance at the LCWD WWTP was evaluated for the feasibility of biofiltration as an APT technology for both treatment and hydraulic performance. This chapter covers observed performance of the LCWD demonstration from July 2019 to March 2020.

Treatment Performance

The treatment performance of the biofiltration system was evaluated for solids removal through both on-site and laboratory measurements. The biofilter consistently achieved high solids removal, as shown by both on-site turbidity measurements and laboratory TSS measurements. Particle removal also reduced BOD and chemical oxygen demand (COD).

Continuous Treatment Performance Monitoring

Due to inherent limitations of continuous TSS monitoring systems, turbidity is often classified and monitored as suspended solids in wastewater.

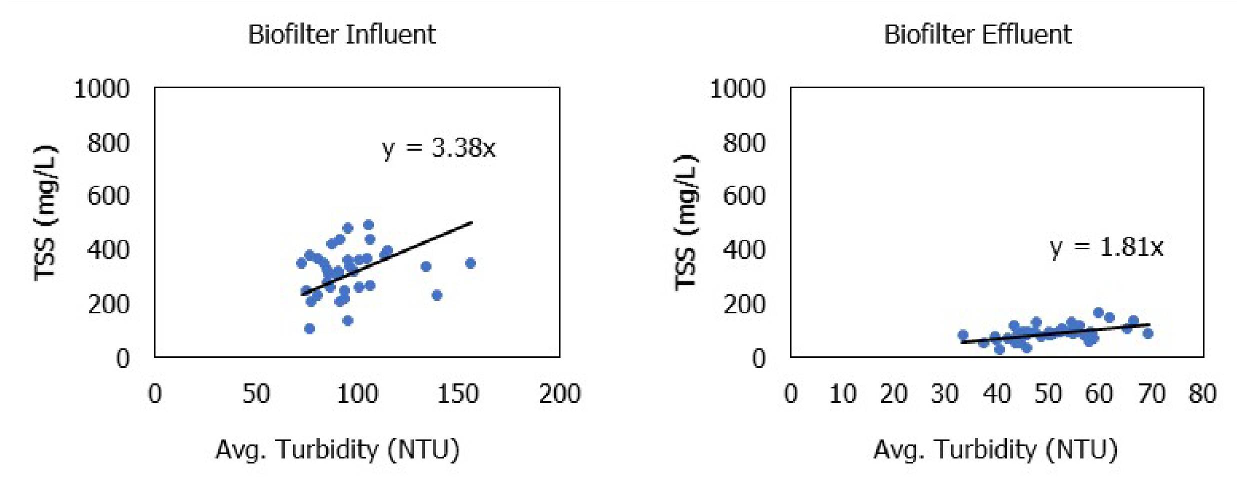
Starting in July 2019, inline turbidimeters (HACH Solitax) continuously monitored the filter's influent and effluent. Correlations were then established between the inline turbidity averages and TSS, measured in composite samples. The filter's continuous TSS removal performance was estimated using these correlations.

Total Suspended Solids to Turbidity Correlation

The demonstration biofilter's influent and effluent turbidities were logged at 10-minute intervals by the HACH SC200 controller. Filter influent and effluent TSS values were also measured periodically using 24-hour composite samples. TSS-to-turbidity correlation ratios were calculated for the biofilter's influent and effluent by correlating the TSS composite measurements with turbidity, averaged over corresponding 24-hour periods. Composite sample results and turbidity data from June 2019 through March 2020 were used to develop these correlations.

Linear correlations of TSS versus turbidity are shown in Figure 14. TSS-to-turbidity correlation factors were 3.38 and 1.81 for the biofilter influent and effluent, respectively. These correlation factors were used to convert turbidity data to TSS values. The correlation factors show the general relationship between TSS and turbidity rather than precise TSS values.

Figure 14: Linear Correlations of Total Suspended Solids Versus Turbidity



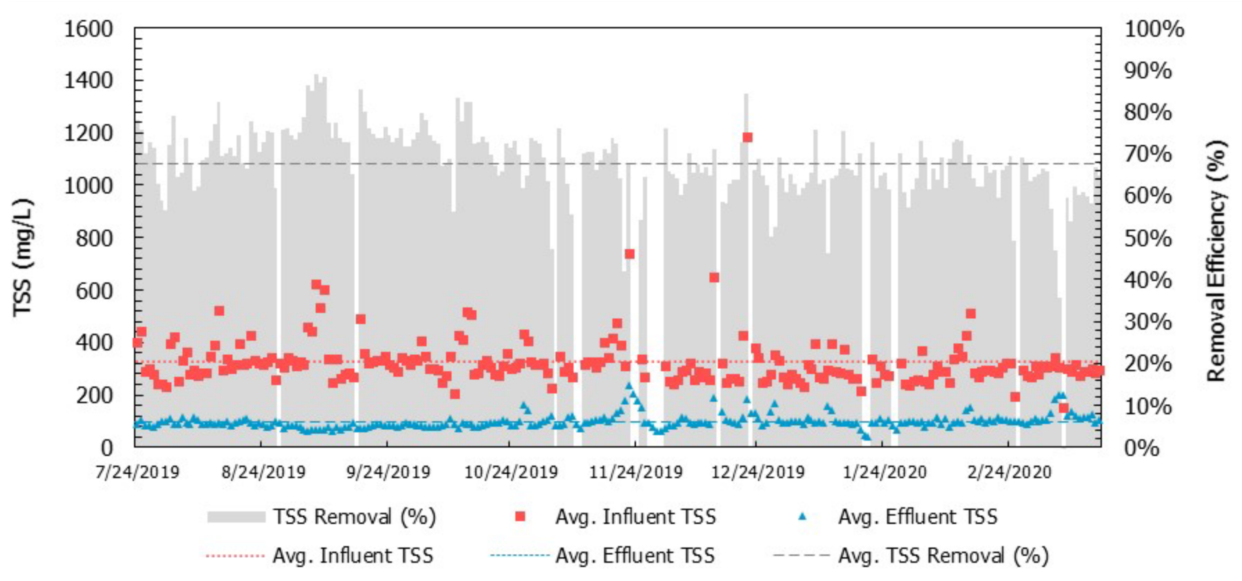
Linear Correlations of TSS versus Turbidity for Biofilter Influent and Effluent.

Source: Kennedy Jenks

Total Suspended Solids Removal Efficiency

As expected, the demonstration biofiltration system performed at a high level for TSS removal. As shown in Figure 15, TSS removal efficiency ranged between 56 and 84 percent since continuous operation began, with an average removal rate of 68 percent. Daily average influent TSS ranged from 151 to 740 milligrams per liter (mg/L), while daily average effluent TSS ranged from 41 to 198 mg/L. This demonstrates the biofilter's ability to handle large variations in raw wastewater solid levels. Overall, average TSS values were 325 and 100 mg/L for biofilter influent and effluent, respectively. TSS daily averages from July 2019 through March 2020 are shown in Figure 15. Gaps in the data represent days when the biofilter was off-line due to operational problems with the influent pump and scheduled maintenance. Peaks in biofilter influent and effluent TSS corresponded with various storm events or plant activities that introduced high amounts of solids to raw wastewater, including draining sludge from drying beds and digester supernatant process returns from the Linda WWTP's solids treatment system.

Figure 15: Average Daily Total Suspended Solids Removal Performance



Average Daily TSS Removal Performance of Biofilter Demonstration, based on turbidity-to-TSS ratios.

Source: Kennedy Jenks

Biofilter Performance Results From Laboratory Sampling

Periodic grab and composite samples for both biofilter influent and effluent were collected and sent to a United States Environmental Protection Agency (US EPA)-certified third-party laboratory for analysis. Data from all sampling conducted from November 2018 to March 2020 are summarized in Table 5 and Table 6. Regular composite sampling started in June 2019. Grab samples were taken in the morning and generally had lower TSS, BOD, and COD compared with composite samples for both filter influent and effluent. All data, however, showed notable removal of these three constituents by the biofilter. A summary of biofilter performance from laboratory sampling appears in Table 7, including Total Kjeldahl Nitrogen (TKN).

While most data showed removal of soluble constituents, fluctuations in biological removal performance were observed throughout this study. From May 2019 through December 2019, operational problems (namely, frequent loss of influent flow due to alarm conditions), likely compromised the biological stability of the filter media. During periods of no influent flow, the biofilm—defined as the aggregation of microbial cells onto the compressible media filter surface—was starved of a food supply. The biofilm then became further depleted as the biofilter went through time-triggered backwash cycles due to "Low Influent Flow" soft shutdown alarm procedures. From December 2019 through February 2020, biological removal was lost entirely. Results from sBOD and sCOD removal performances during this time were inconclusive and omitted from average removal calculations. The loss of biological activity during this time can be explained by:

- Reduction in backwash hydraulic loading rate (HLR), reduced from 6.2 gpm/ft^2 to 3.1-4.2 gpm/ft^2.
- Reduction in influent HLR, reduced from 4.2 gpm/ft^2 to 3.2-3.5 gpm/ft^2.
- Changes in dissolved oxygen (DO) availability within the filter media.
- Offline operation due to alarm conditions, causing loss of influent flow or loss of backwash flow.

Table 5: Laboratory Sample Results

Biofilter Sample Date & Time	Biofilter Sample Type	BOD			COD			sCOD			TSS			TKN		
		Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
11/8/18 12:00	Grab	200	110	45	620†	290	53	x	x	x	470†	52	89	-	-	-
11/14/18 9:20	Grab	260*	140	46	490*	330	33	—	—	—	200*	44	78	—	—	—
11/20/18 14:00	Grab	350*	200	43	760*	400	47	—	—	—	320*	47	85	—	—	—
12/12/18 10:00	Grab	x	x	x	600*	290	52	180*	160	11	220*	40	82	—	—	—
1/9/19 8:30	Grab	270*	72	73	—	—	—	—	—	—	240*	22	91	35*	32	9
2/20/19 8:30	Grab	190	100	47	500	180	64	—	—	—	180	47	74	—	—	—
2/27/19 8:30	Grab	76	58	24	—	—	—	—	—	—	x	x	x	x	x	x
3/6/19 8:30	Grab	—	—	—	410	52	87	—	—	—	330	5.4	98	32	18	44
3/13/19 9:00	Grab	180	130	28	470	150	68	x	x	x	140	25	82	44	38	14
3/14/19 9:00	Grab	230	93	60	420	170	60	89	85	4	190	19	90	38	36	5
4/10/19 9:00	Grab	—	—	—	400	350	13	—	—	—	190	42	78	x	x	x
4/24/19 8:30	Grab	520*	100	81	1300*	230	82	190*	91	52	810*	34	96	—	—	—
5/1/19 8:30	Grab	320	150	53	570	330	42	250	90	64	220	83	62	47	38	19
5/8/19 8:30	Grab	x	x	x	x	x	x	—	—	—	190	97	49	x	x	x
5/20/19 8:30	Grab	190	140	26	330	270	18	78	65	17	130	34	74	32	28	13
5/29/19 8:00	Grab	590	190	68	690	320	54	130	77	41	380	64	83	—	—	—
6/5/19 8:30	24-hr Comp.	470	150	68	1100	350	68	110	93	15	480	54	89	—	—	—
6/12/19 8:30	24-hr Comp.	340	81	76	580	340	41	190	130	32	230	38	83	—	—	—
6/19/19 8:30	24-hr Comp.	x	x	x	810	380	53	93	74	20	330	84	75	—	—	—
6/26/2019 8:30	24-hr Comp.	140	77	45	1100	230	79	130	87	33	970	23	98	—	—	—
7/10/19 8:30	24-hr Comp.	110	90	18	—	—	—	x	x	x	100	20	80	x	x	x
7/17/19 8:30	24-hr Comp.	240	150	38	390	300	23	x	x	x	190	69	64	74	48	35
7/24/19 8:30	24-hr Comp.	140	110	21	790	240	70	67	54	19	1500	64	96	—	—	—
7/25/19 8:30	24-hr Comp.	390	160	59	810	370	54	140	100	29	430	91	79	53	40	25
7/26/19 8:30	24-hr Comp.	460	160	65	720	280	61	96	64	33	440	100	77	56	36	36
7/31/19 8:30	24-hr Comp.	490*	190	61	800*	370	54	—	—	—	520*	130	75	54*	39	28
8/7/19 8:30	24-hr Comp.	x	x	x	750	330	56	x	x	x	420	110	74	56	53	5
8/8/19 8:30	24-hr Comp.	360	160	56	790	360	54	63	61	3	470	150	68	53	45	15
8/14/19 8:30	24-hr Comp.	300	150	50	720	390	46	87	65	25	350	200	43	51	45	12
8/22/19 12:30	24-hr Comp.	500	230	54	770	340	56	100	65	35	490	130	73	50	44	12
9/3/19 9:30	24-hr Comp.	380	140	63	770	310	60	100	98	2	360	87	76	49	34	31
9/4/19 9:30	24-hr Comp.	330	94	72	700	240	66	92	64	30	370	57	85	41	37	10
9/10/19 9:30	24-hr Comp.	410	130	68	610	320	48	91	44	52	310	120	61	41	31	24
9/11/19 10:30	24-hr Comp.	300	190	37	580	330	43	70	64	9	400	190	53	39	37	5
9/12/19 10:30	24-hr Comp.	350	160	54	640	280	56	140	70	50	310	130	58	x	x	x

Biofilter Sample Date & Time	Biofilter Sample Type	BOD			COD			sCOD			TSS			TKN		
		Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
9/17/19 9:30	24-hr Comp.	x	x	x	x	x	x	84	69	18	x	x	x	36	35	3
9/19/19 9:30	24-hr Comp.	260	130	50	x	x	x	110	97	12	260	74	72	44	36	18
9/24/19 9:30	24-hr Comp.	380	130	66	640	320	50	180	77	57	340	95	72	51	33	35
9/26/19 9:30	24-hr Comp.	450	160	64	760	320	58	120	75	38	320	96	70	49	42	14
9/30/19 9:30	24-hr Comp.	530	180	66	800	360	55	—	—	—	360	100	72	50	40	20
10/3/19 9:30	24-hr Comp.	200	77	62	600	320	47	74	70	5	400	99	75	59	41	31
10/8/19 9:30	24-hr Comp.	270	120	56	610	290	52	100	72	28	210	55	74	39	33	15
10/17/19 9:30	24-hr Comp.	210	87	59	520	210	60	73	54	26	250	82	67	46	27	41
10/24/19 9:30	24-hr Comp.	340	170	50	690	350	49	140	110	21	320	100	69	47	35	26
10/29/19 9:30	24-hr Comp.	210	130	38	460	310	33	130	88	32	140	79	44	45	31	31
10/30/19 9:30	24-hr Comp.	320	140	56	670	320	52	110	96	13	x	x	x	66	40	39
11/7/19 9:30	24-hr Comp.	200	100	50	570	340	40	x	x	x	210	170	19	44	42	5
11/12/19 9:30	24-hr Comp.	520	230	56	800	330	59	110	90	18	280	81	71	47	41	13
11/13/19 9:30	24-hr Comp.	300	170	43	550	380	31	x	x	x	250	100	60	x	x	x
11/19/19 9:30	24-hr Comp.	300	170	43	660	330	50	140	120	14	340	110	68	56	49	13
11/21/19 9:30	24-hr Comp.	290	150	48	780	330	58	96	90	6	440	120	73	66	50	24
12/6/19 9:30	24-hr Comp.	470	190	60	740	420	43	270	120	56	480	140	71	x	x	x
12/10/19 9:30	24-hr Comp.	250	150	40	550	360	35	160	140	13	230	88	62	43	41	5
12/11/19 9:30	24-hr Comp.	260	130	50	630	350	44	95	76	20	350	200	43	52	34	35
12/19/19 9:30	24-hr Comp.	540	210	61	1100	330	70	110	90	18	460	98	79	51	41	20
12/23/19 9:30	24-hr Comp.	x	x	x	x	x	x	x	x[†]	x[†]	120	77	36	94	88	6
1/2/20 8:30	24-hr Comp.	340	170	50	730	350	52	x	x[†]	x[†]	330	89	73	x	x	x
1/16/20 8:30	24-hr Comp.	430	180	58	810	340	58	150	140[†]	7[†]	380	84	78	52	40	23
1/23/20 8:30	24-hr Comp.	380	170	55	700	340	51	x	x[†]	x[†]	370	100	73	x	x	x
1/30/20 8:30	24-hr Comp.	340	190	44	670	330	51	140	140[†]	0[†]	350	90	74	x	x	x
2/5/20 8:30	24-hr Comp.	x	x	x	240	220	8	75	68[†]	9[†]	110	28	75	—	—	—
2/6/20 8:30	24-hr Comp.	390	200	49	610	370	39	x	x[†]	x[†]	260	88	66	50	47	6
2/24/20 8:30	24-hr Comp.	—	—	—	—	—	—	—	—	—	270	73	73	—	—	—
2/27/20 8:30	24-hr Comp.	250	170	32	510	370	27	180	170[†]	6[†]	190	58	69	51	43	16
3/4/20 8:30	24-hr Comp.	470	270	43	620	350	44	150	130	13	310	79	75	45	40	11
3/5/20 8:30	24-hr Comp.	420	240	43	630	370	41	150	130	13	220	94	57	—	—	—

Laboratory sample results. Notes:

*** Filter influent samples were grabbed from biofilter influent in the annular space of the FlexFilter tank, at the same time which grab samples of biofilter effluent were taken.**

x = Result is excluded from further analysis due to suspected sampling and/or analysis error.

[†] Loss of biological removal between December 2019 and February 2020 (discussed below). Samples omitted from average removal performance.

Source: Kennedy Jenks

Table 6: Monthly Laboratory Sample Results

Biofilter Effluent Sample Date & Time	Biofilter Effluent Sample Type	VSS			cBOD			Ammonia			Total Phosphorus			Ortho-Phosphate		
		Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
3/13/19 9:00	Grab	—	—	—	x	x	x	43	17	60	5	3.9	22	—	—	—
3/14/19 9:00	Grab	—	—	—	230	94	59	43	41	5	4.9	4	18	3.6	3.5	3
4/24/19 8:30	Grab	700*	33	95	—	—	—	—	—	—	—	—	—	—	—	—
5/1/19 8:30	Grab	—	—	—	330	150	55	47	38	19	5.5	4.4	20	4.2	3	29
5/8/19 8:30	Grab	—	—	—	—	—	—	x	x	x	—	—	—	—	—	—
7/25/19 8:30	24-hr Comp.	—	—	—	380	160	58	x	x	x	6.9	5.1	26	x	x	x
7/26/19 8:30	24-hr Comp.	—	—	—	440	150	66	x	x	x	7.4	4.3	42	3.7	3.6	3
7/31/19 8:30	24-hr Comp.	—	—	—	460*	180	61	38*	36	5	7.8*	4.8	38	3.3*	2.8	15
8/7/19 8:30	24-hr Comp.	—	—	—	x	x	x	x	x	x	7.2	6.5	10	x	x	x
8/8/19 8:30	24-hr Comp.	—	—	—	350	130	63	x	x	x	7.6	6.3	17	x	x	x
8/14/19 8:30	24-hr Comp.	—	—	—	x	x	x	x	x	x	6.6	4.6	30	3.3	3.2	3
8/22/19 12:30	24-hr Comp.	490	130	73	450	150	67	x	x	x	6.3	5.9	6	x	x	x
9/3/19 9:30	24-hr Comp.	360	86	76	330	110	67	40	37	8	6.9	4.1	41	3.9	3.1	21
9/4/19 9:30	24-hr Comp.	—	—	—	220	90	59	48	40	17	6.1	4.6	25	5.4	4.3	20
9/10/19 9:30	24-hr Comp.	—	—	—	270	140	48	39	36	8	6.3	3.9	38	4.2	3.4	19
9/11/19 10:30	24-hr Comp.	400	190	53	280	170	39	40	37	8	5	4.4	12	3.8	3.4	11
9/12/19 10:30	24-hr Comp.	—	—	—	330	160	52	x	x	x	6	5	17	x	x	x
9/17/19 9:30	24-hr Comp.	56	41	27	110	90	18	41	36	12	4.1	3.9	5	3.5	3	14
9/19/19 9:30	24-hr Comp.	—	—	—	230	140	39	48	39	19	5.5	4.4	20	3.8	3.3	13
9/24/19 9:30	24-hr Comp.	—	—	—	—	—	—	47	38	19	6.6	3.9	41	3.7	3.2	14
9/26/19 9:30	24-hr Comp.	—	—	—	240	100	58	55	46	16	6.9	5.5	20	5.6	4.9	13
9/30/19 9:30	24-hr Comp.	360	100	72	410	150	63	44	40	9	6.4	4.3	33	4.4	3.5	20
10/3/19 9:30	24-hr Comp.	—	—	—	140	68	51	44	38	14	8.4	5	40	4.5	3.6	20
10/8/19 9:30	24-hr Comp.	210	55	74	240	120	50	45	39	13	12	9.6	20	4	3.5	13
10/17/19 9:30	24-hr Comp.	250	82	67	200	68	66	48	28	42	6.2	4.3	31	4.8	3.9	19
10/24/19 9:30	24-hr Comp.	320	100	69	320	150	53	42	37	12	6.1	4.3	30	3.9	3.3	15
10/29/19 9:30	24-hr Comp.	140	79	44	200	130	35	49	39	20	5.7	4	30	4.3	3.3	23
10/30/19 9:30	24-hr Comp.	—	—	—	310	120	61	47	41	13	8.9	4.5	49	4	3.5	13
11/5/19 9:30	24-hr Comp.	x	x	x	x	x	x	39	38	3	4.5	4.3	4	3.2	2.8	13
11/7/19 9:30	24-hr Comp.	—	—	—	170	72	58	42	41	2	5.8	5.3	9	x	x	x
11/12/19 9:30	24-hr Comp.	—	—	—	230	120	48	44	43	2	6.5	5	23	x	x	x
11/13/19 9:30	24-hr Comp.	240	100	58	250	170	32	x	x	x	5.5	5.3	4	x	x	x
11/19/19 9:30	24-hr Comp.	340	110	68	290	170	41	x	x	x	7.8	6.4	18	x	x	x
11/21/19 9:30	24-hr Comp.	—	—	—	250	160	36	56	49	13	11	6.7	39	5.8	4.8	17
12/6/19 9:30	24-hr Comp.	470	140	70	480	140	71	x	x	x	x	x	x	x	x	x

Biofilter Effluent Sample Date & Time	Biofilter Effluent Sample Type	VSS			cBOD			Ammonia			Total Phosphorus			Ortho-Phosphate		
		Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
12/10/19 9:30	24-hr Comp.	230	88	62	230	110	52	x	x	x	6.1	5.2	15	x	x	x
12/11/19 9:30	24-hr Comp.	350	200	43	250	90	64	x	x	x	6.1	3.6	41	3.5	3.3	6
12/19/19 9:30	24-hr Comp.	450	96	79	500	180	64	x	x	x	7.7	4.9	36	3.8	3.6	5
12/23/19 9:30	24-hr Comp.	110	77	30	x	x	x	x	x	x	21	20	5	x	x	x
1/2/20 8:30	24-hr Comp.	320	86	73	340	160	53	x	x	x	6.6	5.8	12	x	x	x
1/16/20 8:30	24-hr Comp.	360	73	80	400	170	58	x	x	x	7	4.3	39	3.8	3.6	5
1/23/20 8:30	24-hr Comp.	—	—	—	360	150	58	x	x	x	7.5	6.3	16	x	x	x
1/30/20 8:30	24-hr Comp.	340	90	74	310	140	55	x	x	x	x	x	x	x	x	x
2/6/20 8:30	24-hr Comp.	—	—	—	170	150	12	—	—	—	—	—	—	—	—	—

Monthly Laboratory Sample Results. Note: x = Result is excluded from further analysis due to suspected sampling and/or analysis error.

Source: Kennedy Jenks

Table 7: Influent and Effluent Characterization From Laboratory Sample Results

Constituent	Average (mg/L)	Min (mg/L)	Max (mg/L)	Average Removal (%)
BOD Influent	337	140	590	—
BOD Effluent	154	77	270	52.0 ± 12.2 (n=47)
COD Influent	639	390	810	—
COD Effluent	315	52	420	50.0 ± 12.7 (n=47)
sCOD† Influent	115	63	250	—
sCOD† Effluent	83	44	130	24.9 ± 15.4 (n=33)
TSS Influent	308	110	490	—
TSS Effluent	89	19	200	69.8 ± 11.8 (n=52)
TKN Influent	49	32	74	—
TKN Effluent	39	18	53	19.6 ± 11.5 (n=38)
sBOD† Influent	67	38	120	—
sBOD† Effluent	53	25	110	22.3 ± 15.0 (n=18)
VSS* Influent	305	56	490	—
VSS* Effluent	101	41	200	62.6 ± 15.7 (n=19)
cBOD Influent	293	110	500	—
cBOD Effluent	132	68	180	52.3 ± 13.4 (n=35)
Ammonia Influent	45	39	56	—
Ammonia Effluent	38	17	49	15.1 ± 12.9 (n=22)
Total Phosphorus Influent	7	4.1	12	—
Total Phosphorus Effluent	5	3.6	9.6	24.3 ± 12.4 (n=37)
Ortho-Phosphate Influent	4	3.2	5.8	—
Ortho-Phosphate Effluent	4	2.8	4.9	13.7 ± 6.9 (n=24)

Summary of biofilter performance from laboratory sample results. Notes:

*** VSS sampling occurred later in the biofiltration study when hydraulic performance of the system improved. VSS sampling was included in biweekly analysis, compared to weekly analysis of constituents such as TSS.**

† Loss of biological removal occurred between December 2019 and February 2020. Samples omitted from average removal performance.

Source: Kennedy Jenks

Hydraulic and Operational Performance

The biofilter is equipped with a programmable logic controller (PLC), which logs influent flow rate, backwash flow rate, terminal headloss, and alarm data at 5-minute intervals. The biofilter's hydraulic performance was evaluated on both filter loading and production rates. Continuous monitoring of influent flow rate, backwash (BW) flow rate, and filter water level was logged at 5-minute intervals and stored on a USB drive located in the biofilter's PLC. A processing program provided by WesTech extracted data from the PLC for loading rate calculations.

Due to initial intermittent operation of the biofilter and various start-up operational issues (as described in the *Demonstration System Operations and Testing Progress Report No. 2*), flow data were not consistently recorded until July 2019.

Hydraulic and Solids Loading Parameters

The hydraulic and solids loading parameters, which are used for design, are defined as the (1) hydraulic loading rate, (2) reject ratio, and (3) solids loading rate. Each of these parameters is defined as follows.

Hydraulic Loading Rate. The nominal hydraulic loading rate (HLR) is calculated as

$$\mathrm{HLR} = \frac{Q_{inf}}{A_m} \qquad (1)$$

HLR = hydraulic loading rate, gal/min•ft^2

Q_{inf} = volume of influent/min, gal/min

A_m = total active area of the biofilter media, ft^2

Solids Loading Rate. The solids loading rate onto the biofilter's filter media is determined by using the influent flow rate and mass of TSS in the influent. The solids loading rate (SLR) is:

$$\mathrm{SLR} = \frac{(Q_{inf} \times TSS_{inf})}{A_m} \qquad (2)$$

SLR = solids loading rate, lbs/ft^2•day

Q_{inf} = volume of influent/min, gal/min

TSS_{inf} = average influent TSS concentration, mg/gal [Note (mg/gal)/3.79= mg/L]

A_m = total active area of the biofilter media, ft^2

Backwash Reject Ratio. The backwash reject water (BRW) ratio is:

$$\mathrm{BRW} = \frac{V_b}{V_f} \qquad (3)$$

BRW = backwash reject water ratio (percentage)

V_b = volume of effluent used for backwash, gal

V_f = volume of filtered influent, gal

For the biofiltration demonstration system, V_f was assumed to equal the volume of influent that entered the biofilter. The volume absorbed by filter media as influent travels through the filter bed was assumed to be negligible. For a full-scale demonstration installation, an effluent flow meter is recommended to obtain closer V_f values.

Hydraulic Loading Rates

During the first phase of continuous overnight operation, from July through October 2019, a target HLR of 5 gpm/ft^2 was set for the demonstration biofilter. A target HLR of 5 gpm/ft^2 had been obtained from the biofilter's results in an earlier primary effluent filtration study (Caliskaner et al. 2015). To achieve the target HLR with the total filtration area of 19.6 ft^2, the influent flow rate was adjusted to 100 gallons per minute (gpm).

After analyzing hydraulic performance data from the first phase of operation, various actions improved the biofilter's production rate. In subsequent operational phases, lower HLRs were evaluated by reducing the influent flow rate. Decreasing the HLR was intended to slow down fouling of the filter media and allow longer filtration run times. When filtration run times are greater than 1.5 hours, the time available in a day for the biofilter to spend in backwash is reduced, which reduces the total daily reject water volume.

Due to design limitations specific to the demonstration-scale biofilter (non-actuated influent valve and hydraulic profile of influent pipeline), it was difficult to maintain the biofilter at lower influent flow rates. Influent flow rates were often hard to stabilize due to siphoning conditions and solids buildup in the influent pipeline. Manual adjustments were made to the influent pinch valve and influent pump's VFD when personnel were on site to obtain daily influent flow rates close to the target set point. However, fluctuations in influent flow rate were observed from 40 to 220 gpm. In November 2019, a standpipe was installed on the influent pipeline to prevent siphoning and allow flow to be solely controlled by the pump's VFD set point. While influent flow rate stability improved, fluctuations continued from influent surges to the plant's head works and changes in the primary clarifier's influent channel aeration. Challenges with influent flow rate controls are not expected to occur in a full-scale system.

Target HLR and influent flow rates for each testing period are summarized in Table 8. Daily average influent flow rates and HLRs are shown in Figure 16. The impact of influent flow rate on the biofilter's reject ratio will be discussed in subsequent sections. Gaps in data correspond to days when the biofilter fell offline due to low influent flow conditions or was placed offline for maintenance. In November 2019, the biofilter went offline during weekends if abnormal operational activities occurred at the WWTP (for example, draining of sludge drying beds to WWTP headworks in a short period of time). Placing the biofilter offline helped to prevent blinding of the filter media from high solids loading.

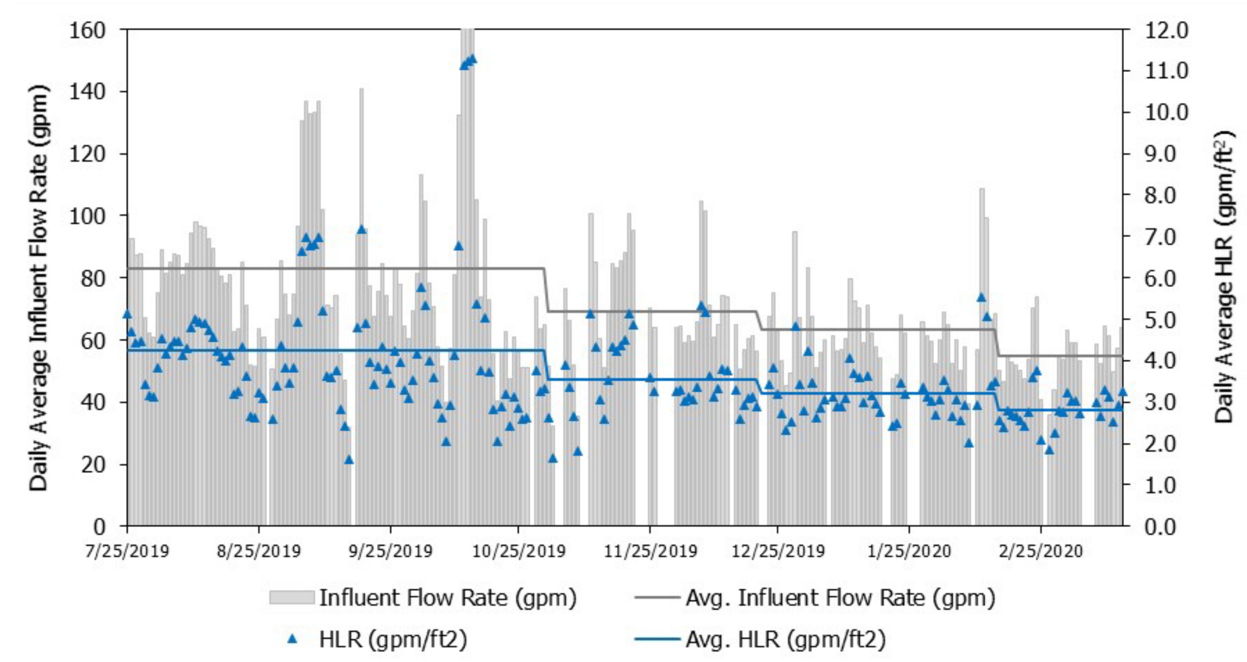
Table 8: Average Hydraulic Loading Rate and Influent Flow Rate per Testing Period

Testing Period	Target HLR (gpm/ft²)	Observed HLR (gpm/ft²)	Average Influent Flow Rate (gpm)
I: 07/25/19 to 10/31/19	3.5	4.2	83
II: 11/01/19 to 12/20/19	3.5	3.5	69
III: 12/21/19 to 02/14/20	3.3	3.2	63
IV: 02/15/20 to 03/15/20	3.0	2.8	55

Average HLR and influent flow rate to the biofilter during each HLR testing period

Source: Kennedy Jenks

Figure 16: Average Daily Flow Rate and Hydraulic Loading Rate



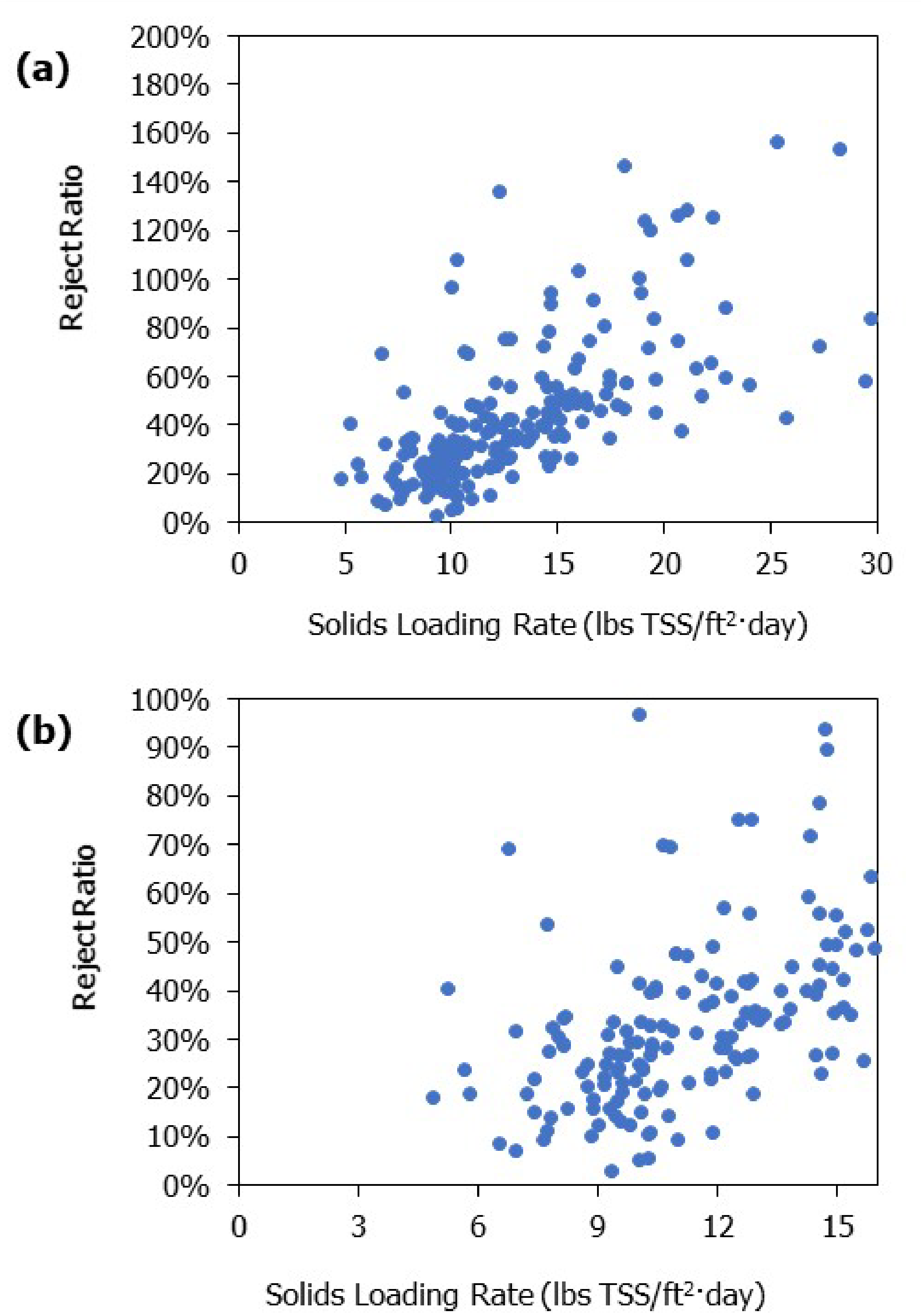
Average daily flow rate and average daily HLR during continuous operation of biofilter.

Source: Kennedy Jenks

Solids Loading Rates

The SLR, defined as the mass of solids applied to the filter surface per unit of time, is strongly dependent on solids concentration in the influent stream and on HLR. In the biofiltration demonstration, solids are removed through physical filtration through the filter media. As higher concentrations of solids are present in the influent stream, the filter media saturates faster and reduces filtration run times. As seen in Figure 17, higher SLRs correlated to higher reject ratios. This was expected since shorter filtration times caused lower total daily filtered volumes and higher backwash volumes from increased backwash frequencies.

Figure 17: Correlation Between Solids Loading Rate and Reject Ratio



(a) Correlation between SLR and reject ratio of the biofilter system. (b) Snapshot of reject ratio data between for SLRs between 5 and 16 lbs TSS/ft^2-day.

Source: Kennedy Jenks

Backwash Reject Ratio

Backwash typically begins when water in the filter basin reaches a certain level due to head-loss buildup on the filter media. The backwash reject ratio, defined as the ratio of daily rejected volume to filtered volume, was used to both evaluate filter hydraulic performance and develop relevant design and operational criteria. A backwash reject ratio of 20 to 25 percent or lower was required for the biofiltration system to be considered an economically feasible treatment technology.

For the biofilter, key drivers of the reject ratio included HLR, SLR, backwash flow rate, backwash frequency, backwash duration, and terminal head-loss set point. Since filtration does not occur when the biofilter is in a backwash cycle (approximately 35 minutes per cycle) different strategies were evaluated to increase daily filtered volume and decrease daily backwash volume. The following changes were tested to reduce to the reject ratio:

- Decreased influent flow rate and HLR. Expected outcome:
    - Increased filtration run time, thus increasing total daily filtered volume.
    - Decreased backwash frequency, thus decreasing total daily rejected volume.
- Decreased backwash flow rate. Expected outcome:
    - Decreased total daily backwash volume.

Table 9 provides a summary of the influent and backwash changes that were tested and their impacts on reject ratios. The backwash duration and terminal head loss value were not changed in this study. For future work, it is recommended that lower backwash durations and higher terminal head loss values be evaluated.

Figure 18 summarizes reject ratios observed at various daily average influent flow rates and backwash flow rates. On operational days with a reject ratio of greater than 100 percent, a greater volume of backwash was used than the volume of filtered effluent that was produced. This occurred when influent loading to the biofilter was high (when the flow rate was greater than 100 gpm (HLR greater than 5 gpm/ft^2), or the influent TSS was high (greater than 400 mg/L). During high influent loading conditions, it was common for the biofilter to be in backwash for a total of 8 or more hours in a day (compared with an average of 3 to 6 hours per day during normal influent conditions). Additionally, at high backwash flow rates (greater than 90 gpm), reject ratios above 40 percent were common. This occurred since, during each 35-minute backwash cycle, filtered effluent was supplied to the biofilter for 25 minutes. Higher backwash flow rates drove up the total volume used during each backwash cycle. In general, reducing the backwash flow rate improved the reject ratio; however, it is important to track the impact on treatment performance. Reducing backwash supply can reduce the amount of biofilm or solids removed during a backwash cycle, which in turn increases the amount of residual material on the filter media (results in short filtration run times). The minimum backwash flow rate to effectively clean the biofilter media from solids and biofilm overgrowth was not evaluated in this study.

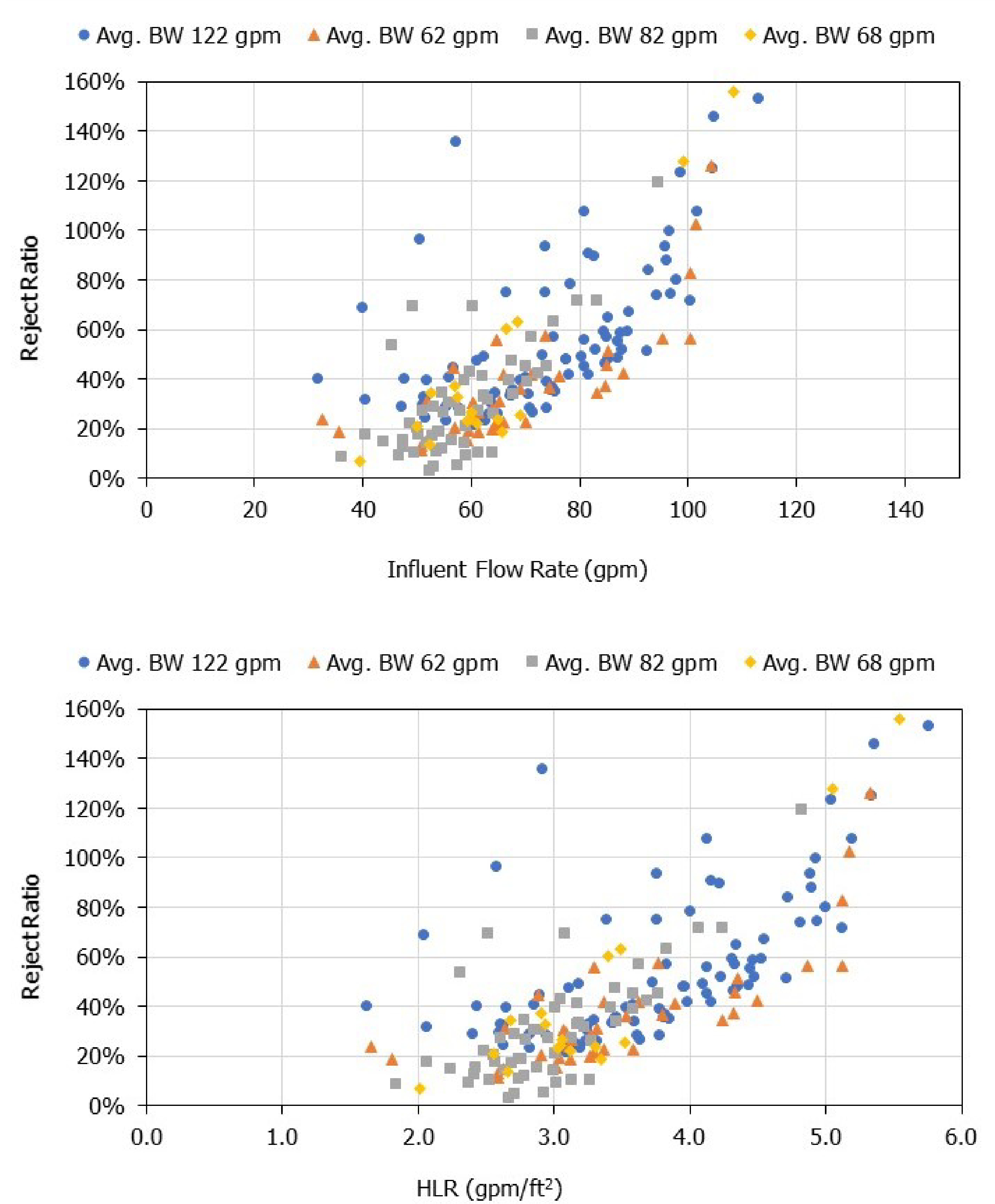
Table 9: Average Operating Conditions by Testing Phase

Testing Phase	Average Influent Flow Rate (gpm)	Average Influent HLR (gpm/ft^2)	Average BW Flow Rate (gpm)	Average SLR (lbs TSS/ ft^2•day)	Average Time in Filtration (hrs/day)	Average Time in Backwash (hrs/day)	Reject Ratio
I: 07/25 to 10/31	83	4.2	122	18.2	18	6	48%
II: 11/01 to 12/20	69	3.5	62	13.8	17	6	33%
IIIa: 12/21 to 01/24	63	3.2	83	11.4	17	6	41%
IIIb: 01/25 to 02/14	64	3.3	68	12.7	16	6	29%
IV: 02/15 to 03/15	55	2.8	81	9.9	20	3	17%

Summary of average daily influent flow rate, HLR, and BW flow rate with respective reject ratio for the testing phase.

Source: Kennedy Jenks

Figure 18: Observed Backwash Reject Ratios

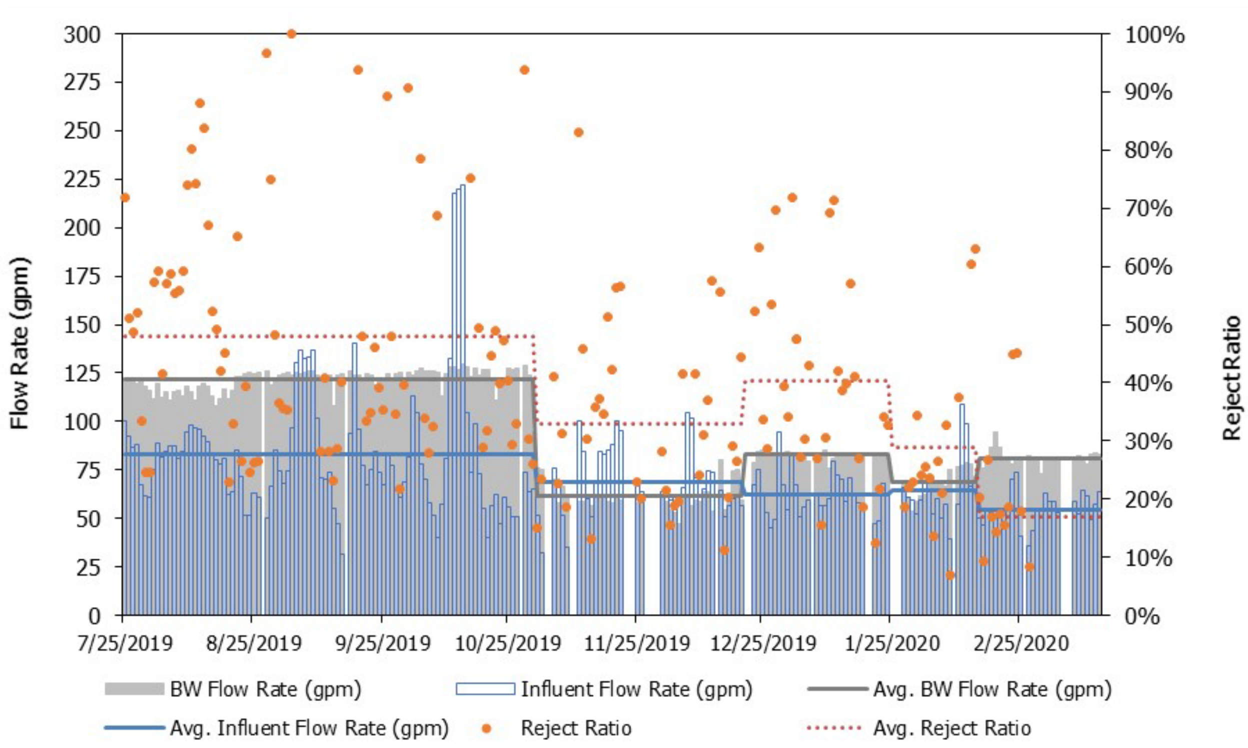


Observed reject ratios at various backwash flow rates and influent flow rates.

Source: Kennedy Jenks

Figure 19 summarizes daily average influent flow rate, backwash flow rate, and reject ratio for the biofiltration demonstration. Various backwash flow rates were tested to gain a better understanding of the set point's impact on hydraulic performance. Due to design limitations in the backwash supply valve type (no actuator), it was challenging to maintain backwash flow rate setpoints lower than 80 gpm. At setpoints between 60 to 80 gpm, backwash flow rate was often difficult to stabilize as the valve operated in a further closed position than manufacturer recommended (causing more back pressure from the backwash supply pump). Manual adjustments were made to the backwash supply valve to obtain backwash flow rates close to the target setpoint. However, at backwash flow rate setpoints of 60 gpm and 70 gpm, alarm conditions would occur as the backwash supply valve failed to trigger closed, causing the biofilter to shut down. While reject ratio results looked promising at lower backwash setpoints, a backwash flow rate of 80 gpm was used during the last phase of the study to eliminate the alarm shutdown.

Figure 19: Daily Average Reject Ratio, Influent Flow Rate, and Backwash Flow Rate



Daily average reject ratio, influent flow rate, and backwash flow rate for biofiltration demonstration.

Source: Kennedy Jenks

Process Simulation Summary of Biofiltration

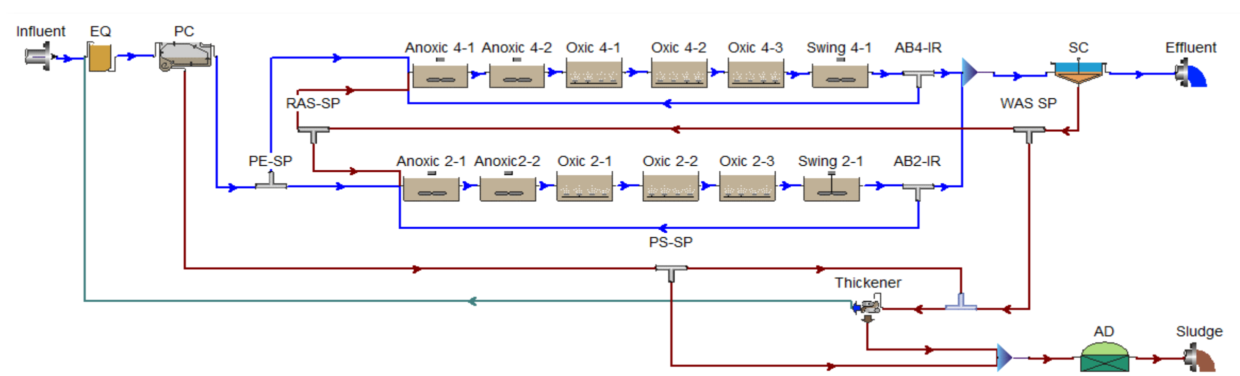
Wastewater process simulations were performed to predict system energy benefits and estimate the downstream impact of full-scale biofiltration. Simulations were run for the deployment site at LCWD WWTP. Additional process simulations were conducted for full-scale treatment at the Lancaster Water Reclamation Plant (WRP) and the City of Manteca Wastewater Quality Control Facility (WQCF), which were demonstration sites for the parallel CEC primary filtration demonstration project using PCDF (EPC-14-076). The simulations evaluated biofiltration for potential reductions in secondary treatment energy requirements and increases in digester gas production, which were two of the main project measurement goals. Other possible downstream treatment impacts (for example, denitrification, increase in secondary treatment capacity) were also evaluated in process simulations. This section summarizes the approach and key findings of the process simulations. Detailed process simulation reports are provided in Appendix A.

Simulation Methodology

Process simulations were performed using the BioWin 6.0 simulator developed by EnviroSim of Ontario, Canada (EnviroSim Associates Ltd. 2019). The BioWin simulator uses complex kinetic biological interactions to predict material transformations and pollutant removals in different processes at a WWTP. The simulator enables the user to predict WWTP behavior and performance under different conditions by simulating physical treatment processes (such as clarification and filtration) and biological treatment processes (such as carbonaceous oxidation, nitrification, denitrification, and biomass production). Full-scale results of the simulations were verified by comparing simulator estimates with hand-calculated estimates.

The flow schematic used in the baseline simulation with primary clarification and the comparison simulation with primary biofiltration at LCWD WWTP are presented in Figure 20 and Figure 21, respectively.

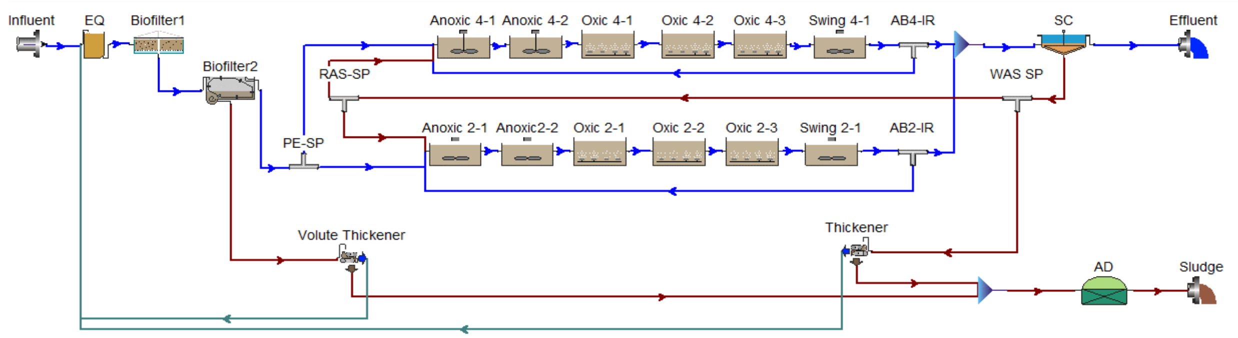
Figure 20: Baseline Simulation With Primary Clarification



Baseline simulation with primary clarification for LCWD WWTP.

Source: Kennedy Jenks

Figure 21: Comparison Simulation With Primary Biofiltration



Comparison simulation with primary biofiltration.

Source: Kennedy Jenks

Simulation Scenarios

Performance of primary biofiltration was simulated under the operating scenarios summarized in Table 10 for each of the three WWTPs, except where noted as LCWD only. Simulator calibration for the primary biofiltration was not conducted as representative full-scale performance data were not available for downstream processes.

Table 10: Simulation Scenarios and Objectives

Simulation	Description	Objective
S1	Simulation using primary clarification for primary treatment	Establish the baseline simulation with primary clarification for comparison purposes
S2	Simulation using biofiltration for primary treatment	Evaluate impact of primary biofiltration on actual oxygen requirement (AOR), aeration/ mixing for aerated basins, digester gas production, and secondary effluent nitrate plus nitrite nitrogen (NOx-N)
S3	Simulation S2 with a reduced secondary treatment volume to match mixed liquor suspended solids (MLSS) in Simulation S1	Evaluate impact of primary biofiltration on secondary process treatment volume reduction
S4 (LCWD only)	Simulation S2 with reduced airflow to meet plants' effluent limit for NO_X-N of 10 mg/L	Evaluate airflow reduction and redistribution as a method to meet effluent NOx-N limit with primary biofiltration. Evaluate aeration energy saving under an optimized plant operational condition.
S5 (LCWD only)	Simulation S2 and dissolved oxygen (DO) in aeration basin assumed to be 6 mg/L	Evaluate aeration demand under the current plant operating conditions.

Simulation	Description	Objective
S1A, S2A & S3A (LCWD only)	Simulation at a shorter SRT	Evaluate how the operating SRT changes the relative impact of primary biofiltration. SRT reduced from 22.3 days to 15 days.
S1B, S2B & S3B (LCWD only)	Simulation for different influent wastewater	Evaluate how the plant-specific influent wastewater characteristics change the estimated impact of primary biofiltration. The influent wastewater characteristics in the LCWD WWTP are revised with wastewater characteristics similar to the Manteca WQCF. SRT reduced from 22.3 days to 15 days.

Seven simulation scenarios and objectives for three WWTPs.

Source: Kennedy Jenks

Simulation Results and Estimated Benefits

Simulated benefits are estimated in this section by comparing Simulation S1 (primary clarifier) to simulations using the biofilter, as summarized in Table 11. Results of the other simulations are shown in Appendix A.

Table 11: Summary of Simulated Results

Parameter	LCWD WWTP	Manteca WQCF	Lancaster WRP
Secondary Process Volume Requirement (MG/MGD of wastewater treated)[b]			
With Primary Clarifier	0.78	0.60	0.39
With Primary Biofilter	0.73	0.42	0.30
Decrease with Biofilter	6%	30%	22%
Power for Mixing in Secondary Aeration Basins (HP/MGD of wastewater treated)[b]			
With Primary Clarifier	65	77	68
With Primary Biofilter	57	62	55
Decrease with Biofilter	12%	20%	19%
Digester Gas Flow (scfm/MGD of wastewater treated)[a]			
With Primary Clarifier	7.9	14.7	12.7
With Primary Biofilter	10.5	17.5	14.3
Increase with Biofilter	33%	19%	12%
Secondary Effluent NOx-N (mg/L)[a,c]			
With Primary Clarifier	6.8	4.1	3.9
With Primary Biofilter	14.5	6.1	7.3
Increase with Biofilter	115%	51%	88%
With Primary Biofilter and ASB DO management/reduction	9.3	—	—
Increase with Biofilter and DO reduction	17%	—	—

Summary of benefits, comparing Simulation S1 for primary clarification to: (a) Simulation S2, (b) Simulation S3, and (c) Simulation S4. Additional simulations and detailed modeling results are included in Appendix A.

Source: Kennedy Jenks

Based on the results of the simulations, key findings for implementation of primary biofiltration replacing primary clarification follow.

- Primary biofiltration is estimated to reduce secondary process actual oxygen requirements (AOR) by diverting the 5-day carbonaceous biochemical oxygen demand (cBOD) from the secondary process to the anaerobic digester. The aeration energy decrease associated with reduction in AOR is estimated to be 14 to 20 percent in the three WWTPs simulated. The relative reduction is expected to vary depending on plant-specific influent wastewater characteristics.
- Primary biofiltration is estimated to increase digester gas flow by diverting additional amounts of volatile suspended solids (VSS) and COD to anaerobic digestion. The increase in digester gas production varied from 12 to 33 percent in the three WWTP simulations. A WWTP with a higher increase in both TSS and

COD removal rates tends to see a greater benefit of increased gas production than one with a smaller increase in these removal rates.

- Primary biofiltration is estimated to increase secondary process treatment capacity by diverting TSS and CBOD from the secondary process. The secondary process is estimated to be able to handle an additional 6 to 30 percent of influent flow with primary biofiltration at the three WWTPs. As shown in the simulation results in Appendix A, the relative impact on the secondary treatment capacity can vary depending on the plant-specific influent wastewater characteristics and the SRT of the secondary process.
- Primary biofiltration is expected to increase secondary effluent NOx-N since it removes additional CBOD that could have been used for depletion of DO in the internal recycle stream and denitrification in the anoxic zones. In the WWTP simulations, the secondary effluent NOx-N concentration is estimated to increase with primary biofiltration. The percentage increase in NOx-N concentration is estimated to be higher for WWTPs that have a higher internal recycle rate from an aerobic zone to an anoxic zone with a higher DO concentration and a higher increase in the primary CBOD removal rate. CBOD is consumed by heterotrophic organisms in the following secondary process. Oxygen is a preferred electron acceptor over nitrate in the oxidation of CBOD. Therefore, the heterotrophic organisms consume DO first before consuming NOx-N in the presence of DO. Thus, minimizing the negative impact of residual DO from the return stream becomes an even more important consideration for primary biofiltration when evaluating applications at a WWTP with NOx-N limits. The secondary effluent NOx-N can be reduced to below the effluent quality limit by reducing the DO in the activated sludge basin (ASB). Supplying external carbon to the anoxic zone or bypassing a portion of influent wastewater around primary biofiltration and sending it directly to the secondary process can be considered as alternative methods for reducing the effluent NOx-N.

Summary of Measurement and Verification Study

A third-party energy audit firm, BASE Energy, Inc., conducted a M&V study for the biofiltration system, summarized here. The detailed M&V report is provided in Appendix B.

Measurement and Verification Methodology

Data loggers were installed on the demonstration-scale biofiltration system as well as on the existing full-scale primary filtration system to measure power usage. Additional logged data, daily monitoring reports, and process information were obtained from LCWD WWTP. Secondary aeration power consumption baselines were established with air blower power use that was either directly logged by BASE Energy or obtained from the plant's SCADA logs. The baseline line aeration power consumption was normalized by the plant's treated flow volume and secondary process BOD loading. Aeration power consumption for proposed, full-scale primary biofiltration systems was projected based on the normalized baselines and the expected reduction in BOD loading on the secondary treatment process.

Additional loggers were installed on the plant's equipment at LCWD WWTP to evaluate power consumption of all plant equipment. The methodology and results for analysis of all plant equipment power use can be found in Appendix B.

Measurement and Verification Energy Savings Estimation for Secondary Treatment

For the M&V study, hydraulic, treatment, and power usage data were obtained for all three primary treatment systems at LCWD. Over the 6-month study, average wastewater flows to the primary clarifier, demonstration-scale biofilter, and full-scale primary filter were 1.78, 0.092, and 0.576 MGD, respectively.

Secondary treatment aeration savings estimated from M&V are summarized in Table 12. Based on M&V, aeration power is expected to be reduced by approximately 30 percent with a full-scale primary biofiltration system based on reduced BOD loading on the secondary treatment process.

Table 12: Potential Blower Energy Savings Summary for a Full-Scale Primary Biofiltration or Primary Filtration System

Parameters	Primary Clarifier System (Baseline)	Full-Scale Primary Biofiltration	Full-Scale Primary Filtration System
Plant Flow (MGD)	2.45	2.45	2.45
BOD Removal (%)	36	55	66
Projected Blower Power based on Airflow (kW)	72.62	50.31	37.99
Projected Blower Power Reduction (kW)	—	22.31	34.64
Aeration Blower Savings Compare to Baseline (%)	—	31%	48%

Projected aeration blower savings for a full-scale primary biofiltration or primary filtration treatment system.
Source: Kennedy Jenks

Measurement and Verification Primary Treatment Energy Consumption Comparison

A primary biofiltration system's largest power consumption is from the backwash blower. The average specific power consumption of the biofiltration system was large due to an oversized blower used in the demonstration-scale unit. It was concluded that the backwash blower size was at least twice the size of what would be required in a full-scale system. Future testing and analysis are required to optimize the blower size to provide effective aeration during backwash. For a full-scale system, specific power consumption is expected to improve.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

Summary

Manufacturers, engineers, academia, and utilities have supported APT since its inception. In California alone, biofiltration could directly apply to approximately 300 WWTPs throughout the state, with a total capacity of more than 4,000 MGD. For this estimate, only the municipal WWTP market segment was considered. The operational and treatment results of biofiltration from the demonstration project will allow municipalities to evaluate the suitability of this technology at their facilities. Quantification of energy savings at the demonstration sites will provide incentives for WWTPs to consider when adopting biofiltration as APT. The technology may also apply to industrial wastewater treatment.

In addition to implementation at WWTPs, the results of this project also have extensive research value for governmental agencies, academia, and manufacturers. The research results, technical reports, operational and design criteria, and modeling studies produced during this project all contribute to overall institutional knowledge of the technology.

Strategy

The project team conducted the following activities to disseminate knowledge from the biofiltration project to both the industry and the public.

- Met with and presented project results to public agencies, utilities, and practitioners in the wastewater treatment field.
- Made presentations at state and national conferences from 2018 to 2019, with future presentations planned through 2021.
- Made presentations at professional and society meetings.
- Wrote articles for publications targeted to agencies with WWTPs.
- Published technical articles in conference proceedings.
- Prepared project flyers.

Completed Activities

The technology and knowledge transfer activities to date are summarized in Table 13.

Table 13: Timeline of Technology Transfer Activities to Date

Date	Audience	Activity Type	Activity Description
Feb. 2018	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the primary filtration project at the Pacific Water Conference and included a discussion of biofiltration. Approximately 80 people attended the presentation.
Feb. 2018	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the primary filtration project at the North Texas Section of the Water Environment Association of Texas seminar and included a discussion of biofiltration.
Feb. 2018	Public utility	Presentation/ workshop	Met with SFPUC to update them about the primary filtration and biofiltration project progress and results.
Apr. 2018	Public utilities, consulting engineers, and operators	Site visit	At California Water Environment Association's 2018 Annual Technical Conference, conducted a technical site tour to the primary filtration and biofiltration systems at LCWD WWTP. Approximately 40 people (utility managers/engineers/operators) from 10 different utilities/ agencies attended the tour.
Apr. 2018	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the primary filtration project at the California Water Environment Association's 2018 Annual Technical Conference and included a discussion of biofiltration.
May 2018	Public utility	Site visit	Conducted a site tour to the primary filtration and biofiltration systems at Linda WWTP for City of Manteca Public Works Department management team
May 2018	Public utility	Presentation/ workshop	Presentation to Sand Island WWTP in Hawaii.
May 2018	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the primary filtration project at the 2018 Texas Water Conference and included a discussion of biofiltration.
June 2018	Public utility	Presentation/ workshop	Met with SFPUC to update them about the primary filtration and biofiltration project progress and results.
Sept. 2018	Public utilities, consulting engineers, academia, and operators	National conference presentation	Presented the primary filtration project at WEFTEC 2018 conference in New Orleans, LA. Also held a workshop on physical processes for carbon redirection, including biofiltration.

Date	Audience	Activity Type	Activity Description
Oct. 2018	Public utility	Site visit	Conducted a site tour to the primary filtration and biofiltration systems at Linda WWTP for City of San Mateo Public Works Department management and engineering team
March 2019	Public utility	Presentation/ workshop	Presentation to South Tahoe Public Utility District
June 2019	General	Technical paper submittal	Submitted a technical paper regarding the biofiltration project for WEFTEC 2019 conference proceedings.
June 2019	Public utility	Presentation/ workshop	Met with Los Angeles County Sanitation District to update them about the primary filtration and biofiltration project progress and results.
Aug. 2019	Public utility	Presentation/ workshop	Presentation to Southern California Edison.
Sept. 2019	Public utilities, consulting engineers, academia, and operators	Regional conference presentation	Presented the primary filtration project at the 2019 Pacific Northwest Clean Water Association conference and included a discussion of biofiltration.
Sept. 2019	Public utilities, consulting engineers, academia, and operators	National conference presentation	Presented the biofiltration project at WEFTEC 2019 conference in Chicago, IL.
Aug. 2019	General	Abstract submitted and accepted	Submitted an abstract for the biofiltration project for California Water Environment Association's 2020 conference. Abstract was selected for presentation.
Dec. 2019	General	Abstract submitted	Submitted an abstract for the biofiltration project for WEFTEC 2020 conference proceedings.
Dec. 2019	Public utility	Presentation/ workshop	Met with SFPUC Oceanside Plant staff to update them about the primary filtration and biofiltration project progress and results.
Dec. 2019	Public utility	Presentation/ workshop	Presentation to King County (Seattle, WA) on primary filtration and biofiltration technologies.
Dec. 2019	Public utilities	Presentation/ workshop	Presentation at a special KJ seminar in Everett, WA for several WA agencies.

Date	Audience	Activity Type	Activity Description
Dec. 2019	Public utilities	Presentation/ workshop	Presentation at a special KJ seminar in Federal Way, WA, for several WA agencies.
Jan. 2020	Public utilities, consulting engineers, academia, and operators	Regional conference presentation	Presentation on primary filtration and biofiltration at Water Environment Association of Texas Central Section in Austin.
Feb. 2020	Private operator	Presentation/ workshop	Met with Constellation Brands/Mondavi Wines to discuss primary filtration and biofiltration project progress and results, and applicability of technologies to food/beverage industry.
Feb. 2020	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the biofiltration project at the Pacific Water Conference in Hawaii.
Feb. 2020	Public utility	Presentation/ workshop	Met with SFPUC Oceanside Plant staff to update them about the primary filtration and biofiltration project progress and results.
March 2020	Public utilities and operators	Presentation/ workshop	Presentation on primary filtration at KJ Water Quality Breakfast in Sacramento for local utilities and operators.

Timeline of Technology Transfer Activities to Date.

Source: Kennedy Jenks

In 2017 and 2018, the biofiltration project was primarily discussed and presented at conferences in conjunction with the parallel primary filtration project at the LCWD WWTP. The Water Environment Federation Technical Exhibition Conference (WEFTEC) is the largest national conference concerning wastewater treatment and is a prime platform for emerging technologies to be vetted by the industry. The technical paper submittal and the presentation at WEFTEC 2019 provided excellent visibility for the biofiltration project.

Upcoming Activities

The following technology and knowledge transfer activities are anticipated to be done by the PI after completion of the project.

- Continuation of activities similar to those described in Table 13.
- Site visits for interested parties to the biofilter system at the LCWD WWTP.
- Meetings with public utilities and agencies operating WWTPs, Investor-Owned Utilities, consulting engineers, and operators.
- At least three presentations per year at state and national conferences through 2021. Planned conferences include the WEFTEC, California Water Environment Association, Pacific Northwest Clean Water Association, Texas Water, and Pacific Water Conference.

Status of Technology and Market Adoption

The biofiltration system demonstrated in this project was concluded to be promising for the wastewater treatment industry because of the observed high primary treatment performance levels. But the hydraulic performance of the system was not as feasible as some of the other emerging advanced primary treatment technologies. The project's PI, Dr. Caliskaner, and the system manufacturer, WesTech Inc., are currently pursuing opportunities to advance this technology to make it more commercially attractive and technically feasible as an advanced primary treatment system. Based on the project results, modifications and upgrades are proposed for the biofiltration system to achieve longer filter run times and to increase hydraulic filtration rates. With the proposed alterations, the upgraded biofiltration system will be more economically feasible requiring less footprint and providing more treatment capacity. Market adoption of the biofiltration technology is expected to be faster after successful demonstration of the proposed hydraulic improvements.

CHAPTER 5: Conclusions and Recommendations

Achievement of Overall Project Objectives

This project successfully advanced the technology to the goal of demonstrating that biofiltration is a technically viable and commercially advantageous approach for substantial energy savings at WWTPs. As the first biofiltration project developed for advanced primary treatment (APT), the project accomplished the objective to install and demonstrate a biofiltration system at an existing WWTP. The results of the other eight metrics (listed in Section 1.2) used to determine the project's success are presented and discussed in this chapter.

Biofiltration Demonstration Performance

Biofiltration performance results are summarized by operation, treatment, and hydraulics in this section, based on two primary project goals.

- Demonstrate biofiltration removal efficiencies for TSS, VSS and total, particulate, and soluble BOD.
- Develop operational, maintenance, and design criteria for full-scale installations.

Summary of Biofiltration Removal Efficiencies

The average biofiltration removal efficiencies, based on laboratory analyses, are shown in Table 14. Overall, the biofiltration system demonstrated consistent solids removal performance, regardless of variations in influent loading rates. The range of removal efficiencies were 36 to 90 percent for TSS, 27 to 80 percent for VSS, 21 to 76 percent for total BOD, 13 to 87 percent for COD, and 5 to 60 percent for soluble BOD.

Table 14: Summary of Average Removal Performance

	COD	sCOD*	BOD	sBOD*	cBOD	TSS	TKN	Ammonia	VSS
Avg. Removal	50.0%	24.9%	52.0%	22.3%	52.3%	69.8%	19.6%	15.1%	62.6%
Avg. Influent (mg/L)	639	115	337	67	293	308	49	45	305
Avg. Effluent (mg/L)	315	83	154	53	132	89	39	38	101

*** Summary of average removal performance for the biofiltration demonstration from laboratory analysis results. Note: *Loss of biological removal occurred between December 2019 and February 2020. Samples were omitted from average removal performance.**

Source: Kennedy Jenks

While soluble removal of BOD and COD was observed for periods of operation, the demonstration-scale biofiltration system showed inconsistent soluble removal. In the demonstration-scale system, frequent loss of influent flow occurred during alarm conditions or power outages. During periods of no influent flow, fluctuations in soluble removal performance were expected as the biofilm was starved of its food supply. Biofilm development and stability were additionally impacted by operational changes to the system, which was expected for a biological treatment system. For a full-scale installation, controls can be implemented that maximize operation time of the system and minimize the time the biofilter is offline. Further testing will be needed to determine how operational parameters such as chlorine dosing, solids loading rate (SLR), influent HLR, backwash HLR, and DO availability affect biofilm development and stability.

Summary of Operational Parameter Testing

Field testing of operational parameters focused primarily on sustaining feasible treatment performance and reducing the biofilter's backwash reject ratio, which is used to evaluate the efficiency and feasibility of emerging APT technology. For the biofilter, key drivers of the reject ratio included HLR (of the influent and backwash flow rates), filtration run time, backwash run time, and head loss depth. In this study, the impacts of HLR and backwash flow rate on reject ratio were studied. Table 15 summarizes the average influent flow rate, influent HLR, and backwash flow rate studied.

Table 15: Summary of Operational Parameters Studied

Testing Phase	Average Influent HLR (gpm/ft^2)	Average Influent SLR (lbs TSS/ft^2• day)	Average BW HLR (gpm/ft^2)	Average Reject Ratio	Average Daily Filtered Volume (gpd)	Average Daily BW Volume (gpd)
I: 7/25/19 – 10/31/19	4.2	18.2	6.2	48%	61,000	31,000
II: 11/1/19 – 12/20/19	3.5	13.8	3.1	33%	51,000	16,000
IIIa: 12/21/19 – 1/24/20	3.2	11.2	4.2	40%	53,000	22,000
IIIb: 1/25/20 – 2/14/20	3.3	12.7	3.5	29%	48,000	14,000
IV: 2/15/20 – 3/15/20	2.8	9.9	4.1	17%	64,000	11,000

Summary of Operational Parameters Studied.

Source: Kennedy Jenks

It appears that the required influent HLR and backwash HLR are 2.8–3.3 gpm/ft^2 and 3.5–4.1 gpm/ft^2, respectively, to maintain hydraulic efficiency of the biofiltration system. Further research is needed to determine the minimum influent HLR and backwash HLR needed to maintain biological removal efficiency and biofilm stability.

The influent HLR was observed to have an impact on the biofilter's BRW ratio. Lowering the influent HLR in Phase 2 through Phase 4 lowered the BRW ratio. In addition, a comparison between Phase 3a and Phase 4, where the influent HLR was reduced by approximately 10 percent (the same target BW HLR set point was used), showed an improved BRW ratio of approximately 50 percent.

The BW HLR also affected the BRW ratio. Lowering the BW HLR also lowered the BRW ratio. A comparison between Phase 3a and Phase 3b, in which the BW flow rate was reduced by approximately 10 percent (the same target influent flow rate set point was used), showed an improved BRW ratio of approximately 25 percent.

An observed result of this demonstration testing was that lowering the BW HLR improved the BRW ratio, but operationally the biofilter was unable to consistently maintain BW flow rate set points at less than 80 gpm (HLR 4.1 gpm/ft^2). When the BW flow rates were between 60-70 gpm (HLR 3.1–3.6 gpm/ft^2), the biofilter would perform consistently for 3 to 5 days but would alarm ("Filter 1 BW Supply Fail to Close" alarm) and initiate a hard shutdown, which had to be manually reset by someone on site. This is a demonstration-specific issue and could be resolved by installing actuated valves to help control backwash flow rates.

Similarly, lowering the influent flow rate improved the BRW ratio though the biofilter was operationally limited at low influent flow rates. At low influent pump set points less than 50 gpm (HLR 2.6 gpm/ft^2), the pump speed was too low to effectively prime the influent pipeline. After one or two days without anyone on site to monitor it, the biofilter alarmed ("Low Influent Flow" alarm) and entered a soft shut-down mode, which also had to be manually reset. This demonstration-specific issue could also be resolved by installing actuated valves to help control influent flow rates.

Project Changes Based on Successful Performance

Biofiltration as primary filtration, or as a replacement for primary clarification, demonstrated a more consistent performance than anticipated, so the project operated continuously as a primary filtration system instead of switching back to primary effluent filtration or changing to a polishing step after primary clarification, as originally planned. The reasons for continued primary filtration included that primary filtration in general is expected to have more full-scale implementations (compared with primary effluent filtration applications), and that if a system successfully works for primary filtration, handling the full primary treatment load, it will work for primary effluent filtration as a polishing step.

Design Criteria for Full-Scale Operation

While operational parameter testing identified the ranges of optimum HLR and SLR for the demonstration system, additional testing is still required before establishing design criteria for full-scale installations. Table 16 summarizes the operational parameters that yielded the most promising results for hydraulic performance of the demonstration-scale system. Recommendations for additional testing are also included in Table 16.

Table 16: Summary of Operational Parameters, Recommended Design Criteria, and Future Considerations

Parameter	Observed Range	Estimated Design Criteria	Target Criteria for Future Demonstrations	Considerations
Influent HLR	1.6–11.3 gpm/ft^2	2.8–3.3 gpm/ft^2	2.8 to 4.0 gpm/ft^2	• Target criteria for future demonstrations corresponded to BRW ratios of less than 20% Lower influent HLRs correspond to lower BRW ratios • Insufficient influent HLR can negatively impact biological removal by starving the biofilm • Insufficient influent HLR can negatively impact hydraulic performance (BRW ratio) by reducing total daily filtered volume (filtration run times are longer, but less flow is processed) • High HLR can negatively impact hydraulic performance (BRW ratio) by reducing the total daily filtered volume (filtration run times are shorter as the media fouls faster)
Backwash HLR	2.4–6.6 gpm/ft^2	3.5–4.1 gpm/ft^2	3.9 to 4.1 gpm/ft^2	• Target criteria for future demonstrations corresponded to BRW ratios of less than 20% • Lower backwash HLRs correspond to lower BRW ratios • Insufficient backwash HLR can negatively impact biological removal o An increased amount of biofilm is left on the filter media due to overgrowth • Insufficient backwash HLR can negatively impact solids removal o An increased amount of residual solids are left on filter media after a backwash cycle

Parameter	Observed Range	Estimated Design Criteria	Target Criteria for Future Demonstrations	Considerations
Influent SLR	4.9–43.7 lbs TSS/ft^2/day	7.2–14.9 lbs TSS/ft^2/day	7.2–14.9 gpm/ft^2	• Target criteria for future demonstrations correspond to BRW ratios of less than 15-20% • Higher SLRs correspond to higher BRW ratios ○ The filter media becomes saturated with solids and organic material which leads to faster fouling and greater DO needed for effective biological removal
Terminal Head loss Depth	37 inches	—	40–96 inches	• Design criteria will need to be developed in future demonstrations to evaluate the minimum and maximum terminal head loss values for effective treatment • Greater terminal head loss values are expected to improve BRW ratio as filtration run time (and total daily filtered volume) are increased • Greater backwash HLR will be needed to effectively clean the increased surface area of filter media

Parameter	Observed Range	Estimated Design Criteria	Target Criteria for Future Demonstrations	Considerations
Chlorine Dosing Rate	5 mg/L	—	0–10 mg/L	• Design criteria will need to be developed in future demonstrations to evaluate the impact of no chlorine dosing and high chlorine dosing • Chlorine dosing will directly impact biological treatment performance ○ Insufficient chlorine dosing will result in biofilm overgrowth (the rate of bacterial production is greater than the rate of biofilm removal by chlorine) ▪ Excess biofilm can slough off from the filter media during filtration and enter the filtered effluent stream, which reduces treatment performance ○ Chlorine overdosing will result in biofilm die-off (the rate of bacterial production is less than the rate of biofilm removal by chlorine) • Chlorine dosing is not expected to significantly impact BRW ratio

Summary of Operational Parameters Studied and Recommended Design Criteria.

Source: Kennedy Jenks

Comparison of Biofiltration Demonstrations

As discussed in Section 2, there are currently three primary treatment systems operating at the LCWD WWTP–the biofiltration demonstration-scale system, the parallel full-scale primary filtration system using PCDF, and the WWTP's permanent primary clarifiers. Table 17 provides a comparison of these systems.

Table 17: Comparison of Primary Treatment Systems at Linda County Water District Wastewater Treatment Plant

	Biofilter	Primary Filter	Primary Clarifier
			
Supplier	WesTech Engineering, Inc.	Aqua Aerobic Systems, Inc.	—
Filter Media	Compressible Media Filter	Pile Cloth Disc Filter	—
Pore Size	Gradient porosity*	5 µm	—
Average Design Flow	0.09 MGD	1.5 MGD	2.5 MGD
Reject Streams	Backwash	Backwash, Solids Waste, Scum Waste	Solids Waste, Scum Waste
Reject Ratio	20–25%	8–12%	—
Removal Mechanisms	Physical Filtration, Biological Degradation	Physical Filtration, Sedimentation	Sedimentation
Primary Treatment Footprint (ft^2)	110	220	2,400
Average Flow Treated per Footprint (MGD/ft^2)	0.0013	0.0068	0.0010

Comparison of biofiltration demonstration to primary cloth disk filtration and conventional primary clarification at LCWD WWTP. Note: *The biofilter's filter bed increases in density from top to bottom due to lateral compression that occurs when the tank fills.

Source: Kennedy Jenks

Energy Savings

Biofiltration provides substantial energy savings for secondary activated-sludge processes, as quantified by both computer process simulations and an M&V study. The aeration power savings estimated from each approach are summarized in Table 18. The results differ for the two studies because the computer process simulations used more conservative assumptions and normal operational conditions, while the M&V study used field data from the deployments that reflected start-up operational situations with more abnormalities.

Table 18: Projected Annual Aeration Power Savings from Full-Scale Biofiltration

Parameter	Annual Aeration Power Savings[a], kWh
From Process Simulation	144,000
From M&V	372,000
Average	264,000

[a] Projected Aeration Power Savings from Full-Scale Biofiltration at Linda WWTP (with an average daily flow rate of 2.5 MGD) based on observed secondary treatment aeration power consumption of ~ 1,300 kilowatt-hours per MG of flow treated.

Source: Kennedy Jenks

Additional ways in which biofiltration impacts a WWTP's energy use follow.

- Decrease in Anoxic Zone Mixing Power Requirement: For plants undergoing either design or upgrades, a smaller secondary treatment basin can be placed downstream of a primary filter while maintaining the same MLSS as with a primary clarifier. Based on process simulations run for the deployment site at LCWD WWTP, and at additional simulations for Lancaster WRP and the City of Manteca WQCF, a reduction in secondary treatment basin size reduces the mixing volume of the anoxic portion, thereby reducing mixing power requirements by 5 to 30 percent, based on process-simulation findings.
- Increase in Digester Gas Production: Plants with cogeneration may benefit from the diversion of greater amounts of high-gas-value primary solids during primary treatment. Digester gas production at the deployment sites is expected to increase by 12 to 33 percent, based on process simulation findings.
- Change in Primary Treatment Power: Although secondary treatment consumes the largest share of power at a WWTP, primary treatment also accounts for a portion of power consumption. Power consumption for the primary biofilter versus primary clarifier is not expected to significantly impact overall energy use as much as secondary treatment. Further analysis is needed, however, to

optimize both backwash aeration requirements and blower size for a biofiltration system.

Conclusion

In conclusion, the performance results of this project indicate that biofiltration shows promise as a technically feasible approach for improving wastewater treatment efficiency and providing energy and cost savings at wastewater treatment plants.

Technical Feasibility

Biofiltration also shows promise as a technically feasible alternative to conventional primary wastewater treatment.

- Biofiltration Shows Consistent Solids Treatment Performance of Raw Wastewater: Operational performance of the demonstration system at LCWD WWTP for 10 months demonstrated this technology's ability to effectively treat raw wastewater. Biofiltration demonstrated consistent solids removal performance regardless of variations in the influent loading rate.
- Biofiltration Shows Promising Biological Treatment Performance of Raw Wastewater: Operational performance of the demonstration system at LCWD WWTP demonstrated this technology's ability to biologically treat raw wastewater. During periods of operation, biofiltration demonstrated consistent removal of soluble material regardless of variations in the influent loading rate. Biological removal performance was impacted, however, by operational challenges specific to the demonstration-scale system including loss of influent flow, and operational changes applicable to a full-scale system (for example, HLR, SLR, chlorine dosing).
- Operational Parameter Testing Identified Optimal Hydraulic Performance Range: It was concluded that the optimum influent HLR and influent backwash flow rate is 2.8-3.3 gpm/ft^2 and 3.5 - 4.1 gpm/ft^2 , respectively, to maintain hydraulic efficiency of the biofiltration system with a BRW ratio of less than 20 percent. The configuration of the demonstration limited the system's ability to operate at ideal parameters; for future testing, actuated valves are recommended to help control both the influent and backwash flow rates.
- Additional Testing Will Firm up Design Parameters: Before design criteria for full scale systems can be established, additional testing will be required to both evaluate the impact of chlorine dosing rates on biological removal and strategize how best to increase filter run times.

Energy Savings for Wastewater Treatment Plants

Biofiltration offers the following energy savings potential for WWTPs:

- Reduced Aeration Energy: As a result of the higher organics removal achieved with biofiltration, the annual electrical energy requirement for aeration in Linda

WWTP activated sludge basins (approximately 1,200,000 kWh annually as measured during the M&V study) could be reduced by 15 to 20 percent. This can translate to a reduction of 180,000 to 240,000 kWh (approximately $35,000 to $47,000 based on $0.20/kwh) at an average daily flow rate of 2.5 MGD.

- Increased Biogas Production: As a result of the higher organic energy content of volatile suspended solids removed by biofiltration, renewable biogas energy production from anaerobic digestion is projected to increase by 10 to 30 percent.

Biofiltration Provides Increased Flexibility in WWTP Design:

- Reduced Primary Treatment Footprint: Primary biofiltration reduces the footprint of primary treatment by approximately 15 to 20 percent, which translates to major cost savings, particularly for wastewater treatment plants with limited available land.
- Improved Secondary Treatment Efficiency: Improved primary effluent quality and reduced organics loading upstream of the secondary biological treatment process also either increase existing secondary-treatment capacity or decrease the required secondary-treatment footprint.

Future Demonstration and Research Direction

As discussed above, additional testing is required before establishing design criteria for full-scale installations. Some recommended testing follows.

- Chlorine Dosing Study:
    - Investigate the impact of chlorine dose during backwash cycles on both soluble BOD and soluble COD removal.
    - Applied chlorine dosage rate was approximately 5 mg/L throughout the duration of the study. Chlorine dosage will need to change proportionately to the backwash flow rate to effectively maintain biofilm on the filter media.
    - A chlorine study will help determine how much chlorine is required to manage biofilm growth on the filter media.
- Filtration Optimization Study: Additional methods should be investigated to increase the time spent in filtration, increase the volume of filtered effluent produced during filtration, and decrease the time spent in backwash (in biofiltration systems, simultaneous filtration and backwash are not possible) to maximize system efficiency and maintain biological removal. Potential adjustments follow.
    - Increase the terminal head loss values to allow more head to develop over the filter media before triggering a backwash cycle.

- Increase the filtration depth by adding media by an additional 10 to 20 percent to allow longer filtration cycles as more surface area is available for influent loading.

CHAPTER 6: Benefits to Ratepayers

As California's ambitious multi-year energy-reduction goals progress, municipal wastewater treatment plants are increasingly motivated to reduce their energy consumption and move toward net-zero energy use. As shown in this project, biofiltration offers a viable alternative to decrease energy consumption for wastewater treatment and simultaneously increase energy recovery in the form of biogas production. Californians would benefit from installing biofiltration systems at the state's wastewater treatment plants in several ways.

Cost Savings

Reduced Wastewater Utility Costs

Reduced capital (i.e., for new or WWTP expansion projects) and energy operation costs for wastewater treatment plants from biofiltration could benefit ratepayers through reduced wastewater customer fees.

Reduced Electric Utility Fees

Reduced wastewater treatment energy use, coupled with increased biogas production, could reduce electric utility costs.

Environmental Benefits

Reduced Greenhouse Gases

The increased diversion of organics to the anaerobic digester for biogas production will reduce the amount of greenhouse gases, major contributors to climate change, currently produced at wastewater treatment plants.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
ADF	Average daily flow
AOR	Actual oxygen requirement
APT	Advanced primary treatment
ASB	Activated sludge basin
Biofiltration	A treatment technology in which particulate material is removed mainly through physical filtration and organic material is removed through biological degradation.
BOD	Biochemical oxygen demand
BRW	Backwash reject water
cBOD	5-day carbonaceous biochemical oxygen demand
CMF	Compressible media filter
COD	Chemical oxygen demand
DO	Dissolved oxygen
EPIC (Electric Program Investment Charge)	The Electric Program Investment Charge, created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.
gpd	Gallons per day
gpm	Gallons per minute
HLR	Hydraulic loading rate
HMI	Human-machine interface
hp	Horsepower
kW	Kilowatt
LCWD	Linda County Water District
M&V	Measurement and verification
MGD	Million gallons per day
MLSS	Mixed liquor suspended solids
NO_X-N	Nitrate plus nitrite nitrogen
NTU	Nephelometric turbidity units
O&M	Operation and maintenance

Term	Definition
PCDF	Pile cloth depth filter
PLC	Programmable logic controller
Primary filtration	Primary filtration, also referred to as raw wastewater filtration, is filtration of screened raw wastewater as a treatment alternative to conventional primary clarification process at wastewater treatment plants.
sBOD	Soluble biochemical oxygen demand
SCADA	Supervisory Control and Data Acquisition
scfm	Standard cubic feet per minute
sCOD	Soluble chemical oxygen demand
SLR	Solids loading rate
SRT	Solids retention time
TSS	Total suspended solids
TKN	Total Kjeldahl nitrogen
VFD	Variable frequency drive
VSS	Volatile suspended solids
WWTP	Wastewater treatment plant

REFERENCES

Bolzonella, David; Pavan, Paolo; Battistoni, Paolo; Cecchi, Franco. 2005. "Mesophilic anaerobic digestion of waste activated sludge: influence of the solid retention time in the wastewater treatment process." *Process Biochemistry*. 40(2005): 1453-1460.

Caliskaner, Onder; Tchobanoglous, George; Reid, Terry; Kunzman, Bill; Young, Ryan; Ramos, Nick. 2015. *Evaluation and Demonstration of Five Different Filtration Technologies as an Advanced Primary Treatment Method for Carbon Diversion*. Proceedings of the Water Environment Federation. (2015): 795-818.

Caliskaner, Onder; Tchobanoglous, George; Reid, Terry; Young, Ryan; Downey, Mike; Kunzman Bill. 2016. *Advanced Primary Treatment via Filtration to Increase Energy Savings and Plant Capacity*. Proceedings of the Water Environment Federation. (2016): 782-794.

Caliskaner, Onder; Wu, Zoe; Lund, Julia; Paez, Catrina (Kennedy/Jenks Consultants). 2019. *Raw Wastewater Filtration to Reduce Secondary Treatment Electrical Energy Demand.*; Final Project Report. California Energy Commission. Project Number: EPC-14-076.

Caliskaner, Onder; Young, Ryan; Ramos, Nick; Young, Ryan (Kennedy/Jenks Consultants). 2015. *Primary Effluent Filtration as an Intermediary Wastewater Treatment Step Project; Final Demonstration Evaluation Project Report*. California Energy Commission. Project Number PIR-11-018.

Electric Power Research Institute and Water Research Foundation. 2013. *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries.* http://www.waterrf.org/Pages/Projects.aspx?PID=4454.

EnviroSim Associates Ltd. 2017. BioWin (version 5.3).

Metcalf & Eddy. 2014. *Wastewater Engineering - Treatment and Reuse (5th Edition).*

M/J Industrial Solutions. 2003. Municipal Wastewater Treatment Plant Energy Baseline Study. PG&E New Construction Energy Management Program. Pacific Gas and Electric Co. http://www.lb7.uscourts.gov/documents/11-22601.pdf.

U.S. Environmental Protection Agency (U.S. EPA). 2013. *Energy Efficiency in Water and Wastewater Facilities: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs*. Local Government Climate and Energy Strategy Guides. https://www.epa.gov/sites/production/files/2015-08/documents/wastewater-guide.pdf