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FINAL PROJECT REPORT

Raw Wastewater Filtration to Reduce Secondary Treatment Electrical Energy Demand

Gavin Newsom, Governor

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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 CEC 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.

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- 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.

Raw Wastewater Filtration to Reduce Secondary Treatment Electrical Energy Demand is the final report for Contract Number EPC-14-076 conducted by Kennedy Jenks Consultants. The information from this project contributes to THE Energy Research and Development Division's EPIC Program.

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ABSTRACT

Wastewater treatment accounts for a significant portion of municipal energy use. Conventional wastewater treatment uses primary clarification for solids removal and secondary activated sludge treatment for organics removal. Primary filtration is an emerging advanced primary treatment technology that replaces primary clarification with filtration of screened raw wastewater. Compared to primary clarification, primary filtration improves energy efficiency of wastewater treatment by removing greater amounts of solids and organics in the primary treatment step. The project quantified energy savings from primary filtration by implementing a full-scale primary filtration system at the Linda County Water District Wastewater Treatment Plant (2017–2019) and two demonstration-scale systems at the Lancaster Water Reclamation Plant (2017–2018) and the City of Manteca Wastewater Quality Control Facility (2018–2019).

Primary filtration saves energy savings by removing substantially more organic material compared to conventional primary treatment, resulting in much lower electricity consumption for aeration in the downstream biological treatment step and higher digester gas energy production. Estimated annual energy savings range from $22,000 to $35,000 per million gallons per day of wastewater treatment plant average capacity. Additional benefits include lower capital costs, smaller footprint requirements for the primary treatment step, and higher treatment capacity of the biological treatment aeration basins.

Keywords: wastewater treatment, primary filtration, raw wastewater filtration, carbon diversion, advanced primary treatment, pile cloth depth filtration, aeration energy, digester gas production

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Introduction

Wastewater treatment consumes a significant amount of energy. According to the United States Environmental Protection Agency, energy consumption at drinking water and wastewater treatment facilities in 2013 accounted for approximately 3 percent to 4 percent of energy use in the United States. In general, wastewater treatment plants use 1,600 kilowatt hours to 3,300 kilowatt hours of electricity per million gallons of flow treated according to a 2013 Electric Power Research Institute study. A typical wastewater treatment plant employs up to four treatment levels: preliminary, primary, secondary, and tertiary. The preliminary stage removes large debris and coarse particles using mechanical screens or grit removal systems. Primary treatment removes settleable solids and floatable material, typically through primary clarification. Secondary treatment removes organics using a biological process, such as the activated sludge process. The tertiary stage, or advanced treatment, consists of additional treatment or disinfection to meet specific regulatory requirements or effluent objectives. In addition to treatment of the 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, representing between 30 percent and 60 percent of energy use at most plants according to a study by M/J Industrial Solutions in 2003. Aeration of the activated sludge process accounts for most of that energy use.

Wastewater treatment plans commonly use filtration to remove finer particles in the tertiary treatment. There has been growing interest in filtration as an emerging technology for advanced primary treatment. A 2012 project sponsored by the California Energy Commission (PIR 11-018) evaluated various filtration technologies for primary effluent filtration, in which effluent leaving the primary clarifier is filtered to remove additional suspended solids prior to secondary treatment. Primary effluent filtration was found to improve primary effluent quality and reduce aeration energy demand in the secondary activated sludge process, resulting in significant energy and capital savings. Informed by these results, this project uses filtration technology to treat raw wastewater after preliminary treatment in place of primary clarification.

Before this project, no full-scale primary filtration system had been implemented and operated at a wastewater treatment plant. This project implements and operates a primary filtration system to assess technical performance and the potential for significant energy savings compared to conventional primary clarification treatment.

Project Purpose

The purpose of this project was to demonstrate that the replacement of conventional primary clarification with primary filtration is a technically viable and commercially attractive way to achieve significant energy savings at wastewater treatment plants by:

- Quantifying electrical energy savings resulting from reduced aeration demand in the downstream activated sludge process and/or from operation of a smaller activated sludge basin.

- Quantifying biogas production from increased diversion of solids during primary treatment.
- Quantifying capital cost savings from reduced primary and secondary treatment footprint.
- Evaluating long-term stable operation of primary filtration with consistent hydraulic and treatment performance.
- Investigating additional downstream treatment impacts of primary filtration that may require modification to existing treatment processes.
- Developing operational, maintenance, and design criteria for full-scale installations.

This project is important for Californians because the potential cost savings at wastewater treatment plants could reduce wastewater fees for customers. Ultimately, if this technology were adopted across California, the large reduction in energy consumption for wastewater treatment, combined with increased biogas production, could reduce peak electricity loads on California's energy grid and decrease electrical utility costs.

Project Process

The project installed primary filtration at three deployment sites in California: the Linda County Water District Wastewater Treatment Plant in Olivehurst (Yuba County), the Lancaster Water Reclamation Plant in Lancaster (Los Angeles County), and the City of Manteca Water Quality Control Facility in Manteca (San Joaquin County).

Description of Deployments

This project installed the first full-scale primary filtration system in the United States. The system was installed at the Linda County Water District Wastewater Treatment Plant. The system, with an average design capacity of 1.5 million gallons per day (mgd), included a solids-handling system to thicken reject streams from the filter and direct concentrated solids to an anaerobic digester for increased biogas production. The full-scale system has been in continuous operation since August 2017 at an average daily flow rate of 0.3 mgd to 0.7 mgd.

The project installed demonstration-scale primary filters at the Lancaster Water Reclamation Plant and the City of Manteca Wastewater Quality Control Facility. The installation at Lancaster operated at approximately 0.02 mgd from November 2016 to December 2017. The installation at Manteca operated at rates between 0.03 mgd and 0.12 mgd from February 2018 to March 2019. Data included in this report for the Linda County and Manteca systems goes through December 2018.

Adaptation of Filter Technology for Primary Treatment

Compared to the typical use of filtration in tertiary treatment, the pile cloth depth filtration systems used in this project were specifically modified for primary treatment application. Pile cloth depth filtration uses vertically oriented, submerged pile cloth filter disks connected by a center tube inside a filter basin. Wastewater is filtered outside-in from both sides of each filter disk, and filtered effluent is discharged through the center tube. During filtration, solids may build up on the filter media surface to restrict flow, resulting in a filter head loss. The head loss causes a rise in water level inside the basin. Backwash is initiated periodically to reduce head loss and recover the water level by reversing flow through the filter media to wash off accumulated solids. The backwash reject water is discharged from the filter basin as a reject stream.

For primary treatment, the filtration basin was redesigned to collect settleable solids in the space below filter disks and floatable material at the water surface. The settleable solids are pumped out periodically also as part of the filter reject stream. The combined reject stream is further processed to concentrate the solids to achieve increased biogas production.

Quantification of Energy Savings

Using the treatment and hydraulic performance results obtained from the demonstration systems, the project team conducted computer process simulation and third-party energy measurement and verification to quantify energy savings associated with primary filtration. The computer process simulation used observed hydraulic and treatment performance to evaluate full-scale implementation of primary filtration for each of the three deployment sites, as well as for six additional municipal wastewater treatment plants representative of typical plants in California. The researchers selected six representative plants to cover a spectrum of sizes and treatment processes. The project team conducted the energy measurement and verification study by directly logging power consumption of the demonstration filters and associated equipment.

Project Results

The results of the project demonstrated successfully that primary filtration is a technically viable and cost-effective approach to reduce energy use at wastewater treatment plants. Key findings of the project include:

- Technical feasibility: Primary filtration demonstrated consistent operational, hydraulic, and treatment performance across all three deployments:
    - Primary filtration consistently removed 75 percent to 85 percent of suspended solids and 40 percent to 60 percent of organics from screened raw wastewater. These removal rates are higher than typical rates of 50 percent to 60 percent of suspended solids and 20 percent to 30 percent of organics by a conventional primary treatment system.
    - Full-scale primary filtration is a feasible replacement of primary clarification. The full-scale installation at the Linda County Water District Wastewater Treatment Plant has operated for a year and a half without experiencing significant operational issues.
- Reduced wastewater energy costs: Estimated annual energy savings range from \$22,000 to \$35,000 per mgd of a treatment facility’s average capacity.
    - Due to higher removal efficiency for organic material achieved with primary treatment, electrical energy for aeration in activated sludge basin is estimated to be reduced by 15 percent to 30 percent. The corresponding annual aeration power savings is between \$9,000 and \$17,000 per mgd of a treatment facility’s average capacity.
    - The higher organic energy content of volatile suspended solids removed by primary filtration could increase renewable biogas energy production from anaerobic digestion by 30 percent to 40 percent. The corresponding digester gas

power recovery increase is between $13,000 and $18,000 per mgd of a treatment facility's average capacity.

- Reduced wastewater capital costs: Estimated capital cost savings range from $640,000 to $1.1 million per mgd of a treatment facility's average capacity, depending on influent wastewater characteristics and system specific requirements.
    - Primary filtration reduces the footprint of conventional primary treatment by approximately 60 percent to 70 percent, which translates to significant cost savings, particularly for wastewater treatment plants with limited land availability.
    - The improved primary effluent quality, coupled with reduced organics loading (upstream of the secondary biological treatment process), can increase existing secondary treatment capacity or decrease the footprint required for secondary treatment.

Primary filtration can help to achieve California's Senate Bill 350 goals to reduce costs, reduce greenhouse gas emissions, and help achieve a statutory requirement to double energy efficiency savings by 2030. There is growing motivation among municipal wastewater treatment plants to reduce energy consumption and achieve net-zero energy use. As described above, primary filtration offers a viable alternative to decrease energy consumption for wastewater treatment and to increase energy recovery in the form of biogas production.

Californians could benefit from implementing primary filtration at wastewater treatment plants through:

- Reduced wastewater utility fees: The reduced capital and operational costs for wastewater treatment plants could enable a municipality with a growing population to treat a larger amount of wastewater without raising customer fees.
- Reduced electric utility fees: The higher removal of organic matter in primary filtration results in lower secondary treatment aeration electricity consumption and higher gas energy production in anaerobic digestion (because of the high energy content of solids removed by the filter). The reduced wastewater energy use coupled with increased biogas production could reduce peak load on California's energy grid and decrease electrical utility costs.
- Reduced greenhouse gases: The increased diversion of organic materials to the anaerobic digester for biogas production will reduce the greenhouse gases produced from wastewater treatment.

CHAPTER 1: Introduction

1.1 Background

A significant amount of energy is consumed in municipal wastewater treatment. A typical wastewater treatment plant consists of up to four treatment steps: preliminary, primary, secondary, and tertiary. The preliminary stage removes large debris and coarse particles via mechanical screens and/or grit removal systems. Primary treatment removes settleable solids and floatable material, typically through primary clarification.

Secondary treatment removes organics using a biological process, such as aerated activated sludge process. Secondary treatment is typically the most energy intensive portion of the treatment process, with aeration of the activated sludge process accounting for most of the energy use.

The tertiary stage, or advanced treatment, consists of additional treatment and/or disinfection to meet specific regulatory requirements or effluent objectives. In addition to treatment of the liquid streams, many wastewater treatment plants also produce biogas (a renewable energy source) from removed solids in a process known as anaerobic digestion.

Although filtration is commonly used at wastewater treatment plants (WWTPs), its current use is generally limited to tertiary treatment. Primary filtration is an emerging technology that has not previously been implemented at any WWTP in the world to achieve significant energy savings compared to conventional primary treatment (i.e. primary clarification). Successful implementation of primary filtration can provide substantial energy-saving benefits over conventional primary wastewater treatment.

In a previous advanced primary treatment (APT) demonstration project, sponsored by the California Energy Commission, primary effluent filtration (i.e. the filtration of effluent from primary clarification) was demonstrated for five different filter technologies at the Linda County Water District (LCWD) WWTP (Caliskaner, Tchobanoglous, et al. 2015; Caliskaner, Young, & Ramos 2015). Primary effluent filtration was found to be an effective intermediary step prior to secondary treatment. Primary effluent filtration was found to produce energy savings by decreasing the energy required for aeration, reducing tank size requirements of secondary treatment and increasing digester gas production.

Motivated by the success of primary effluent filtration, this project demonstrated the use of primary filtration, the filtration of raw wastewater after preliminary treatment. This project evaluated the technical performance and energy saving potential of primary filtration as a viable replacement for conventional primary treatment (i.e. primary clarification).

Compared to primary clarification, primary filtration improves energy efficiency of wastewater treatment and offers key advantages, including:

- Substantially higher removal of organic material, resulting in significantly lower electricity consumption in the downstream aerated activated sludge basins (ASBs).
- Smaller footprint requirements both for primary and secondary treatment steps.

- Increased digester gas energy production.
- Increased treatment capacity of the biological treatment aeration basins.

The primary filtration system in this project uses pile cloth disk filtration (PCDF), a filtration technology which, as demonstrated in previous studies, was successfully used also for primary effluent treatment.

1.2 Overall Project Objectives

The overall objective of this project was to demonstrate that raw wastewater filtration (i.e. primary filtration) is a technically viable and commercially attractive approach to achieve significant electrical energy savings at WWTPs. Primary filtration has already shown great potential as an APT technology for improved wastewater treatment efficiency. In 2014, a primary filtration pilot using PCDF was conducted in Rockford, Illinois. The pilot showed PCDF can be feasibly applied in primary treatment while achieving higher removal rates of solids and organics from screened raw wastewater than primary clarification (Ma et al. 2015). The increased diversion of carbon during primary treatment and the improved primary effluent quality can help WWTPs realize greater energy savings (Ma et al. 2015; Caliskaner et al. 2016). Additional testing of primary filtration was necessary to understand the impact of primary filtration in the context of the entire wastewater treatment process and to provide confidence for WWTPs to adopt the technology.

This project seeks to accomplish the following through the demonstration of primary filtration:

- Quantification of electrical energy savings resulting from reduced aeration demand in downstream activated sludge process and/or from operation of a smaller activated sludge basin.
- Quantification of biogas production from increased diversion of solids during primary treatment.
- Quantification of capital saving from reduced primary and secondary treatment footprint and operational energy savings.
- Evaluation of long-term, stable operation of primary filtration at consistent hydraulic and treatment performance.
- Investigation of additional downstream treatment impacts of primary filtration which may require modification to existing treatment processes.
- Development of operational, maintenance, and design criteria for full-scale installations.

1.3 Project Overview

Primary filtration was performed at three deployment sites, which are documented in Table 1. A full-scale primary filtration system (including filter reject thickening system) was installed at the LCWD WWTP and has been in operation since August 2017. Data included in this report for the LCWD WWTP full-scale system goes through December 2018. Demonstration-scale filter systems were deployed at the Lancaster Water Reclamation Plant (Lancaster WRP) from November 2016 to December 2017 and at the City of Manteca Wastewater Quality Control Facility (Manteca WQCF) from February 2018 to March 2019. Performance of each deployment was evaluated through online monitoring equipment, regular sampling, and third-party laboratory analysis. Computer process simulation and measurement and verification (M&V)

were conducted to project energy and capital savings resulting from full-scale implementation of primary filtration.

Table 1: Summary of Demonstration Deployments

Deployment Site	Plant Average Annual Flow (mgd)	Deployment Duration	Primary Filter Scale	Primary Filter Daily Average Flow (mgd)
Linda County Water District Wastewater Treatment Plant (Olivehurst, California)	1.4	August 2017 – current	Full-Scale	0.3-0.7
Lancaster Water Reclamation Facility (Lancaster, California)	14	November 2016 – December 2017	Demonstration-Scale	0.02
City of Manteca Wastewater Quality Control Facility (Manteca, California)	9.87 (rated capacity)	February 2018 – March 2019	Demonstration-Scale	0.03-0.12

Mgd = million gallons per day

Source: Kennedy Jenks Consultants

CHAPTER 2: Demonstration at Linda County Water District Wastewater Treatment Plant

2.1 Site Specific Objectives

The specific objectives of the full-scale primary filtration project at the LCWD WWTP (August 2017 to December 2018) were:

- Quantify the reduction in electrical power required for aeration in the activated sludge process, due to primary filtration. The results are described in Chapter 5.
- Determine the decrease in electrical power required for mixing due to the reduced activated sludge volume requirements. The results are described in Chapter 5.
- Determine the overall capital and electrical energy savings resulting from the increased secondary treatment capacity. The results are described in Chapter 5.
- Validate the performance of modifications to the CDF system needed to address higher solids and fat, oil, and grease (FOG) content (compared to primary clarifier effluent).
- Demonstrate filter removal efficiencies for biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), volatile suspended solids (VSS), and total suspended solids (TSS)
- Develop operational, maintenance, and design criteria for full-scale installations.
- Conduct a third-party measurement and verification (M&V) process. The results are described in Section 5.4.

2.2 System Description

A full-scale primary filter unit was installed at LCWD WWTP from February 2017 to April 2017. The filter has been in continuous operation since August 2017. Full operational period of the LCWD system is expected to last 30 months through March 2020. This chapter covers observed performance of the LCWD demonstration from August 2017 to December 2018.

2.2.1 Overview of LCWD WWTP

The LCWD WWTP is located near Marysville in Yuba County, California. It is a tertiary treatment facility that consists of two (2) rectangular primary clarifiers, four (4) ASBs, two (2) circular secondary clarifiers, six (6) compressible media tertiary filters, one (1) chlorine contact basin, and two (2) digesters. Treated wastewater is discharged to the Feather River. 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 currently operates at an average daily flow (ADF) of 1.4 mgd. In November 2018, connection was made from City of Marysville’s sewer system to the LCWD WWTP. ADF at LCWD WWTP is estimated to double to 2.8 mgd after consistent plant operation with Marysville’s connection.

2.2.2 Demonstration Filter System Components

The primary filtration project uses a primary filter to replace the primary clarifiers for primary treatment purposes at the LCWD WWTP. The system is the first full-scale installation of primary filtration at a WWTP and consists of a primary filter unit and a solids handling system. The design ADF is 1.5 mgd, with a maximum capacity of 2.5 to 3.0 mgd. The filter treats raw wastewater and discharges filtered effluent to the plant's secondary treatment processes. Reject flows from the filter go through the solids handling system to produce sludge of suitable thickness for the WWTP's anaerobic digester.

2.2.2.1 System Intake and Discharges

The primary filtration system at the LCWD WWTP is installed in an open area between the plant's primary clarifiers and ASBs. A process flow diagram of the full-scale primary filtration system at start-up is shown in Figure 1. The primary filter receives (screened) raw wastewater diverted from the influent channel of the primary clarifiers via gravity-flow. Primary filter effluent is conveyed by gravity to ASB No. 4, where it is currently combined with primary effluent from the plant's primary clarifiers.

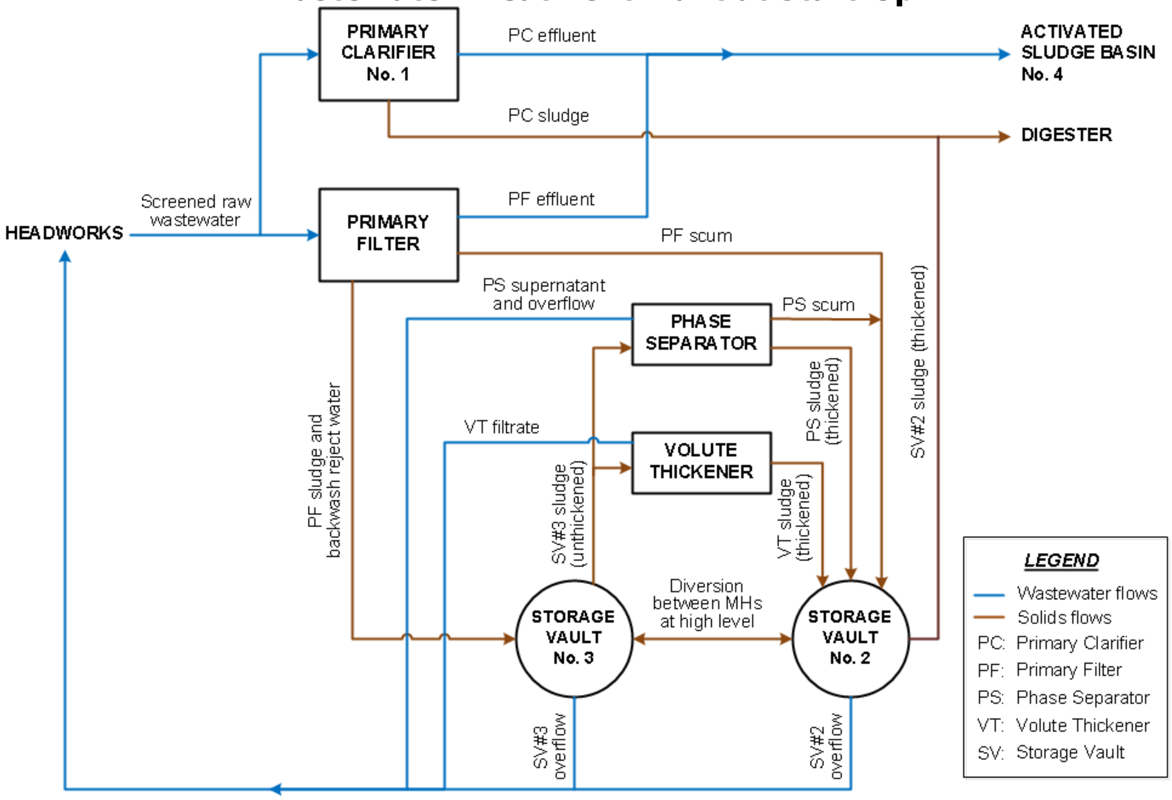
The primary filter also discharges backwash reject water (BRW) and filter sludge (FS) to a backwash equalization vault (Storage Vault No. 3) and scum to a thickened sludge storage vault (Storage Vault No. 2). A flow diagram of the solids handling processes at start-up is shown in Figure 2. The mixture of thinner sludge and BRW from Storage Vault No. 3 is thickened by either the Volute Thickener or the Phase Separator. Thickened sludge from both thickeners is directed to Storage Vault No. 2, then pumped to the WWTP's anaerobic digester for further processing.

Since start-up, the following modifications have been made to facilitate operation of the filter at full capacity and to minimize interference to the plant's treatment process:

- The phase separator was taken out of operation in February 2018 due to observed anaerobic conditions in the gravity-settling tank.
- The diversion between Storage Vault Nos. 2 and 3 was blocked off in May 2018 to prevent excessive dilution of the thickened sludge in Storage Vault No. 2 by the filter reject waters from Storage Vault No. 3.
- After receiving wastewater flows from nearby City of Marysville, the LCWD WWTP started operating a second ASB (ASB No. 2) in November 2018. One additional ASB also can be brought online when plant flow exceeds 9 mgd in peak flow conditions. Currently, primary filter effluent is sent to ASB No. 4. Primary clarifier effluent is distributed across all operating ASBs, including supplementing primary filter effluent in ASB No. 4. Additional piping modification is being constructed in early 2019 to enable parallel secondary treatment, so primary filter effluent and primary clarifier effluent can be treated separately by ASBs Nos. 4 and 2, respectively.

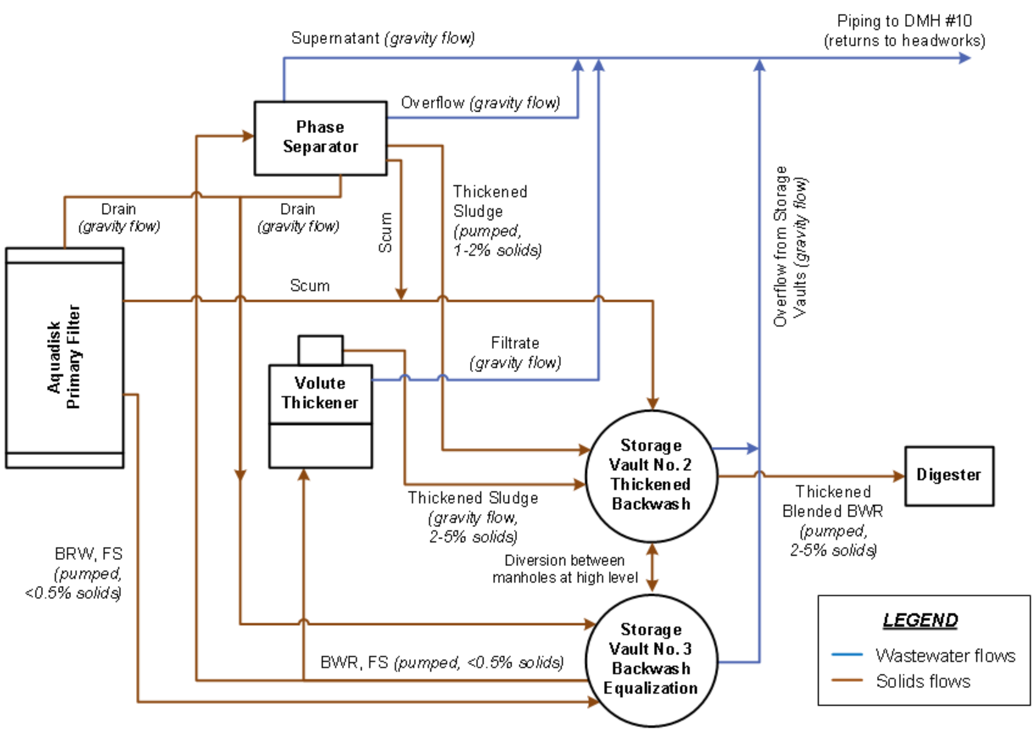
The overall system and solids handling flow diagrams were updated in November 2018 to reflect the changes listed above. Updated flow diagrams are shown in Figure 3 and Figure 4, respectively. A photograph of the primary filtration system is shown in Figure 5.

Figure 1: Primary Filtration System at Linda County Water District Wastewater Treatment Plant at Start-Up



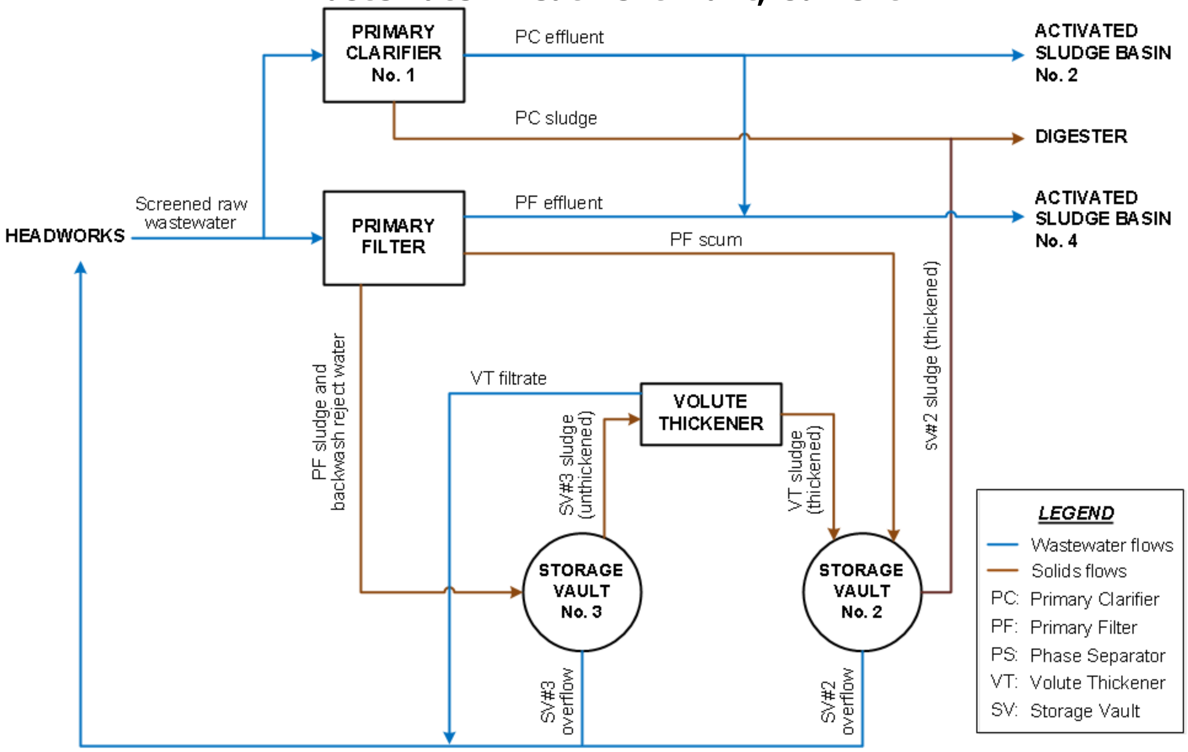
Source: Kennedy Jenks Consultants

Figure 2: Solids Handling Processes at Start-Up



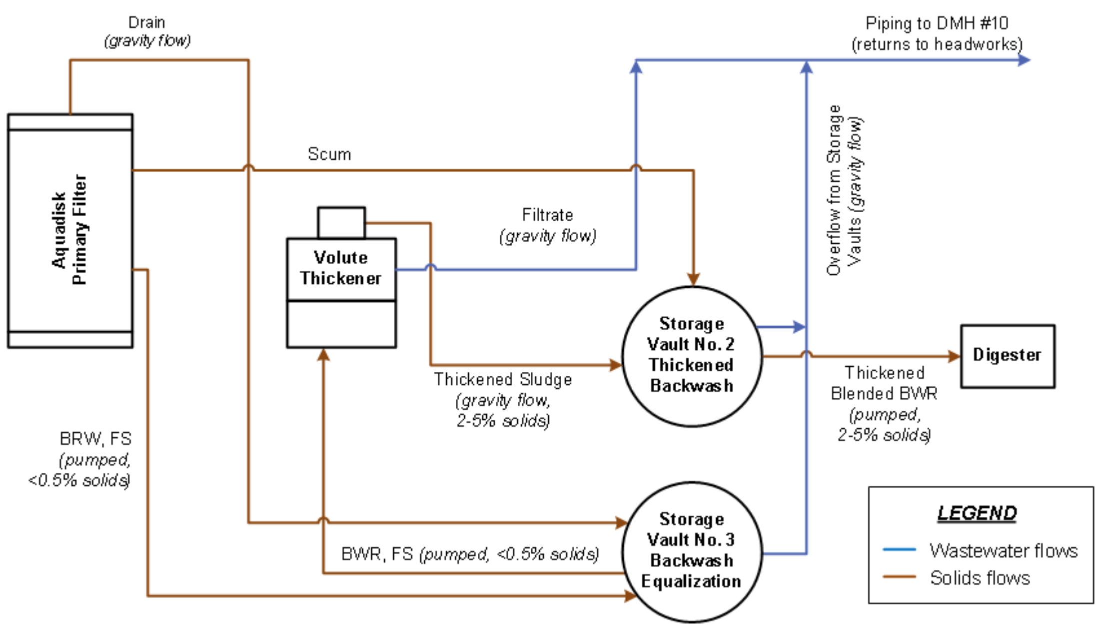
Source: Kennedy Jenks Consultants

Figure 3: Primary Filtration System at the at Linda County Water District Wastewater Treatment Plant, Current



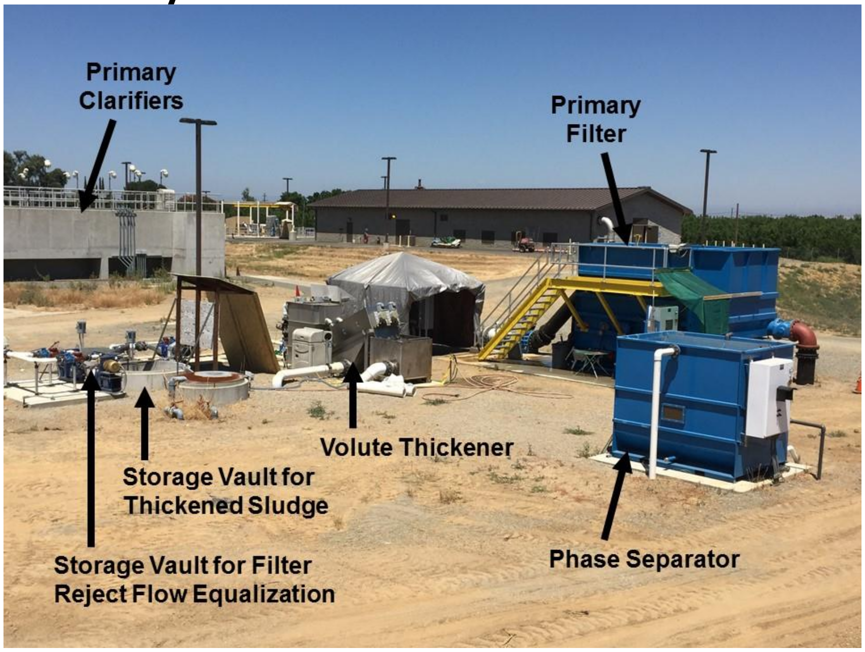
Source: Kennedy Jenks Consultants

Figure 4: Solids Handling Processes, Current



Source: Kennedy Jenks Consultants

Figure 5: Primary Filtration System at Linda County Water District Wastewater Treatment Plant



Source: Kennedy Jenks Consultants

2.2.2.2 Primary Filter

The primary filter at the LCWD WWTP is an AquaPrime AD-3 unit supplied by Aqua-Aerobics Systems, Inc. (AASI). AquaPrime uses PCDF to filter wastewater outside-to-inside through filter disks. The installation at the LCWD WWTP consists of eight (8) cloth media disks with a total filtration area of 432 ft^2 and is designed to treat an ADF of 1.5 mgd. The OptiFiber PES-14 pile cloth media on the filters is a polyester fiber blend with a nominal pore size of 5 µm. The filter tank measures 19.5 ft. long, 11.1 ft. wide, and 13 ft. high. ADF and system footprint can be used to compare hydraulic surface area (treatment capacity per square foot) of the primary filter to the primary clarifier at LCWD WWTP. The full-scale primary filter has an approximate treatment footprint of 220 ft^2 for 1.5 mgd average capacity and the primary clarifier has an approximate treatment footprint of 2,400 ft^2 for 2.5 mgd average capacity. The filter has five main operational cycles: filtration, backwash, solids waste, solids conditioning, and scum removal. Operation is controlled by an Allen-Bradley programmable logic controller (PLC) located inside a control panel with a human-machine-interface (HMI) display. Influent backwash, solids waste, recirculation, and waste discharge valves are all automated, with flows adjusted by proportional-integral-derivative (PID) feedback loops. Realtime monitoring, remote control, and data logging is available via a supervisory control and data acquisition (SCADA) system.

- Filtration mode: In filtration mode, raw wastewater is gravity-fed from the plant's primary clarifier influent channel to the filter's influent channel. The influent wastewater flows over a weir into the filter basin, where heavy solids settle to the bottom to form FS and floatables stay on top of the water surface to form scum. Remaining suspended solids are filtered by the filter disks. Filtrate is channeled by the filter frames into a centertube and routed to the effluent chamber. Effluent is discharged by gravity to the plant's ASB No. 4, where it is currently combined with effluent from the primary clarifier.

- Backwash mode: Over time, the filter builds up head loss as solids are trapped by the cloth media. The water level in the filter basin rises as head loss increases. Backwash to clean the filter media is initiated at a basin level setpoint or is based on an elapsed time period. The filter waste pump draws filter effluent inside-out through the filter disks. Backwash shoes mounted on each side of each disk provide liquid suction to clean off solids. The disks are rotated by a drive motor so the entire media surface comes into contact with the backwash shoes. BRW is pumped through the four backwash valves, each connected to backwash shoes from two disks. The disks can be set to wash simultaneously or in a sequence of two or four disks at once.
- Solids waste mode: To prevent FS contacting filter cloth media surface, FS is discharged via solids wasting. Solids waste mode is initiated after a set number of backwashes since the last solids waste cycle or based on an elapsed time interval. The waste pump pumps the FS sequentially through three solids waste valves at the bottom of the filter basin and into Storage Vault No. 3.
- Solids conditioning mode: After every preset number of solids wasting or after a preset time interval, the filter performs a solid conditioning cycle. FS from solids wasting is recirculated within the filter basin instead of discharged to Storage Vault No. 3. The recirculation of FS prevents anaerobic conditions developing at the bottom of the basin. Filter pH is monitored to ensure pH stays above 5.5.
- Scum removal mode: Scum is removed from the filter basin water surface at a set time interval. During scum removal, the water level in the basin rises above the scum weir, and the scum valve opens to discharge scum over the weir and into Storage Vault No. 2.

2.2.3 Sludge Thickening System

Primary filtration typically produces combined filter reject flows containing less than 0.5 percent solids, which requires thickening prior to anaerobic digestion. The full-scale primary filtration installation at the LCWD WWTP includes two thickening devices, the Volute Thickener and the Phase Separator.

- The Volute Thickener, supplied by Process Wastewater Technologies LLC (PWTech), is the main sludge thickener for the project. The thickener includes a flash mixing tank, a flocculation tank, and two dewatering drums. A dilute solids mixture containing BRW and FS is pumped from Storage Vault No. 3 to the flash mixing tank and dosed with an acrylamide-based polymer. The mixture is then gently mixed in the flocculation tank to facilitate floc formation. The flocculated mixture is processed by the dewatering drums, each with a design capacity of 150 gallons per minute (gpm). Each drum is 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 the primary filter demonstration, the thickener is operated to achieve target output of 2 to 12 percent solids.
- The Phase Separator, supplied by AASI, is a supplemental sludge thickener for the project with a design capacity of 35 gpm. The separator thickens BRW and FS by

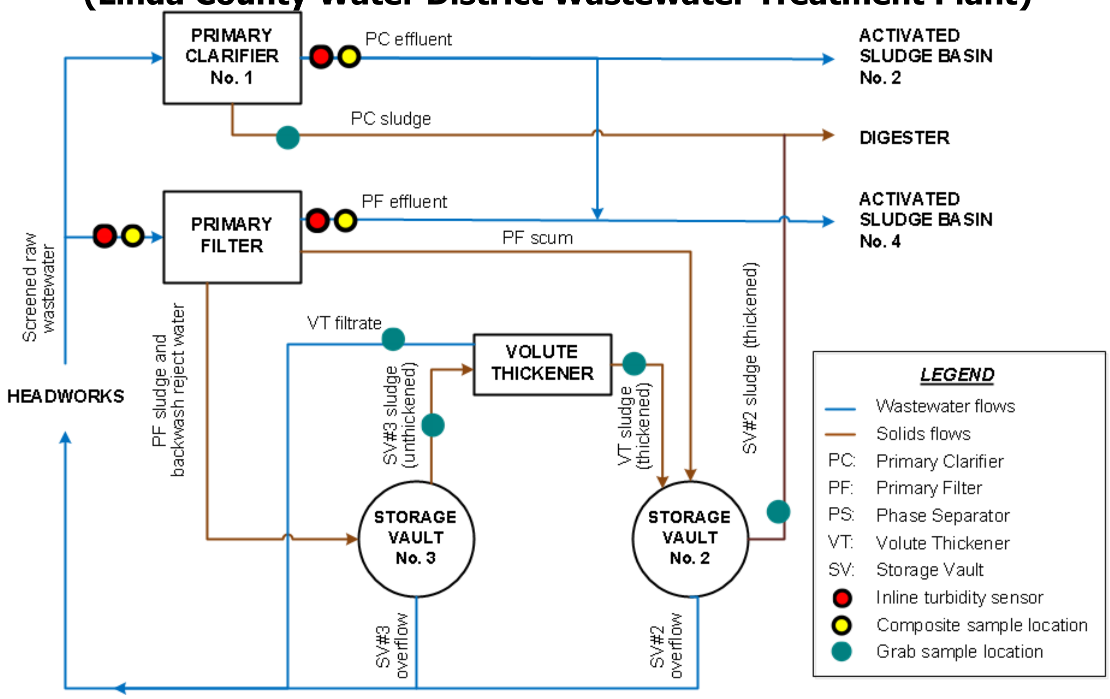
gravitational separation up to 1.5 to 2 percent solids. The separator unit measures 11 ft long by 8 ft wide by 8 ft high. Thickened separator sludge is discharged to Storage Vault No. 2 based on setpoint for discharge flow rate, duration, and time interval.

2.2.4 Sampling and Monitoring Equipment

Operation of the demonstration project includes equipment for continuous monitoring, as well as grab and composite samples to be analyzed by the LCWD lab and third-party labs. In addition to constituent monitoring, third-party energy verification confirmed the energy savings for this emerging technology application.

A diagram of all sampler and sensor locations is shown in Figure 6.

Figure 6: Primary Filtration System Sampler and Sensor Locations (Linda County Water District Wastewater Treatment Plant)



Source: Kennedy Jenks Consultants

2.2.4.1 Field Analysis

Field analysis is performed with the monitoring and control system installed onsite.

- Continuous performance monitoring: A SCADA system for the primary filtration system was set up to record data at 5-second intervals. Logged data include mode of operation, filter influent flow, filter reject flow rates, waste pump vacuum, basin level, and basin pH. The system also allows for remote monitoring and control of the primary filtration system. The filter is equipped with inline turbidity sensors (Hach Solitax) in the influent and effluent basins. Turbidity data are stored on the controller (Hach SC200) and also logged by the SCADA system.
- Nitrate control system: Since the primary filter system removes a greater organic load than the existing primary clarifiers, there is concern that an insufficient organic presence entering the activated sludge basins could potentially impact denitrification process. The nitrate control system is set up to provide supplemental carbon feed to

support the denitrification process as needed. The nitrate control system consists of a Nitrack Controller and Micro-C 2000 carbon feed source, both supplied by Environmental Operating Solutions, Inc. The Nitrack Controller system is designed to allow for dynamic adjustment of the supplemental carbon feed rate based on a nitrate concentration set-point. The system includes a PLC and operation screen. The Nitrack Controller receives nitrogen measurements from two (2) Nitratax sensors supplied by HACH. Micro-C 2000 is added as needed.

2.2.4.2 Third-Party Energy Measurement and Verification

BASE Energy performed third-party energy M&V for the primary filtration project. BASE Energy quantified the energy savings associated with primary filtration by comparing the energy consumption for existing plant's baseline and for the replacement of primary clarification with primary filtration. The results are described in Section 5.4.

2.3 Installation of Full-Scale System

2.3.1 Installation Timeline

Construction of the demonstration system took place from November 2016 to April 2017. The timeline for design, installation, and start-up of the primary filtration demonstration system at LCWD WWTP is given in Table 2.

Table 2: Deployment Installation Timeline (Linda County Water District Wastewater Treatment Plant)

Month	Task Completed
November 2016	• Demolition & clearing of construction site • Pouring of concrete slabs
December 2016	• Curing of concrete slabs
January 2017	• Delivery of major process equipment
February 2017	• Installation of AquaPrime primary filter, Phase Separator, and Volute Thickener • Installation of pipelines • Installation of electrical system
March 2017	• Installation of submersible and self-prime pumps
April-June 2017	• System testing and initial start-up

Source: Kennedy Jenks Consultants

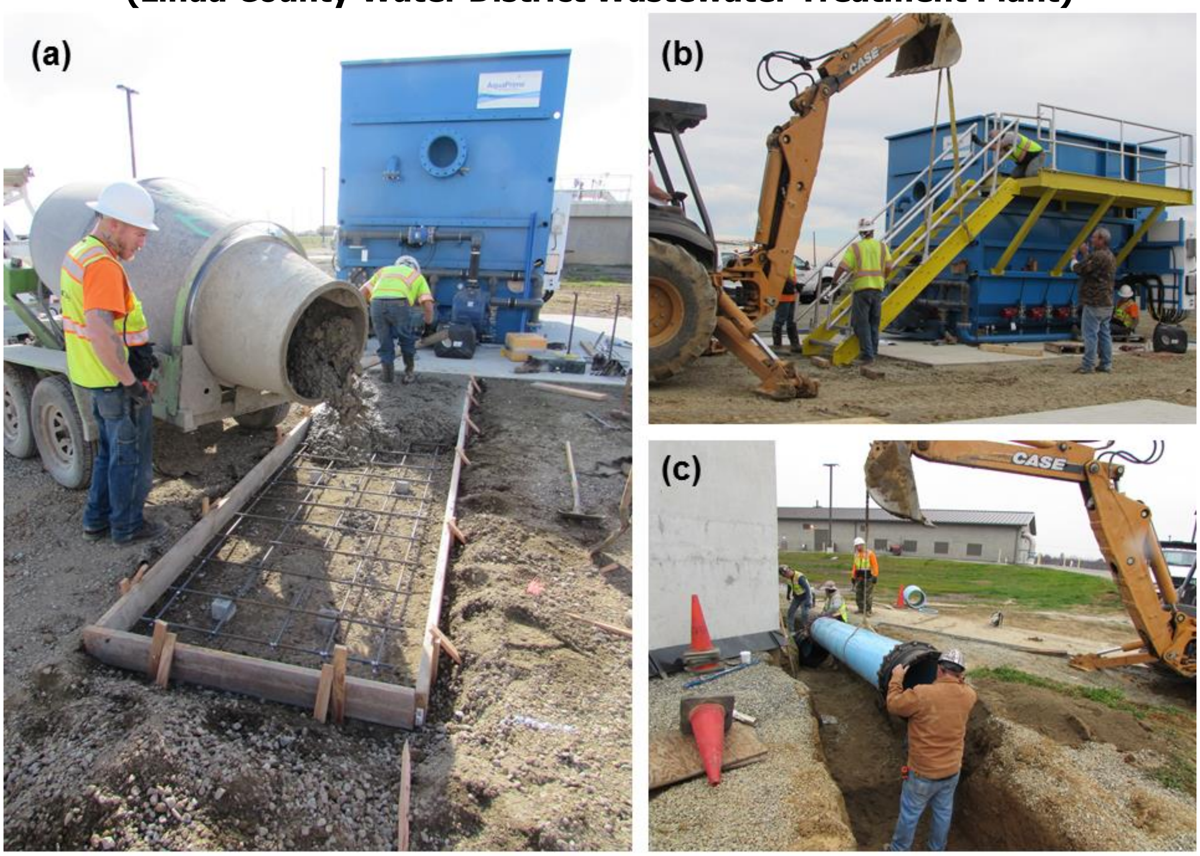
The inside of the empty filter is shown in Figure 7. The tank includes eight PCDF disks. The installation of the tank is shown in Figure 8.

Figure 7: Inside of Filter Tank
(Linda County Water District Wastewater Treatment Plant)

Interior of the primary filter tank at LCWD WWTP, with eight cloth media filter disks.

Source: Kennedy Jenks Consultants

Figure 8: Photographs of Construction Work
(Linda County Water District Wastewater Treatment Plant)



(a) Concrete slab is poured for the primary filtration system. (b) AquaPrime filter tank is installed. (c) underground piping is laid.

Source: Kennedy Jenks Consultants

2.3.2 Start-up

Construction of the primary filter system at the LCWD WWTP was completed in April 2017. Testing of the system was conducted in subsequent months, with intermittent operation of the filter in July 2017. Continuous, full-time operation of the primary filter began in August 2017 along with intermittent operation of the sludge thickening system.

Prior to startup of the primary filtration system, secondary treatment flow and operations at the LCWD WWTP were transferred from ASB No. 2 to ASB No. 4 over one week. The district had been only operating ASB No. 2 for biological treatment. ASB No. 4 is located closest to the demonstration primary filter site, and piping and valves have been installed to allow ASB No. 4 to receive primary effluent from both the primary filter system and primary clarifiers.

The following steps were taken as part of the transfer of operations:

- Installation of dissolved oxygen sensor in ASB No. 4 prior to flow transfer;
- Confirmation of proper operation of aeration equipment, air lines, and modulating valves; and
- Confirmation of functioning SCADA alarms and correct setpoints for ASB No. 4.

Subsequent monitoring after the flow transfer included:

- Confirmation by the LCWD operators that the modulating valve on the aeration airline in ASB No. 4 was operating within design parameters
- When operation of ASB was stabilized (e.g., 1 to 2 weeks after successful diversion of primary filter effluent to ASB No. 4), the LCWD operators worked with the aeration blower manufacturer and/or service representative to troubleshoot the aeration control system. This is an existing issue at the plant that also could be affecting the nitrification/denitrification process.

2.4. Operation and Maintenance

The primary filter has been in continuous operation since August 2017. Full operational period of the LCWD system is expected to last 30 months through March 2020.

2.4.1 Standard Operating Procedures

The standard operation of the primary filtration project during average daily flow includes:

- Primary filtration of 1.4 mgd
- Thickening of 130 gpm of BRW
    - 80 gpm through Volute Thickener
    - 50 gpm through Phase Separator
- Pumping of 25 gpm of thickened, blended backwash to the digester

Alarms from the project which have been incorporated in the LCWD WWTP's SCADA system are summarized in Table 3. The alarms notify the WWTP operators and project staff of deviations for the filter and backwash systems.

Table 3: Programmed Alarms
(Linda County Water District Wastewater Treatment Plant)

Parameter	Value	Equipment	Description
AquaPrime Filter			
Inflow Rate	Equals zero or less than 10%	Flow meter	Restricted filter inflow means flow is sent to standby primary clarifier
Overflow	High alarm: overflow weir elevation	Level transmitter	Filter overflows to filter effluent chamber and flows to ASB with filtered effluent
Overflow	High high alarm: 4-inch above overflow weir*	Level transmitter	
High Backwash Rate	Continuous backwash for > 1 hour	Filter PLC	Not ideal operating conditions
Backwash Pump Offline	Off	Pump	Will cause filter to overflow triggering the overflow conditions listed above
Storage Vault No. 3			
Phase Separator Feed Pump	Off	Pump	No backwash flow diverted to Phase Separator (ADF = 50 gpm)
Mixing Pump Offline	Off	Pump	Solids will begin to settle in SV
Overflow to (E) SV #7	Overflow pipe invert elevation	Level transmitter	Overflow volume returned to headworks
Potential Spill	1 ft below rim	Level switch	Triggered if 8-inch overflow pipe is not keeping up with BRW flow
Phase Separator			
Solids Removal Pump Offline	Off	Pump	May cause phase separator to utilize overflow outlet
Inflow Rate	Equals zero	Flow meter	No backwash flow diverted to Phase Separator (ADF = 50 gpm)
Overflow	Overflow elevation	Level transmitter	Overflow sent to (E) SV #7 and returned to headworks
Volute Thickener			
Thickener Feed Pump	Off	Pump	Volute Thickener is offline during ADF conditions. Volume sent to digester will be 86,400 gal over 16 hrs (30% of digester capacity)
Inflow Rate	Equals zero	Flow meter	
Thickener Feed Pump AND Backwash (BW) Frequency	Off AND < 6 min (avg last 3 cycles)	Pump AND Filter PLC	Volute Thickener is offline during peak hour flow (PHF) conditions. Volume sent to digester will be

Parameter	Value	Equipment	Description
Inflow rate AND Backwash Frequency	Equals zero AND < 6 min (avg last 3 cycles)	Flow meter AND Filter PLC	224,160 gal over 8 hrs (75% of digester capacity)
Storage Vault No. 2			
Mixing Pump Offline	Off	Pump	Solids will begin to settle in SV
1 of 2 Thickened Sludge Pump Offline	Off	Pumps	One pump can meet ADF conditions, but not PHF conditions. With 1 pump offline, 90 gpm @ 1.4% solids will return (via overflow) to headworks during PHF conditions.
Both Thickened Sludge Pumps Offline	Off	Pumps	With 2 pumps offline, 25 gpm @ 2.5% solids will return (via overflow) to headworks during ADF. 180 gpm @1.4% solids during PHF.
Flow to Digester	Equals zero	Flow meter	See condition above with both thickened sludge pumps offline
Overflow to (E) SV #7	Overflow pipe invert elevation	Level transmitter	Overflow volume returned to headworks
Potential Spill	1 ft below rim	Level switch	Triggered if 8-inch overflow pipe is not keeping up with BW flow

* **High high alarm is set at a higher manhole water level than high alarm.**

Source: Kennedy Jenks Consultants

2.4.2 Risk Management Strategy

The potential risks associated with the project are summarized in Table 4. Mitigating measures were built into the project to protect the WWTP. These measures are allowable for specified amounts of time, and SCADA alarms are associated with all potential risks.

2.4.2.1 Primary Filter Manual Shutdown Procedures

The manual shutdown procedures for the primary filter are as follows: Make sure the standby primary clarifier weir gates are open to receive plant flow. Shutdown flow to the primary filter system through the filter PLC screen. Manually closing the 16-inch plug valve will prevent any more water from entering primary filter system. Backwash system equipment should turn off as backwash reject water stops being produced. Backwash system equipment should be shut down in reverse order of the startup procedures. When any of the equipment or storage vaults are empty, it is recommended that they be thoroughly cleaned.

For the equipment located within the storage vaults, the following interlocks are provided:

- Both submersible mixers will shut down on a fault.
- Feed pumps to the Volute Thickener and the Phase Separator will shut down on low water level and pump fault

Table 4: Risk Management During Startup
(Linda County Water District Wastewater Treatment Plant)

Potential Risk	Designed/Automated Mitigating Measures	Response Following Failed Mitigation
High Filter Backwash Rate	1. Backwash system has been sized for continuous backwash 2. Reduce filter flow by 20 percent	Shut down filter; divert flow to existing primary clarifier
Filter Influent Modulating Valve Not Operable	Manual plug valve installed	Manual shut-off via plug valve
Filter Cannot Keep Up With Inflow	Overflows to filtered effluent chamber	N/A
Filter Cannot Keep Up With Inflow	High alarm restricts flow through modulating valve	Manual restriction via plug valve
Spill from Storage Vault #3	Overflow line from SV #3 (backwash reject) sent to headworks	Shut down filter; divert flow to existing primary clarifier
Spill from Storage Vault #2	Overflow line from SV #2 (thickened backwash) sent to headworks	Shut down filter; divert flow to existing primary clarifier
Phase Separator Overflow	Overflow line piped to existing plant SV and returned to headworks	Shut down Phase Separator

Source: Kennedy Jenks Consultants

2.4.3. Field Log

A summary of regular field activities, such as sampling and maintenance of the system, is included below. Section 2.4.4 provides key lessons learned from issues that occurred when operating the primary filter and thickener system.

- Perform clean-in-place (CIP) on the filter media to lower the observed rising vacuum pressures during filter backwash events. CIP is discussed in further in Section 5.2.1.
- Drain primary filter basin to inspect filter cloth and replace filter disc (as needed).
- Clear obstructions to filter sensors and clean sensors regularly.
- Adjust thickener settings (i.e. feed flow speed) to increase or decrease sludge thickness.
- Unclog thickener drum if there is build-up instead of drainage through outlet pipe.
- Replace polymer for thickener as needed.
- Perform manual operation of scum removal or backwash operations to help restore hydraulic performance.
- Review alarm messages and manually reset to clear alarms.
- Have technicians from companies visit to troubleshoot programming and operation of primary filter and thickener.

- Dilute thickened sludge with water when thickened sludge pumps have trouble drawing flow.
- Repair tubing connector on the polymer injection system when clogged or broken.

The field log is included in Table 5.

Table 5: Field Log (Linda County Water District Wastewater Treatment Plant)

Date	Tasks Completed
7/31/17	Continuous overnight operation of the primary filter began.
10/16/17-10/19/17	Filter was tested at high flows by opening the influent valve all the way. Flow reached 1 mgd.
12/5/17	Primary filter basin was drained for filter cloth inspection.
12/6/17	Filter disks were disassembled. One section from each of six filter disks were removed and replaced with a new filter disk section. Used filter disks were taken by vendor (AASI) for further analysis
12/7/17	Primary filter was restarted.
12/8/17	Loggers were installed for energy measurement and verification.
12/13/17	Collected Storage Vault 2 and 3 total suspended solids (TSS) samples at different time points in settling.
12/13/17	Filter was shut off for one hour and samples were taken from the storage vaults at four different timepoints to test solids settling. Filter effluent composite sampler malfunctioned. Polymer connection to the thickener (AMCON Volute Thickener) broke off.
12/18/17	Power outage occurred over the weekend.
12/19/17	Filter effluent composite sampler (HACH) refrigeration was supposed to be fixed by local mechanic. However, the sampler could not be powered on, so no work was done on it.
12/20/17	Thickener operation had been stopped due to alarms and had to be restarted twice. Two ISCO composite samplers were set up.
12/22/17	Obstruction in filter effluent turbidimeter was cleared. Volute Thickener operation had been stopped due to alarms and had to be restarted twice. Problem is suspected to be caused by thick sludge. Flow was increased to make the sludge thinner.
12/26/17	Cleaned all sensors. Thickener sludge was very thin in the morning, possibly due to a small leak at polymer hose. The leak was fixed, and feed flow was slowed to 15 Hz to thicken the sludge. Phase separator had 3 ft of sludge and 8 in. of scum and was drained to clear. Filter was manually set to perform a scum removal.
12/27/17	Phase separator tank was found empty due to valve being left open after draining on the previous day. Valve was shut and Phase separator tank was refilled around 12:30 PM. Feed flow was increased to 17 Hz on the thickener due to very thick sludge.
12/29/17	NorCal performed pressure test on the thickened effluent pipe. Test was successful. Forced scum removal on the primary filter.
1/2/18	All sensors were cleaned. Scum removal was forced on the primary filter and on the phase separator tank. Connected new tote of polymer to the Thickener.
1/3/18	One-hour composite filter samples were collected at the filter as samplers were not started on the previous day. Adjusted thickener setting to reduce sludge thickness.

Date	Tasks Completed
1/5/18	Polymer tote was found empty. Volute Thickener was taken offline. Phase separator was drained to clear accumulating solids. Data were downloaded from loggers for energy measurement and verification.
1/8/18	All sensors were cleaned. SCADA laptop, which had been malfunctioning, was disconnected and sent to vendor (AASI) for repair.
1/10/18	Power to samplers was off in the morning. Reset the power at the outlet and took 1-hr composite samples at the filter. Samples were sent to an external lab (BC Labs) for testing. Set up samplers for 24-hour composites to be taken from Thursday to Friday morning.
1/12/18	Filter and phase separator were cleaned.
1/15/18	All sensors were cleaned. Regular maintenance was performed.
1/17/18	SCADA computer was re-installed after taken off on 1/8/18. Sampler tubings were replaced.
1/19/18	Volute Thickener polymer was delivered. The drum could not be easily hooked up to the thickener. A poly-dolly was ordered to hold the drum.
1/22/18	All sensors were cleaned. Regular maintenance was performed. Poly-dolly was delivered and polymer was hooked up to the thickener.
1/23/18	Volute Thickener was restarted.
1/24/18	Filter flow was increased from 20% to 33% of total plant flow.
1/31/18	Filter flow was increased from 33% to 50% of total plant flow, with solids returned to headworks. Mixing pump in Storage Vault No. 2 did not appear to be working. Total organic carbon equipment (Biotector) was picked up by manufacturer (HACH).
2/2/18	A new mixing pump was placed into Storage Vault No. 2 but could not be confirmed to be working. Sensors (HACH) were verified to be reading within 5% error of the 800 NTU calibration standard.
2/5/18	Technician from PWTech was onsite to review operation of the thickener. Programming changes were made to correctly create daily data logs. Settings were changed to improve performance. Multiple samples were taken from the thickener and analyzed onsite.
2/6/18	Cellular modem was purchased for the thickener to enable remote access. Analogs were run from the thickener panel to the Telstar panel to possibly allow the thickener to directly read turbidities in the future. Multiple samples were taken from the thickener and analyzed onsite.
2/7/18	Electrical punchlist items were reviewed with Telstar.
2/9/18	Composite sampler (Teledyne ISCO) was set up for the primary clarifier effluent. BASE Energy engineer performed data logging onsite. HACH technician serviced the filter influent, filter effluent, and Storage Vault No. 2 composite sampler controllers, as well as all probes on the SC 1000. TNEMEC began coating all above ground pipes.
2/12/18	Filter went into continuous backwash mode on 2/10 and was shut off from remote. Upon returning the filter online on morning of 2/12, tank level stayed at overflow level. Backwashing setting was changed from backwashing one valve at a time to two valves at a time, which allowed tank level to stay below overflow level. TNEMEC continued coating all above ground pipes.
2/13/18	TNEMEC continued coating all above ground pipes.
2/14/18	TNEMEC finished coating all above ground pipes.

Date	Tasks Completed
2/15/18	Thickener had lost communication to variable frequency drive (VFD) overnight and was restarted.
2/16/18	Filter was operating normally. Thickener had lost VFD communication overnight and was restarted.
2/19/18	Filter was operating normally.
2/20/18	Thickened sludge pumps had trouble drawing flow. A hose was run down along the suction pipe to add water to break up thickened sludge. Pumps were able to draw flow after water was added for 10 min.
2/21/18	Thickened sludge pumps failed to run. Pump motors turned on after resetting breakers. Suction lines were cleared on both pumps. Neither pump was drawing flow
2/23/18	Prime was checked on both thickened sludge pumps.
2/27/18	Filter backwash pump failed on 2/26 and could not be restarted from remote. Pump was found to have a VFD fault. VFD was reset, but pump vibrated much more than normal and backwash (BW) vacuum pressure oscillated between 0-5 in. Hg. Filter was taken offline. Turbidity meter output settings were corrected on HACH controllers. Telstar corrected calibrations in program and was able to get turbidity values to be picked up correctly by SCADA. The old BW vacuum transmitter was placed back on the filter. Calibration could not be done due to BW pump being inoperable.
3/7/18	BW pump was found to have a VFD fault. Fault was cleared and pump ran normal once returned to service. Filter was turned back online. Two heavy duty submersible mixing pumps (Flygt, a Xylem Brand) were placed into Storage Vault No. 2.
3/12/18	Phase separator was turned back online. A new tote of micro-C was connected to the Nitrack Controller (a control program for optimizing the use of micro-C).
3/13/18	Polymer injection system for the thickener was found clogged in the morning.
3/14/18	Clean-in-place (CIP) was conducted for the primary filter. Volute Thickener polymer injection system was unclogged.
3/15/18	Composite samples were collected from filter influent, filter effluent, and primary clarifier influent (12-hr samples, post-CIP).
3/19/18	AASI programmed in storage vault spill control strategies. Storage vault high level alarm was triggered due to false alarm, which shut off the BW pump. AASI returned the pump online.
3/20/18	Filter backwash pump was offline for three hours due to new alarm controls implemented on 3/19.
3/21/18	Thickener drum clogged late 3/20 night while running on constant drum speed. Drum was removed to clear the clog.
3/22/18	VFD drives within thickener panel were rearranged to minimize communication interferences.
3/23/18	Thickener was reprogrammed to add a drum speed-up phase and to automatically attempt to re-establish communication after alarms.
3/26/18	Thickener drum clogged on 3/24 while running on constant drum speed. Drum was removed to clear the clog. Settings were changed to variable drum speed.
3/28/18	Two Nitratax sensors (one at end of activated sludge basin (ASB), one not in service) and two turbidity sensors (Solitax) (one at Volute Thickener influent, one not in service) were serviced onsite. HACH SC1000 controller was also

Date	Tasks Completed
	examined. SD card slot was found to be detached from motherboard. Composite samples were taken and sent to BC Labs.
3/29/18	Storage Vault No. 2 was pumped down. The tops of the four mixing pumps in the storage vault were not visible with the storage vault level low.
4/2/18	Thickener was clogged on 3/31. Screw was pulled out to begin clearing the clog. Two smaller mixing pumps were pulled out of Storage Vault No. 2. Filter was turned offline for 24 hours to connect Storage Vault No. 4 to Storage Vault No. 3.
4/3/18	A second HACH Nitratax sensor was installed near the end of the anoxic zone and connected to the Nitrack Controller. Thickener drum was unclogged. Thickener returned online in the afternoon.
4/4/18	Air mixer was installed in Storage Vault No. 2.
4/6/18	Filter was overflowing due to storm conditions. Thickener was turned offline overnight.
4/9/18	Storage Vault level alarm settings were tested. Thickener was turned offline overnight.
4/10/18	Tested storage vault level alarms for shutting down waste pump (failed on first try and went into continuous backwash; passed on subsequent tries). Left thickener and thickened sludge pumps on to run overnight.
4/11/18	Collected samples. Cleared out accumulated solids in thickener sump. Continued to run thickener and thickened sludge pumps on auto settings.
4/12/18	Set float in Storage Vault No. 2. Installed blank tube on Drum 2 of thickener. Continued to run thickener and thickened sludge pumps on auto settings.
4/13/18	Polymer ran out overnight. Low polymer alarm on the thickener is not triggered, causing the thickener to continue to run without polymer. Filter storage vault level alarms caused backwash pump to run continuously in the morning. Polymer alarm was fixed, and a new drum was hooked to the thickener. Thickener and thickened sludge pumps were turned offline for the weekend.
4/16/18	Cleanup of project site. Two non-working mixing pumps were pulled from Storage Vault No. 2. Float anchored in Storage Vault No. 3. Volute Thickener ran well - left offline overnight.
4/17/18	Finished cleanup in preparation of a site tour. Thickener ran well.
4/18/18	Filter was turned offline to install air break downstream of the waste pump. Entire system to be off for 24 hours.
4/19/18	Pumped out remaining solids waste in the phase separator. Installation of air break was completed. System was left offline.
4/20/18	Returned filter online in the morning. Filter was backwashing one valve at a time and waste pump was cavitating. Switched back to backwashing via two valves at once, and cavitation ceased. Volute Thickener ran well during the day and was left offline for the weekend.
4/23/18	Waste pump cavitated in the morning. AASI adjusted BW flow from remote. Pump stopped cavitating with BW flow decreased from 130 to 95 gpm per valve. Thickener ran well throughout the day. *Overnight operation:* Filter flow was reduced to 20% of plant flow. Thickener and thickened sludge pumps were left on. Thickened sludge pumps set to run from start level of 8.5 ft to stop level of 6 ft in Storage Vault 2. System to be monitored from remote control for the next two days.

Date	Tasks Completed
4/25/18	Overnight operation went fine from 4/23-4/25. Storage Vault 2 sludge was slightly too thin (visually looked ~1% solids). Filter had been mostly backwashing based on time interval setpoint of 60 min. Thickener flow rate was decreased from 150 to 120 gpm to thicken the sludge. Backwash time interval setpoint was increased to 75 min. Entire system was left to continue to run in auto with filter flow at 20% of plant flow.
4/26/18	Thickener alarmed out around 8 PM on 4/25. Filter backwash cycles stopped as programmed, but continuous solids waste started around midnight and continued until filter was manually brought offline at 8 AM next morning. 30,000+ gal of un-thickened wastewater was pumped to digester overnight, causing temperature of the digester to drop significantly. Volute Thickener drum appeared to be slightly clogged, which likely triggered the shutdown. Drum was cleared by hosing down with water and running in manual. Thickener ran fine upon restart. AASI checked alarm programming but could not identify cause of the continuous SW. Entire system was shut down in the afternoon and will only be operated with K/J onsite until issues are resolved.
4/30/18	AASI added new interlock on 4/27 which would immediately switch filter back to filtration mode after storage vault High Level alarm trips, instead of completing an ongoing waste cycle. New control was tested by manually initiating BW and SW and worked properly. Filter and thickener were run during the day. Thickener was turned off for the night. Filter was kept online at 50% of plant flow.
5/2/18	BASE Energy engineer performed data logging. Thickener spilled some solids into the sump in the morning. Filter was shut off overnight to keep storage vault levels low for next day's work.
5/3/18	Plant staff plugged diversion between Storage Vault Nos. 2 and 3. Bottom third of the overflow pipe in each storage vault was also blocked by screwing on a rubber piece in place. Filter was returned online.
5/4/18	Telstar finished all electrical items on punchlist. Storage Vault No. 2 level raised by 5 ft overnight with thickener off. Thickener was left off for the weekend.
5/11/18	Thickened Sludge Pump No. 2 was repaired and both thickened sludge pumps were confirmed to be working.
5/15/2018 - 5/17/18	Maintenance was performed. Filter influent flow PID loop was adjusted to better stabilize at desired flow setpoint.
5/25/18	Filter was found to be locked in a solids waste cycle with Solids Waste Valve No. 3 stuck open. Filter was turned offline.
5/29/18	Programming for solids waste sequencing was fixed from remote by filter manufacturer. Upon returning online, a significant displacement in a section of waste pump discharge piping was observed. Minor leakage occurred during solids wasting. Filter was put back offline.
6/7/18	Contractor repaired waste pump discharge pumping. Filter was put online.
6/11/18	Leakage recurred during solids wasting from the same spot in waste pump discharge piping. Filter was turned offline.
6/15/18	Contractor redid the leaking piping.
6//20/18	Filter was returned online. No further issue was observed.
6/26/18 - 6/27/18	CIP was performed on the filter.

Date	Tasks Completed
7/3/18	Small leak was observed at thickened sludge pumps discharge.
7/17/18-7/19/18	Backwash Valve No. 1 was replaced after valve failed to open during backwash on multiple occasions. A new CIP procedure was tested without use of detergent.
7/26/18	Filter was set to take 50% of plant flow, increased from 20%.
8/2/18	Tubing connector broke on the polymer injection system of the thickener.
8/6/18	Tubing connector on the polymer injection system of the thickener was replaced.
8/8/18	Excessive alarms from the filter was calling out to plant staff. Same tubing connector broke again on the polymer injection system of the thickener.
8/15/18	Influent valve on filter stopped self-adjusting based on setpoint flow percentage.
8/17/18	Increased cavitation noises were again observed with filter waste pump.
8/21/18	Tubing connector and other parts were replaced on the polymer injection system for the thickener. Issue was observed with plant water connection to the polymer.
8/27/18	Filter was changed back to receiving 20% of plant flow, deceased from 50%, after plant's primary clarifiers experienced issues with low flow.
9/4/18	Piping on thickened sludge pumps' discharge was repaired.
9/11/18-9/13/18	Filter was shut down due to plant power issue and experienced continuous wasting after returning online. Programming was performed from remote and filter was returned online on 9/13 without further issues.
10/4/18-10/5/18	Filter was shut off for 24 hours due to construction at the plant.
10/22/18	AASI technician was onsite to inspect issues with filter influent valve not opening automatically to the correct position.
10/23/18	A tour of the demonstration system was conducted for staff from another WWTP.
10/24/18	Filter influent valve was repaired.
10/30/18	Newly implemented filter alarms and controls were tested and found to be working.
11/2/18	Thickener screen display was unresponsive. Leak was also observed at a solenoid valve on the polymer injection system.
11/9/18	Telstar programmer was onsite to resolve alarm callout issue.
11/12/18	LCWD WWTP began to receive flow from nearby City of Marysville during day time. Flow to the filter was still adjusted to setpoint 20% of plant flow based on the original LCWD portion only.
11/16/18	Thickener screen display issue was fixed. Polymer injection system was found to be set up incorrectly.
11/19/18	Turbidimeters were cleaned after filter effluent turbidimeter gave erratic readings.
12/4/18	Filter influent valve was tested at higher flow rates. Flow did not match setpoint when set to receive over 90% of plant flow.
12/5/18	CIP was performed on the filter. Filter controls were checked. Aeration basin airflow, nitrate, and dissolved oxygen (DO) were found to be incorrectly tagged in the filter SCADA system. Data were downloaded off loggers for energy measurement and verification.

Source: Kennedy Jenks Consultants

2.4.4. Summary of Issues and Resolutions

Various issues arose during primary filter operation from August 2017 to December 2018 and the corrective actions taken are summarized in Table 6, which includes considerations needed to address the issues in a full-scale system. Many of the issues experienced with filter operation in this demonstration can be mitigated in future, permanent installations by accounting for lessons learned from the demonstration as well as with more thorough equipment testing before operation, and by including more redundancy in the design and installation, which is more typical for a commercial full-scale installation.

Issues related to the solids handling system are summarized in Table 7. The solids handling system was specifically designed for operation at LCWD WWTP, thus the potential for some of the issues in future systems may depend on similarity to the design at LCWD WWTP. Most of the issues experienced with the Volute Thickener, which was the main device for thickening of FS, may also be applicable with other similar thickening technologies. Similar to primary filter operation, many of the issues experienced with the solids handling system can also be mitigated in future, permanent installations.

Issues related to the sampling and monitoring system are summarized in Table 8.These issues are not expected to impact future full-scale implementations, as the sampling and monitoring equipment are used only to collect data for the demonstration.

The primary filter proved to be robust and reliable system. The sensors, cross-checks, and alarms worked to help maintain performance of the system and resolve operational issues.

The operation and maintenance required for primary filtration is comparable to what is required for primary clarification. The key differences between the two systems are that primary filtration relies on filter media with small pore size for higher treatment efficiency and is more complex in terms of automation. For both systems, activities such as scum removal, sludge removal, pump maintenance, and basin cleaning can be managed by operators at the plant.

Primary filtration can have various applications based on the needs of the facility. For a facility with aging primary clarifiers, primary filtration can be a complete replacement for a primary clarification. Aging clarifiers can be used as a backup or contingency system, a flow equalization basin, or to thicken primary filter backwash. For new facilities, primary filtration can be a total replacement for primary clarification.

Table 6: Issues and Resolutions Related to Primary Filter Operation (Linda County Water District Wastewater Treatment Plant)

Date	Incident/Issue	Cause	Corrective Action	Considerations for Future Full-Scale System	Score*
12/7/17	Transmitter gives a backwash vacuum pressure reading approximately 7-8 in. Hg higher than the gage.	Possibly due to faulty gage	A new gage was installed in March 2018 and discrepancy was corrected.	Issue can be prevented or addressed with regular maintenance.	1
2/10/18 - 2/12/18	Filter got stuck on continuous backwash on 2/10/18 and was shut off. Upon returning online on 2/12/18, tank level stayed at overflow level.	Operation setpoint for backwash system was unable to keep up with loading	Filter setting was changed to open two valves at a time during backwash.	Possible to see similar issues. Operator setting should be reviewed and changed if problems occur.	2
2/27/18 – 3/7/18	Filter waste pump failed to run.	Filter waste pump VFD fault	Pump VFD fault was reset on 3/7/18.	VFD faults can occur in full-scale systems.	2
3/20/18	Filter waste pump was offline for three hours after new alarm control programming was implemented.	False alarms were triggered in PLC	Programming changes were made.	Programming logic needs to be tested to prevent similar issue.	1
4/6/18	Flow was going over the overflow weir for multiple hours.	High influent flow during storm exceeded peak design criteria of the filter	None needed.	Filter may be designed to overflow when hydraulic loading rate exceeds peak design capacity	2
4/18/18	Filter waste pump had experienced cavitation for multiple months	Filter waste pump suspected to be pulling in air	An air break was installed on 4/18 downstream of the waste pump.	Cavitation can be an issue when similar pump configuration is used.	2

Date	Incident/Issue	Cause	Corrective Action	Considerations for Future Full-Scale System	Score*
4/29/18	Filter was stuck in continuous solids waste cycles overnight after Volute Thickener shut off unexpectedly. Filter reject water continuously overflows from Storage Vault No. 3 to Storage Vault No. 2, causing thin sludge to be pumped to digester.	Unknown issue in filter PLC programming	Preventative actions were taken. Filter waste pump was re-programmed to switch off immediately upon receiving alarm from solids handling system. Connection between the storage vaults was plugged on 5/3 to prevent pumping un-thickened filter reject flow to the digester.	Programming logic needs to be tested to prevent similar issue.	1
5/8/18 – 5/11/18	Backwash Valve No. 1 on the filter got stuck in the closed position.	Filter backwash Valve No. 1 appeared to be faulty during frequent opening and closing	Filter was shut off for three days. Valve was manually opened on 5/11/18 to allow filter operation. On 5/16/18, valve was put back on auto without immediate issues.	Hardware malfunctioning is likely to occur but can be corrected in a timely manner	2
5/15/18 – 5/17/18	Filter waste pump had experienced continual cavitation.	Filter waste pump suspected to be pulling in air while getting to setpoint flow	Waste flow PID loop was adjusted	Cavitation can be an issue when pumps are used.	2
5/25/18 – 6/15/18	Filter was locked in continuous solids waste with one of the valves stuck open. Upon returning online, a section waste pump suction line was displaced by an inch, causing minor leakage.	Possible pressure build-up in filter waste line	A section of waste flow piping was replaced	Problem can occur depending on filter waste flow plumbing.	1

Date	Incident/Issue	Cause	Corrective Action	Considerations for Future Full-Scale System	Score*
6/27/18	Filter waste pump had experienced continual cavitation.	Filter waste pump cavitation suspected to be due to filter media fouling	Clean-in-place (CIP) was conducted on 6/27.	CIP should be implemented every 2 to 6 months to prevent media fouling depending on wastewater characteristics.	2
9/10/18 – 9/12/18	Filter shut down briefly due to plant power issue. Filter got stuck on solids waste upon returning online.	Programming issue in PLC induced by sudden shutdown	Programming was fixed from remote.	Programming issue can occur with PLCs.	1

Score on estimated probability scale (0-3) of occurrence in future full-scale system, 0 = not likely; 1 = somewhat likely, 2 = likely, 3 = very likely

Source: Kennedy Jenks Consultants

Table 7: Issues and Resolutions Related to Solids Handling System (Linda County Water District Wastewater Treatment Plant)

Date	Incident/Issue	Reason	Corrective Action	Considerations for Future Full-Scale System	Estimated Probability of Occurrence in Future Full-Scale System*
12/13/17	Connector on the tubing from the polymer container to the Volute Thickener snapped off.	Tubing connector breakage on the polymer injection system, possibly caused by freezing temperature	Connector was replaced on the same day.	Problem could occur with a similar polymer injection system for thickening system.	1
12/20/17 - 12/22/17	Alarms were triggered on the Volute Thickener, causing the unit to shut off multiple times.	Volute Thickener alarms were triggered, possibly due to very thick sludge	Volute Thickener was restarted each time and alarms were reset. On 12/22, feed flow was increased to 19 Hz to make the sludge thinner.	Problem could occur with similar alarms/controls integrated with the thickening system.	1
12/26/17	Excessive solids accumulation (3ft of sludge, 8 in. of scum) in the phase separator.	Anaerobic conditions suspected to be developing in the Phase Separator basin	Phase Separator was drained to clear of solids.	Problem could occur if similar gravitational thickening device is used.	2
12/26/17	Small leak at polymer hose of Volute Thickener. Very thin sludge was observed coming out of the thickener.	Tubing connector loosened on the polymer injection system	Leak was fixed, Feed flow to Volute Thickener was slowed to 15 Hz (77 gpm) to produce thicker sludge.	Problem could occur with a similar polymer injection system for thickening system.	1
1/5/18 - 1/15/18	Polymer ran out.	Leakage suspected in polymer injection system	A new drum of polymer was ordered previous week. Volute Thickener was returned online when the drum arrived.	Problem could occur with a similar polymer injection system for thickening system.	1

Date	Incident/Issue	Reason	Corrective Action	Considerations for Future Full-Scale System	Estimated Probability of Occurrence in Future Full-Scale System*
2/15/18 - 2/16/18	Alarms were triggered on the Volute Thickener two nights in a row, causing the unit to shut off overnight.	VFD alarms on the Volute Thickener PLC	Volute Thickener was restarted each time and alarms were rest.	Problem could occur with similar alarms/controls integrated with the thickening system.	1
2/20/18	Thickened sludge pumps failed to draw flow.	Loss of prime in the thickened sludge pumps and/or air leak from pump suction lines suspected	One pump was re-primed on 2/23. Suction leak was fixed on the other pump in May.	Problem could occur with pumps in the systems.	1
3/14/18 – 3/15/18	Volute Thickener polymer injection system was clogged.	Clogging within the polymer injection system	Tubing for polymer injection was flushed.	Problem could occur with a similar polymer injection system for thickening system.	1
3/21/18, 3/26/18, 3/31/18	Volute Thickener drum was clogged overnight.	Sludge was over-thickened while Volute Thickener drum was tested on constant speed	Drum was disassembled and cleaned. Thickener was reprogrammed to self-adjust drum speed based on friction. Operational settings were adjusted.	Problem occurred during testing.	N/A
4/13/18	Volute Thickener produced thin sludge overnight due to lack of polymer	Polymer ran out in the polymer injection system	Polymer drum was replaced. Sensor was fixed to stop thickener operation when there’s no polymer.	Polymer level needs to be checked frequently.	1

Date	Incident/Issue	Reason	Corrective Action	Considerations for Future Full-Scale System	Estimated Probability of Occurrence in Future Full-Scale System*
4/26/18	Filter reject water continuously overflows from Storage Vault No. 3 to Storage Vault No. 2, causing thin sludge to be pumped to digester.	Storage vaults were connected at a lower level than the Storage Vault overflow lines	Connection between the storage vaults was plugged on 5/3.	Problem specific to installation at LCWD WWTP.	N/A
7/3/18 – 9/4/18	Small leak was observed at thickened sludge pumps discharge line.	Suspected improper PVC glue was used in initial construction.	Piping was repaired on 9/4/18.	Problem specific to installation at LCWD WWTP.	N/A

*** 0: not likely; 1: somewhat likely, 2: likely, 3: very likely, N/A: not applicable in general full-scale installations**

Source: Kennedy Jenks Consultants

Table 8: Issues and Resolutions Related to Sampling and Monitoring System (Linda County Water District Wastewater Treatment Plant)

Date	Incident/Issue	Corrective Action	Reason	Considerations for Future Full-Scale System
11/16/17	SCADA stopped recording data. System eventually shut off and could not be rebooted.	Computer was replaced on 12/13/17.	SCADA laptop malfunctioned	This SCADA issue is not expected to be a problem for full-scale system.
12/6/17	Refrigeration failed to work for the primary filter effluent HACH composite sampler	Compressor was replaced in March 2018.	Sampler refrigeration system malfunctioned	Samplers needed specifically for demonstration.
12/7/17	Transmitter gives a backwash vacuum pressure reading approximately 7-8 in. Hg higher than the gage.	A new gage was installed in March 2018 and discrepancy was corrected.	SCADA system issue possibly due to faulty gage	Issue can be prevented or addressed with regular maintenance.
12/13/17	Filter effluent composite sampler stopped responding to any of the keys on the panel.	Desiccant was replaced.	Sampler malfunctioned, possibly due to moisture	Samplers needed specifically for demonstration.
1/5/18 - 1/17/18	SCADA workstation failed to properly turn on.	Hard drive was replaced by AASI.	SCADA laptop malfunctioned	SCADA issues not expected to be a problem for full-scale system.
1/8/18	Power was lost to the composite samplers at primary filter influent and effluent.	Power was reset at the outlet.	Likely due to heavy rain	Samplers needed specifically for demonstration.
1/18/18	SCADA again encountered issues with data logging.	A backup laptop will be set up.	SCADA laptop malfunctioned	SCADA issues not expected to be a likely problem for full-scale system.
1/24/18	Thin ice formed in the effluent composite sample which was collected over 24 hours in the ISCO Avalanche sampler.	Issue to be monitored.	Sampler refrigeration system malfunctioned	Samplers needed specifically for demonstration.
8/15/18 - current	Controllers on a HACH composite sampler and an ISCO Avalanche sampler by the primary clarifier effluent channel stopped powering on.	ISCO controller was repaired. Hach sampler required replacement of electrical cords and have yet to been repaired.	Issue suspected with power at the outlet supplying the samplers	Samplers needed specifically for demonstration.

Date	Incident/Issue	Corrective Action	Reason	Considerations for Future Full-Scale System
11/17/18 – 11/19/18	Filter effluent turbidimeter showed erratic readings.	Turbidimeter was removed and re-installed	Possible interference from solids sticking onto turbidimeter probe	Inline monitoring system needed specifically for demonstration study. If such sensors are used, regular cleaning is recommended.

Source: Kennedy Jenks Consultants

2.5. Primary Filter Performance

The treatment performance of the demonstration system at the LCWD WWTP was evaluated for the feasibility of primary filtration as an APT technology, in terms of both treatment and hydraulic performance.

2.5.1. Treatment

The treatment performance of the demonstration system at the LCWD WWTP was evaluated for the feasibility of primary filtration as an APT technology. Over the operational period, the primary filter consistently achieved high solids removal, as shown by both onsite turbidity measurements and laboratory TSS measurements. Particle removal also resulted in reduction of BOD_5 and COD.

2.5.1.1 Continuous Performance Monitoring

Due to limitations of commercially available continuous TSS monitoring systems, turbidity is often monitored instead as a measurement of suspended solids in water. During the entire demonstration, inline turbidimeters (HACH Solitax) provided continuous monitoring of the filter influent and effluent. Correlations were then established between inline turbidity averages and TSS measured in composite samples. Continuous TSS removal performance by the filter is estimated using these correlations.

Total Suspended Solids to Turbidity Correlation

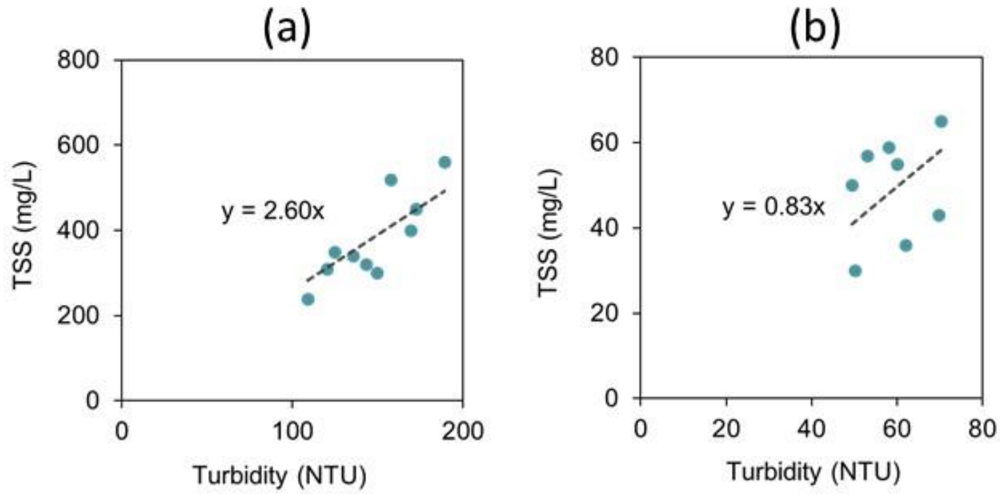
The demonstration primary filter influent and effluent turbidities were logged at 10-minute averages by the HACH SC200 controller. Filter influent and effluent TSS values were measured periodically using 24-hour composite samples. TSS-to-turbidity correlation ratios were calculated for the primary filter influent and effluent by correlating the TSS composite measurements with turbidity averaged over corresponding 24-hour periods. Composite sample results and turbidity data from February to June 2018 were used to develop these correlations.

Linear correlations of TSS versus turbidity are shown in Figure 9. TSS-to-turbidity correlation factors were found to be 2.60 and 0.83 for the primary filter influent and effluent, respectively. These correlation factors were used to convert turbidity data to TSS values (see Section 4.1.2). The correlation factors were meant to provide a general relationship between TSS and turbidity, rather than giving precise values of TSS.

TSS Removal Efficiency

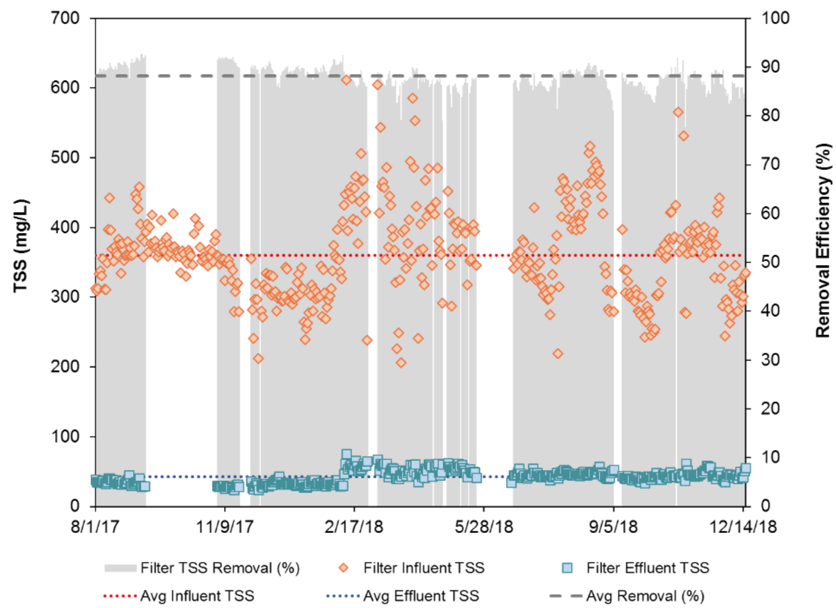
The demonstration primary filtration system has performed at a high level in terms of TSS removal, as anticipated. As shown in Figure 10, TSS removal efficiency has ranged between 78 and 94 percent since start-up of the system, with an average removal rate of 88 percent. Daily average influent TSS ranged from 200 to 620 mg/L, while daily average effluent TSS ranged from 15 to 80 mg/L. This demonstrates the primary filter's ability to handle large variations in raw wastewater quality due to time of day (customer use in the daytime versus nighttime), seasonal fluctuations, and storm events (stormwater infiltration). Overall average TSS values were 360 and 40 mg/L for filter influent and effluent, respectively. Conventional primary clarification systems typically remove 50 to 60 percent of TSS.

Figure 9: TSS-to-Turbidity Correlation for (a) Primary Filter Influent and (b) Primary Filter Effluent (Linda County Water District Wastewater Treatment Plant)



Source: Kennedy Jenks Consultants

Figure 10: TSS Removal Efficiency (Linda County Water District Wastewater Treatment Plant)



Source: Kennedy Jenks Consultants

2.5.1.2 Performance Results from Laboratory Sampling

Periodic grab and composite filter influent and effluent samples were taken and sent to a third-party laboratory for analysis. Data from all sampling conducted from August 2017 to December 2018 are summarized in Table 9 and Table 10. Regular composite sampling started in late December 2017. The grab samples were taken in the morning and generally had lower TSS, BOD_5, and COD compared to the composite samples for both filter influent and effluent. All data, however, showed a significant removal of these three constituents by the primary filter. Performance design goals for primary clarifiers are typically between 50 and 60 percent removal for TSS and 20 to 30 percent removal for BOD.

Table 9: Laboratory Sampling Results — BOD and COD (Linda County Water District Wastewater Treatment Plant)

Date & Time	Plant Flow Treated by Filter (%)	Sample Duration	BOD_5 Filter Influent (mg/L)	BOD_5 Filter Effluent (mg/L)	BOD_5 Removal Efficiency (%)	COD Filter Influent (mg/L)	COD Filter Effluent (mg/L)	COD Removal Efficiency (%)
8/2/17 10:00	20	Grab	160	120	25	370	300	19
8/4/17 9:00	20	Grab	63	30	52	420	270	36
8/7/17 9:00	20	Grab	220	92	58	450	260	42
8/9/17 8:30	20	Grab	200	140	30	250	200	20
8/11/17 8:30	20	Grab	160	110	31	320	220	31
8/14/17 9:00	20	Grab	150	93	38	360	210	42
8/29/17 9:00	20	Grab	-	-	-	-	-	-
8/29/17 10:00	20	Grab	-	-	-	-	-	-
9/6/17 9:30	20	Grab	130	82	37	480	160	67
11/14/17 14:00	20	Grab	-	-	-	620	270	56
11/14/17 17:00	20	Grab	-	-	-	870	350	60
11/14/17 20:00	20	Grab	-	-	-	690	340	51
11/20/17 10:00	20	Grab	-	-	-	-	-	-
11/20/17 11:00	20	Grab	-	-	-	-	-	-
11/20/17 13:00	20	Grab	-	-	-	-	-	-
12/20/17 10:30	20	24-hr	-	-	-	-	-	-
12/27/17 10:00	20	24-hr	190	170	11	300	260	13
1/3/18 10:40	20	2-hr	190	120	37	400	160	60
1/10/18 10:30	20	1-hr	150	65	57	380	170	55
1/17/18 9:00	20	24-hr	390	130	67	980	860	12
1/24/18 8:30	33	24-hr	260	120	54	460	240	48
2/7/18 8:30	50	24-hr	350	130	63	550	230	58
2/14/18 8:30	50	24-hr	420	160	62	660	290	56
2/21/18 8:30	50	24-hr	440	130	70	660	230	65
3/28/18 8:30	50	24-hr	500	120	76	680	190	72
4/4/18 8:30	50	24-hr	320	100	69	930	230	75
4/11/18 8:30	50	24-hr	350	140	60	480	230	52
4/25/18 8:30	20	24-hr	290	100	66	570	220	61
5/2/18 8:30	20	24-hr	320	130	59	660	250	62

Date & Time	Plant Flow Treated by Filter (%)	Sample Duration	BOD_5 Filter Influent (mg/L)	BOD_5 Filter Effluent (mg/L)	BOD_5 Removal Efficiency (%)	COD Filter Influent (mg/L)	COD Filter Effluent (mg/L)	COD Removal Efficiency (%)
6/27/18 8:30	20	Grab	290	99	66	650	240	63
7/5/18 8:30	20	Grab	140	95	32	300	220	27
7/11/18 8:30	20	24-hr	250	120	52	510	230	55
7/25/18 8:30	50	24-hr	250	85	66	410	170	59
8/1/18 8:30	50	24-hr	410	76	81	820	170	79
8/8/18 8:30	50	24-hr	380	120	68	800	320	60
8/15/18 8:30	50	24-hr	390	150	62	740	340	54
8/22/18 8:30	50	24-hr	-	-	-	670	270	60
8/29/18 8:30	20	24-hr	300	120	60	580	220	62
9/5/18 8:30	20	Grab	-	-	-	570	220	61
9/12/18 8:30	20	Grab	120	150	-25	370	300	19
9/19/18 8:30	20	24-hr	-	-	-	550	280	49
9/26/18 8:30	20	24-hr	240	99	59	480	200	58
10/3/18 8:30	20	24-hr	230	100	57	520	280	46
10/10/18 8:30	20	24-hr	340	110	68	640	270	58
10/17/18 8:30	20	24-hr	270	150	44	620	380	39
10/24/18 8:30	20	24-hr	510	190	63	990	390	61
10/31/18 8:30	20	24-hr	340	130	62	520	280	46
11/7/18 8:30	20	24-hr	270	110	59	940	330	65
11/14/18 8:30	20	Grab	260	68	74	490	130	73
11/20/18 8:30	20	24-hr	350	120	66	760	260	66
11/28/18 8:30	20	24-hr	210	120	43	430	240	44
12/12/18 8:30	20	24-hr	210	160	24	600	320	47
12/19/18 8:30	20	24-hr	220	100	55	480	280	42
Avg.*			316	120	60	619	257	57
Min.*			210	76	-	410	170	-
Max.*			500	160	-	940	380	-
Std. Dev.*			111	37	-	140	50	-

*** Only includes 24-hr composite samples taken between January and December 2018. Data on 1/17/18 and 10/24/18 are excluded due to TSS being outside of three standard deviations from the average.**

Source: Kennedy Jenks Consultants

Table 10: Laboratory Sampling Results — TSS and TKN (Linda County Water District Wastewater Treatment Plant)

Date & Time	Plant Flow Treated by Filter (%)	Sample Duration	TSS Filter Influent (mg/L)	TSS Filter Effluent (mg/L)	TSS Removal Efficiency (%)	TKN Filter Influent (mg/L)	TKN Filter Effluent (mg/L)	TKN Removal Efficiency (%)
8/2/17 10:00	20	Grab	87	44	49	-	-	-
8/4/17 9:00	20	Grab	280	49	83	-	-	-
8/7/17 9:00	20	Grab	420	54	87	-	-	-
8/9/17 8:30	20	Grab	230	43	81	-	-	-
8/11/17 8:30	20	Grab	130	44	66	-	-	-
8/14/17 9:00	20	Grab	110	30	73	-	-	-
8/29/17 9:00	20	Grab	210	35	83	-	-	-
8/29/17 10:00	20	Grab	250	32	87	-	-	-
9/6/17 9:30	20	Grab	210	30	86	-	-	-
11/14/17 14:00	20	Grab	200	27	87	-	-	-
11/14/17 17:00	20	Grab	290	32	89	-	-	-
11/14/17 20:00	20	Grab	190	35	82	-	-	-
11/20/17 10:00	20	Grab	75	33	56	-	-	-
11/20/17 11:00	20	Grab	160	34	79	-	-	-
11/20/17 13:00	20	Grab	310	42	86	-	-	-
12/20/17 10:30	20	24-hr	170	33	81	-	-	-
12/27/17 10:00	20	24-hr	85	68	20	-	-	-
1/3/18 10:40	20	2-hr	300	50	83	-	-	-
1/10/18 10:30	20	1-hr	250	69	72	44	33	25
1/17/18 9:00	20	24-hr	-	-	-	56	42	25
1/24/18 8:30	33	24-hr	240	36	85	48	41	15
2/7/18 8:30	50	24-hr	350	43	88	44	39	11
2/14/18 8:30	50	24-hr	450	59	87	51	41	20
2/21/18 8:30	50	24-hr	300	55	82	53	43	19
3/28/18 8:30	50	24-hr	520	30	94	42	31	26
4/4/18 8:30	50	24-hr	560	57	90	42	31	26
4/11/18 8:30	50	24-hr	310	65	79	44	51	-16
4/25/18 8:30	20	24-hr	320	50	84	50	43	14
5/2/18 8:30	20	24-hr	400	58	86	49	45	8
6/27/18 8:30	20	Grab	340	51	85	-	-	-

Date & Time	Plant Flow Treated by Filter (%)	Sample Duration	TSS Filter Influent (mg/L)	TSS Filter Effluent (mg/L)	TSS Removal Efficiency (%)	TKN Filter Influent (mg/L)	TKN Filter Effluent (mg/L)	TKN Removal Efficiency (%)
7/5/18 8:30	20	Grab	65	41	37	40	41	-2
7/11/18 8:30	20	24-hr	210	40	81	46	38	17
7/25/18 8:30	50	24-hr	230	42	82	43	38	12
8/1/18 8:30	50	24-hr	240	24	90	54	47	13
8/8/18 8:30	50	24-hr	400	62	85	56	42	25
8/15/18 8:30	50	24-hr	410	89	78	50	46	8
8/22/18 8:30	50	24-hr	350	64	82	50	34	32
8/29/18 8:30	20	24-hr	250	55	78	42	33	21
9/5/18 8:30	20	Grab	340	56	84	41	34	17
9/12/18 8:30	20	Grab	160	38	76	52	40	23
9/19/18 8:30	20	24-hr	240	70	71	43	38	12
9/26/18 8:30	20	24-hr	240	55	77	41	33	20
10/3/18 8:30	20	24-hr	280	57	80	48	41	15
10/10/18 8:30	20	24-hr	250	55	78	53	40	25
10/17/18 8:30	20	24-hr	270	99	63	49	50	-2
10/24/18 8:30	20	24-hr	440	130	70	58	47	19
10/31/18 8:30	20	24-hr	250	48	81	46	40	13
11/7/18 8:30	20	24-hr	270	77	71	53	45	15
11/14/18 8:30	20	Grab	200	26	87	56	37	34
11/20/18 8:30	20	24-hr	320	62	81	54	37	31
11/28/18 8:30	20	24-hr	310	26	92	45	29	36
12/12/18 8:30	20	24-hr	220	40	82	46	36	22
12/19/18 8:30	20	24-hr	350	40	89	44	38	14
Avg.*			316	54	82	48	40	17
Min.*			210	24	-	41	29	-
Max.*			560	99	-	56	51	-
Std. Dev.*			89	17	-	4	6	-

*** Only includes 24-hr composite samples taken between January and December 2018. Data on 1/17/18 and 10/24/18 are excluded due to TSS being outside of three standard deviations from the average.**

Source: Kennedy Jenks Consultants

2.5.2. Hydraulic/Operational

Hydraulic performance of the primary filter was evaluated based on filter loading and production rates.

2.5.2.1 Filter Loading Rates

The primary filter loading rates were measured in terms of both hydraulic loading rate (HLR) and solids loading rate (SLR). The loading rates change based on flow rate of the filter. The SLR also changes based on the filter influent TSS level.

Hydraulic Loading Rates

The filter daily average and maximum influent flow and corresponding HLR are shown in Figure 11. Influent flow for the demonstration primary filter system was set to 20 percent of the LCWD WWTP influent flow at start-up. The filter system has eight filter disks, with a total filtration area of 430.4 ft^2. During August 2017 to mid-January 2018, daily average filter influent flow mostly ranged from 200 to 250 gpm (0.29 to 0.36 mgd), which corresponds to HLR of 0.45 to 0.55 gpm/ft^2. The filter was also tested at higher flow rates for two weeks at the end of August 2017 and for three days in mid-October 2017. The filter influent flow was increased to 33 percent of the plant's influent flow on January 24, 2018 and then again to 50 percent on January 31, 2018. The filter flow setpoint stayed at 50 percent until the end of April, when it was reduced again to 20 percent due to additional work needed for the solids handling system. The filter also was tested at 50 percent of plant flow for approximately one-month from mid-July to mid-August 2018.

To date, the filter has not been operated consistently at average design capacity of 1.5 mgd. Filter influent did exceed 2.3 mgd on two occasions during storm events in March and April of 2018. On other occasions, the filter was manually tested at higher flow rates during day operation, as shown by the peaks in Figure 11.

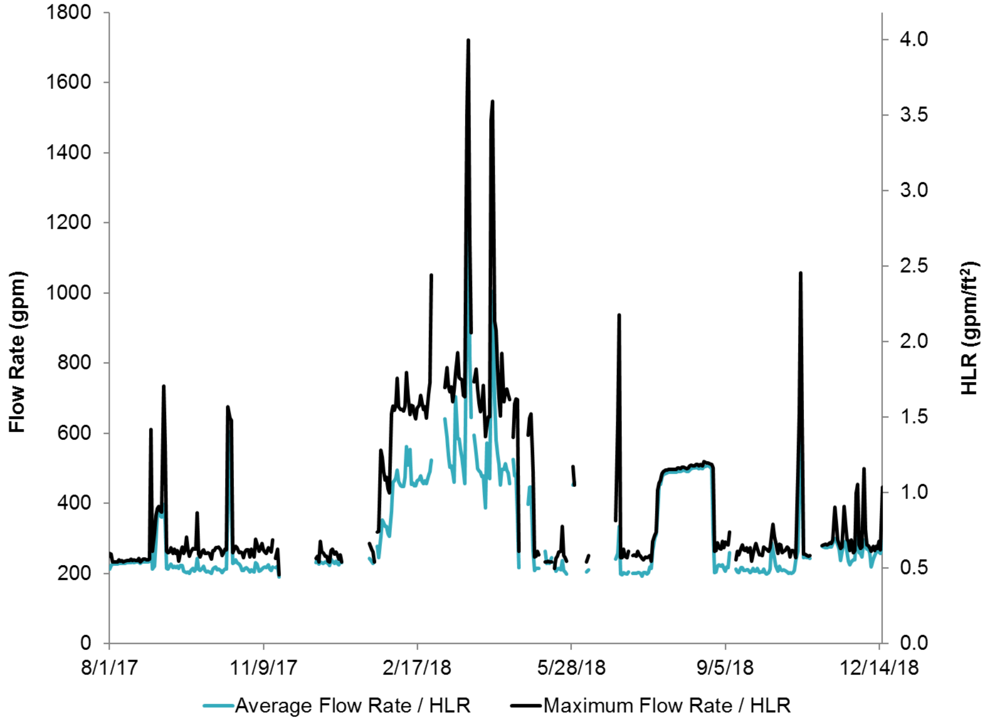
Solids Loading Rates

SLR for the demonstration system is shown in Figure 12. SLR was strongly dependent on HLR during the 17 months of filter operation. At setpoint of 20 percent of plant flow, filter SLR was typically between 2 and 3 $lbs/day\text{-}ft^2$, with a noticeable increase after the plant started receiving wastewater from City of Marysville in November 2018. At setpoint of 50 percent of plant flow, filter SLR typically ranged from 6 to 8 $lbs/day\text{-}ft^2$, with a maximum of 8-10 $lbs/day\text{-}ft^2$ reached during storm events.

2.5.2.2 Production and Reject Rates

Filter media fouling is expected in a primary filtration system. Periodic backwashing is a regular operation and maintenance activity that helps restore performance of filter media and hydraulics of the system. The volumes of filtered effluent, BRW, and SW for the demonstration primary filter system are shown in Figure 13. The daily filter reject ratios are shown in Figure 14. Combined daily flow reject ratios were below 10 percent under normal operating conditions, where the filter was backwashing based on head loss build-up.

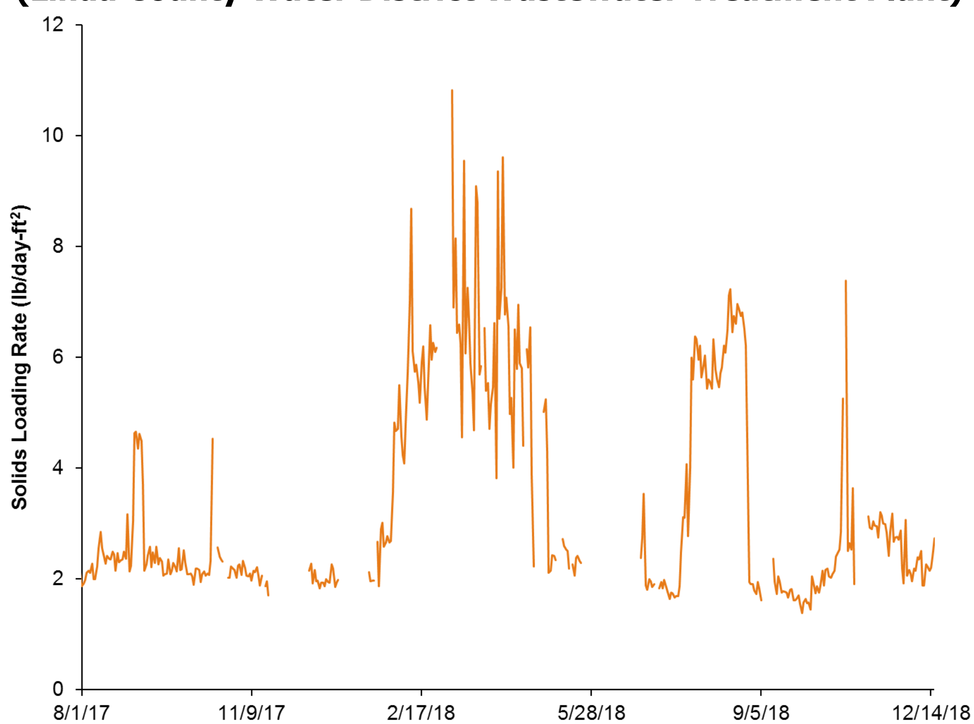
Figure 11: Daily Average Influent Flow and Hydraulic Loading Rate (Linda County Water District Wastewater Treatment Plant)



Gaps in data are due to issues described in Section 2.5.1.

Source: Kennedy Jenks Consultants

Figure 12: Daily Average Solids Loading Rate (Linda County Water District Wastewater Treatment Plant)



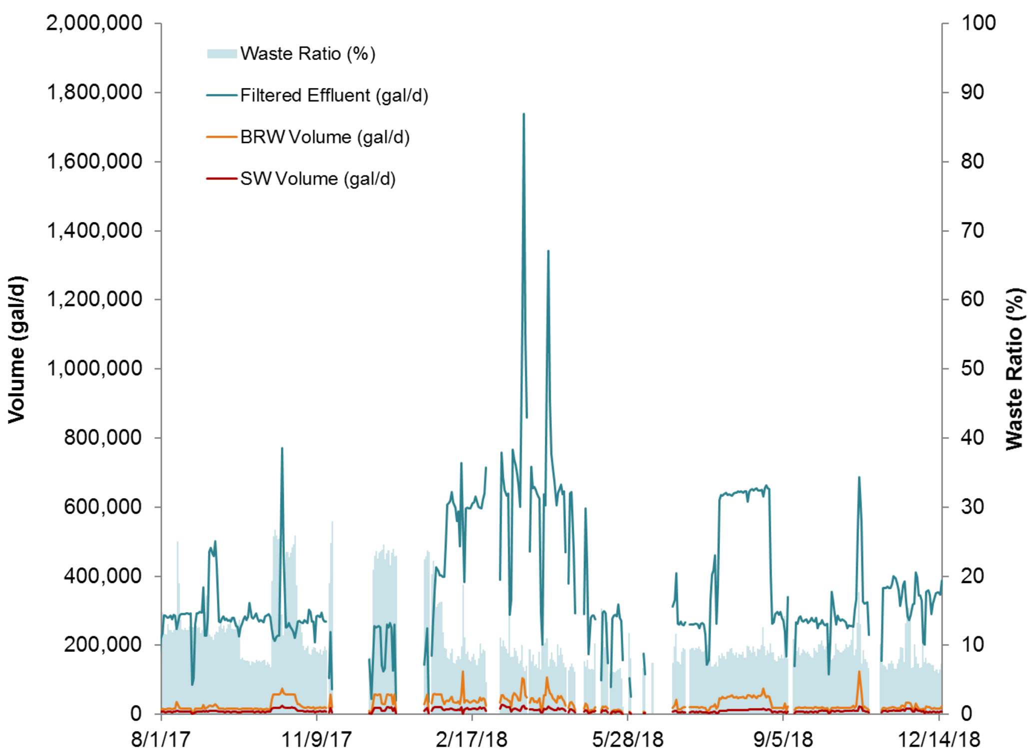
Gaps in data are due to issues described in Section 2.5.1.

Source: Kennedy Jenks Consultants

Average vacuum pressures during wasting cycles are shown in Figure 15. For the PCDF, backwash vacuum pressure corresponds to the ease at which water is pulled inside-out through the disk during a backwash cycle. High backwash vacuum pressures can be indicative of excess build-up of substances clogging the filter media pores, such as in media fouling.

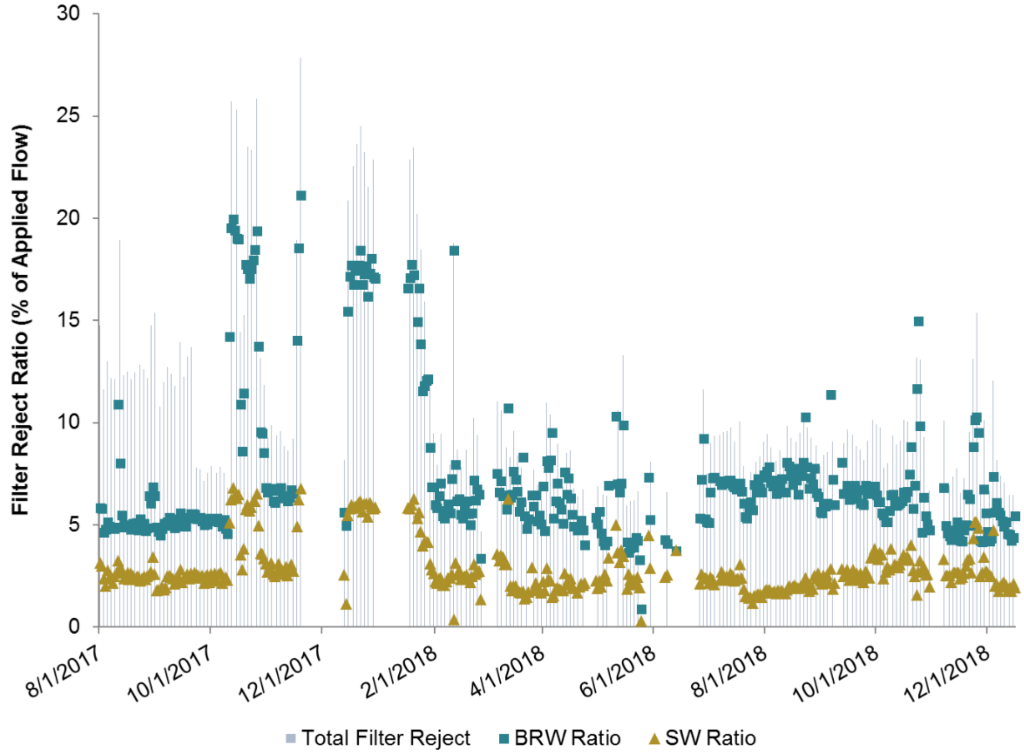
Backwash is typically set to initiate when water in the filter basin reaches a certain level due to headloss build-up on the filter media. Due to high backwash vacuum pressures and waste pump cavitation issues, the filter system was scheduled to perform a backwash at least every 30-45 minutes from October 11 to October 27, 2017 and after November 17, 2017. It is suspected that high waste vacuum pressures were caused by fouling of filter media. Vacuum pressures dropped significantly immediately after each filter clean-in-place (CIP) performed and steadily climbed up again in the days after.

Figure 13: Total Filtered and Wasted Volumes (Linda County Water District Wastewater Treatment Plant)



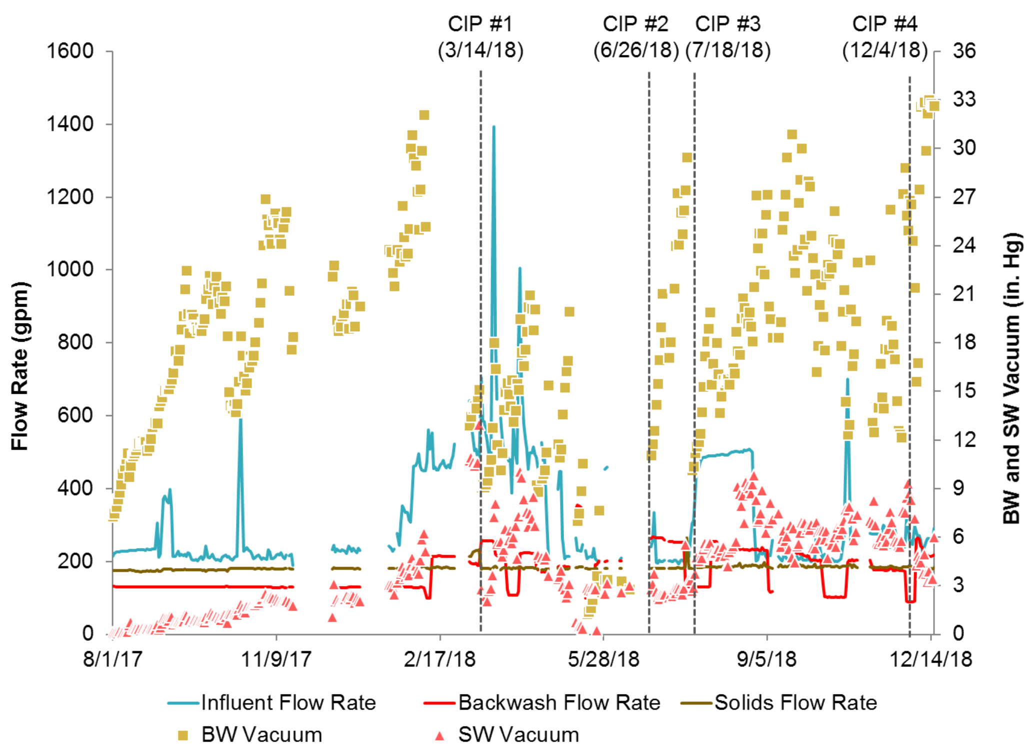
Source: Kennedy Jenks Consultants

Figure 14: Daily Average Filter Reject Flow Ratios (Linda County Water District Wastewater Treatment Plant)



Source: Kennedy Jenks Consultants

Figure 15: Filter Flows and Waste Vacuum Pressures (Linda County Water District Wastewater Treatment Plant)



Lines show when clean-in-place (CIP) was conducted for the filter media.

Source: Kennedy Jenks Consultants

CHAPTER 3: Demonstration at Lancaster Water Reclamation Plant

3.1. Site Specific Objectives

The specific objectives of the demonstration primary filtration project at the Lancaster Water Reclamation Plant (WRP) from November 2016 to December 2017 were:

- Demonstrate filter removal efficiencies for BOD_5, COD, VSS, and TSS.
- Evaluate the hydraulic performance of the demonstration PCDF system.
- Validate the performance of modifications to the PCDF system needed to address higher solids and FOG content.
- Estimate the reduction in electrical power required for aeration in the activated sludge process, due to raw wastewater filtration. The results are described in Chapter 5.
- Conduct a third-party M&V process for aeration energy savings resulting from primary filtration. The results are described in Section 5.4.

3.2. System Description

A demonstration-scale primary filter unit was installed at Lancaster WRP in October 2016 and was in operation until December 2017. This chapter covers observed performance from the entirety of the Lancaster demonstration.

3.2.1. Overview of Lancaster WRP

The Lancaster WRP is located at 1865 West Avenue D, north of the City of Lancaster, in northern Los Angeles County (see Figure 16). The WRP is owned and operated by District 14 of the Los Angeles County Sanitation District (LACSD).

The Lancaster WRP was placed in operation in 1959 and currently provides tertiary treatment for up to 18 mgd of wastewater. The Lancaster WRP serves a population of approximately 160,000 people from across much of the City of Lancaster, parts of the City of Palmdale, and portions of unincorporated county area. Lancaster WRP produces recycled water that is used for landscape irrigation, municipal and industrial purposes in the city of Lancaster, and to maintain water levels in Apollo Lakes Regional Park and Piute Ponds. In addition to producing recycled water, the Lancaster WRP processes all wastewater solids generated at the plant. The wastewater solids are anaerobically digested, centrifugally dewatered, and further dried in drying beds. The dried biosolids are hauled away and beneficially used. Methane gas is produced during the digestion process and is used to heat the anaerobic digesters. A flow diagram of the current plant with the addition of the primary filter system is shown in Figure 17.

Figure 16: Location of the Lancaster Wastewater Reclamation Plant

Source: Base map from Google Maps

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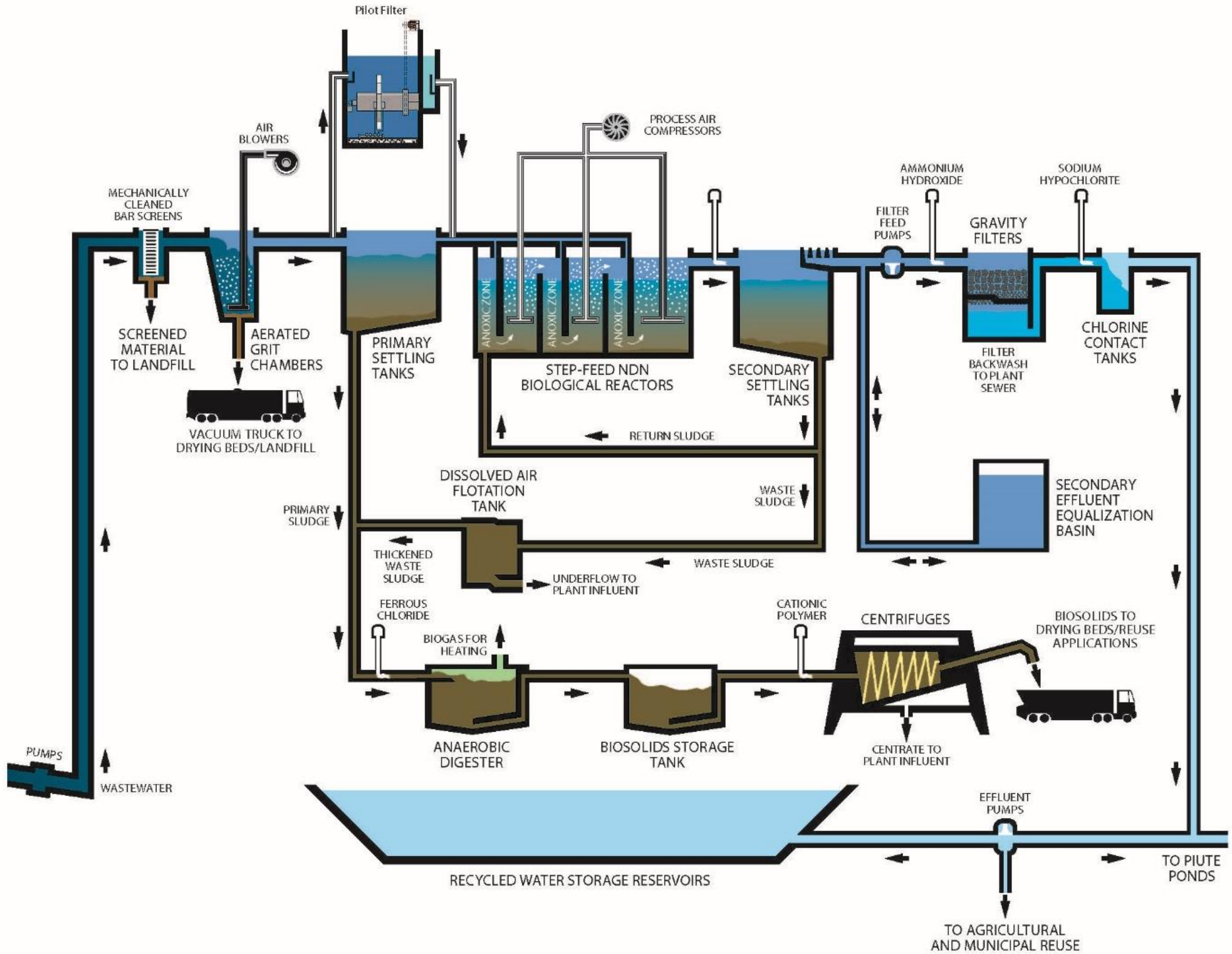
Figure 17: Lancaster Wastewater Reclamation Plant Flow Diagram



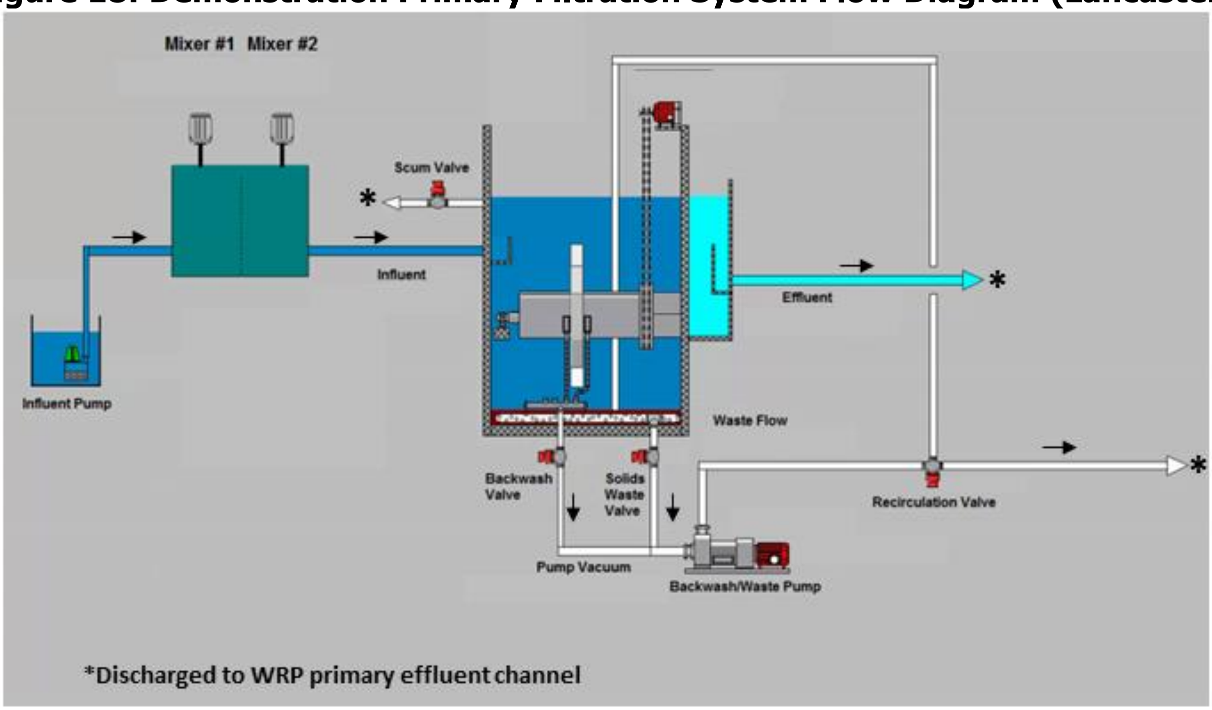
Source: Lancaster Water Reclamation Plant, Los Angeles County Sanitation Districts

3.2.2. Demonstration System Components

The demonstration primary filter system at the Lancaster WRP consisted of a primary filter unit with a treatment capacity of approximately 60 gpm. A flow diagram of the demonstration system is shown in Figure 18. System components include the following:

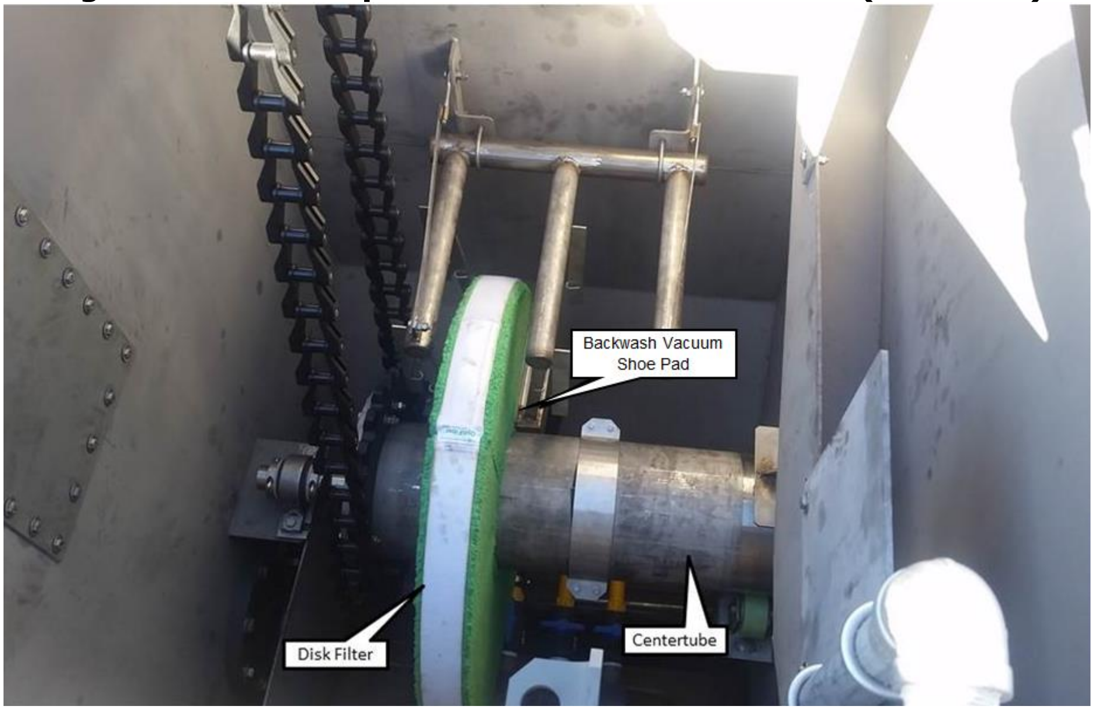
- Primary filter: The primary filter unit deployed at the Lancaster WRP uses PCDF and consists of one filter disk, as shown in Figure 19. The filter is provided by AASI and had the same modes operation as the full-scale filter at the LCWD WWTP.
- Influent: A small fraction of the raw wastewater at the Lancaster WRP was directed to the demonstration primary filter system. Raw wastewater, after passing through initial screening, was pumped to the filter tank through an approximately 200 foot-long 3-inch PVC pipe that ran along the WRP primary clarifier basins. The influent pump is installed in the primary clarifier influent channel, as shown in Figure 20.
- Effluent and Discharges: Filtered effluent was discharged to the WRP primary effluent channel via a 4-inch hose. Additional system discharges include filter backwash, sludge, scum, and overflow, which are also discharged to the primary effluent channel via 2- and 4-inch hoses, as shown in Figure 21 and Figure 22. These volumes of these additional waste discharges were very small relative to the plant flow. Thus, the discharges to the primary effluent had negligible impact on secondary treatment processes at the WRP.

Figure 18: Demonstration Primary Filtration System Flow Diagram (Lancaster)



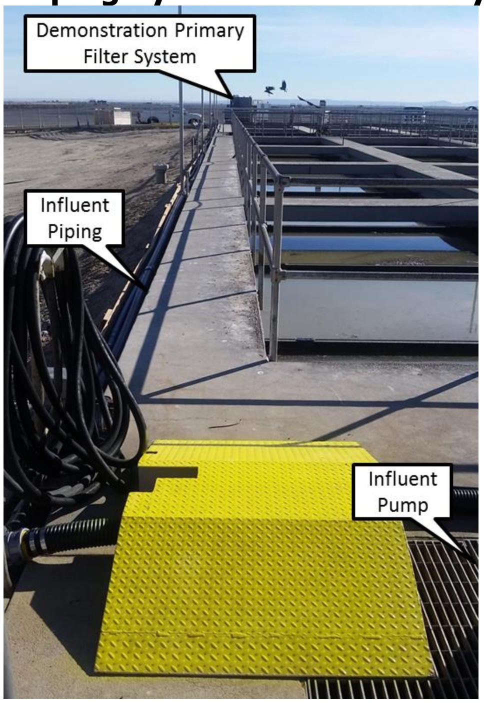
Source: Kennedy Jenks Consultants

Figure 19: Cloth Depth Disk Filter Inside the Tank (Lancaster)



Source: Kennedy Jenks Consultants

Figure 20: Influent Piping System to the Primary Filter (Lancaster)



Source: Kennedy Jenks Consultants

Figure 21: Primary Filter System Discharge Piping (Lancaster)

Source: Kennedy Jenks Consultants

Figure 22: Primary Filter System Discharge Locations (Lancaster)

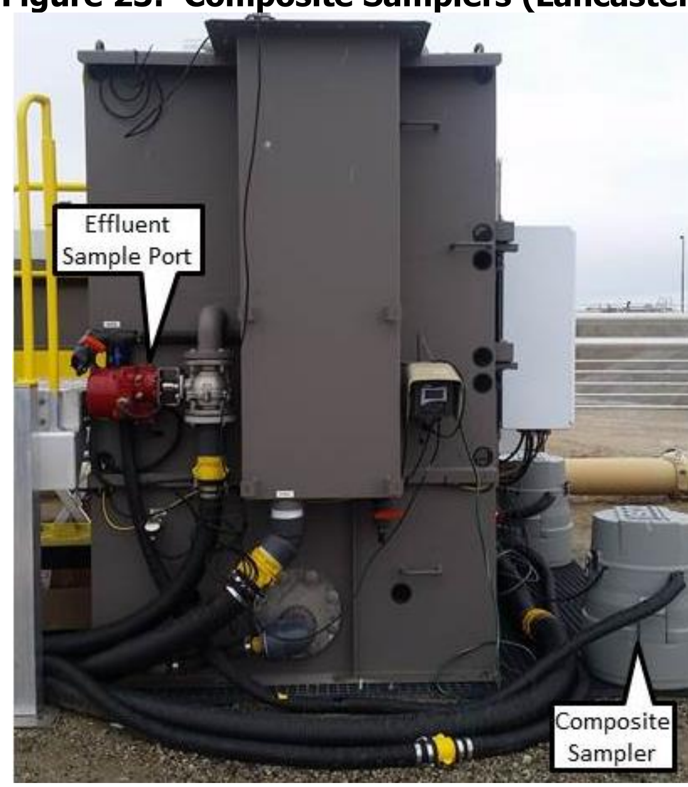
Source: Kennedy Jenks Consultants

3.2.3. Sampling and Monitoring Equipment

The demonstration primary filter system at the Lancaster WRP was equipped with composite samplers, turbidity sensors, flow meters, and a data logging and remote control system, as described below. The sampling and monitoring system allowed for evaluation of primary filter performance.

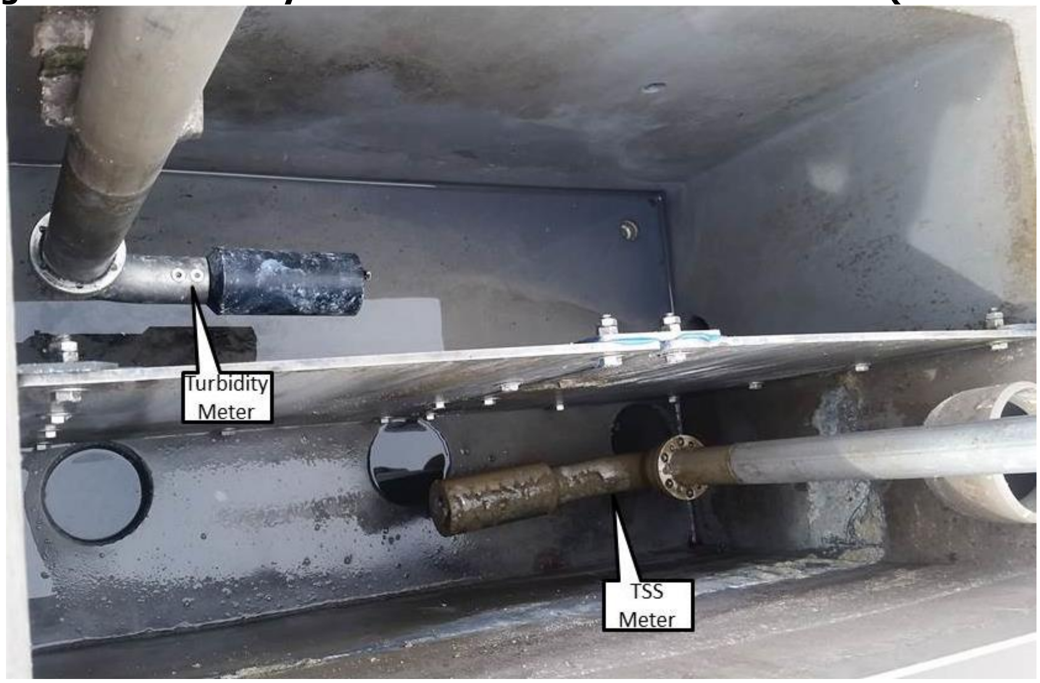
- Composite samplers: Samples were collected in 4-gallon polyethylene containers, using portable composite samplers (3710; Teledyne ISCO) connected to influent and effluent sample ports. The sampler connection to the effluent sample port is shown in Figure 23. Composite samples were over 24-hour periods on select days. Composite samples were sent to a third-party laboratory for TSS, VSS, BOD_5, COD, and FOG analysis.
- Turbidimeters/TSS sensors: Inline turbidimeters (Solitax sc; HACH) were installed in the filter influent and effluent channels. TSS/turbidity sensors also were installed at the influent tank and along the primary effluent channel to capture additional data. The meters installed in the influent tank are shown in Figure 24.
- Flow meters: Electromagnetic flowmeters (KROHNE) were installed at the influent connection and backwash pipe.
- Data logging/PLC system: A PLC was used to control and monitor multiple filter components. Operational or system alarms were also registered via PLC when abnormal conditions occur. The controller provided for automatic operation of all process modes and includes an HMI to allow user input to control filter operation. In addition, a laptop computer was used as the system SCADA computer, which provided real time displays, historical logging, and alarm event logging. The SCADA communicated directly with the PLC and could be accessed remotely. The PLC panel is shown in Figure 25. SCADA logged data included mode of operation, filter influent flow, filter reject rates, waste pump vacuum, basin level, and basin pH.

Figure 23: Composite Samplers (Lancaster)



Source: Kennedy Jenks Consultants

Figure 24: Turbidity and TSS Meters in Influent Channel (Lancaster)



Source: Kennedy Jenks Consultants

Figure 25: PLC Panel (Lancaster)

Source: Kennedy Jenks Consultants

3.3. Operation and Maintenance

The demonstration primary filter system was delivered to the Lancaster WRP on November 7, 2016. Installation of the filter system occurred over a three-day period between November 7 and 9. During these days, the piping and the influent pump were installed, and the PLC and SCADA were set up. Composite samplers were set up on December 7, 2016. The influent pump was initially placed at the bottom of the influent channel. It was subsequently raised approximately 6-8 inches to collect influent of more representative quality.

After set-up in November 2016, minor adjustments were made to the system. These adjustments included installation of insulation and heat tracing along influent and effluent sampling lines, as well as simplification of discharge line routes. In addition, a recirculation valve was installed on January 3, 2017 to re-suspend grit and other dense materials which had settled to the bottom of the filter tank.

3.3.1 System Setpoints

After start-up of the demonstration system in November 2016, the primary filter operated at an average hydraulic loading rate (HLR) of 3.25 gpm/ft^2 over a nearly 2-month period. This HLR translated to a flowrate of 35 gpm. In early January, filtration rates were adjusted down to an HLR of 2 gpm/ft^2 and flow of 23 gpm because of the high solids loading conditions observed at Lancaster. These rates were maintained for subsequent months. Throughout the demonstration period, minor adjustments were also made to solids waste settings in response to observations of filter system performance and conditions at the Lancaster WRP.

The major set points for the system, including changes, are summarized in Table 11. Backwash was performed when the filter tank level reached the specified start backwash level of 5.75 ft. Solids waste and scum removal occurred at specified time intervals or number of backwashes, whichever was more frequent.

Backwash recovery is measured as the decrease in water level following a backwash. Average recovery for the primary filter at the Lancaster WRP is between 0.3 and 0.4 ft, less than the average recovery of 1 ft. observed for the full-scale system at the LCWD WWTP.

3.3.2. Field Log

The operational and maintenance performance of the demonstration primary filter system was examined during site visits. Regular field operation included walkthrough of the site and visual inspection of the filter influent and effluent wastewater quality and system component conditions. Field logs were kept on all observations pertaining to system operation.

Table 11: System Setpoints (Lancaster)

Test Conditions	Start of Test	Change 1	Change 2	Change 3	Change 4	Change 5	Change 6
Date of Change	11/7/16	11/18/16	12/1/16	1/4/17	1/30/17	4/4/17	4/20/17
Cloth Type	PF-14	PF-14	PF-14	PF-14	PF-14	PF-14	PF-14
Hydraulic Loading Rate (gpm/ft^2)	3.25	3.25	3.25	2.1	2.1	2.1	2.1
Flow (gpm)	35	35	35	23	23	23	23
Filter Tank Level Set-Up							
High Tank Level (ft)	7	7	7	7	7	7	7
Start BW Level (ft)	5.75	5.75	5.75	5.75	5.75	5.75	5.75
BW Duration Per Valve (seconds)	26	26	26	26	26	26	26
BW Flow (gpm)	32.5	32.5	32.5	32.5	32.5	32.5	32.5
Start Scum Removal Level (ft)	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Minimum Level for BW (ft)	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Minimum Level for Solids Waste (ft)	0.75	0.75	0.75	0.75	0.75	1.00	1.00
Solids Waste Set-Up							
Solids Waste Time Interval (min)	30	30	30	30	30	90	90
No. of Backwashes between Solids Waste Events	3	30 *	5 *	3 *	3	3	3
Solids Waste Duration (seconds)	20	20	20	50 †	50	40	50
SW Flow (gpm)	32.5	32.5	32.5	32.5	32.5	32.5	32.5
Scum Removal Set-Up							
Scum Removal Interval (hours)	8	8	8	8	8	4 ‡	2 §
Scum Removal Duration (sec)	60	60	60	60	60	300 ‡	60 §
No. of Backwashes Between Scum Removal	30	30	30	30	30	300 ‡	300 §
Solids Conditioning Mode Set-Up							
Solids Condition Mode Time Interval (hrs)	N/A	N/A	N/A	N/A	4	4	4
Solids Conditioning Duration (seconds)	N/A	N/A	N/A	N/A	52	52	52
No. of Backwashes between SCM Events	N/A	N/A	N/A	N/A	30	30	30

Orange highlighted values indicate setting changes.

*** Adjustments were made to backwash and sludge removal settings to reach more optimal reject ratios. Increase to every 30 backwashes on 11/18/16 appears to have been unintentional.**

† Adjustment made to solids waste duration in response to solids waste build-up. Sludge should remain below 1.5 ft, as the bottom of the filter disk is at about 1.3-1.5 feet from the filter tank bottom.

‡ Settings were changed to increase scum removal frequency (based on time interval of 4 hours) and duration (300 sec).

§ Scum removal frequency was increased again to every 2 hours. Scum removal duration was changed back to 60 sec.

Source: Kennedy Jenks Consultants

3.3.2.1 Summary of Regular Field Operations and Observations

Site visits were made regularly to ensure proper functioning of the filter system and implement corrective actions needed. Observations from site visits are summarized in Table 12.

Table 12: Field Log (Lancaster)

Date	Observations
11/8/16, 11/9/16	Installation of primary filter system. No major issues interfering with proper functioning of the filter system were observed.
11/23/16	Piping was re-configured to connect only the backwash pipe to the 100-gal tank (holding tank on top of effluent chamber). All other pipes discharged directly to the primary effluent chamber. Valve handle was removed on the discharge side of the 100-gal tank to prevent accidental closure.
12/6/16	Turbidity meters were calibrated. Sludge judge showed 1-2 ft. of sludge at the bottom of the filter tank. No leaks, cracks, or other unusual conditions were observed.
12/22/16	Filter influent and effluent grab samples were collected. Tubing and sample valve froze over which prevented composite sampling earlier in the week. Tubing and sample lines were insulated on this day. Sludge at the filter tank bottom was approximately 1.5 ft. No leaks, cracks, or other unusual conditions were observed.
1/3/17	Heat tracing was put in along tubing to prevent continued freezing of sample lines. High levels of cloth and wipes (that passed through preliminary treatment) were observed, which resulted in obstruction of backwash vacuum hose. Re-circulation header was installed. Sludge at the filter tank bottom was approximately 1.5 ft. No leaks, cracks, or other unusual conditions were observed.
1/26/17	Tank was drained to install new level transducer. Transducer replacement was not completed on this day. Sludge at the filter tank bottom was approximately 1 ft. before draining. Signs of rodents eating tubing insulation were observed and reported by on-site lab technician. No leaks, cracks, or other unusual conditions were observed.
1/31/17	Faulty transducer was replaced to re-establish two (2) functioning pressure transducers.
2/21/17	Power was out on the SCADA panel and needed to be re-established. Measured about 4 in. of sludge. Numerous rags/larger debris from the filter influent were observed to be accumulated inside the tank. No leaks, cracks, or other unusual conditions were observed.
2/27/17	Power was out on the SCADA panel and needed to be re-established. No leaks, cracks, or other unusual conditions were observed.
3/1/17	Connections/power splitters were evaluated and protected from rain and moisture, in response to power outages on SCADA panel.

Date	Observations
3/27/17	Power was lost on the SCADA panel on 3/23/17. Power was re-established same day, but the computer was not re-booted until 3/27/17. During the 3/27/17 site visit, the filter was discovered to not be working, apparently due to issues with the backwash valve. The backwash valve fuse was replaced, but the new fuse blew shortly after replacement. A solution was not found that day, so the filter was taken offline.
3/30/17	Site visit was conducted to inspect the system and address the backwash valve malfunction. The tank was drained and cleaned. Backwash valve and pipe were inspected for clogging, but no clogging was found. The backwash valve fuse (1 Amp) was replaced with a new fuse (1 ½ Amp). The valve appeared to be working, but HMI showed alarms of failure to close. During cleaning and inspection, the filter disk was taken apart (one-half of the disk removed) and visually inspected. The pH meter and turbidity meters were calibrated. Multi-sampler was installed on the filter influent side. The system was brought online again by the early evening but failed again within 2-3 hours.
4/4/17	The backwash valve and actuator were replaced with new parts. Tubing for effluent sampler was found to be cracked and was replaced with used influent sampler tubing. The filter was brought back online with minor additional adjustments made on 4/5/17.
4/10/17	Power was lost to SCADA panel on 4/8/17. Power was re-established, and system was re-started.
5/18/17	Filter system went down due to clogging of the influent pump. Debris was cleaned out, and the system was restarted.
5/31/17	A wellness check was conducted on the filter. The tank was cleaned. No unusual observations were made. Third-party energy audit was also set up.
7/3/17	Influent pump stopped drawing in water on 6/30/17. Unusually high amounts of debris and rags were observed in the influent channel. Debris was cleared, and system was re-started.
7/12/17	Pump was obstructed by the chain holding up the pump, possibly due to pump adjustments made on 7/3/17. Obstruction was cleared.
7/26/17	Pump was obstructed with debris and rags. Debris was removed, pump was raised, and a hoist was installed.
8/25/17	Influent pump was obstructed with debris and rags. Debris was removed, and system was re-started.
8/29/17	Onsite check-up was conducted. Sampling was performed on filter influent and effluent through 8/30/17. Primary channel was inspected to assess whether to move the influent pump. No changes were made.
9/7/17	Inspection of filter system was conducted.
9/28/17	Unit was examined, and the backwash pump appeared to be clogged. No correction could be made.
9/29/17	Backwash pump was examined, but no obstruction was found. No correction could be made.
10/6/17	Backwash lines were disassembled and cleared of debris.

Date	Observations
12/4/17, 12/5/17	Sampling performed. Set up on first day, collection on 2nd day.
12/12/17	Final samples collected and decommissioning began.
12/13/17	Decommissioning continued. Pilot system packed up.
12/14/17	All final equipment packed up. Final run through performed to make sure all items appropriately packed or addressed.
12/15/17	Loading and offsite transportation of the pilot and all equipment.

Source: Kennedy Jenks Consultants

3.3.2.2 Unusual Events/Conditions

High solids events were one of the primary noteworthy events experienced at the Lancaster WRP, with potential impacts to the demonstration system. High solids events with turbidity levels above 500 nephelometric turbidity units (NTU) were frequently observed. Maximum turbidity on many days reached the turbidimeter's maximum reading of 4,000 NTU. In all instances, the filter continued functioning properly, and high solid reduction rates were maintained during those events.

Additionally, high debris loading at the Lancaster WRP clogged the filter intake pump on several occasions. In June and July, substantial rag and debris buildup occurred at the intake pump. In these instances, the system was taken offline to remove the blockage and to adjust the pump setup. The levels of large debris observed at the intake are attributed to ineffective screening system at the Lancaster WRP. While this type of loading was problematic for the demonstration-scale system, clogging of the intake system is not anticipated for a full-scale system.

A power outage occurred at the power plant on February 18, 2017, which coincided with a heavy rain event. Another heavy rain event occurred the following weekend on February 25 and 26. Following these rain events, power was lost on the SCADA panel. Additional power outages were experienced for unidentified reasons. These types of system shutdowns due to power outages are not likely to occur for full-scale installations.

3.3.3. Summary of Issues and Resolutions

Adjustments were made after start-up, and corrective actions were taken to maintain proper functioning and operation of the filter system. These actions were taken in response to system interruptions, minor equipment malfunctions, changes to plant operations, or other plant and filter conditions. A summary of incidents and corrective actions taken is provided in Table 13.

Minor malfunctions of the demonstration system appurtenances, including fuses, relays, and sensors are likely to occur at one point or another during full-scale implementation. For these reasons, designing a full-scale system should take into consideration the ease of replacing or repairing these components. Pressure transducers showed damage during replacement and may warrant consideration of alternative options, such as sonic probes.

For a full-scale primary filtration system, it is crucial that the system can handle variations in water quality, including unexpected high solids loading that was experienced at the Lancaster WRP. This demonstration system handled these events well and minor malfunctions provided valuable data and information to properly design a full-scale system to handle similar conditions. In addition to high levels of suspended solids, another issue encountered was that the Lancaster WRP screening and grit removal processes passed a significant amount of papers, wipes, and large debris. The existing screening at the WRP consists of a ½" bar screen and a comminutor (a shredding machine used to reduce solids to a smaller particle size for downstream processing).. For full-scale installations, a finer screen (*e.g.* ¼ to ⅜") is recommended.

Table 13: Demonstration System Challenges and Corrective Actions (Lancaster)

Date	Incident/Issue	Related to Primary Filter?	Corrective Action	Impacted System Com-ponent	Reason	Considerations for Full-Scale System	Estimated Probability of Occurrence in Full-Scale System*
11/9/16	Solids waste valve blew a fuse.	Yes	Fuse was replaced on same day.	Solids waste valve	Equipment malfunction	Spare fuse would normally be available for full scale system for ease of replacement/repair.	1
12/8/16	High solids loading event, during unexpected Lancaster WRP cleaning of influent wet well. Influent pump became obstructed. There was concern regarding proper functioning of the filter system.	No	Pump was briefly shut down to dislodge obstruction. Filter continued operating properly, despite being in continuous backwash. Highest water level stayed below the overflow level.	Backwash system, influent pump	Unusual high influent load conditions	Water quality variations likely for full-scale implementation. Peak solids conditions should be considered for backwash system and hydraulics design.	0
12/8/16	Scum valve stopped opening automatically, resulting from a bad relay on the open circuit.	No	The relay was replaced and system continued functioning properly.	Scum valve	Equipment malfunction	Spare relays would normally be available for full scale system for ease of replacement/repair.	1

Date	Incident/Issue	Related to Primary Filter?	Corrective Action	Impacted System Com-ponent	Reason	Considerations for Full-Scale System	Estimated Probability of Occurrence in Full-Scale System*
12/8/16	SCADA lost communication and caused the remote logging system to go offline. Reason for lost communication is unknown; unknown if related to high solids event.	No	Laptop (SCADA computer) was re-booted on 12/9/16. Filter system continued to run during lost communication.	SCADA	Equipment malfunction	Not expected to be a problem for full-scale systems with plant operators.	0
1/3/17	Recirculation header installed in filter tank. During installation, one backwash vacuum hose was found to be clogged. The plant is passing a lot of paper and wipes through the preliminary screening system to the primary filter.	Yes	Vacuum hose was unclogged. For future full-scale installation, finer screen is recommended for upstream treatment process. Existing screening is 1/2" bar screen and comminutor.	Backwash Reject System	Unusual plant influent conditions	For full-scale installation, a finer screen is typically recommended for headworks upstream of primary filter system.	0
1/4/17	Low level pressure transducer failed. System continued to operate normally on backup sensor. Transducers were slightly damaged	Yes	Pressure transducer was replaced on 1/31/17 to maintain 2 functioning transducers.	Backwash Start System	Equipment malfunction	May require alternative method of measuring water levels, such as sonar or radar.	2

Date	Incident/Issue	Related to Primary Filter?	Corrective Action	Impacted System Com-ponent	Reason	Considerations for Full-Scale System	Estimated Probability of Occurrence in Full-Scale System*
2/21/17	Power was lost to SCADA. Reasons are unclear, but could include: 1) SCADA panel did not reset when power was lost at WRP on 2/18/17. 2) Power chords exposed to the elements.	No	Ground fault circuit interrupter (GFCI) was reset on SCADA panel.	SCADA	Possibly improperly protected power chords.	Not expected to be a problem for full-scale systems with plant operators.	0
2/27/17	Power was lost to SCADA. Possibly due to exposed power chords.	No	GFCI was reset on SCADA panel.	SCADA	Possibly improperly protected power chords.	Not expected to be a problem for full-scale systems with plant operators.	0
3/27/17	Power was lost to SCADA on 3/23/17. Reasons unknown.	No	GFCI was reset on SCADA panel.	SCADA	Equipment malfunction suspected	SCADA issues not expected to be a problem for full-scale system.	0
3/27/17	Backwash valve failed.	Yes	Backwash valve and actuator were replaced on 4/4/17.	Backwash Valve	Equipment malfunction suspected	Backwash system design should consider peak solids conditions.	3

Date	Incident/Issue	Related to Primary Filter?	Corrective Action	Impacted System Com-ponent	Reason	Considerations for Full-Scale System	Estimated Probability of Occurrence in Full-Scale System*
4/8/17	Power was lost to SCADA. Possibly due to rain event on 4/8/17.	No	GFCI was reset on SCADA panel.	SCADA	Possibly improperly protected power chords.	Not expected to be a problem for full-scale systems with plant operators.	0
5/18/17	Filter system went down due to clogging of the influent pump.	No	Debris was cleared from the pump.	Influent Pump	Excess debris, clogging	Water quality variations likely for full-scale implementation, but less debris anticipated upstream of full-scale primary filter systems.	0
6/30/17	Influent pump stopped drawing in water due to clogging.	No	Debris was cleared from the pump.	Influent Pump	Excess debris, clogging	Water quality variations likely for full-scale implementation, but less debris anticipated upstream of full-scale primary filter systems.	0
7/10/17	Influent pump was obstructed by chain holding up pump.	No	Obstruction was cleared on 7/12/17	Influent Pump	Obstruction by equipment	Not expected to be a problem for full-scale systems due to different intake set up.	1

Date	Incident/Issue	Related to Primary Filter?	Corrective Action	Impacted System Com-ponent	Reason	Considerations for Full-Scale System	Estimated Probability of Occurrence in Full-Scale System*
7/16/17	Influent pump stopped drawing in water due to substantial clogging. Filter system was offline from 7/16/17-7/25/17.	No	Debris was cleared from the pump, modifications made (pump raised and hoist installed), and system brought back online on 7/26/17.	Influent Pump	Excess debris, clogging	Water quality variations likely for full-scale implementation, but less debris anticipated upstream of full-scale primary filter systems.	0
8/25/17	Influent pump stopped drawing in water due to clogging.	No	Debris was cleared from the pump.	Influent Pump	Excess debris, clogging	Water quality variations likely for full-scale implementation, but less debris anticipated upstream of full-scale primary filter systems.	0
9/12/17	System shut down sue to power failure, followed by continuous solids wasting.	No	System was reset remotely on 9/13/17.	Demonstration System	Power failure at plant.	Not expected to be a problem for full-scale systems due to power backup.	1
9/26/17	Power loss at plant required system reset.	No	System was reset remotely.	Demonstration System	Power failure at plant.	Not expected to be a problem for full-scale systems due to power backup.	1
9/27/17	Backwash pump stopped generating flow. Unit was taken offline.	Yes	Backwash lines were disassembled and cleared of debris on 10/6/17.	Backwash pump/line	Excess debris, clogging	Less debris anticipated for full-scale implementation.	0

Date	Incident/Issue	Related to Primary Filter?	Corrective Action	Impacted System Com-ponent	Reason	Considerations for Full-Scale System	Estimated Probability of Occurrence in Full-Scale System*
10/11/17	Backwash pump stopped functioning properly. Unit was taken offline.	Yes	Lines cleared without action taken by 10/13/17.	Backwash pump/line	Excess debris, clogging	Less debris anticipated for full-scale implementation.	0
11/10/17	Intake clogged.	No	Unit taken offline on 11/13/17. Intake hosing was cleared of clogging and unit was put back online on 11/29/17.	Intake hose at pilot unit	Excess debris, clogging	Less debris anticipated for full-scale implementation.	0

*** Scale for estimated probability: 0 = not likely; 1 = somewhat likely, 2 = likely, 3 = very likely. It is expected that WWTPs which implement full-scale primary filtration will have a grit removal process with a fine screen of ⅜” (or smaller) upstream. In case of systems with no grit removal, a fine screen of ¼” is recommended**

Source: Kennedy Jenks Consultants

3.4. System Performance

The treatment performance of the demonstration system at the Lancaster WRP was evaluated for the feasibility of primary filtration as an APT technology, in terms of both treatment and hydraulic performance.

3.4.1 Treatment

The treatment performance of the demonstration system at the Lancaster WRP was evaluated for the feasibility of primary filtration as an APT technology. During its operation, the primary filter consistently achieved high solids removal, as shown by both onsite turbidity measurements and laboratory TSS measurements. Particle removal also resulted in reduction of BOD_5 and COD.

3.4.1.1 Continuous Performance Monitoring

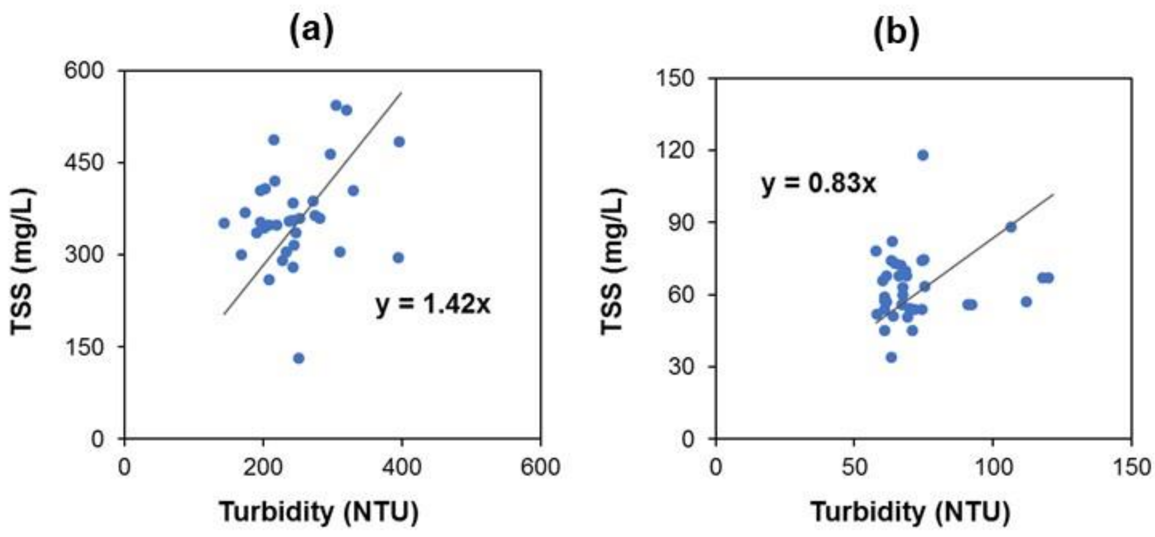
During the entire demonstration, inline turbidimeters (HACH Solitax) provided continuous monitoring of the filter influent and effluent. Correlations were established between inline turbidity averages and TSS measured in composite samples; daily TSS removal performance by the filter is estimated using these correlations.

Total Suspended Solids to Turbidity Correlation

Filter influent and effluent turbidities were continuously logged by SCADA at 5-second intervals. Filter influent and effluent TSS values were measured periodically using 24-hour composite samples. TSS-to-turbidity correlation ratios were calculated for the primary influent and effluent by correlating the TSS composite measurements with turbidity averaged over corresponding 24-hour periods. Turbidity data points exceeding 500 NTU were not considered in this analysis due to unreliability of turbidimeter readings at such high values.

Linear correlations of TSS versus turbidity are shown in Figure 26.

Figure 26: TSS-to-Turbidity Correlation for (a) Primary Filter Influent and (b) Primary Filter Effluent (Lancaster)



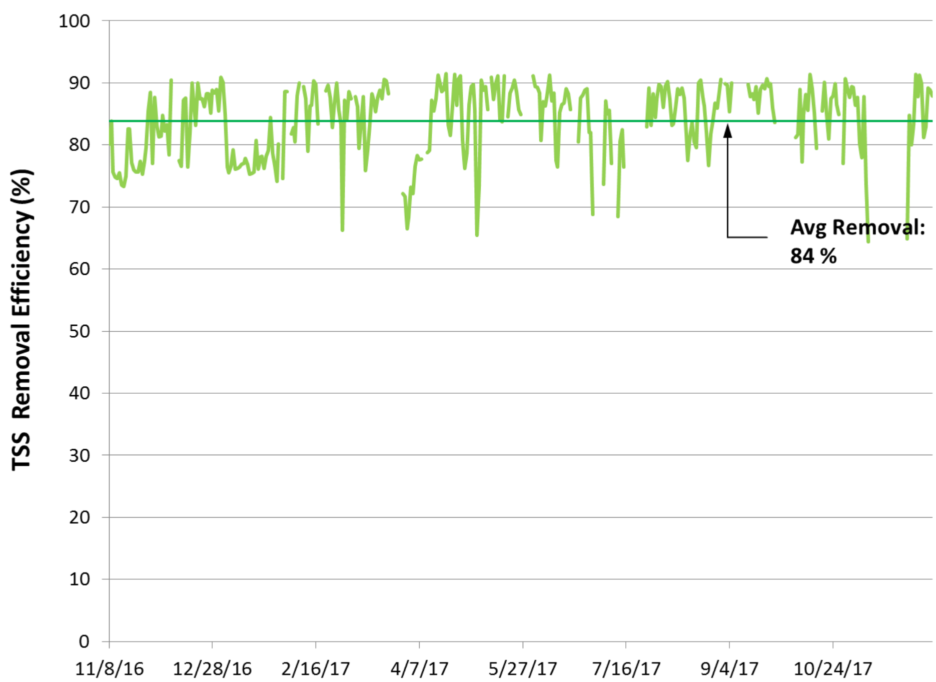
Source: Kennedy Jenks Consultants

TSS-to-turbidity correlation factors were found to be 1.42 and 0.83 for the primary filter influent and effluent, respectively. These correlation factors were used to convert daily average turbidity logged by SCADA to TSS. The correlation factors were meant to provide a general relationship between TSS and turbidity, rather than giving precise values of TSS.

Total Suspended Solids Removal Efficiency

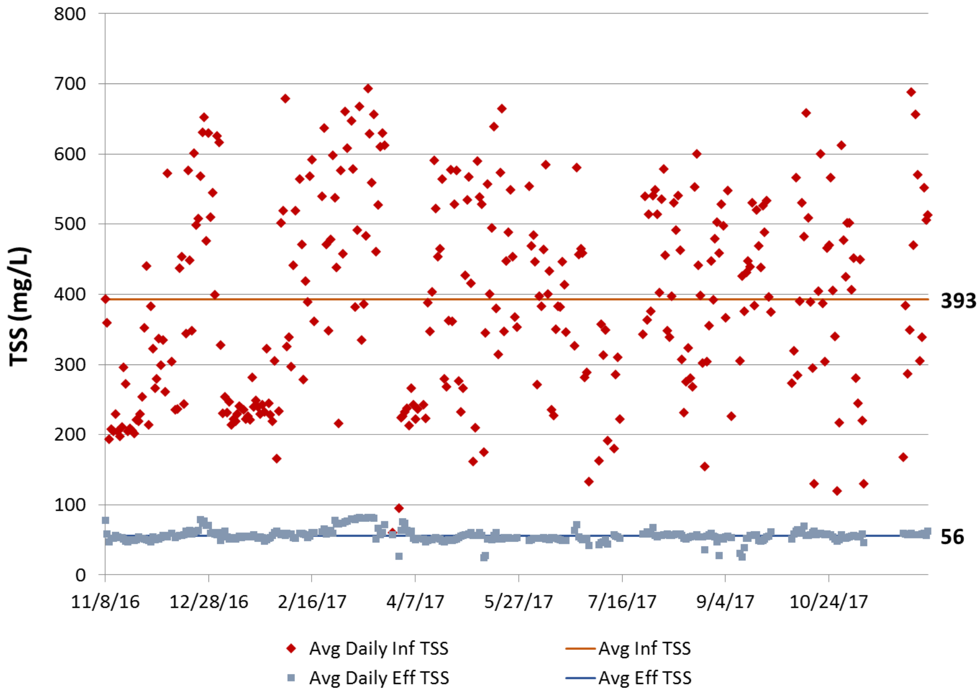
The demonstration primary filtration system performed at a high level in terms of TSS removal, as anticipated. As shown in Figure 27, TSS removal efficiency has averaged 84 percent during the 12-month operation period, with a range between 62 and 93 percent since start-up of the system. The daily average filter influent and effluent TSS values are shown in Figure 28. A large variation in daily average influent TSS from 90 to 700 mg/L was observed. Daily average effluent TSS, however, remained relatively stable between 25 and 80 mg/L. This demonstrates the primary filter's ability to handle large variations in raw wastewater quality. Overall average TSS values were 393 and 56 mg/L for filter influent and effluent, respectively. Conventional primary clarification systems typically remove 50 to 60 percent of TSS. For a wastewater treatment facility with influent TSS of 400 mg/L, effluent TSS values (after primary clarification) can range from 160 to 200 mg/L.

Figure 27: TSS Removal Efficiency (Lancaster)



Source: Kennedy Jenks Consultants

Figure 28: Average Influent and Effluent TSS (Lancaster)



Source: Kennedy Jenks Consultants

3.4.1.2 Filter Performance Results from Laboratory Sampling

In addition to the field performance data continuously recorded by SCADA (turbidity, pH, head loss, flow rate), multiple grab and composite filter influent and effluent samples were taken and analyzed for TSS, VSS, BOD5, and COD . Samples collected since November 2016 are summarized in Table 14 and Table 15 for parameters which included hourly analysis and in Table 16 and Table 17 for additional parameters. The average values from the laboratory analyses are summarized in Table 18.

The high TSS removal rates determined via continuous field turbidity measurements were confirmed by the composite samples analyzed in laboratory for TSS. The grab and composite samples showed an average TSS removal efficiency of 83 percent, compared with removal efficiency of 84 percent based on TSS values converted from online turbidity readings. The confirmation of the TSS removal efficiency validates the approach of using TSS to turbidity correlation to obtain estimates of average daily TSS values.

Other constituents were also removed through primary filtration. Average BOD_5 and COD removal efficiencies are 52 percent and 54 percent, respectively. Average Total Kjeldahl Nitrogen (TKN) removal efficiency was 15 percent. These constituents were likely removed in their particulate form.

Table 14: Laboratory Sampling Results for TSS, VSS, and BOD (Lancaster)

Date	Sample Duration	TSS Filter Influent (mg/L)	TSS Filter Effluent (mg/L)	TSS Removal (%)	VSS Filter Influent (mg/L)	VSS Filter Effluent (mg/L)	VSS Removal (%)	BOD_5 Filter Influent (mg/L)	BOD_5 Filter Effluent (mg/L)	BOD_5 Removal (%)
11/10/16	grab	260	28	89	260	28	89	190	76	60
12/6/16	grab	320	78	76	320	78	76	92	95	-3
12/22/16	grab	190	30	84	160	30	81	130	63	51
12/29/16	24-hr	--	52	--	--	52	--	--	250	-
1/6/17	24-hr	370	41	89	370	41	89	300	150	50
1/12/17	24-hr	280	38	86	280	38	86	290	150	48
1/19/17	24-hr	320	58	82	320	58	82	270	140	48
1/24/17	24-hr	300	45	85	364	69	81	--	--	--
1/26/17	24-hr	353	34	90				--	--	--
1/30/17	24-hr	616	63.3	90	--	--	--	--	--	--
2/2/17	24-hr	304	54.4	82	--	--	--	--	--	--
2/7/17	24-hr	336	51.2	85	--	--	--	--	--	--
2/9/17	24-hr	364	50.7	86	--	--	--	--	--	--
2/13/17	24-hr	368	54	85	--	--	--	--	--	--
2/16/17	24-hr	536	45	92	--	--	--	--	--	--
2/23/17	24-hr	484	54	89	--	--	--	--	--	--
3/1/17	24-hr	290	56	81	--	--	--	--	--	--
3/2/17	24-hr	348	56	84	--	--	--	--	--	--
3/9/17	24-hr	404	57	86	--	--	--	--	--	--
3/13/17	24-hr	404	67	83	--	--	--	--	--	--
3/17/17	24-hr	544	67	88	--	--	--	--	--	--
3/21/17	24-hr	1140	88	92	--	--	--	--	--	--
4/11/17	24-hr	220	72	67	--	--	--	--	--	--
4/21/17	24-hr	652	74	89	--	--	--	--	--	--
4/24/17	24-hr	420	59	86	--	--	--	--	--	--
4/27/17	24-hr	356	54	85	--	--	--	--	--	--
5/2/17	24-hr	384	68	82	--	--	--	--	--	--

Date	Sample Duration	TSS Filter Influent (mg/L)	TSS Filter Effluent (mg/L)	TSS Removal (%)	VSS Filter Influent (mg/L)	VSS Filter Effluent (mg/L)	VSS Removal (%)	BOD_5 Filter Influent (mg/L)	BOD_5 Filter Effluent (mg/L)	BOD_5 Removal (%)
5/4/17	24-hr	464	74	84	--	--	--	--	--	--
5/15/17	24-hr	296	57.3	81	--	--	--	--	--	--
5/18/17	24-hr	132	57	57	--	--	--	--	--	--
5/22/17	24-hr	360	73	80	--	--	--	--	--	--
6/2/17	24-hr	354	78	78	--	--	--	--	--	--
6/5/17	24-hr	408	82	80	--	--	--	--	--	--
6/8/17	24-hr	348	74	79	--	--	--	--	--	--
6/15/17	24-hr	344	68	80	--	--	--	--	--	--
6/20/17	24-hr	396	52	87	--	--	--	--	--	--
6/28/17	24-hr	488	66	86	--	--	--	--	--	--
7/14/17	24-hr	260	--	--	--	--	--	--	--	--
7/31/17	24-hr	280	74.7	73	--	--	--	--	--	--
8/3/17	24-hr	352	70	80	--	--	--	--	--	--
8/24/17	24-hr	364	56	85	--	--	--	--	--	--
8/28/17	24-hr	360	118	67	--	--	--	--	--	--
8/29*/17, 08:45	1-hr	620	--	--	--	--	--	400	--	--
8/29*/17, 09:45	1-hr	320	46	86	--	--	--	210	130	38
8/29*/17, 10:45	1-hr	340	43	87	--	--	--	280	120	57
8/29*/17, 11:45	1-hr	340	41	88	--	--	--	360	140	61
8/29*/17, 12:45	1-hr	400	--	--	--	--	--	360	--	--
8/29*/17, 13:45	1-hr	390	--	--	--	--	--	430	--	--
8/29*/17, 14:45	1-hr	400	--	--	--	--	--	450	--	--

Date	Sample Duration	TSS Filter Influent (mg/L)	TSS Filter Effluent (mg/L)	TSS Removal (%)	VSS Filter Influent (mg/L)	VSS Filter Effluent (mg/L)	VSS Removal (%)	BOD_5 Filter Influent (mg/L)	BOD_5 Filter Effluent (mg/L)	BOD_5 Removal (%)
8/29*/17, 15:45	1-hr	320	--	--	--	--	--	420	--	--
8/29*/17, 16:45	1-hr	320	--	--	--	--	--	340	--	--
8/29*/17, 17:45	1-hr	330	--	--	--	--	--	380	--	--
8/30/17, 07:45	1-hr	--	26	--	--	--	--	--	110	--
9/5/17	24-hr	388	68	82	--	--	--	--	--	--
9/7/17	24-hr	336	72	79	--	--	--	--	--	--
9/20/17	24-hr	316	63	80	--	--	--	--	--	--
9/25/17	24-hr	304	60	80	--	--	--	--	--	--
10/12/17	24-hr	536	110	79	--	--	--	--	--	--
10/17/17	24-hr	376	63	83	--	--	--	--	--	--
10/19/17	24-hr	412	62	85	--	--	--	--	--	--
10/23/17	24-hr	336	50	85	--	--	--	--	--	--
10/26/17	24-hr	456	56	88	--	--	--	--	--	--
10/30/17	24-hr	324	90	72	--	--	--	--	--	--
11/2/17	24-hr	360	60	83	--	--	--	--	--	--
11/6/17	24-hr	336	62	82	--	--	--	--	--	--
Average*		**372**	**59**	**83**	**296**	**49**	**83**	**321**	**117**	**52**

Source: Kennedy Jenks Consultants

Table 15: Laboratory Sampling Results for COD and FOG (Lancaster)

Date	Sample Duration	COD Filter Influent (mg O_2/L)	COD Filter Effluent (mg O_2/L)	COD Removal (%)	FOG Filter Influent (mg/L)	FOG Filter Effluent (mg/L)	FOG Removal (%)
11/10/16	grab	590	240	59	--	--	--
12/6/16	grab	630	320	49	--	--	--
12/22/16	grab	290	150	48	10	4	62
12/29/16	24-hr	--	430	--	--	10	--
1/6/17	24-hr	810	330	--	34	17	50
1/12/17	24-hr	590	300	--	29	11	62
1/19/17	24-hr	670	320	--	27	13	52
1/24/17	24-hr	656	268	59	--	--	--
1/26/17	24-hr	661	287	57	--	--	--
1/30/17	24-hr	879	437	50	--	--	--
2/2/17	24-hr	621	327	47	--	--	--
2/7/17	24-hr	651	312	52	--	--	--
2/9/17	24-hr	648	282	56	--	--	--
2/13/17	24-hr	744	361	51	--	--	--
2/16/17	24-hr	798	310	61	--	--	--
2/23/17	24-hr	679	317	53	--	--	--
3/1/17	24-hr	716	334	53	--	--	--
3/2/17	24-hr	614	297	52	--	--	--
3/9/17	24-hr	756	315	58	--	--	--
3/13/17	24-hr	766	367	52	--	--	--
3/17/17	24-hr	891	344	61	--	--	--
3/21/17	24-hr	1920	434	77	--	--	--
4/11/17	24-hr	494	347	30	--	--	--
4/21/17	24-hr	1070	310	71	--	--	--
4/24/17	24-hr	799	334	58	--	--	--
4/27/17	24-hr	814	315	61	--	--	--
5/2/17	24-hr	709	339	52	--	--	--
5/4/17	24-hr	761	332	56	--	--	--

Date	Sample Duration	COD Filter Influent (mg O_2/L)	COD Filter Effluent (mg O_2/L)	COD Removal (%)	FOG Filter Influent (mg/L)	FOG Filter Effluent (mg/L)	FOG Removal (%)
5/15/17	24-hr	654	363	44	--	--	--
5/18/17	24-hr	699	321	54	--	--	--
5/22/17	24-hr	664	343	48	--	--	--
6/2/17	24-hr	587	313	47	--	--	--
6/5/17	24-hr	767	351	54	--	--	--
6/8/17	24-hr	677	318	53	--	--	--
6/15/17	24-hr	632	286	55	--	--	--
6/20/17	24-hr	712	338	53	--	--	--
6/28/17	24-hr	872	333	62	--	--	--
7/14/17	24-hr	614	--	--	--	--	--
7/31/17	24-hr	669	331	51	--	--	--
8/3/17	24-hr	657	293	55	--	--	--
8/24/17	24-hr	712	278	61	--	--	--
8/28/17	24-hr	699	328	53	--	--	--
8/29/17, 08:45	1-hr	820	--		620	--	--
8/29/17, 09:45	1-hr	--	--	--	320	46	86
8/29/17, 10:45	1-hr	--	--	--	340	43	87
8/29/17, 11:45	1-hr	--	--	--	340	41	88
8/29/17, 12:45	1-hr	600	--		400	--	--
8/29/17, 13:45	1-hr	--	--	--	390	--	--
8/29/17, 14:45	1-hr	--	--	--	400	--	--
8/29/17, 15:45	1-hr	--	--	--	320	--	--
8/29/17, 16:45	1-hr	640	--		320	--	--
8/29/17, 17:45	1-hr	--	--	--	330	--	--
8/30/17, 07:45	1-hr	648	282	56	--	--	--
9/5/17	24-hr	781	323	59	--	--	--
9/7/17	24-hr	675	275	59	--	--	--
9/20/17	24-hr	730	311	57	--	--	--
9/25/17	24-hr	733	326	56	--	--	--

Date	Sample Duration	COD Filter Influent (mg O_2/L)	COD Filter Effluent (mg O_2/L)	COD Removal (%)	FOG Filter Influent (mg/L)	FOG Filter Effluent (mg/L)	FOG Removal (%)
10/12/17	24-hr	940	346	63	--	--	--
10/17/17	24-hr	745	318	57	--	--	--
10/19/17	24-hr	440	291	34	--	--	--
10/23/17	24-hr	700	329	53	--	--	--
10/26/17	24-hr	816	308	62	--	--	--
10/30/17	24-hr	639	407	36	--	--	--
11/2/17	24-hr	690	293	58	--	--	--
11/6/17	24-hr	776	336	57	--	--	--
Average *		**712**	**319**	**54**	**25**	**11**	**56**

*** Based on values within two standard deviations**

Source: Kennedy Jenks Consultants

Table 16: Laboratory Sampling Results for Additional Parameters (Lancaster)
TKN, Ammonia, and Nonvolatile Suspended Solids

Date	Sample Duration	TKN Filter Influent (mg/L)	TKN Filter Effluent (mg/L)	TKN Removal (%)	Ammonia Filter Influent (mg/L)	Ammonia Filter Effluent (mg/L)	Ammonia Removal (%)	Nonvolatile Suspended Solids Filter Influent (mg/L)	Nonvolatile Suspended Solids Filter Effluent (mg/L)	Nonvolatile Suspended Solids Removal (%)
1/24/2017	24-hr	47.2	37	22	30.6	30.3	1	100	25	75
1/26/2017	24-hr	58.5	44.2	24	38.2	36.8	4	--	--	--
1/30/2017	24-hr	60	43.2	28	35.8	32.2	10	--	--	--
2/2/2017	24-hr	46.6	43.8	6	37.2	37.8	-2	--	--	--
2/7/2017	24-hr	47.5	40.8	14	33.6	34.2	-2	--	--	--
2/9/2017	24-hr	51.2	45	12	32.4	33	-2	--	--	--
2/13/2017	24-hr	54.2	45.2	17	35.3	35.4	0	--	--	--
2/16/2017	24-hr	51.2	40.5	21	36	36	0	--	--	--
2/23/2017	24-hr	47	41	13	35.6	36.3	-2	--	--	--
3/1/2017	24-hr	49.5	41.5	16	36.4	37.4	-3	--	--	--
3/2/2017	24-hr	44.4	40	10	35.8	37	-3	--	--	--
3/9/2017	24-hr	66	42.2	36	38.3	37.5	2	--	--	--
3/13/2017	24-hr	43.6	42	4	35.1	34.7	1	--	--	--
3/17/2017	24-hr	56.5	46	19	30.3	29.2	4	--	--	--
3/21/2017	24-hr	79	42.5	46	35.8	32.2	10	--	--	--
4/11/2017	24-hr	50.5	45.8	9	34.2	34.4	-1	--	--	--
4/21/2017	24-hr	49.5	38	23	38.1	35.9	6	--	--	--
4/24/2017	24-hr	47	36.5	22	35.2	35.7	-1	--	--	--
4/27/2017	24-hr	52	72	-38	35	34.7	1	--	--	--
5/2/2017	24-hr	62	42.2	32	35.3	37.1	-5	--	--	--
5/4/2017	24-hr	64.5	44.6	31	35.3	40.2	-14	--	--	--
5/15/2017	24-hr	47	49	-4	33.6	35	-4	--	--	--
5/18/2017	24-hr	64.5	48.6	25	34.7	35.3	-2	--	--	--
5/22/2017	24-hr	54	44.2	18	32.7	34.5	-6	--	--	--
6/2/2017	24-hr	49.7	40.5	19	30.7	33.2	-8	--	--	--
6/5/2017	24-hr	49	39.2	20	31.6	33.6	-6	--	--	--

6/8/2017	24-hr	49.2	42	15	32.1	33.3	-4	--	--	--
6/15/2017	24-hr	45.8	39.8	13	31.1	31.6	-2	--	--	--
6/20/2017	24-hr	55	44.5	19	33.9	34.2	-1	--	--	--
6/28/2017	24-hr	48.6	40.5	17	33.6	32.8	2	--	--	--
7/14/2017	24-hr	44.8	--	--	--	--	--	--	--	--
7/31/2017	24-hr	50	46.2	8	--	34.8	--	--	--	--
8/3/2017	24-hr	37.8	34.8	8	--	70	--	--	--	--
8/24/2017	24-hr	51	45.6	11	--	56	--	--	--	--
8/28/2017	24-hr	59	43	27	--	33.8	--	--	--	--
9/5/2017	24-hr	52	42.5	18	--	32.4	--	--	--	--
9/7/2017	24-hr	49	43.2	12	--	31.7	--	--	--	--
9/20/2017	24-hr	38.5	35.2	9	--	33.4	--	--	--	--
9/25/2017	24-hr	51.5	48	7	--	31.6	--	--	--	--
10/12/2017	24-hr	52	39	25	--	30.4	--	--	--	--
10/17/2017	24-hr	48.6	42.5	13	--	34.3	--	--	--	--
10/19/2017	24-hr	50.5	40.2	20	--	33.2	--	--	--	--
10/23/2017	24-hr	53.5	43.5	19	--	33.9	--	--	--	--
10/26/2017	24-hr	50.5	43.2	14	--	36.3	--	--	--	--
10/30/2017	24-hr	46.9	42.5	9	--	31.7	--	--	--	--
11/2/2017	24-hr	44.2	39.5	11	--	34.2	--	--	--	--
11/6/2017	24-hr	47.5	42.8	10	--	34.7	--	--	--	--
11/9/2017	24-hr	49.4	39.8	19	--	31.8	--	--	--	--
Average *		**50**	**42**	**15**	**34**	**35**	**-1%**	**100**	**25**	**75%**

*** Based on values within two standard deviations**

Source: Kennedy Jenks Consultants

Table 17: Laboratory Sampling Results for Additional Parameters (Lancaster)
Settleable Solids and COD, Soluble

Date	Sample Duration	Settleable Solids Filter Influent (mg O_2/L)	Settleable Solids Filter Effluent (mg O_2/L)	Settleable Solids Removal (%)	COD, Soluble Filter Influent (mg/L)	COD, Soluble Filter Effluent (mg/L)	COD, Soluble Removal (%)
1/24/2017	24-hr	19	0.4	98	118	111	6
1/26/2017	24-hr	353	0.2	100	133	118	11
1/30/2017	24-hr	25	0.1	100	255	307	-20
2/2/2017	24-hr	19	0.1	99	226	221	2
2/7/2017	24-hr	21	0.2	99	204	199	2
2/9/2017	24-hr	23	0.2	99	196	187	5
2/13/2017	24-hr	26	0.2	99	248	228	8
2/16/2017	24-hr	27	0.2	99	140	120	14
2/23/2017	24-hr	20.5	0.2	99	205	205	0
3/1/2017	24-hr	25	0.2	99	242	210	13
3/2/2017	24-hr	24	0.1	100	205	205	0
3/9/2017	24-hr	29	0.2	99	145	127	12
3/13/2017	24-hr	31	0.2	99	212	210	1
3/17/2017	24-hr	40	0.2	100	212	182	14
3/21/2017	24-hr	75	0.1	100	367	272	26
4/11/2017	24-hr	13	0.5	96	147	132	10
4/21/2017	24-hr	60	0.1	100	150	102	32
4/24/2017	24-hr	23	0.1	100	200	227	-14
4/27/2017	24-hr	23	0.1	100	127	135	-6
5/2/2017	24-hr	23	0.1	100	127	135	-6
5/4/2017	24-hr	33	0.2	99	127	127	0
5/15/2017	24-hr	20	0.2	99	233	221	5
5/18/2017	24-hr	22	0.1	100	208	188	10
5/22/2017	24-hr	24	0.1	100	218	211	3
6/2/2017	24-hr	24	0.2	99	178	178	0
6/5/2017	24-hr	28	0.2	99	178	183	-3
6/8/2017	24-hr	25	0.2	99	135	125	7
6/15/2017	24-hr	24	0.2	99	123	110	11

Date	Sample Duration	Settleable Solids Filter Influent (mg O_2/L)	Settleable Solids Filter Effluent (mg O_2/L)	Settleable Solids Removal (%)	COD, Soluble Filter Influent (mg/L)	COD, Soluble Filter Effluent (mg/L)	COD, Soluble Removal (%)
6/20/2017	24-hr	30	0.1	100	120	140	-17
6/28/2017	24-hr	26	0.2	99	248	193	22
7/14/2017	24-hr	--	--	--	--	--	--
7/31/2017	24-hr	--	--	--	--	213	--
8/3/2017	24-hr	--	--	--	--	150	--
8/24/2017	24-hr	--	--	--	--	150	--
8/28/2017	24-hr	--	--	--	--	191	--
9/5/2017	24-hr	--	--	--	--	177	--
9/7/2017	24-hr	--	--	--	--	147	--
9/20/2017	24-hr	--	--	--	--	177	--
9/25/2017	24-hr	--	--	--	--	197	--
10/12/2017	24-hr	--	--	--	--	126	--
10/17/2017	24-hr	--	--	--	--	124	--
10/19/2017	24-hr	--	--	--	--	114	--
10/23/2017	24-hr	--	--	--	--	167	--
10/26/2017	24-hr	--	--	--	--	124	--
10/30/2017	24-hr	--	--	--	--	207	--
11/2/2017	24-hr	--	--	--	--	131	--
11/6/2017	24-hr	--	--	--	--	192	--
11/9/2017	24-hr	--	--	--	--	104	--
Average *		**28**	**0.2**	**99%**	**181**	**165**	**4%**

*** Based on values within two standard deviations**

Source: Kennedy Jenks Consultants

Table 18: Sampling Results Summary (Lancaster)

Constituent	Influent * [mg/L] Min	Influent * [mg/L]	Influent * [mg/L] Averag	Effluent * [mg/L] Min	Effluent * [mg/L] Max	Effluent * [mg/L] Averag	Avg. Remov d	# of Sample
TSS	132	652	372	28	90	59	83	64
VSS	160	370	296	28	78	49	83	7
BOD_5	130	450	321	63	150	117	52	16
COD	440	1070	712	240	407	319	54	57
FOG	10	34	25	4	17	11	56	4
TKN	38	65	50	35	49	42	15	48
Ammonia	30	38	34	29	40	34	0	30
Settleable Solids	13	75	28	0.1	0.2	0.2	99	30
COD, Soluble	118	255	181	102	228	165	4	30

*** Based on values within two standard deviations. Nonvolatile suspended solids not included due to only one sample measured.**

Source: Kennedy Jenks Consultants

3.4.2. Hydraulic/Operational

Hydraulic performance of the primary filter was valuated based on filter loading and production rates. Although the primary filter frequently experienced high solids loading throughout the demonstration, the system generally showed a feasible level of hydraulic performance.

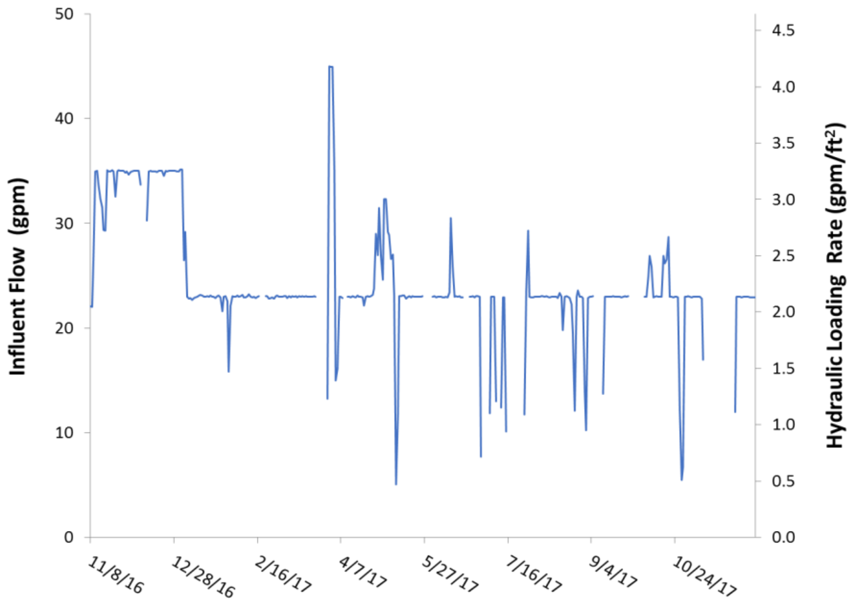
3.4.2.1 Filter Loading Rates

The filter loading rates were measured in terms of both HLR and SLR. Application rates were controlled by changing HLR. The SLR changes based on the HLR and the filter influent TSS level.

Hydraulic Loading Rates

The filter influent flow and corresponding HLR are shown in Figure 29. Influent flow for the demonstration primary filter system was initially set to 35 gpm in November 2016 and lowered to 23 gpm in January 2017. Corresponding initial and reduced HLRs are 3.25 and 2.10 gpm/ft^2, respectively. The HLR was calculated based on the filter disk area of 10.76 ft^2. In contrast, primary clarifiers are characterized by a surface overflow rate, which is flow divided by the surface area of the settling basin.

Figure 29: Daily Average Influent Flow and Hydraulic Loading Rate (Lancaster)

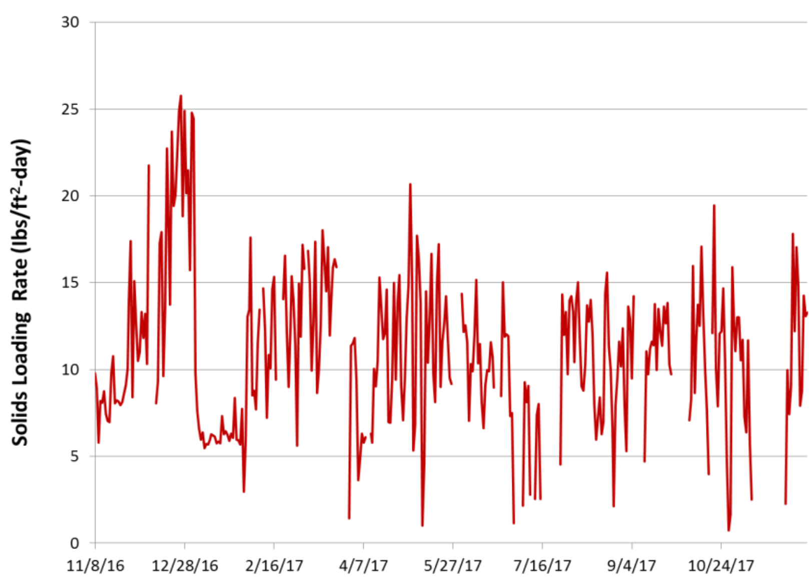


Source: Kennedy Jenks Consultants

Solids Loading Rates

SLR for the demonstration system is shown in Figure 30. SLR increased rapidly from approximately 8 to 25 lbs/day-ft^2 over the first two months of filter operation. Under average operational conditions, SLR is anticipated to be between 5 and 7.5 lbs/day-ft^2. The filter flow was reduced in January 2017 to keep SLR values closer to the desired range. After the reduction in filter influent flow, SLR decreased to mostly under 15 lbs/day-ft^2. Overall average SLR was approximately 13.9 lbs/day-ft^2 under initial influent flow and 10.3 lbs/day-ft^2 after flow reduction in December.

Figure 30: Daily Average Solids Loading Rate (Lancaster)

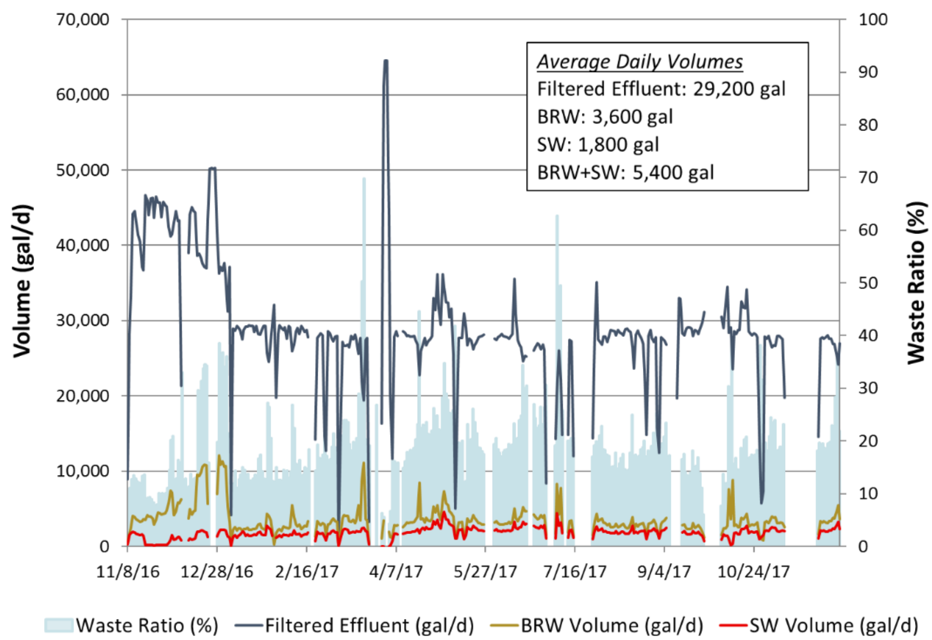


Source: Kennedy Jenks Consultants

3.4.2.2 Backwash and Solids Waste

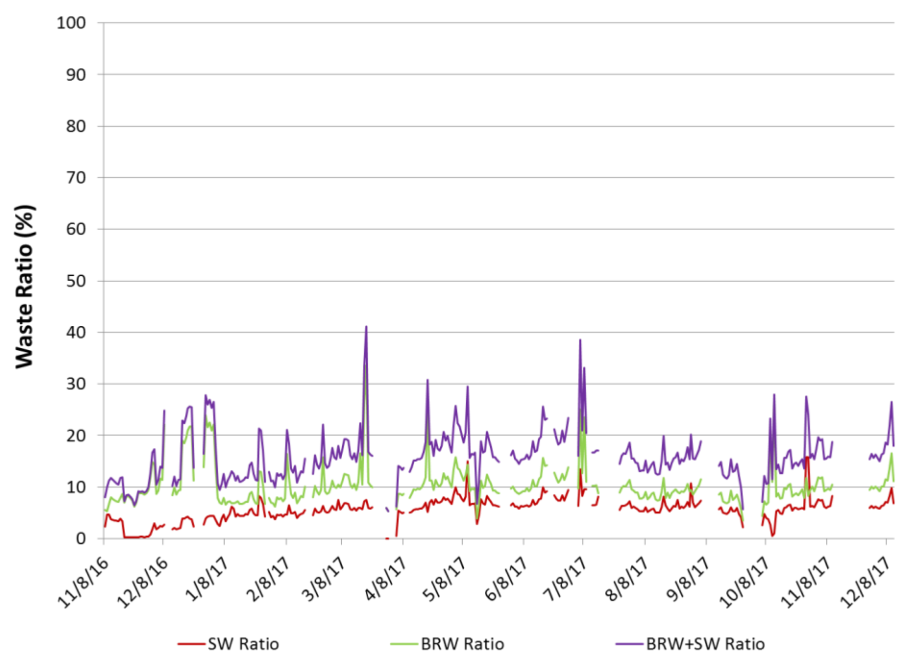
Figure 31 shows the volumes of filtered effluent, BW, and SW for the demonstration primary filter system. Figure 32 shows the corresponding BRW and SW ratios. BRW and SW ratios have averaged approximately 12 percent and 6 percent, respectively. It should be noted that the operation of the demonstration primary filter system at the Lancaster WRP was not optimized to reduce or minimize SW ratio.

Figure 31: Total Filtered and Wasted Volumes (Lancaster)



Source: Kennedy Jenks Consultants

Figure 32: Daily Average Waste Ratios (Lancaster)



Source: Kennedy Jenks Consultants

CHAPTER 4: Demonstration at City of Manteca Water Quality Control Facility

4.1. Site Specific Objectives

The specific objectives of the demonstration primary filtration project at the Manteca Water Quality Control Facility (WQCF) from February 2018 to December 2018 are:

- Demonstrate filter removal efficiencies for BOD_5, COD, VSS, and TSS.
- Evaluate the hydraulic performance of the demonstration PCDF system.
- Validate the performance of modifications to the PCDF system needed to address higher solids and FOG content.
- Estimate the reduction in electrical power required for aeration in the activated sludge process, due to raw wastewater filtration. Analysis included in Chapter 5.
- Conduct a third-party M&V process for aeration energy savings resulting from primary filtration. The results are described in Section 5.4.

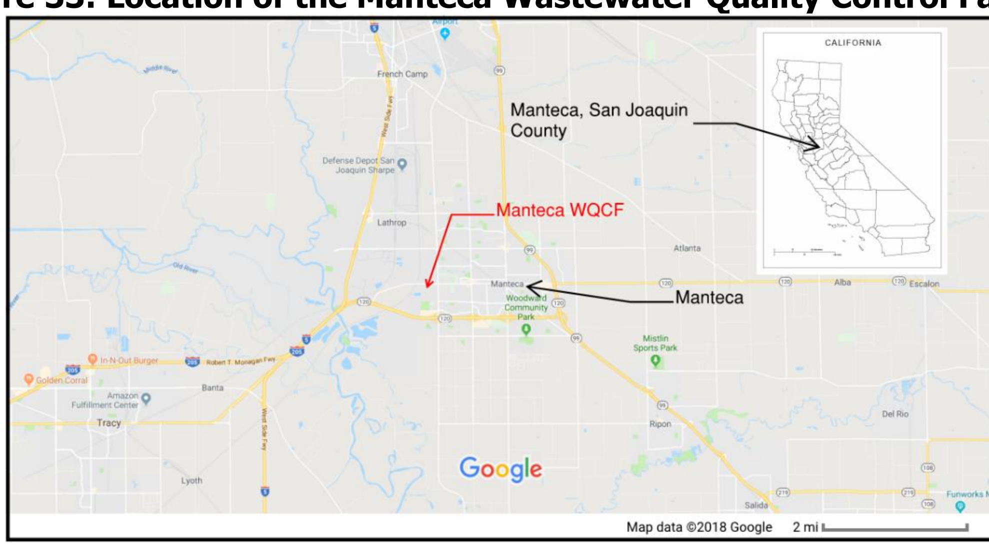
4.2. System Description

A demonstration-scale primary filter unit was installed at Manteca WQCF in February 2018 for one-year operation. This chapter covers observed performance of the Manteca demonstration from February 2018 to December 2018.

4.2.1. Overview of Manteca WQCF

The Manteca WQCF is located at 2450 West Yosemite Avenue, in the City of Manteca, in southern San Joaquin County (see Figure 33). The facility is owned and operated by the City of Manteca.

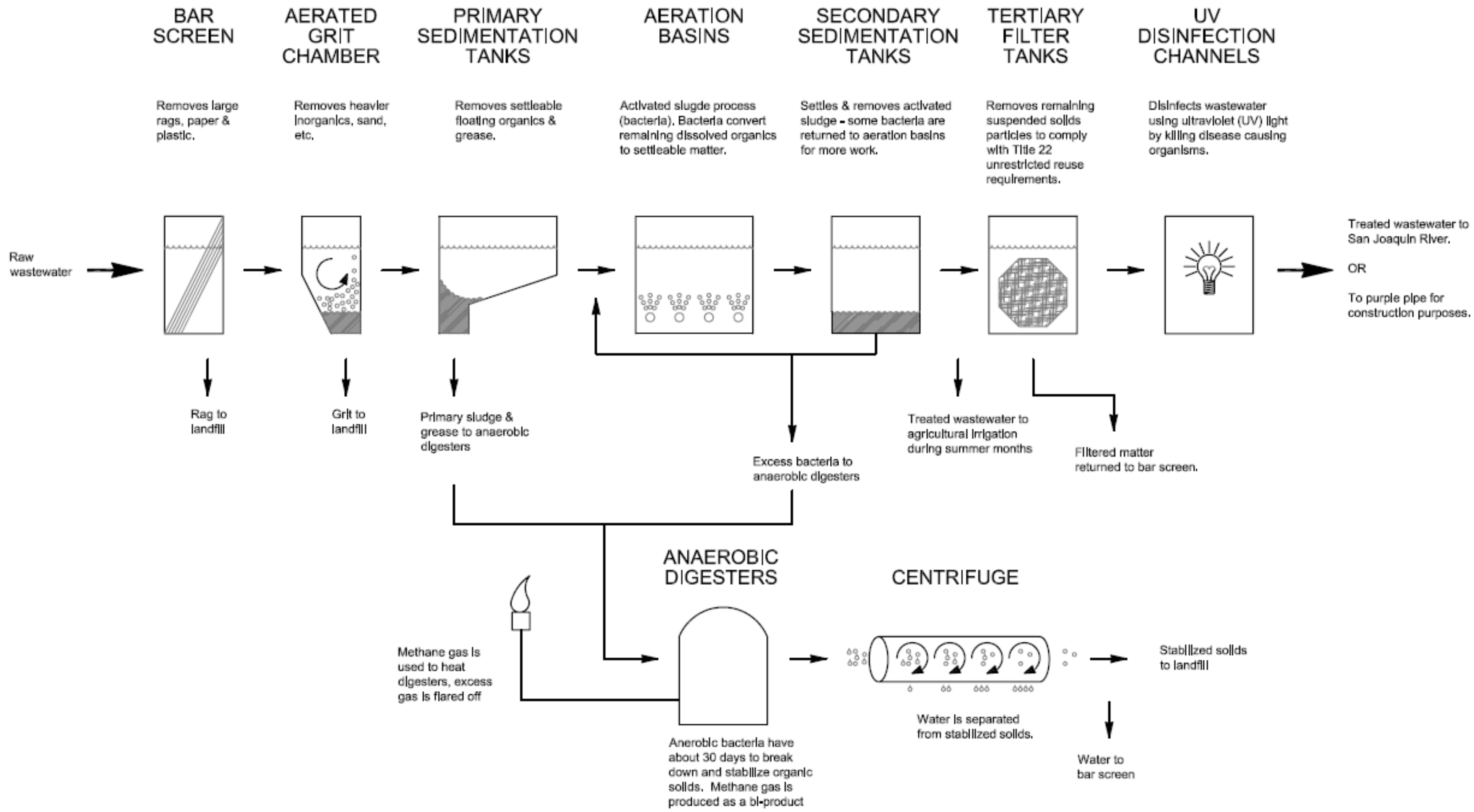
Figure 33: Location of the Manteca Wastewater Quality Control Facility



Source: Kennedy Jenks Consultants

The Manteca WQCF currently provides tertiary treatment for up to 9.87 mgd of wastewater. The Manteca WQCF serves a population of approximately 85,000 people from the City of Manteca, portions of the City of Lathrop, and Raymus Village. The facility is comprised of an influent pump station with mechanical screens that serve two parallel, conventional treatment systems known as the northside and southside treatment systems. Primary treatment is identical in both systems and consists of primary clarification. At the northside treatment system, primary effluent can undergo additional treatment through two bio-towers with high-rated plastic media. Secondary treatment for both treatment systems are the same, consisting of activated sludge, including nitrification and denitrification, followed by secondary sedimentation. Secondary effluent from both the northside and southside treatment systems is combined prior to undergoing tertiary filtration and ultraviolet light disinfection. A flow diagram of the plant is shown in Figure 34.

Figure 34: Manteca Wastewater Quality Control Facility Treatment Process Flow Diagram



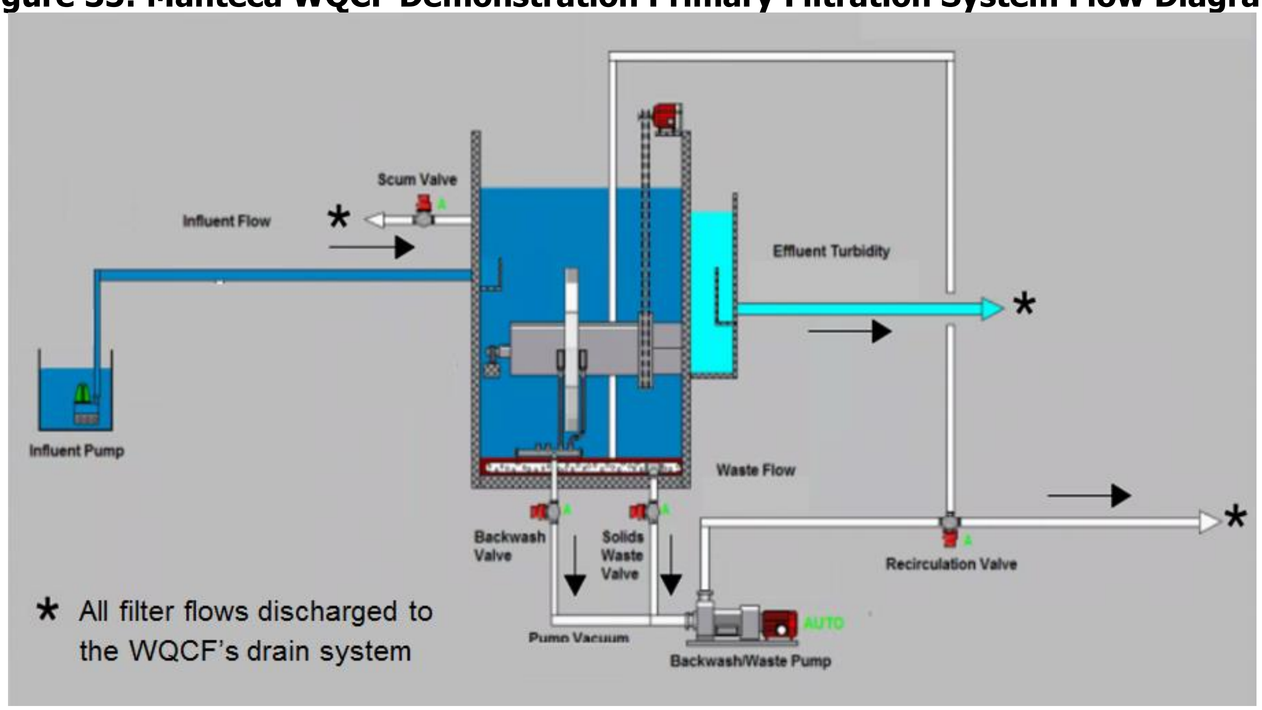
Source: City of Manteca Wastewater Quality Control Facility

4.2.2. Demonstration Filter Components

The demonstration primary filter system at the Manteca WQCF consists of a primary filter unit with a treatment capacity of approximately 4 gpm/ft^2. A flow diagram of the demonstration system is shown in Figure 35. A detailed description of the system is provided below.

- Primary filter: The PCDF filter, identical to the unit deployed at the Lancaster WRP, is provided by AASI. The filter unit was installed at Manteca WQCF in February 2018 with one filter disk, with a second disk added on April 18, 2018.
- Influent: A small fraction of the raw wastewater at the Manteca WQCF (less than 3 percent of the Southside Facility flow) is directed to the demonstration primary filter system. Raw wastewater, after passing through initial screening and degritting, is pumped to the filter tank through an approximately 50 foot-long 3-inch flex hose that runs along the WQCF primary clarifier basins, down from the Headworks building, and across the grit dewatering equipment. The influent pump is located in the primary clarifier influent channel, as shown in Figure 36.
- Effluent and Discharges: Filtered effluent is discharged back to the WQCF primary influent channel via a 4-inch hose, which is connected to a drain located next to the grit dewatering equipment. Additional system discharges include filter backwash, sludge, scum, and overflow, which are also discharged to the tank drain via 2- and 4-inch hoses connected to a combined filter effluent manifold, as shown in Figure 37 and Figure 38. The volumes of these additional waste discharges are very small relative to the plant flow. Thus, the discharges to the tank drain have negligible impact on treatment processes at the WQCF.

Figure 35: Manteca WQCF Demonstration Primary Filtration System Flow Diagram

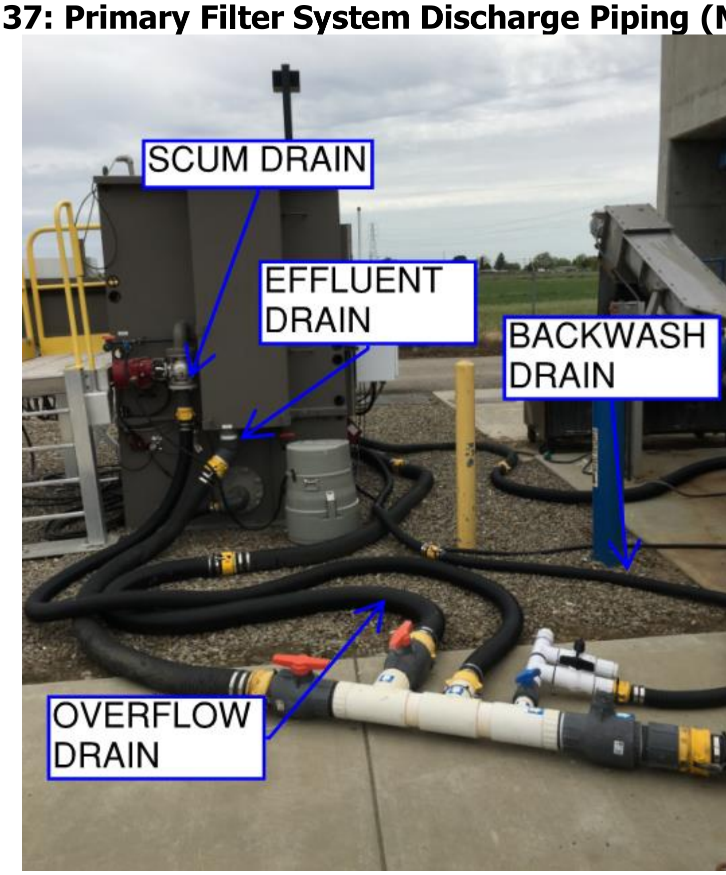


Source: Kennedy Jenks Consultants

Figure 36: Influent Piping System to the Primary Filter (Manteca)

Source: Kennedy Jenks Consultants

Figure 37: Primary Filter System Discharge Piping (Manteca)



Source: Kennedy Jenks Consultants

Figure 38: Primary Filter System Discharge Locations (Manteca)

Source: Kennedy Jenks Consultants

4.2.3. Sampling and Monitoring Equipment

The demonstration primary filter system at the Manteca WQCF is equipped with composite samplers, turbidity sensors, flow meters, and a data logging and remote control system. The sampling and monitoring equipment are identical to equipment used for the Lancaster WRP deployment, as described in Section 3.2.3.

4.3. Operation and Maintenance

The demonstration primary filter system was delivered to the Manteca WQCF on February 6, 2018. Installation of the filter system occurred over a three-day period between February 12 and 14. During these days, the piping and the influent pump were installed, and the PLC and SCADA were set up. Composite samplers were set up on February 13, 2018. The influent pump was initially placed at the bottom of the influent channel. It was subsequently raised approximately 3 inches to prevent influent pump shut off due to suction of debris into the pump.

Since set-up in February 2018, minor adjustments have been made to the system. These adjustments include raising the influent pump in the influent channel while connected to a chain hoist, and subsequent suspension of the influent pump in the influent channel from a wooden beam, only using the chain hoist as a backup for potential extraction as needed.

4.3.1 System Setpoints

Since start-up of the demonstration system in February 2018, the primary filter operated at an average HLR of 2 gpm/ft^2 over approximately a 3-month period. This HLR translates to a flowrate of 21.5 gpm (with a filtration surface area of 10.8 ft^2). On March 27, 2018, adjustment of the filtration rate to an HLR of 3 gpm/ft^2 was attempted; however, siphoning issues on the influent line prevented the filter from maintaining the desired HLR. The filtration rate was then returned to an HLR of 2 gpm/ft^2 and flow of 21.5 gpm. On April 18, 2018, a second disk was added, bringing the filtration area to 21.6 ft^2, after which the siphoning issues were fixed and the filtration rate was increased to 3 gpm/ft^2 (or 65 gpm) on April 20, 2018.

These rates were maintained for subsequent months. Throughout the demonstration period, minor adjustments were also made to solids waste settings in response to observations of filter system performance.

The major set points for the system, to-date, are summarized in Table 19. Backwash is performed when the filter tank level reaches the specified start BW level of 6.3 ft. Solids waste and scum removal occur at specified time intervals or number of backwashes, whichever is more frequent. Similar to the Lancaster WRP deployment, typical recovery level from backwash is between 0.3 and 0.4 ft. This indicates the demonstration-scale systems typically achieve a lower recovery than the full-scale system at the LCWD WWTP.

Table 19: System Setpoints (Manteca)

Test Conditions	Start of Test	Change 1	Change 2	Change 3	Change 4	Change 5	Change 6
Date of Change	2/14/18	3/26/18	4/20/18	4/23/18	7/16/18	11/7/18	11/23/18
Cloth Type	PF-14	PF-14	PF-14	PF-14	PF-14	PF-14	PF-14
Hydraulic Loading Rate (gpm/ft^2)	2.0	2.0	3.0	3.0	4.0	2.0	3.0
Flow (gpm)	21.5	21.5	65.0	65.0	85.0	32.5	65.0
Filter Tank Level Set-Up							
High Tank Level (ft)	7	7	7	7	7	7	7
Start BW Level (ft)	6.30	6.30	6.30	6.30	6.30	6.30	6.30
BW Duration Per Valve (seconds)	26	26	26	26	26	26	26
BW Flow (gpm)	32.5	32.5	32.5	65.0	65.0	65.0	65.0
Start Scum Removal Level (ft)	6.15	6.15	6.15	6.15	6.15	6.15	6.15
Minimum Level for BW (ft)	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Minimum Level for Solids Waste (ft)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Solids Waste Set-Up							
Solids Waste Time Interval (min)	240	240	240	240	240	240	240
No. of Backwashes between Solids Waste Events	4	3 *	3	3	3	3	3
Solids Waste Duration (seconds)	30	30	30	30	30	30	30
SW Flow (gpm)	32.5	32.5	32.5	32.5	32.5	50	50
Scum Removal Set-Up							
Scum Removal Interval (hours)	12	12	12	12	12	12	12
Scum Removal Duration (sec)	60	60	60	60	60	60	60

Test Conditions	Start of Test	Change 1	Change 2	Change 3	Change 4	Change 5	Change 6
No. of Backwashes Between Scum Removal	500	500	500	500	500	500	500
Solids Conditioning Mode Set-Up							
Solids Condition Mode Time Interval (hrs)	8	8	8	8	8	8	8
Solids Conditioning Duration (seconds)	52	52	52	52	52	52	52
No. of Backwashes between SCM Events	50	50	50	50	50	50	50

Orange highlighted values indicate setting changes.

* **Adjustment made to sludge removal settings in response to solids waste build-up. Sludge should remain below 1.5 ft, as the bottom of the filter disk is at about 1.3-1.5 feet from the filter tank bottom.**

Source: Kennedy Jenks Consultants

4.3.2 Operation of the Primary Filter System

Site visits were conducted every 1 to 4 weeks from February to December 2018. The operational and maintenance performance of the demonstration primary filter system was examined during site visits. Regular field operation included walkthrough of the site and visual inspection of the filter influent and effluent wastewater quality and system component conditions. Field logs were kept on all observations pertaining to system operation.

4.3.2.1 Unusual Events/Conditions

To date, heavy rain events have been the primary noteworthy events experienced at the Manteca WQCF. Stormwater infiltration increases solids loading to the facility and increases turbulence in the influent channel (especially during the initial stages of a storm event). Rain events on February 26, 2018 and March 1, 2018 were the likely causes of influent pump flow interruptions on the same days. The storms likely caused the chain hoist suspending the influent pump to drop unexpectedly, creating suction to the bottom of the influent channel. Similarly, a heavy rain event, on March 15, 2018, likely caused the chain hoist chain to move irregularly and catch in the influent pump impeller. These types of system shutdowns due to heavy rain events are not likely to occur for full-scale installations.

Issues with waste pump were more frequent in July and August 2018. It is possible more power fluctuations were experienced at the plant during this time.

4.3.2.2 Field Log

The field log is included in Table 20.

Table 20: Field Log (Manteca)

Date	Observations
2/12/18 - 2/14/18	Installation of primary filter system. No major issues interfering with proper functioning of the filter system were observed.
2/26/18	(Remotely monitored) Influent flow was ramping up to set point but failing to maintain full flow. Maybe clogged.
2/27/18	Influent pump was lifted out of the channel and inspected. It had been fully submerged and was not clogged. It was replaced slightly above the bottom of the channel and began functioning properly. Most likely cause was loss of flow due to suctioning.
3/1/18	(Remotely monitored) Influent pump abruptly stopped providing influent to the filter. Pump still getting power/rotation. No SCADA alarms.
3/2/18	Chain hoist suspending the influent pump had lowered. This caused the influent pump to suction to the bottom of the channel and abruptly lose flow. A wooden beam was installed from which to suspend the influent pump with the chain hoist as a backup. Influent flow returned to normal.
3/6/18	Sludge blanket level was observed to be 1 – 1.5 ft. in depth. Monitored for potential need to increase solids wasting frequency.
3/15/18	(Remotely monitored) The influent pump VFD faulted. Cause unknown.
3/16/18	The influent pump was pulled out of the influent channel. It was found that the chain hoist chain had gotten caught in the pump impeller. The impeller was cleared, and the chain hoist chain was secured outside of the influent channel to prevent a repeat occurrence. The influent pump resumed proper operation.
3/20/18	Sludge blanket level was observed to be just under 1.5 ft in depth at its deepest location in the influent tank. It was decided to increase the solids wasting frequency from once every 4 backwashes to once every 3 backwashes.
3/26/18	Solids wasting frequency increased from once every 4 backwashes to once every 3 backwashes.
3/27/18	Turbidimeters recalibrated (15% down with 800 NTU standard solution). HLR changed from 2 gpm/ft^2 to 3 gpm/ft^2 from 11:30 am - 1:15 pm. Influent flow did not stabilize - flow returned to 2 gpm/ft^2.
4/17/18	(Remotely monitored) Influent flow was not stabilizing properly; influent pump PID loop adjustments made starting at 9:20 am. Filter off overnight starting at 4:30 pm.
4/18/18	Filter back on 9:40 am - 11 am. Down from 11 am - 2:30 pm. Second disk installed. 10' section of influent pipe removed - path to filter made more direct. Influent flow stabilized at 21.5 gpm (1 gpm/ft^2).
4/19/18	PID adjustments made starting at 11:30am to reach 2 gpm/ft^2 (43 gpm). Mostly unstable at 25 gpm (11:30am - 3:30pm). Left at 32 gpm starting at 3:30 pm - mostly unstable flow.
4/20/18	PID adjustments made starting 7:30 am. Filter attempting (unsuccessfully) to reach 32 gpm until 1:30 pm. Ball valve on influent line throttled to various degrees (1:30 - 2:30pm). Full range of desired flow rates stably reached. Flow rate set stably at 65 gpm (3 gpm/ft^2) at 2:30 pm.
4/23/18	(Remotely monitored) 6:15 am - BW pump placed in 'Auto' (was in 'Manual'). Also, PID control changed from 'Local' to 'Cascade' and upper speed limit changed from 50% to 90%.
5/8/18	Sludge blanket was observed to be very thin (less than 0.5 ft.) due to reduced residence time from doubling of filter flow. Solids waste frequency was decreased from every 4 to every 5 backwash events.

Date	Observations
5/15/18	Sludge blanket was still thin (around 0.5 ft.). Solids waste frequency was reduced again to every 6 backwash events.
6/19/18	Sludge blanket was observed to be around 0.5-1.2 ft., as desired. A thick layer of solids had accumulated around the rim of the filter from scum at the surface and was hosed off.
7/3/18	Loggers for energy measurement and verification were installed on the filter system.
7/18/18	Filter flow was increased to 86 gpm (4 gpm/ft^2).
7/24/18	Loggers were checked and verified to be working properly.
8/14/18	A thicker scum layer than normal was observed. Scum removal was manually initiated.
8/31/18	Scum valve began experiencing issues with opening during scum removal
9/18/18	Scum buildup was observed in the tank due to the malfunctioning scum valve.
10/7/18-10/23/18	Filter was shut off to repair the scum valve. A new backwash shoe system was installed to improve backwash efficiency. HLR was set to 2 gpm/ft^2 when the filter returned to operation on 10/23.
11/13/18	Leak was observed from the flange at the filter waste pump discharge. Bolts on the flange were tightened.
12/5/18	An issue with the level transmitter was fixed. The flange on the filter waste pump discharge was found to be leaking again and the bolts were re-tightened.
12/18/18	Loggers for energy measurement and verification were removed from the filter system.

Source: Kennedy Jenks Consultants

4.3.3. Summary of Issues and Resolutions

Since start-up, adjustments have been made and corrective actions were taken to maintain proper functioning and operation of the filter system. These actions were taken in response to system interruptions, minor equipment malfunctions, changes to plant operations, or other plant and filter conditions. A summary of incidents and corrective actions taken is provided in Table 21.

Minor malfunctions of the demonstration system appurtenances, including fuses, relays, and sensors are likely to occur at one point or another during full-scale implementation. For these reasons, designing a full-scale system should take into consideration the ease of replacing or repairing these components. Pressure transducers showed damage during replacement and may warrant consideration of alternative options, such as sonic probes.

For a full-scale primary filtration system, it is crucial to ensure the system can handle variations in water quality, including unexpected high solids loading. So far, this demonstration system has been handling these events well; observed minor malfunctions will provide valuable data and information to properly design a full-scale system to handle similar conditions.

Table 21: Issues and Resolutions during Primary Filter System Operation (Manteca)

Date	Incident/Issue	Related to Primary Filter?	Impacted System Component	Reason	Considerations for Full-Scale System	Corrective Action	Estimated Probability of Occurrence in Full-Scale System*
2/26/18	Influent pump failed to maintain full flow due to suction onto the bottom of the influent channel.	No	Influent pump	Influent pump suspended too close to bottom of channel	Not expected to be a problem for full-scale systems with properly designed pump station.	Influent pump lifted and replaced ~3 inches above the bottom of the influent channel.	0
3/1/18	Influent pump abruptly failed to draw flow.	No	Influent pump	Storm event caused crane supporting influent pump to drop lower	Not expected to be a problem for full-scale systems with properly designed pump station.	Influent pump lifted and replaced ~3 inches above the bottom of the influent channel. Influent pump suspended by 4X4 with crane as backup.	0
3/15/18	Influent pump VFD fault.	No	Influent pump	Chain hoist supporting influent pump was lodged in pump impeller	Not expected to be a problem for full-scale systems with properly designed pump station.	Influent pump was cleared of obstruction and chain was secured.	0
3/27/18	Unstable influent flow observed. Flow was not able to maintain new setpoint HLR of 3 gpm/ft^2 with any stability.	No	Influent pump	Influent pump siphoning	Not expected to be a problem for full-scale systems with properly designed pump station.	Influent flow PID loop was adjusted, a 10 ft. section of influent piping was removed, and the influent line shutoff ball valve was throttled.	0

Date	Incident/Issue	Related to Primary Filter?	Impacted System Compone nt	Reason	Considerations for Full-Scale System	Corrective Action	Estimated Probability of Occurrence in Full-Scale System*
5/16/18	Filter waste pump drive motor faulted, inhibiting backwash and solids waste.	Yes	Filter waste pump	Drive motor fault	Drive motor issues can occur in full-scale systems, but systems can be designed with backup.	Fault was cleared and alarm was reset by programmer from remote.	2
7/29/18 - 7/30/18	Filter waste pump failed to run after power issue was experienced.	Yes	Filter PLC and waste pump	Power loss	Full-scale systems are likely to be less susceptible to power fluctuations.	Power was restored by programmer from remote.	1
8/10/18 - 8/13/18	Filter was stuck in continuous solids waste mode.	Yes	Filter PLC	PLC issue	Possible to experience control issues in full-scale systems, but issue can be responded to faster.	Filter was reset from remote.	2
8/18/18 - 8/20/18	Filter waste pump failed to run.	Yes	Filter waste pump	Unknown	Cause of issue cannot be determined to provide further information for full-scale system.	Pump was reset by programmer from remote.	1
8/27/18 - 8/28/18	Filter was offline for a few hours due to power issue.	No	Filter PLC	Power loss	Full-scale systems are likely to be less susceptible to power fluctuations.	Power was restored.	1

Date	Incident/Issue	Related to Primary Filter?	Impacted System Compone nt	Reason	Considerations for Full-Scale System	Corrective Action	Estimated Probability of Occurrence in Full-Scale System*
8/31/18 – 10/16/18	Scum valve failed to open.	Yes	Filter scum valve	Valve failure	Possible to experience control issues in full-scale systems, but issue can be responded to faster.	Scum valve was replaced on 10/16/18.	2

*** 0: not likely; 1: somewhat likely, 2: likely**

Source: Kennedy Jenks Consultants

4.4 System Performance

The treatment performance of the demonstration system at the Manteca WQCF was evaluated for the feasibility of primary filtration as an APT technology, in terms of both treatment and hydraulic performance.

4.4.1 Treatment

The treatment performance of the demonstration system at the Manteca WQCF was evaluated for the feasibility of primary filtration as an APT technology. During its operation, the primary filter consistently achieved high solids removal, as shown by both onsite turbidity measurements and laboratory TSS measurements. Particle removal also resulted in reduction of BOD_5 and COD.

4.4.1.1 Continuous Performance Monitoring

During the entire demonstration, inline turbidimeters (HACH Solitax) provided continuous monitoring of the filter influent and effluent. Correlations were established between inline turbidity averages and TSS measured in composite samples; daily TSS removal performance by the filter is estimated using these correlations.

Total Suspended Solids to Turbidity Correlation

For the demonstration primary filtration system at the Manteca WQCF, filter influent and effluent turbidities were continuously logged by SCADA at 5-second intervals. Filter influent and effluent TSS values were measured periodically using 24-hour composite samples. TSS-to-turbidity correlation ratios were calculated for the primary influent and effluent by correlating the TSS composite measurements with turbidity averaged over corresponding 24-hour periods.

Linear correlations of TSS versus turbidity are shown in Figure 39. TSS-to-turbidity correlation factors were found to be 2.28 and 0.72 for the primary filter influent and effluent, respectively. These correlation factors were used to convert daily average turbidity logged by SCADA to TSS measured in lab. These correlation factors were meant to provide a general relationship between TSS and turbidity, rather than giving precise values of TSS.

Total Suspended Solids Removal Efficiency

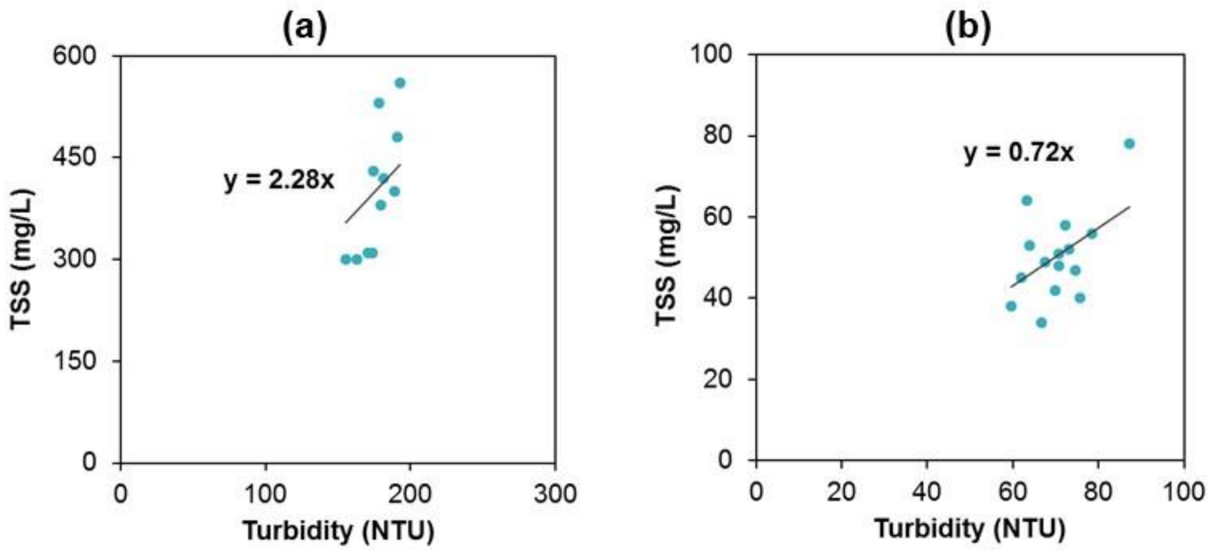
The demonstration primary filtration system has performed at a high level in terms of TSS removal, as anticipated. As shown in Figure 40, TSS removal efficiency has averaged 87 percent during the first nine months of operation of the filter system at Manteca WQCF. Daily influent and effluent TSS averaged 405 and 53 mg/L, respectively. Daily average influent TSS showed some variation from 300 to 600 mg/L, but daily average effluent TSS was observed to be consistently around 50 mg/L except for days with waste pump issues. In a conventional primary clarification system with 50 to 60 percent TSS removal efficiency, effluent TSS values can range from 160 to 200 mg/L when influent TSS is 400 mg/L.

4.4.1.2 Filter Performance Results from Laboratory Sampling

In addition to the field performance data continuously recorded by SCADA, multiple grab and composite filter influent and effluent samples have been taken and analyzed since start-up. Data from laboratory analyses from February to December 2018 are summarized in Table 22 and Table 23.

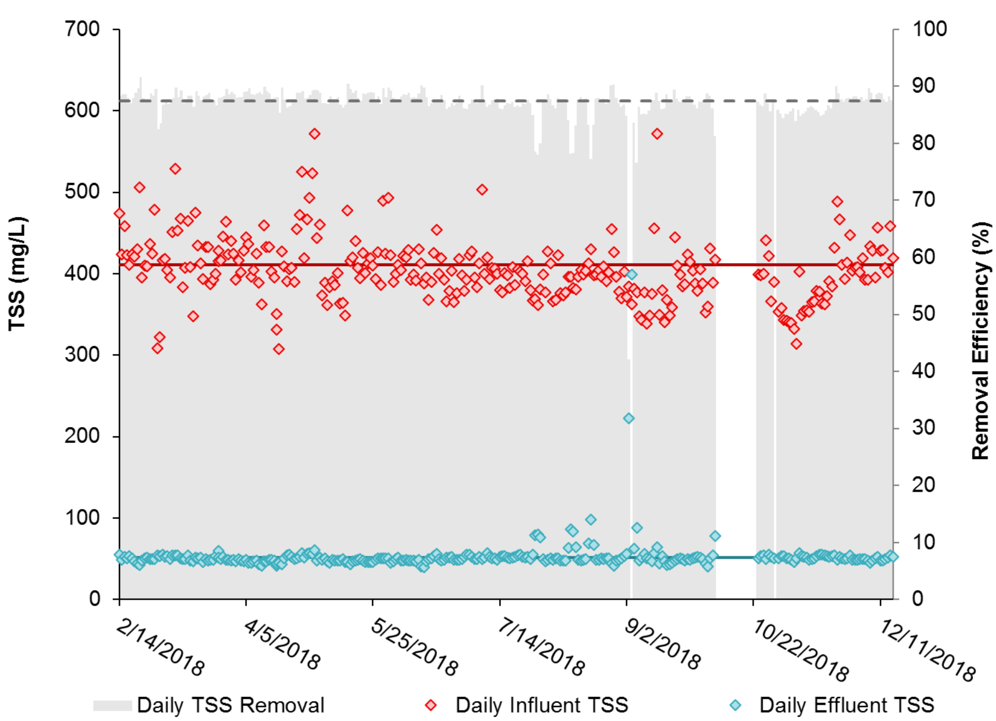
Laboratory results showed a TSS removal rate of 83 percent, which is slightly lower than the calculated TSS removals from turbidity data. Other constituents were also removed through primary filtration. Average BOD_5 and COD removal efficiencies are 47 percent and 50 percent, respectively. Average TKN removal efficiency was 16 percent. No significant removal by the filter was observed for soluble chemical oxygen demand (sCOD).

Figure 39: TSS-to-Turbidity Correlation for (a) Primary Filter Influent and (b) Primary Filter Effluent (Manteca)



Source: Kennedy Jenks Consultants

Figure 40: TSS Removal Performance (Manteca)



Source: Kennedy Jenks Consultants

Table 22: Laboratory Sampling Results (Manteca) — TSS, VSS, and BOD

Date	HLR (gpm/ft^2)	TSS Filter Influent (mg/L)	TSS Filter Effluent (mg/L)	TSS Removal Efficiency (%)	VSS Filter Influent (mg/L)	VSS Filter Effluent (mg/L)	VSS Removal Efficiency (%)	BOD_5 Filter Influent (mg/L)	BOD_5 Filter Effluent (mg/L)	BOD_5 Removal Efficiency (%)
3/13/18	2	480	58	88	450	58	87	590	250	58
3/20/18	2	420	34	92	420	34	92	670	170	75
3/27/18	2	400	48	88	400	48	88	610	220	64
4/3/18	2	380	49	87	380	49	87	450	160	64
4/10/18	2	530	64	88	530	64	88	380	190	50
4/24/18	2	430	51	88	430	51	88	300	170	43
5/8/18	3	300	100	67	300	100	67	440	190	57
5/15/18	3	190	53	72	190	53	72	230	130	43
6/19/18*	3	560	40	93	-	-	-	-		-
7/3/18*	3	63	47	25	63	47	25	280	180	36
7/17/18*	3	71	52	27	65	52	20			-
7/31/18	4	310	78	75	300	72	76	240	150	-
8/14/18*	4	100	56	44	100	56	44	170	180	-
8/28/18*	4	880	38	96	-	-	-	550	160	-
9/18/18	4	300	45	85	-	-	-	240	160	33
10/2/18	4	310	42	86	-	-	-	220	190	14
12/18/18*	3	640	50	92	610	50	92	640	130	80
Avg.*		368	57	83	378	59	83	397	180	50
Min.*		190	34	-	190	34	-	220	130	-
Max.*		530	100	-	530	100	-	670	250	-
Std. Dev.*		93	18	**-**	169	28	**-**	160	32	**-**

*** Dates omitted from statistical summary due to filter influent parameter values out of the range typically observed in the plant's primary influent.**

Source: Kennedy Jenks Consultants

Table 23: Laboratory Sampling Results (Manteca) — COD and TKN

Date	HLR (gpm/ft^2)	COD Filter Influent (mg/L)	COD Filter Effluent (mg/L)	COD Removal Efficiency (%)	TKN Filter Influent (mg/L)	TKN Filter Effluent (mg/L)	TKN Removal Efficiency (%)
3/13/18	2	1200	410	66	-	-	-
3/20/18	2	760	330	57	66	56	15
3/27/18	2	880	390	56	-	-	-
4/3/18	2	890	400	55	77	66	14
4/10/18	2	820	400	51	-	-	-
4/24/18	2	750	410	45	77	69	10
5/8/18	3	680	420	38	72	57	21
5/15/18	3	490	320	35	-	-	-
6/19/18*	3	700	340	51	-	-	-
7/3/18*	3	560	380	32	-	-	-
7/17/18*	3	440	330	25	-	-	-
7/31/18	4	740	380	49	58		-
8/14/18*	4	390	360	8	52	56	-
8/28/18*	4	1300	320	75	77	52	-
9/18/18	4	670	390	42	53	47	11
10/2/18	4	510	370	27	58	44	24
12/18/18*	3	1800	290	84	78	63	19
Avg.*		763	384	47	66	57	16
Min.*		490	320	-	53	44	-
Max.*		1200	420	-	77	69	-
Std. Dev.*		186	31	-	32	29	-

*** Dates omitted from statistical summary due to filter influent parameter values out of the range typically observed in the plant's primary influent.**

Source: Kennedy Jenks Consultants

4.4.2 Hydraulic/Operational

Hydraulic performance of the primary filter was valuated based on fil loading and production rates.

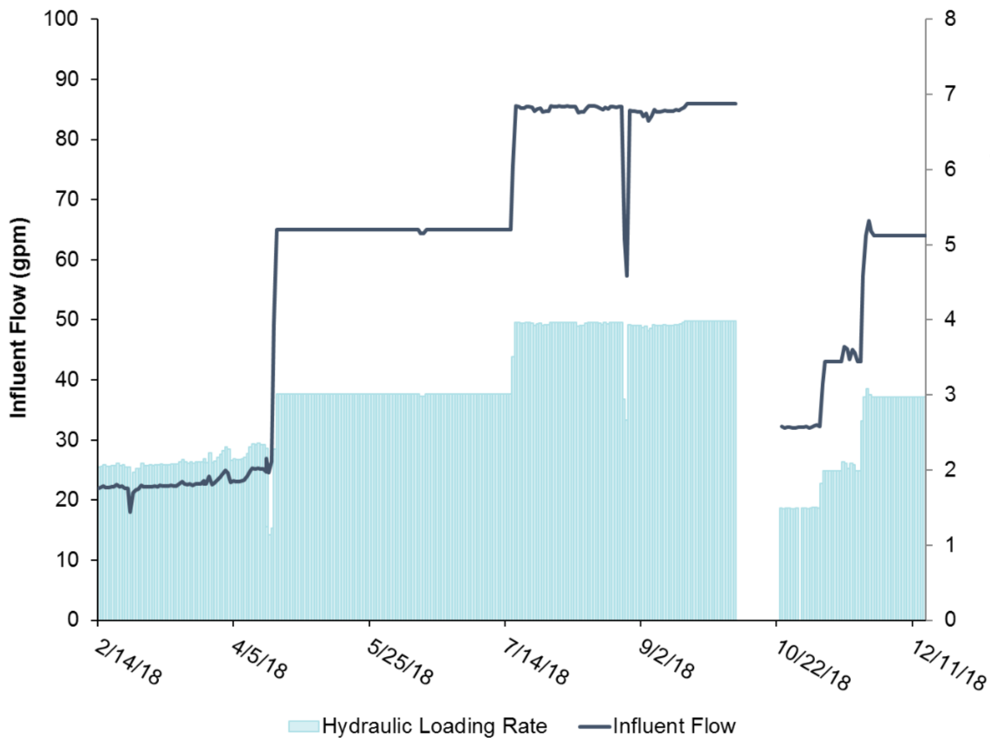
4.4.2.1 Filter Loading Rates

The filter loading rates were measured in terms of both HLR and SLR. Application rates were controlled by changing HLR. The SLR changes based on the HLR and the filter influent TSS level.

Hydraulic Loading Rates

The filter influent flow and corresponding HLR are shown in Figure 41. Filter was operated at HLRs of 2, 3, or 4 gpm/ft^2 from February to August of 2018. The filter experienced some fluctuations at 2 gpm/ft^2 in the first two months of testing due to instability with PID loop control. HLR was calculated based on the filtration area of 10.76 ft^2 per disk. The Manteca demonstration filter was originally installed with a single disk. A second filter disk was added on April 17.

Figure 41: Daily Average Influent Flow and Hydraulic Loading Rate (Manteca)

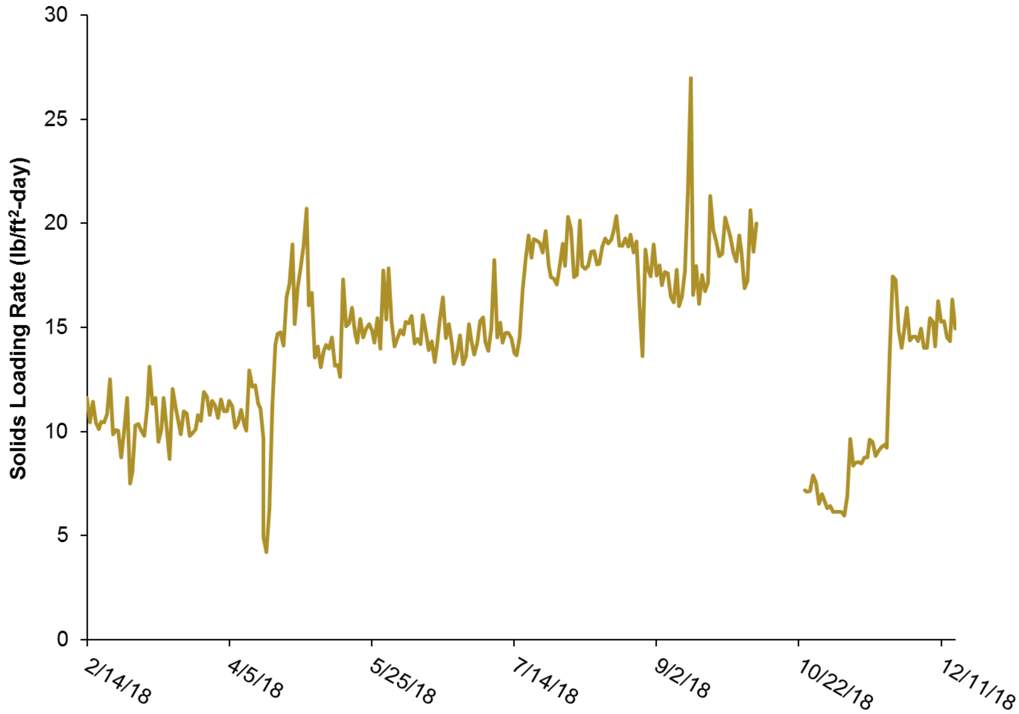


Source: Kennedy Jenks Consultants

Solids Loading Rates

SLR for the demonstration system is shown in Figure 42. SLR of approximately 10, 15, and 20 lb/ft^2-day were observed for testing at HLRs of 2, 3, and 4 gpm/ft^2, respectively.

Figure 42: Daily Average Solids Loading Rate (Manteca)



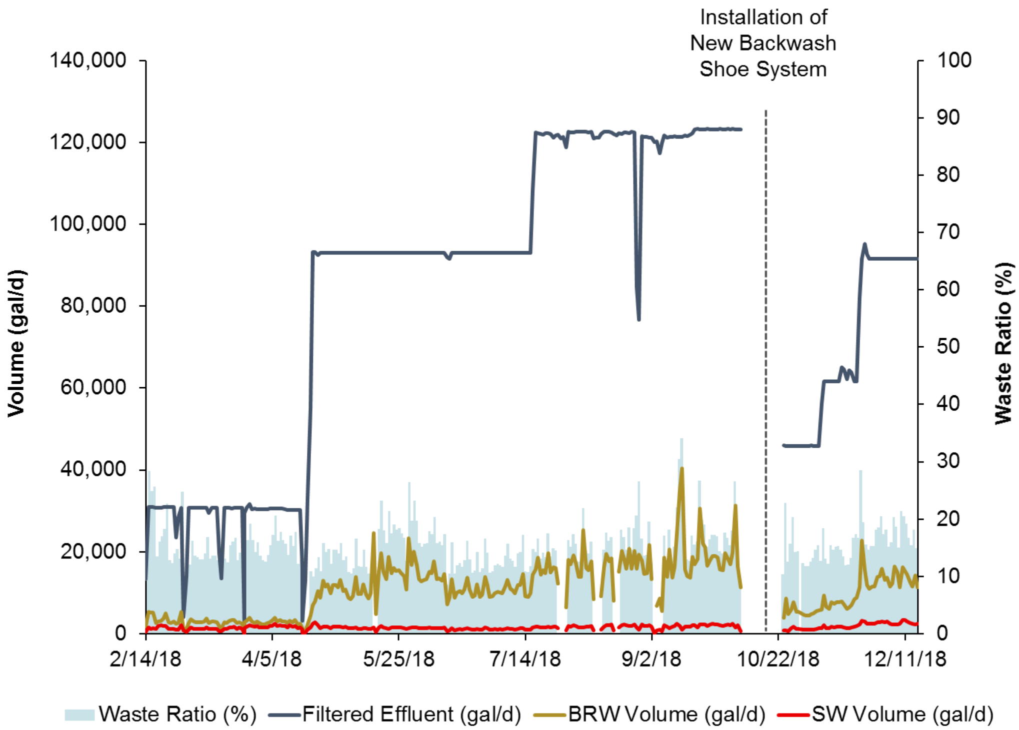
Source: Kennedy Jenks Consultants

Production and Reject Rates

The volumes of filtered effluent, BRW, and solids waste for the demonstration primary filter system are shown in Figure 43. The corresponding BRW and solids waste ratios are shown in Figure 44. Solids waste ratios reduced substantially after the addition of the second filter disk in mid-April 2018. Depth of settleable solids at the bottom of the filter basin also reduced significantly due to 50 percent reduction of residence time at equivalent HLR. Overall combined BRW and SW ratios averaged 15 percent during the ten months of filter operation. It should be noted that the operation of the demonstration primary filter system at Manteca WQCF was not optimized to reduce or minimize reject flow ratios.

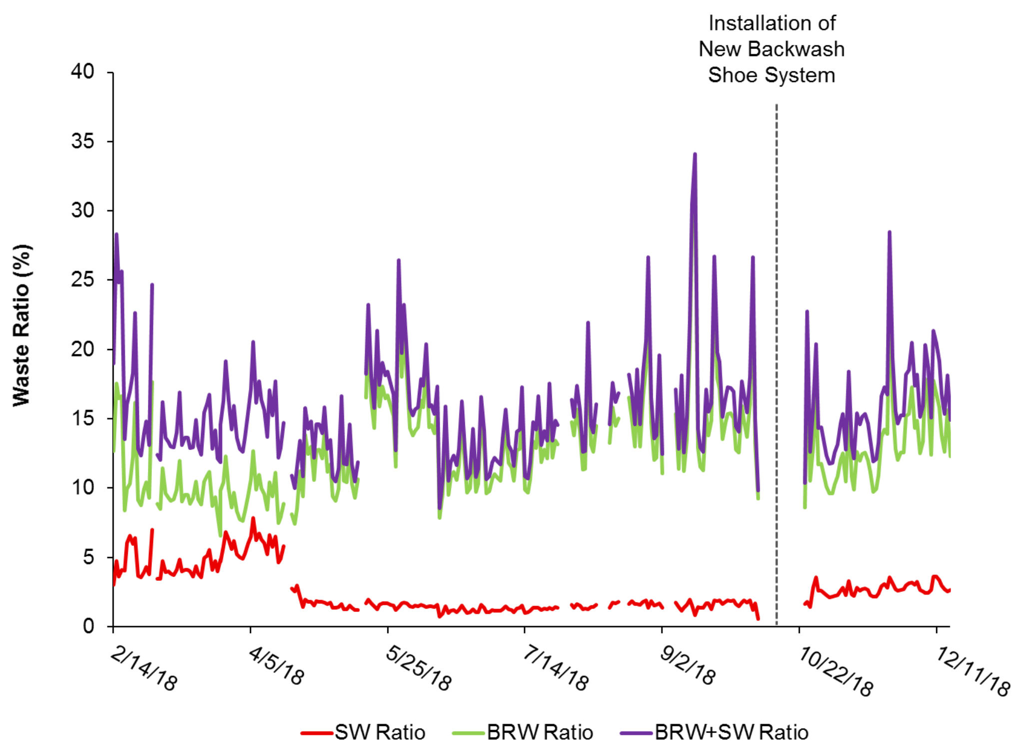
The combined daily BRW and solids waste ratios versus SLR is plotted in Figure 45. The total waste ratio shows a slight positive correlation with SLR, especially for solids waste.

Figure 43: Total Filtered and Wasted Volumes (Manteca)



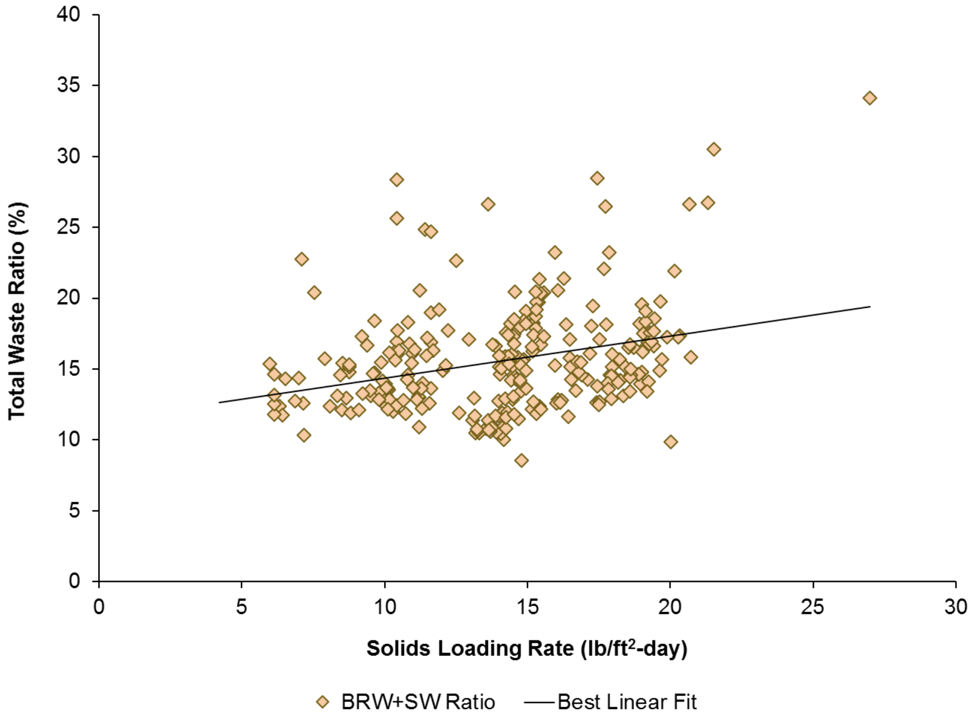
Source: Kennedy Jenks Consultants

Figure 44: Daily Average Waste Ratios (Manteca)



Source: Kennedy Jenks Consultants

Figure 45: Total Waste Ratio versus SLR (Manteca)



Source: Kennedy Jenks Consultants

CHAPTER 5: Conclusions and Summary of Cost Savings

5.1 Achievement of Overall Project Objectives

This project successfully met its overall objective of demonstrating that primary filtration is a technically viable and commercially attractive approach to achieve significant electrical energy savings at WWTPs. The results of the six metrics (listed in Section 1.2) (shown below) that determined project success are presented and discussed in this chapter.

- Quantification of electrical energy savings resulting from reduced aeration demand in downstream activated sludge process and/or from operation of a smaller activated sludge basin.
- Quantification of biogas production from increased diversion of solids during primary treatment.
- Quantification of capital saving from reduced primary and secondary treatment footprint and operational energy savings.
- Evaluation of long-term, stable operation of primary filtration at consistent hydraulic and treatment performance.
- Investigation of additional downstream treatment impacts of primary filtration which may require modification to existing treatment processes.
- Development of operational, maintenance, and design criteria for full-scale installations.

5.2 Primary Filtration Demonstration Performance

Performance results from the three deployments are compared and summarized in terms of operation, treatment, and hydraulics in this section, based on following project goals:

- Evaluation of long-term, stable operation of primary filtration at consistent hydraulic and treatment performance.
- Development of operational, maintenance, and design criteria for full-scale installations.

5.2.1 Summary of Operational and Maintenance Performance

Stable operation and performance of primary filtration was observed at each of the three deployments. The ability of this technology to replace conventional primary treatment has been demonstrated and documented at full-scale by the performance of installation at LCWD WWTP, over a consecutive period of 18 months. Minor operational issues experienced at the deployments were unique to the setup of each demonstration, such as issues related to influent pumps or the sampling and monitoring systems. Main operational and maintenance considerations for full-scale implementation are discussed below.

5.2.1.1 Filter Clean-In-Place

Clean-in-place (CIP) was performed four times for the primary filter at LCWD WWTP between March and December of 2018. A gradual increase in backwash vacuum pressure was observed over the operational period of the filter, due to suspected filter media fouling from substances such as FOG or residual polymer in the plant's recycled streams. A CIP procedure was developed for the primary filter, which involved putting the filter in recirculation for a 24-hour period at an adjusted pH of 11 or greater. The filter backwash vacuum pressure dropped significantly after each CIP was conducted, and as expected increased over operational time. Detergent was added for the CIPs conducted in March and June of 2018. A subsequent CIP was performed without detergent, with no noticeable effect on the immediate reduction of backwash vacuum pressure. The cause of occasional high backwash vacuum pressure and the most effective procedure and frequency for CIP should be further studied.

Each of the eight filter disks used at LCWD WWTP deployment is divided into six equal sections. In addition to CIP, the filter cloth media was changed for a section on two of the eight disks in December 2017 to inspect the used media and investigate the cause of high backwash vacuum pressures. Based on continuous operation of the system at the three deployment sites, frequent replacement of filter media is not expected for future full-scale installations. Expected replacement frequency is about four to five years.

CIP is expected to be a regular maintenance activity in primary filtration applications. Estimated frequency of CIP is between three to six months depending on influent wastewater characteristics.

5.2.1.2 Preliminary Treatment

An effective preliminary treatment system is essential to reduce operational issues with the primary filter. At the Lancaster WRP deployment, a significant amount of large debris and episodic high solids loading were passed through to the filter. Although the filter's treatment performance was not compromised, the high spikes of SLR required lowering of the filter's HLR. Operationally, the filter waste pump is more likely to clog and could require more frequent maintenance or repair.

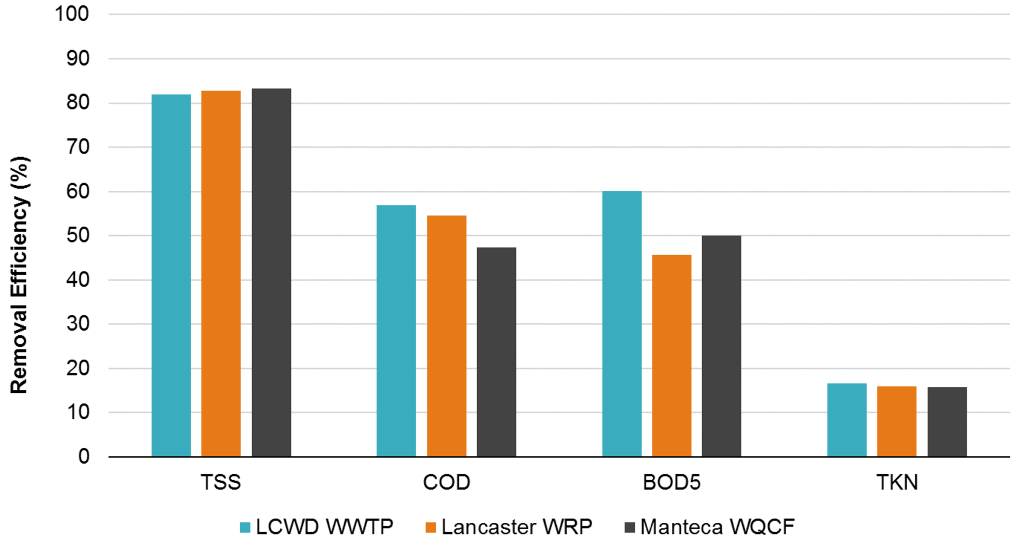
5.2.1.3 Solids Handling

The reject stream from the primary filter typically contains less than 0.2 to 0.3 percent solids, which is too dilute for efficient anaerobic digestion. A solids handling system was implemented as part of the full-scale primary filtration system at LCWD WWTP, using the Volute Thickener to thicken filter reject flow. Although the thickener has not been operated continuously, it has been able to produce the desired sludge thickness of between 2 to 8 percent solids. Any full-scale primary filtration system will likely require installation of a similar sludge thickening system or use of a WWTP's existing sludge thickening system (if the existing system has capacity).

5.2.2 Summary of Treatment Performance

The average removal efficiencies of the three deployments based on laboratory analyses are shown in Figure 46. Overall, primary filtration demonstrated very consistent performance across the deployments, regardless of variations in filter capacity and influent loading rates. The range of average removal efficiencies were 82 to 83 percent for TSS, 47 to 58 percent for COD, 45 to 60 percent for BOD_5, and 15 to 16 percent for TKN. Observed primary filter removal efficiencies are typically 40 to 60 percent higher compared to primary clarifier.

Figure 46: Average Removal Efficiencies of the Primary Filtration Deployments



Source: Kennedy Jenks Consultants

5.2.3 Summary of Hydraulic Performance

Due to difficulty of implementing certain hydraulic features in a scaled-down system, production and waste ratios observed for the demonstration-scale systems likely are not as representative of a full-scale primary filtration system. The full-scale system at LCWD WWTP is likely to better represent the average hydraulic performance of future full-scale implementations. Hydraulic performance results at all three sites are summarized in Table 24. The demonstration-scale filters at the Lancaster WRP and the Manteca WQCF were found to have an average reject ratio of approximately 15 percent, while the full-scale filter at the LCWD WWTP had an average reject ratio of 10 percent.

Table 24: Hydraulic Performance Summary for the Primary Filtration Deployment

Parameter	LCWD WWTP	Lancaster WRP *	Manteca WQCF
Average Daily Filtered Water Volume (gallons)	411,000	28,000	82,000
Average Daily Total Waste Volume (gallons)			
Backwash	29,000	3,000	11,000
Solids Waste	11,000	2,000	2,000
Total	40,000	5,000	12,000
Average Waste Ratio (%)			
Backwash	7	10	13
Solids Waste	3	6	3
Total	10	16	16

*** Hydraulic performance summary for Lancaster WRP considers only filter operation at HLR of 2.2 gpm/ft^2 from January 4 to December 11, 2017.**

Source: Kennedy Jenks Consultants

5.2.4 Design Criteria for Full-Scale Primary Filter Deployment

Design criteria for the full-scale primary filter deployment at the LCWD WWTP is summarized in Table 25.

Table 25: Design Criteria for the Full-Scale Primary Filter Deployment at Linda County Water District Wastewater Treatment Plant

Parameter	Value
Number of Filter Disks	8
Total Filtration Area (ft^2)	432
Flow Capacity (mgd)	
Average	1.0-1.5
Peak	2.5-3.0
Solids Loading Rate (lbs/ft^2-d)	
Average	5
Peak	10
Filter Reject Ratio (%)	
Backwash Reject Water Ratio	8-10
Solids Waste Reject Ratio	2-4
Total Reject Ratio	10-14
Typical Removal Efficiency (%)	
TSS	80-85
COD	55-60
BOD_5	60-65
TKN	10-15

Source: Kennedy Jenks Consultants

The design of a full-scale primary filtration system will need to include considerations for downstream treatment impacts. Conventional primary treatment systems have removal efficiencies of 50 to 60 percent removal for TSS and VSS, 20 to 30 percent removal for BOD and COD, and 5 to 10 percent removal for total organic nitrogen. The improved primary effluent quality from primary filtration generally improves downstream treatment efficiency, but the changes in primary effluent characteristics may also necessitate downstream design and/or operational modifications. These impacts are investigated through process simulation, as discussed in Section 5.3.

5.3 Process Simulation Summary of Primary Filtration

Wastewater process simulations were performed to predict the energy benefits and estimate the downstream impact of full-scale primary filtration. Simulations were run for each of the deployment sites and for six other plants that are representative of WWTPs in California in terms of size and treatment processes. The simulations evaluated primary filtration in terms of potential reduction in secondary treatment energy requirements and increase in digester gas production, which are two of the main project measurement goals, and also considered other possible impacts.

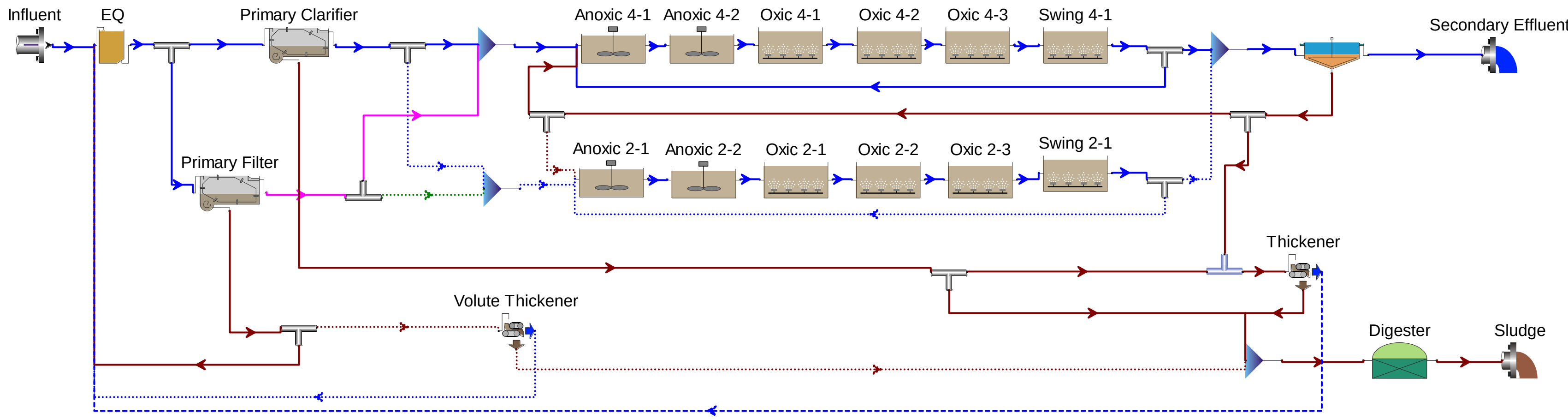
This section summarizes the approach and key findings of the process simulations. Detailed process simulation reports are provided in Appendix A.

5.3.1 Simulation Methodology

Process simulations were performed using the BioWin 5.3 simulator, developed by EnviroSim of Ontario, Canada (EnviroSim Associates Ltd. 2017). 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). The predictive capability of the simulator was validated through calibration with plant operating data, and full-scale results of the simulations were verified by comparing simulator estimates with hand-calculated estimates.

The flow schematic from the simulator for the LCWD WWTP is shown in Figure 47 as an example of simulator set-up. Each simulator was set up to include the full primary and secondary treatment processes and the solids handling process at the respective plant.

Figure 47: Example BioWin Simulator Layout for Linda County Water District Wastewater Treatment Plant



Source: Kennedy Jenks Consultants

5.3.2 Simulations for the Deployment Sites

The simulated treatment processes for each deployment site are summarized in Table 29.

Table 26: Simulations for Each Deployment Site

Simulation	Description	Purpose
S0	Calibrated simulator based on filter performance data and plant process information at the deployment site	Calibrate BioWin simulator for more accurate predictions and use in subsequent simulation scenarios
S1	Simulation using primary clarification for primary treatment	Establish the baseline simulation with primary clarification for comparison purposes
S2	Simulation using primary filtration for primary treatment	Evaluate impact of primary filtration 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 filtration on secondary process treatment volume reduction
S4 (as needed)	Simulation S2 with reduced airflow as a means to meet plants' effluent limit for NO_X-N of 10 mg/L, if necessary	Evaluate airflow reduction and redistribution as a method to meet effluent NOx-N limit with primary filtration

Source: Kennedy Jenks Consultants

5.3.2.1 Simulator Calibration for the Deployment Sites

Simulations for the three deployments were calibrated using data and plant process information (e.g., SCADA, daily monitoring reports, etc.) during a selected demonstration period. For the Lancaster WRP, plant staff had developed a calibrated secondary treatment simulator that pre-dated this effort. This project modified the simulator from Lancaster WRP and added models to simulate the full treatment process; calibration of the secondary treatment process by plant staff was retained.

5.3.2.2 Simulation Results and Estimated Benefits for the Deployment Sites

Simulated benefits are estimated in this section by comparing Simulations S1 and S3 for each deployment, as summarized in Table 27. Results of the other simulations are shown in Appendix A. At all three deployment sites, implementation of full-scale primary filtration is estimated to impact overall plant energy use and operation as discussed below.

Secondary Treatment Energy Saving and Footprint Reduction

As confirmed by the actual treatment performance of the deployments, the simulations indicate that primary filtration improves primary removal rates with reduced levels of TSS and 5-day carbonaceous biochemical demand ($CBOD_5$). BOD is the sum of CBOD and nitrogenous BOD (NBOD); thus, BOD measured at demonstration sites is expected to be higher than CBOD in the simulation. This improved primary removal benefits WWTPs by allowing either (1) modification to the operation of the existing secondary treatment basin or (2) construction of a smaller secondary treatment basin (during plant renovation or expansion). The benefits to secondary biological treatment are as follows:

- Decreased aeration energy: Secondary process AOR decreases due to reduced $CBOD_5$ load in the primary effluent. The estimated amount of aeration savings depends on operational parameters such as SRT[1].
- Decreased secondary biological treatment footprint: Due to the reduced TSS and $CBOD_5$ loading on the secondary biological treatment process, primary filtration reduces the secondary treatment basin volume required to maintain the same concentration of mixed liquor suspended solids (MLSS) and solids retention time (SRT) in the secondary treatment basins. New plants in design or existing plants going through upgrade may opt to use a reduced volume, which results in mixing power savings, construction cost savings, and land use savings.
- Decreased mixing energy for anoxic zone: In addition to the power consumed in the aerated portion of secondary biological treatment, power is also consumed for mixing of the anoxic, or non-aerated, portion of the process. If a WWTP opts to build a smaller secondary treatment basin as a result of implementation of primary filtration, the smaller volume results in further saving in the mixing energy requirement of the anoxic zone.

Compared to the LCWD WWTP and the Manteca WQCF, the Lancaster WRP shows more substantial benefits from implementing a full-scale primary filtration system. The difference can be attributed to Lancaster's secondary treatment process and operation. The Lancaster WRP uses a step-feed activated sludge process, which splits the primary effluent flow to enter at different points of the secondary treatment passes. The Lancaster WRP also operates at a lower SRT, for which the simulations show greater aeration savings for primary filtration.

Improved Digester Gas Production

The simulations indicate that digester gas production increases with primary filtration due to a greater proportion of VSS diverted to anaerobic digestion from the primary treatment process. It should also be noted that primary solids have been observed to have higher gas value than the waste activated sludge (WAS) produced by the secondary process (ex. Bolzonella et al. 2005). The simulated increases in digester gas with primary filtration are shown in Table 30. The results are generally consistent among the three deployment sites, with the differences likely accounted for by variations in wastewater influent characteristics and plant operational conditions.

[1] SRT, or the average time that solids are held in the treatment basins, is one of the critical operational parameters for an activated sludge secondary treatment process. Higher SRT leads to greater concentration of microbes in the secondary treatment basin, which in turn increases aeration requirement. Aeration power use is therefore dependent on each deployment site's operating SRT.

Table 27: Simulated Benefits of Full-Scale Primary Filtration with Reduced Secondary Treatment Basin Volume at the Deployment Sites

Parameter	LCWD WWTP	Lancaster WRP	Manteca WQCF
Volume of Secondary Treatment Basin (Million gallon/mgd of wastewater treated)			
With Primary Clarifier	0.77	0.39	0.60
With Primary Filter	0.62	0.25	0.39
Volume Reduction with Primary Filter	0.16	0.14	0.21
Percent Reduction	20%	36%	35%
Power for Aeration and Mixing in Aerobic Zones (hp/mgd of wastewater treated)			
With Primary Clarifier	47	49	60
With Primary Filter	40	39	53
Power Reduction with Primary Filter	7	10	7
Percent Reduction	14%	20%	11%
Power for Mixing in Anoxic Zones (hp/mgd of wastewater treated)			
With Primary Clarifier	18	16	8
With Primary Filter	14	10	5
Power Reduction with Primary Filter	4	6	3
Percent Reduction	20%	35%	35%
Total Power for Secondary Treatment (hp/mgd of wastewater treated)			
With Primary Clarifier	64	65	68
With Primary Filter	54	49	59
Power Reduction with Primary Filter	10	15	9
Percent Reduction	16%	24%	14%
Digester Gas Volume (scfm/mgd of wastewater treated)			
With Primary Clarifier	8.2	12.9	14.3
With Primary Filter	12.1	19.1	19.4
Gas Volume Increase with Primary Filter	3.9	6.2	5.2
Percent Increase	47%	48%	36%

Source: Kennedy Jenks Consultants

Impact on Nitrate Concentration in Downstream Operations

The simulations indicate that the secondary effluent nitrate concentration may increase due to reduced $CBOD_5$ in the primary effluent, and in some cases the effluent nitrate concentration could exceed the WWTP effluent water quality objective. The maximum discharge limit for nitrate plus nitrite depends on the facility's NPDES permit; typically, it is 10 mg/L for some wastewater treatment facilities in CA. Insufficient $CBOD_5$ during secondary treatment can result in the impartial or limited biodegradation of nitrate to nitrogen gas. A possible method to lower secondary effluent nitrate is to decrease airflow in secondary treatment, as shown in Simulation S4 (see Appendices A.1 to A.3). Since tertiary treatment does not provide additional denitrification, secondary effluent nitrate needs to be controlled in secondary treatment.

5.3.3 Simulations for Representative California Wastewater Treatment Plants

5.3.2.1 Selected Wastewater Treatment Plants

Six WWTP simulators were selected from the inventory of plant simulators developed in other projects by Kennedy Jenks. Two simulators were selected for each of the treatment plant size classifications of small (less than 5 mgd), medium (5 to 20 mgd), and large (more than 20 mgd). Key information on the six WWTPs is summarized in Table 28. All these WWTPs use conventional primary clarifiers (PC) for primary treatment except SS WWTP2, which uses a rotating belt filter/microscreen for the primary treatment.

Simulations performed for each representative WWTP are summarized in Table 29. Full-scale primary filtration at each of the six plants was evaluated for aeration power savings, digester gas production, and expanded secondary treatment capacity. Primary filtration was simulated to match the demonstration facility removal efficiencies as much as possible.

Table 28: Representative Wastewater Treatment Plants Chosen for Simulation

Size Classification	Plant ID	Influent Flow (mgd)
Large Size (More than 20 mgd)	LS WWTP1	30.6 (MMF)
	LS WWTP2*	100 (MMF)
Medium Size (5 to 20 mgd)	MS WWTP1	15.7 (MMF)
	MS WWTP2	16.0 (MMF)
Small Size (Less than 5 mgd)	SS WWTP1	2.9 (AAF)
	SS WWTP2†	4.4 (AAF)

MMF = maximum monthly flow; AAF = average annual flow

*** LS WWTP2 is based on the LCWD WWTP simulator scaled up to a plant capacity of 100 MGD.**

† SS WWTP2's existing primary treatment uses microscreen, which is compared with the primary filtration (using PCDF).

Source: Kennedy Jenks Consultants

Table 29: Simulations for Each Representative Wastewater Treatment Plant

Simulation	Description	Purpose
A	Plant simulation with PC under selected flow and loading condition	Baseline simulation for comparison
B	Comparison simulation with PF replacing PC under the same flow and loading condition and secondary process SRT as Simulation A. Additional simulation with supplemental carbon was conducted if needed to achieve an effluent NOx-N or total nitrogen limit.	Evaluate impact of PF on oxygen demand, aeration/mixing for aerated basins, digester gas production, and secondary effluent NOx-N
C	Comparison simulation with primary filter replacing PC under increased flow and loading conditions and the same process SRT and MLSS as Simulation A. Additional simulation with supplemental carbon was conducted if needed to achieve an effluent NO_X-N or total nitrogen limit.	Evaluate impact of PF on secondary process treatment capacity

Source: Kennedy Jenks Consultants

5.3.2.2 Simulation Results and Estimated Benefits for the Representative Wastewater Treatment Plants

The simulation results for the six representative WWTPs are shown in Appendix A.4. The estimated benefits of full-scale primary filtration for the representative WWTPs is similar to the three deployment sites, as summarized below:

- Decreased aeration energy: Secondary process AOR decreases due to reduced $CBOD_5$ load in the primary effluent.
- Increased digester gas production: Digester gas production increases due to a greater proportion of solids diverted at the primary removal process and the higher gas value of the primary solids.
- Increased secondary treatment capacity: Secondary treatment capacity is expected to increase due to reduced TSS and $CBOD_5$ levels in the primary effluent, which results in capital and land use savings for new construction projects or during future treatment expansion.
- Impact on nitrate concentration in downstream operations: The simulations indicate that secondary effluent nitrate concentration increases due to reduced $CBOD_5$ level in the primary effluent, and in some instances this could exceed the WWTP effluent water quality objective for nitrate, which varies based on the facility's NPDES discharge permit. A possible method to lower secondary effluent nitrate through carbon addition or change in aeration/dissolved oxygen strategy in secondary treatment is discussed in Appendix A.4 for the six representative WWTPs.

The relative impact of primary filtration at each plant depends on factors such as treatment efficiency of the existing primary treatment system and secondary treatment process and operational conditions. A detailed discussion of the differences in simulated benefits among the six WWTPs is provided in Appendix A.4.

5.4. Summary of Measurement and Verification Study

A third-party energy audit firm, BASE Energy, Inc., conducted an M&V study for all three primary filtration deployments that is summarized below. Detailed M&V reports are provided in Appendix B.

5.4.1 Measurement and Verification Methodology

At each deployment, data loggers were installed on the primary filtration system to measure the power usage. Additional logged data, daily monitoring reports, and process information were obtained from each 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_5 loading. Aeration power consumption for proposed, full-scale primary filtration systems were then projected based on the normalized baselines and the expected reduction in BOD_5 loading on the secondary treatment process.

Additional loggers were installed on the plant's equipment for the full-scale installation 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.

5.4.2 Measurement and Verification Energy Savings Estimation

Secondary treatment aeration savings estimated from M&V are summarized in Table 30. Based on M&V, aeration power is expected to reduce by between 25 to 39 percent with full-scale primary filtration based on reduced BOD_5 loading on the secondary treatment process.

Table 30: Measurement and Verification Aeration Power Reduction Estimates for Deployment Sites

Parameter	LCWD WWTP	Lancaster WRP	Manteca WQCF
Plant Flow (mgd)	1.32	14.35	3.56
Required Aeration Power (hp)			
Baseline	26	654	135
Proposed	16	444	101
Required Aeration Power, Normalized to Flow (hp/mgd of wastewater treated)			
Baseline	20	46	38
Proposed	12	31	28
Potential Aeration Power Reduction (%)	39	32	25

Source: Kennedy Jenks Consultants

5.5. Energy Savings

Primary filtration provides significant energy savings for secondary activated sludge process, as quantified by both computer process simulations and M&V study. The aeration power savings estimated from each approach are summarized in Table 31. 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.

Additional ways in which primary filtration impacts a WWTP's energy use are as follows:

- Decrease in Anoxic Zone Mixing Power Requirement: For plants which are going through design or upgrade, a smaller secondary treatment basin can be placed downstream of a primary filter. The primary filter will maintain the same mixed liquor suspended solids (MLSS) as the primary clarifier. The smaller secondary treatment basin reduces the mixing volume of the anoxic portion, thereby reducing mixing power requirement by 20 to 35 percent based on process simulation findings.
- Increase in Digester Gas Production: Plants that have co-generation may benefit from the diversion of a greater amount of high gas value primary solids during primary treatment. Digester gas production at the deployment sites is expected to increase by 36 to 48 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 the power consumption. Power consumption for the primary filter versus primary clarifier is not expected to significantly impact overall energy use.

Table 31: Projected Aeration Power Savings from Implementation of Full-Scale Primary Filtration

Parameter	LCWD WWTP	Lancaster WRP	Manteca WQCF
Aeration Power Savings (%)			
From Process Simulation	14	20	11
From M&V	39	32	25
Average	28	26	18

Source: Kennedy Jenks Consultants

5.6. Cost Estimates

Cost estimation associated with primary filtration was conducted to quantify capital cost savings from reduced primary and secondary treatment footprint and operational energy savings.

5.6.1 Cost Estimate Methodology

Planning-level opinions of probable cost were prepared for primary filtration and primary clarification projects. The opinions of probable cost compare the benefits of primary filtration at a 10-mgd WWTP based on a 30-year life cycle cost to a similarly-sized plant using primary clarification. These conceptual level estimates, which are based on recent Kennedy Jenks project experience and include various WWTP design scenarios, have an expected accuracy range of +50 to -30 percent.

For anaerobic digestion, it is generally desirable to have feed sludge with a solids content of above three to four percent. Different options exist for thickening and/or blending of primary sludge. Two primary sludge handling options were considered for this project: gravity thickening and mechanical thickening (cost estimates for mechanical thickening were based on the Volute Thickener system used at LCWD WWTP). Savings estimates between primary filtration and primary clarification were made by comparing costs associated with the two primary treatment technologies with the same sludge thickening system.

The following main assumptions were made for the cost estimation:

- Net present value (NPV) was calculated for 30-year life, 3 percent discount rate.
- Costs were estimated for a WWTP with a capacity of 10 mgd.
- For minimum savings estimates only, supplemental carbon was used with primary filtration to reduce nitrate levels in secondary effluent (see Section 5.3).

The values used to estimate the minimum, average, and maximum savings are shown in Table 32.

Table 32: Cost Savings of Primary Filtration Replacing Primary Clarification

Parameter	Minimum Savings	Average Savings	Maximum Savings
Aeration basin volume reduction with PF (%)	20	30	35
Blower and airflow reduction with PF (%)	15	20	30
Thickened filter sludge concentration with PF (mg/L)	40,000	40,000	50,000
NO_3-N increase with PF (%)	50	25	0
Land value ($/ft^2)	50	75	100
Labor cost ($/hr)	100	80	60
Anoxic mixing power saving with PF (%)	20	30	35
Digester gas production change with PF (%)	35	40	45

Minimum, average, and maximum savings value used in estimation.

Source: Kennedy Jenks Consultants

5.6.2 Savings Estimates with Primary Filtration

Primary filtration is estimated to save an average $1.6 million per mgd of average WWTP flow capacity over a 30-year period. Minimum savings over a 30-year period were estimated to be at least $830,000 per mgd and maximum savings were estimated to be $2.2 million per mgd of average wastewater treatment plant capacity depending on influent wastewater characteristics and specific site and system requirements.

A cost comparison summary is provided in Table 33 with the breakdown for capital, energy, and overall annual O&M cost savings. A conversion rate of $0.12/kWh was used to convert kWh savings to cost savings.

Table 33: Cost Savings of Primary Filtration Replacing Primary Clarification

Cost Item	Estimated Range of Savings (per mgd of average wastewater treatment plant capacity)
Construction Cost	$640,000 to $1.1 million
Overall Annual O&M	$6,000 to $35,000
Total NPV *	$830,000 to $2.2 million
Annual Power	$22,000 to $35,000
Treatment	$9,000 to $17,000
Digester Energy Recovery	$13,000 to $18,000

***For a 30-year period.**

Source: Kennedy Jenks Consultants

5.7. Summary of Technology Transfer Activities

This project has garnered support from manufacturers, engineers, academia, and utilities since its inception. The high level of interest and support suggests that, upon successful completion of the demonstration project, commercialization of raw wastewater filtration can be expected to quickly gain significant market traction.

In California alone, primary filtration will be directly applicable at approximately 300 WWTPs distributed throughout the state, with a total capacity exceeding 4,000 mgd. For this estimate, only the municipal WWTP market segment is assumed (i.e., potential market of 4,000 mgd municipal wastewater treated in California). The operational and treatment results of primary filtration from the demonstration project will allow municipalities to evaluate suitability of the technology at their facilities. Quantification of energy savings at the demonstration sites can inform WWTP consideration of whether to adopt primary filtration. The technology may also have applicability for industrial wastewater treatment.

In addition to implementation at WWTPs, the results of this project also have significant research value for governmental agencies, academia, and manufacturers. The research results, technical reports, operational and design criteria, and modeling studies produced at the end of this project will contribute to institutions and decision-making strategies.

5.7.1 Technology Transfer Strategy

The project team conducted the following activities, detailed in Table 34, to disseminate knowledge gained from the raw wastewater filtration project to the industry and the public:

- Met with and presented the project to public agencies, utilities, and practitioners in the wastewater treatment field, including South Lake Tahoe Public Utility District, LACSD, San Francisco Public Utilities Commission (SFPUC), Sand Island WWTP (Honolulu, Hawaii), Manteca Public Works, City of Rialto Public Works, Lihue WWTP (Kauai, Hawaii), and Wailua WWTP (Kauai, Hawaii);
- Made at least three presentations per year at state and/or national conferences from 2016 to 2018, with anticipated future presentations through 2021;
- Made approximately 30 presentations at professional and society meetings and client workshops;
- Wrote articles for publications targeted to agencies with WWTPs;

- Published technical papers in Water Environment Federation Technical Exhibition and Conference (WEFTEC)'s 2015, 2016, 2017, and 2018 proceedings. Submitted technical article in peer-reviewed technical Journal; and
- Developed and distributed project flyers to approximately 1,000 audience members at conferences including PNCWA, WEFTEC, California Water Energy Association (CWEA), Pacific Water Conference (PWC), and Texas Water Conference.

5.7.2 Completed Technology/Knowledge Transfer Activities

The technology and knowledge transfer activities to date are summarized in Table 34.

Table 34: Timeline of Technology/Knowledge Transfer Activities to Date

Date	Audience	Activity Type	Activity Description
September 2015	Public utilities, consulting engineers, and operators	National conference presentation	Attended WEFTEC 2015 in Chicago, IL and met with several agencies and utilities to inform them of the project.
October 2015	Public utilities, consulting engineers, and operators	Regional conference presentation	Attended PNCWA 2015 in Boise, ID and met with several agencies, engineers, and utilities to inform them of the project.
October - November 2015	Utilities	Planning	Communicated with WERF regarding independent review of the project by interested utilities in or outside of California.
February 2016	Public utilities, consulting engineers, and operators	Regional conference presentation	Attended PWC in Honolulu, HI to present project progress and next steps, prior pilot results, and estimated benefits of the project.
February 2016	Utilities	Utility meeting & presentation	Met with Sand Island WWTP at Honolulu, HI and Lihue and Wailua WWTPs at Kauai, HI to present the raw wastewater filtration project and estimated benefits.
April 2016	Public utilities, consulting engineers, and operators	Regional conference presentation	Attended the Texas Water 2016 Conference in Fort Worth, TX to present project progress, prior pilot results, and estimated benefits of the project.
April 2016	Public utilities, consulting engineers, and operators	Regional conference presentation	Attended CWEA 2016 conference in Santa Clara, CA to present project progress, prior pilot results, and estimated benefits of the project.
May 2016	Academia / Graduate Students	Seminar	Gave a project presentation to University of California at Davis Civil and Environmental Engineering graduate seminar.
July – August 2016	General	Technical paper submittal	Submitted a technical paper regarding raw wastewater and primary effluent filtration for WEFTEC 2016 conference proceedings.

Date	Audience	Activity Type	Activity Description
September 2016	Public utilities, consulting engineers, academia, and operators	National conference presentation	Attended WEFTEC 2016 in New Orleans, LA and gave a technical presentation on the project.
October 2016	Public utilities, consulting engineers, and operators	Regional conference presentation	Attended PNCWA 2016 in Bend, OR and gave a technical presentation on the project.
December 2016	Utilities	Seminar	Gave a project presentation to several utilities at a seminar sponsored by Kennedy/Jenks.
February 2017	Public utility	Presentation	Gave a project presentation to SFPUC to inform them about the project.
February 2017	Public utilities, consulting engineers, and operators	Regional conference presentation	Gave project presentation at the 2017 PWC in Honolulu, HI.
February 2017	Public utility	Presentation	Gave a project presentation to County of Maui and City and County of Honolulu to inform them about the project
April 2017	Public utilities, consulting engineers, and operators	Regional conference presentation	Gave a project presentation at the 2017 CWEA Conference in Palm Springs, CA.
April 2017	Public utilities, consulting engineers, and operators	Regional conference presentation	Gave a project presentation at the Texas Water 2017 Conference in Austin, TX.
May 2017	Public utility	Site visit	Conducted a site tour to the system at Linda WWTP for City of Rialto Public Works Department management staff.
July 2017	General	Technical paper submittal	Submitted a technical paper regarding raw wastewater and primary effluent filtration for WEFTEC 2017 conference proceedings.
August 2017	Academia	Site visit	Met with Prof. George Tchobanoglous (from University of California, Davis) and Alfieri Pollice (from Italian Water Research Institute) at the LCWD WWTP to show the operation of the demonstration primary filter system.
September 2017	Public utilities, consulting engineers, academia, and operators	National conference presentation	Presented the project at WEFTEC 2017 conference in Chicago, IL. WEF also requested Onder Caliskaner to moderate a special manufacturers' technical session on Advanced Primary Treatment (APT) technologies.

Date	Audience	Activity Type	Activity Description
October 2017	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the project at PNCWA 2017 conference in Vancouver, WA.
October 2017	General	WWTP design book revision	Water Environment Federation (WEF) offered a co-authorship opportunity to Onder Caliskaner for the update of WEF's WWTP design book. Primary filtration and primary effluent filtration projects were included in the new update which was published in October 2017.
November 2017	Public utility	Presentation	Gave a project presentation to the City of Fort Worth to inform them about the project.
February 2018	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the project at PWC. Approximately 80 people attended the presentation.
February 2018	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the project at the North Texas Section of the Water Environment Association of Texas (WEAT-NTS) seminar.
February 2018	Public utility	Presentation/ workshop	Met with SFPUC to update them about the project progress and results.
April 2018	Public utilities, consulting engineers, and operators	Site visit	At CWEA's 2018 Annual Technical Conference, conducted a technical site tour to the system at LCWD WWTP. Approximately 40 people (utility managers/engineers/operators) from 10 different utilities/agencies attended the tour.
April 2018	Public utilities, consulting engineers, and operators	Regional conference presentation	Presented the project at the CWEA's 2018 Annual Technical Conference. Approximately 100 people attended the presentation.
May 2018	Public utility	Site visit	Conducted a site tour to the system 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 project at the 2018 Texas Water Conference.
June 2018	CEC	Internal meeting	Provided update to CEC about the project progress and results.
June 2018	Public utility	Presentation/ workshop	Met with SFPUC to update them about the project progress and results.
June 2018	General	Technical paper submittal	Submitted a technical paper regarding the project for WEFTEC 2018 conference proceedings.

Date	Audience	Activity Type	Activity Description
September 2018	Public utilities, consulting engineers, academia, and operators	National conference presentation	Presented the project at WEFTEC 2018 conference in New Orleans, LA. Also held a workshop on physical processes for carbon redirection.
October 2018	Public utility	Site visit	Conducted a site tour to the system at Linda WWTP for City of San Mateo Public Works Department management and engineering team
December 2018	Public utility	Presentation/ workshop	Workshop was conducted for LACSD.
March 2019	Public utility	Presentation/ workshop	South Tahoe Public Utility District.

Source: Kennedy Jenks Consultants

5.7.3 Project Recognition and Awards

The raw wastewater filtration project gained additional attention in the industry by receiving three awards in 2018 and 2019.

In September 2018, the abstract "Performance of Full Scale and Demonstration-Scale Primary Filtration Projects" was awarded the Best Technical Abstract/Paper at the 2018 WEFTEC Annual Conference in New Orleans, LA.

In January 2019, the primary filtration process was selected for the Engineering and Research – Research Achievement award for the Los Angeles Basin Section of CWEA 2018.

In March 2019, the primary filtration process was selected for the 2019 CWEA statewide Engineering and Research – Research Achievement award.

5.7.4 Upcoming Technology/Knowledge Transfer Activities

The following technology and knowledge transfer activities are anticipated after the completion of the raw wastewater filtration project:

- Continuation of similar activities as in 2018;
- Site visits for interested parties to the primary filter system at the LCWD WWTP;
- Four to six meetings annually with interested utilities; and
- Continue to make at least three presentations per year at state and/or national conferences through 2021. Planned conferences include: WEFTEC, CWEA, PNCWA, Texas Water, and PWC.

5.8 Conclusion

In conclusion, based on the documented performance results at WWTPs in California, it is clear that primary filtration is a technically feasible approach for improving wastewater treatment efficiency and providing energy and cost savings opportunities for wastewater treatment plants.

Primary Filtration is a Technically Feasible Alternative to Conventional Primary Treatment.

- Hydraulic and Treatment Performance: Operational performance of the full-scale installation at LCWD WWTP for over 18 months has demonstrated the ability of this technology to replace conventional primary treatment. Overall, primary filtration demonstrated very consistent performance across the deployments, regardless of variations in filter capacity and influent loading rates.
- Future Design Considerations: Consistent operation of this emerging technology at full-scale identified several key considerations for future installations, including the filter CIP process (as a maintenance requirement), the need for adequate preliminary treatment, and the importance of solids handling.

Primary Filtration Offers Energy Savings Opportunities for WWTPs that Can Benefit California.

- Reduced Aeration Energy: As a result of the higher organics removal achieved with primary filtration the electrical energy requirement for aeration in activated sludge basin is estimated to be reduced by 15 to 30 percent.
- Increased Biogas Production: As a result of the higher organic energy content of volatile suspended solids removed by primary filtration, renewable biogas energy production from anaerobic digestion is expected to increase by 30 to 45 percent.
- Reduced Greenhouse Gases: The increased diversion of organics to the anaerobic digester for biogas production will reduce the greenhouse gases produced from wastewater treatment.

Primary Filtration Offers Cost Savings Benefits for California Ratepayers.

- Reduced Wastewater Utility Costs: The reduced capital and operation costs for wastewater treatment plants could enable a municipality with a growing population to treat a larger amount of wastewater without raising customer fees. Estimated capital cost savings range from $640,000 to $1.1 million per mgd of a facility's average treatment flow capacity. Estimated annual energy savings range from $22,000 to $35,000 per mgd of a facility's average treatment flow capacity.
- Reduced Electric Utility Fees: The reduced wastewater energy use coupled with increased biogas production could result in peak load reduction for California's energy grid and decrease electrical utility costs.

Primary Filtration Provides Increased Flexibility in WWTP Design.

- Reduced Primary Treatment Footprint: Primary filtration reduces the footprint of primary treatment by approximately 60 to 70 percent, which translates to significant cost savings, particularly for wastewater treatment plants with limited land availability.
- Improved Secondary Treatment Efficiency: The improved primary effluent quality coupled with reduced organics loading (upstream of the secondary biological treatment process) increases the amount of wastewater flow that can be treated within the existing secondary treatment footprint.

5.9 Future Demonstration and Research Direction

The results of this project indicate significant potential for primary filtration as an APT technology with significant energy benefits. Benefits of primary filtration can potentially be further magnified by coupling with emerging secondary biological treatment processes, which are more compact and energy efficient than conventional processes. For example, two emerging secondary treatment processes may be particularly suitable downstream of primary filtration. These emerging secondary treatment processes have the potential of reducing the aeration energy consumption of biological treatment by 30 to 50 percent. With this project, primary filtration was shown to reduce the downstream aeration efficiency by 15 to 30 percent. Therefore, overall combined aeration energy savings would be approximately 40 to 65 percent.

- Anaerobic ammonium oxidation (Anammox): Anammox is a shortcut nitrification process, in which ammonium and nitrite are directly converted into nitrogen gas, resulting in significant aeration energy savings compared to conventional treatment method (i.e., conventional nitrification process). While the process has already been widely applied for side-stream (i.e., high nitrogen load flows recycled from biosolids treatment) with significant secondary treatment space and aeration energy saving benefits, challenges remain for application in main liquid stream wastewater treatment (ex. Hauck et al. 2016). Implementation of anammox requires suppression of nitrite-oxidizing bacteria (NOB), which oxidize nitrite to nitrate. The suppression is particularly difficult to achieve under lower temperatures in colder climates or during winter months for mainstream treatment (ex. Hoekstra et al. 2018). The efficiency of anammox process for mainstream wastewater treatment would increase as the ratio of BOD5 to total nitrogen loading is decreased. During this project, it was demonstrated that the influent BOD5 loading is reduced by 45 to 65 percent with primary filtration (versus 25 to 30 percent reduction of conventional primary treatment method) which then would increase the efficiency of downstream anammox process, potentially enabling successful full-scale implementation of anammox for mainstream biological treatment at wastewater treatment plants.
- Aerobic granular sludge (AGS): AGS uses aggregated microbial granules instead of the dispersed flocs in conventional activated sludge process. The faster settling rates of the sludge granules and higher biomass concentration in aerated activated sludge basins lead to significant secondary treatment footprint and energy savings. AGS process works better with soluble BOD_5 material and smaller particulates rather than particulate BOD_5 associated with larger particulate material. One important finding from the primary filtration project is high (i.e., 80 to 90 percent) removal efficiency of particulate BOD_5. The primary filter effluent mainly consists of soluble BOD, and the particulate BOD_5 portion of the primary filter effluent is associated with very small particles (e.g., smaller than 5-10 microns). Dissolved and exceptionally small and regulated particulate matter is easily hydrolysable by the AGS bacteria that are responsible for denitrification of oxidized nitrogen forms. As a result, the larger organic particles that represent a less efficient carbon source for the denitrifying bacteria are sent to the digester (via primary filtration) rather than the AGS reactor. The reduced level of larger organic particulates improves the AGS' efficiency and eliminates the additional oxygen demand required to

oxidize the solids. Thus primary filter effluent quality would further improve the energy efficiency of AGS implemented downstream biological treatment process.

In addition, the full-scale primary filtration demonstration system at the LCWD WWTP can be expanded to treat the entire treatment plant flow and turned into a permanent treatment system for the plant to further investigate and observe long term energy savings of primary filtration. Certain redundancy system components, which were observed to be beneficial during this demonstration project, would also be included to provide more efficient and uninterrupted continuous operation. The existing infrastructure for this demonstration project along with the previous project (PIR 11-018) was constructed with an estimated $1.2 million to $1.5 million of funding from the California Energy Commission. The recommended primary filtration expansion and upgrade project will therefore be constructed at a lower cost utilizing the existing infrastructure already funded by CEC. The system can operate permanently as the main primary treatment system at the plant with the following modifications:

- Expand primary filter capacity to treat an ADF of approximately 3 mgd: The existing filter's average design capacity of 1.5 mgd is based on historical AAF of approximately 1.4 mgd at the LCWD WWTP. In November 2018, wastewater flows from the neighboring City of Marysville joined to the LCWD WWTP. On an annual average basis, this is expected to double the plant's AAF to 2.8 mgd.
- Add redundancy on sludge thickening: Sludge produced from the plant's existing primary clarifiers currently goes straight to anaerobic digestion without additional thickening. The primary filter sludge in this project is handled by the Volute Thickener, rated to treat up to 300 gpm of sludge flow. Additional redundancy will be beneficial to provide uninterrupted operation especially for handling of primary sludge production during future peak flows.

LIST OF ACRONYMS

Term	Definition
AAF	Annual Average Flow
ADF	Average Daily Flow
AGS	Aerobic Granular Sludge
Anammox	Anaerobic ammonium oxidation
APT	Advanced Primary Treatment
ASB	Activated Sludge Basin
BOD_5	5-day Biochemical Oxygen Demand
BRW	Backwash Reject Water
$cBOD_4$	5-day Carbonaceous Biochemical Oxygen Demand
CIP	Clean-In-Place
COD	Chemical Oxygen Demand
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.
FOG	Fat, Oil, and Grease
FS	Filter Sludge
gpm	Gallons per minute
HLR	Hydraulic Loading Rate
HMI	Human-Machine Interface
hp	Horsepower
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
PCDF	Pile Cloth Disk Filtration

Term	Definition
PHF	Peak Hour Flow
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.
SCADA	Supervisory Control and Data Acquisition
scfm	Standard cubic feet per minute
sCOD	Soluble Chemical Oxygen Demand
scum removal	Scum removal is an operational mode of the primary filter whereby scum collected at top of the water surface is discharged to reject stream.
SLR	Solids Loading Rate
SRT	Solids Retention Time
SV	Storage Vault
TSS	Total Suspended Solids
TKN	Total Kjeldahl Nitrogen
VFD	Variable Frequency Drive
VSS	Volatile Suspended Solids
WQCF	Wastewater Quality Control Facility
WRP	Water Reclamation Plant
WWTP	Wastewater Treatment Plant

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APPENDICES

The appendices below are available under separate cover (Publication Number CEC-500-2020-026-APA-B) by contacting Anish Gautam at anish.gautam@energy.ca.gov.

- Appendix A.1: Computer Process Simulation Report for LCWD WWTP
- Appendix A.2: Computer Process Simulation Report for Lancaster WRP
- Appendix A.3: Computer Process Simulation Report for Manteca WQCP
- Appendix A.4: Computer Process Simulation Report for Six Representative WWTPs
- Appendix B: Measurement and Verification of Energy Savings from Primary Filtration