Long Term Operational and Performance Evaluation of Primary Filtration Technology for Carbon Diversion

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ABSTRACT

Primary filtration (PF) is an emerging advanced primary treatment technology which replaces primary clarification with filtration of screened raw wastewater. Compared to primary clarification, primary filtration improves energy efficiency at water resource recovery facilities (WRRF) by removing greater amounts of suspended solids and organics. Energy savings from primary filtration were quantified by deployment of a full-scale primary filtration system at the Linda County Water District WRRF (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 achieves significantly lower aeration electricity consumption (in the downstream biological treatment step) and increased digester gas energy production. Estimated annual energy savings range from $22,000 to $35,000 per million gallons per day of average WRRF flow capacity. Additional benefits include reduced capital costs, smaller footprint requirements, and increased treatment capacity of the biological treatment aeration basins.

KEYWORDS

Primary filtration, raw wastewater filtration, carbon diversion, advanced primary treatment, pile cloth depth filtration, energy savings

INTRODUCTION

A significant amount of energy is consumed for wastewater treatment. Energy consumption at drinking water treatment and water resource recovery facilities (WRRF) make up for approximately 3–4 percent of energy use in the United States (U.S. EPA, 2013). Typical energy use at WRRFs ranges from 1,600 to 3,300 kilowatt hours per million gallons of flow treated (Electric Power Research Institute, 2013). A typical WRRF employs up to four treatment levels: preliminary, primary, secondary, and tertiary. In the preliminary stage large debris and coarse particles are removed via screens and/or grit removal systems. Primary treatment is used to remove settleable solids and floatable material, typically through gravity clarification and surface skimming. In secondary treatment, biodegradable organic constituents are removed using a biological process, such as the activated sludge process. 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 WRRFs also produce biogas (a renewable energy source) from removed solids in a process known as anaerobic digestion.

Secondary treatment is typically the most energy intensive portion of the treatment process, consuming between 30 to 60 percent of the energy uses at most plants (M/J Industrial Solutions, 2003). Aeration of the activated sludge process accounts for most of the energy use. In this project, primary filtration, or filtration of raw wastewater after preliminary treatment, has been evaluated as a viable replacement of conventional primary treatment (*i.e.*, primary clarification) to assess the potential energy savings in addition to capital cost savings and footprint reduction.

Filtration is commonly used at WRRFs for removal of finer particles in tertiary treatment but had not yet been implemented fully for primary treatment. There has been growing interest in filtration as an emerging technology for advanced primary treatment (APT). 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.

Prior to this project, no such full-scale primary filtration system had been implemented and operated at a WRRF to achieve the energy and cost savings (compared to conventional primary treatment) listed above.

OVERALL PROJECT OBJECTIVES

The overall objective of this project was to demonstrate that primary filtration is a technically viable and commercially attractive approach to achieve significant electrical energy savings at WRRFs. Filtration has already shown great potential as an APT technology for improved wastewater treatment efficiency. Various filtration technologies were successfully demonstrated for two years (between 2013 and 2015) for *primary effluent filtration* (PEF), in which effluent leaving the primary clarifier is filtered to achieve additional suspended solids removal 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 (Caliskaner *et al.*, 2015). The operational robustness and reliability of the filters observed for PEF prompted the use of filtration technologies for *primary filtration* to achieve significant energy savings and increase in plant capacity (by promoting carbon diversion). In 2014, a primary filtration pilot using Pile Cloth Depth Filtration (CDF) was conducted in Rockford, Illinois. The pilot showed CDF can be feasibly applied in primary treatment while achieving higher removal rates of solids and organics from screened raw wastewater than primary clarification. The greater diversion of carbon during primary treatment and the improved primary effluent quality can help WRRFs realize greater energy savings (Caliskaner *et al.*, 2016; Ma *et al.*, 2015). 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 WRRFs to adapt 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.
- 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.

PROJECT OVERVIEW

Demonstration of 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 Linda WRRF and has been in operation since August 2017 (Caliskaner *et al.*, 2018). Demonstration-scale filter systems were deployed at the Lancaster Water Reclamation Plant (Lancaster WRP) from November 2016 to December 2017 (Mansell *et al.*, 2018) and at the City of Manteca Wastewater Quality Control Facility (Manteca WQCF) from February 2018 to June 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 Primary Filter Deployments

Deployment Site	Plant Average Annual Flow (mgd)	Deployment Duration	Primary Filter Scale	Primary Filter Daily Average Flow (mgd)
Linda County Water District Water resource recovery facility (Olivehurst, California)	3	August 2017 – current	Full-Scale	0.3-1.5
Lancaster Water Reclamation Facility (Lancaster, California)	14	November 2016 – December 2017	Demonstration-Scale	0.02
City of Manteca Wastewater Quality Control Facility (Manteca, California)	10	February 2018 – June 2019	Demonstration-Scale	0.03-0.12

Note: mgd = million gallons per day

LONG-TERM OPERATION OF FULL-SCALE PF SYSTEM

Two-year performance of the full-scale primary filtration system installed at the Linda WRRF are discussed in this paper. The specific objectives of this primary filtration project are as follows:

- Quantify the reduction in electrical power required for aeration in the activated sludge process, due to primary filtration.
- Determine the decrease in electrical power required for mixing due to the reduced activated sludge volume requirements.
- Determine the overall capital and electrical energy savings resulting from the increased secondary treatment capacity.
- 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 M&V process.

DESCRIPTION OF PF SYSTEM AT THE LINDA WRRF

A full-scale primary filter unit was installed at the Linda WRRF in 2017. The filter has been in continuous operation since August 2017. The Linda WRRF is located near Marysville in Yuba County, California. It is a tertiary treatment facility consisting of two (2) rectangular primary clarifiers, four (4) activated sludge basins (ASBs), two (2) circular secondary clarifiers, six (6) compressible media tertiary filters, one (1) chlorine contact basin, and two (2) digesters. The liquid process was upgraded in 2011, and the solids handling process was upgraded in 2016. In November 2018, connection was made from City of Marysville's wastewater collection system to the Linda WRRF. The WRRF has a capacity of 5 million gallons per day (mgd) and currently operates at an average daily flow (ADF) of approximately 3 mgd.

PF System Components

A primary filtration system is used for primary treatment purposes at the Linda WRRF. The system is the first full-scale installation of primary filtration at a WRRF 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 WRRF's anaerobic digester.

System Intake and Discharges

The primary filtration system at the Linda WRRF 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 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.

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). The mixture of thinner sludge and BRW from Storage Vault No. 3 is thickened by the Volute Thickener System. Thickened sludge is directed to Storage Vault No. 2, then pumped to the WRRF's anaerobic digester for further processing. A photograph of the primary filtration system and associated components is shown in Figure 2.

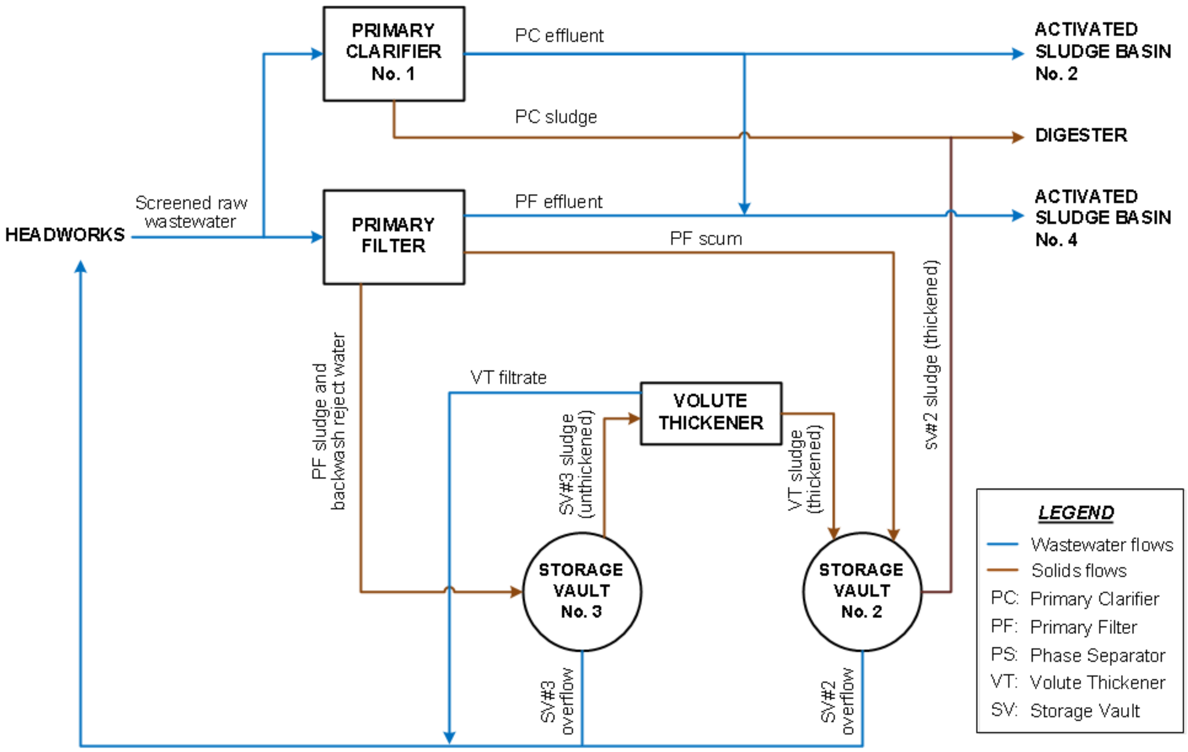

Figure 1. Flow Diagram of the Primary Filtration System at the Linda County Water District Water Resource Recovery Facility

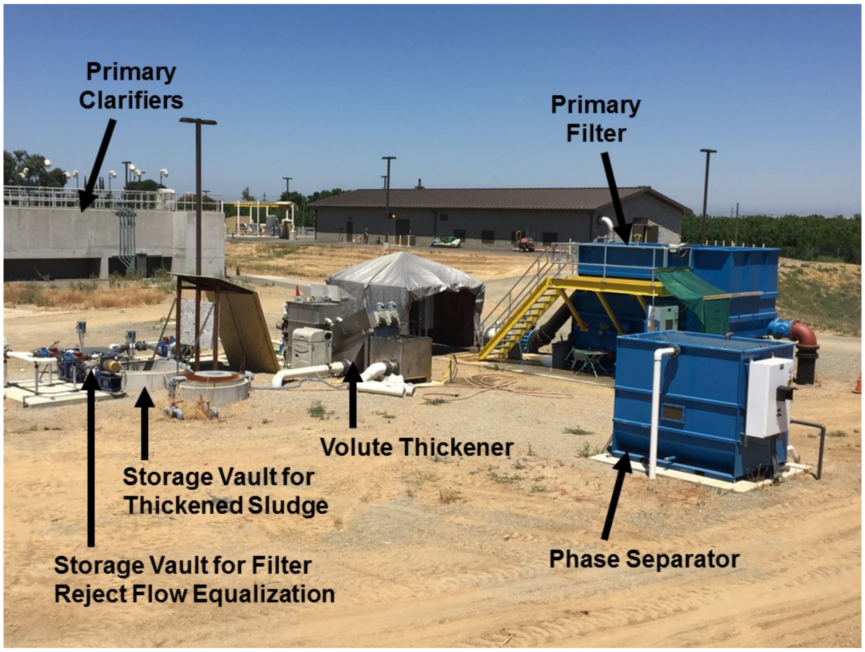

Figure 2. Photograph of the Primary Filtration System at the Linda County Water District Water Resource Recovery Facility

Primary Filter

The primary filter at the Linda WRRF is an AquaPrime AD-3 unit supplied by Aqua-Aerobics Systems, Inc. (AASI, Loves Park, Illinois). Compared to the typical use of filtration in tertiary treatment, the CDF systems used in this project were specifically modified for primary treatment application (see Figure 3). Pile cloth depth filtration uses vertically oriented, submerged pile cloth filter disks connected by a center tube mounted 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 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 re-designed 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 solids to achieve increased biogas production.

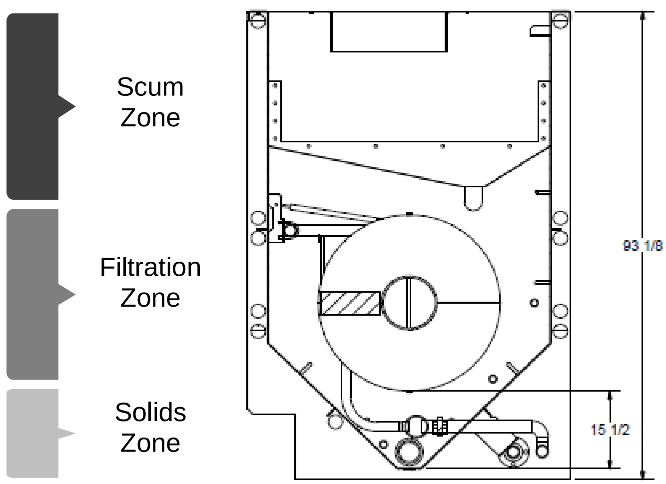

Figure 3. Treatment Zones in CDF Unit Used for Primary Filtration

The installation at the Linda WRRF 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 inside of the empty filter tank is shown in Figure 4.

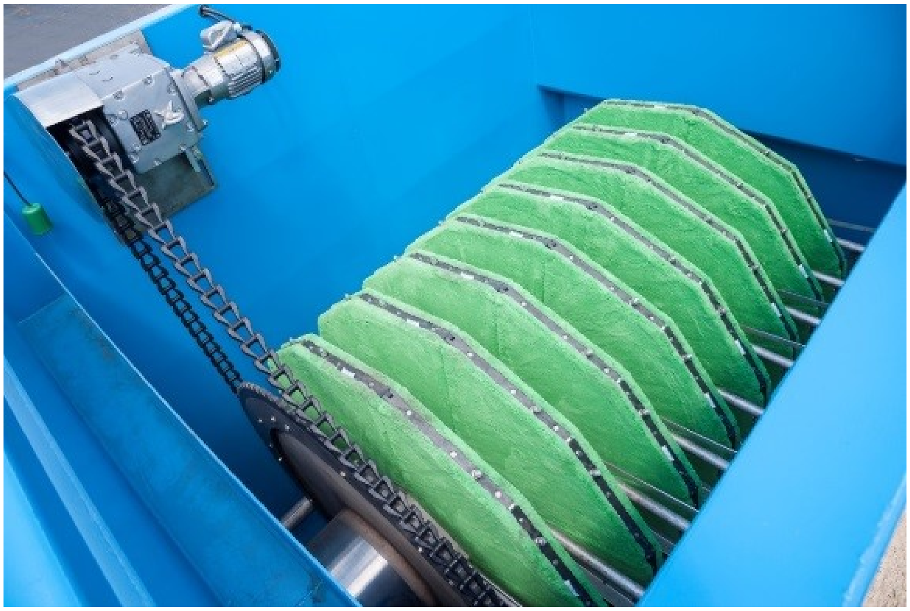

Figure 4. Interior of the Primary Filter Tank at the Linda County Water District Water Resource Recovery Facility, with Eight Cloth Media Filter Disks

The filter tank measures 19.5 ft long, 11.1 ft wide, and 13 ft high (see Figure 5). Construction of the primary filter system at the Linda WRRF 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.

Figure 5. Photograph of the Primary Filter Unit Installed at the Linda County Water District Water Resource Recovery Facility

Primary Filter Operational Cycles

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 supervisory control and data acquisition (SCADA) system.

Filtration

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 primary filter sludge (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 center tube 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 primary clarifier.

Backwash

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. Backwash reject water (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

To prevent FS contacting filter cloth media surface, FS is discharged *via* solids wasting. Solids waste mode is initiated at 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

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 thereby indicating the presence of acidification through anaerobic decomposition.

Scum Removal

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.

Filter Backwash Reject and 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 Volute Thickener, supplied by Process Wastewater Technologies, LLC (Baltimore, Maryland), is the main sludge thickener system for the full-scale primary filtration installation at the Linda WRRF. 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.

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 Linda 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.

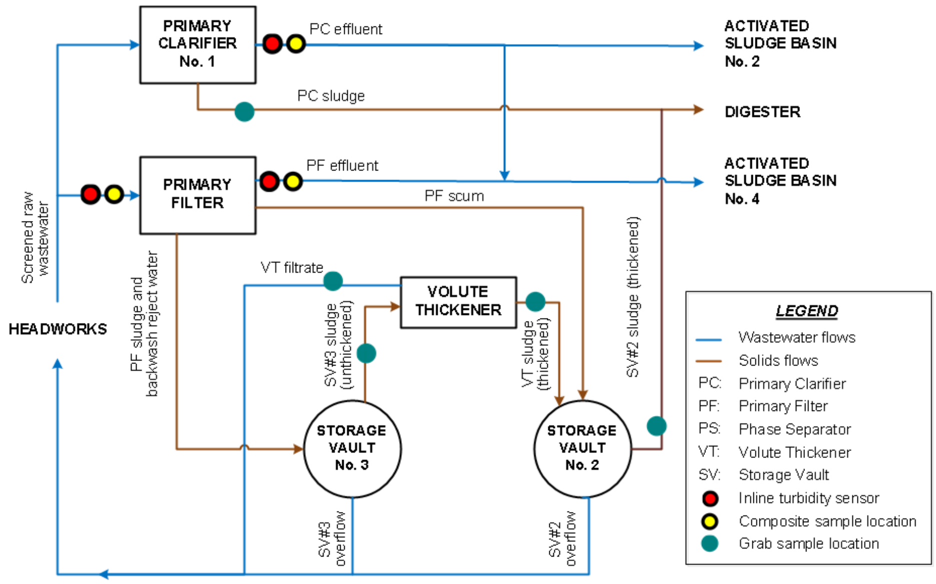

Figure 6. Diagram of the Primary Filtration System Sampler and Sensor Locations at the Linda County Water District Water Resource Recovery Facility

Continuous Performance Monitoring

A SCADA system for the primary filtration system has been 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.

PRIMARY FILTER TREATMENT PERFORMANCE

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

Performance Based on Continuous 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.

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.

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. 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 7, TSS removal efficiency has ranged between 78 and 94 percent since start-up of the system, with an average removal rate of 87 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. Overall average TSS values were 360 and 40 mg/L for filter influent and effluent, respectively.

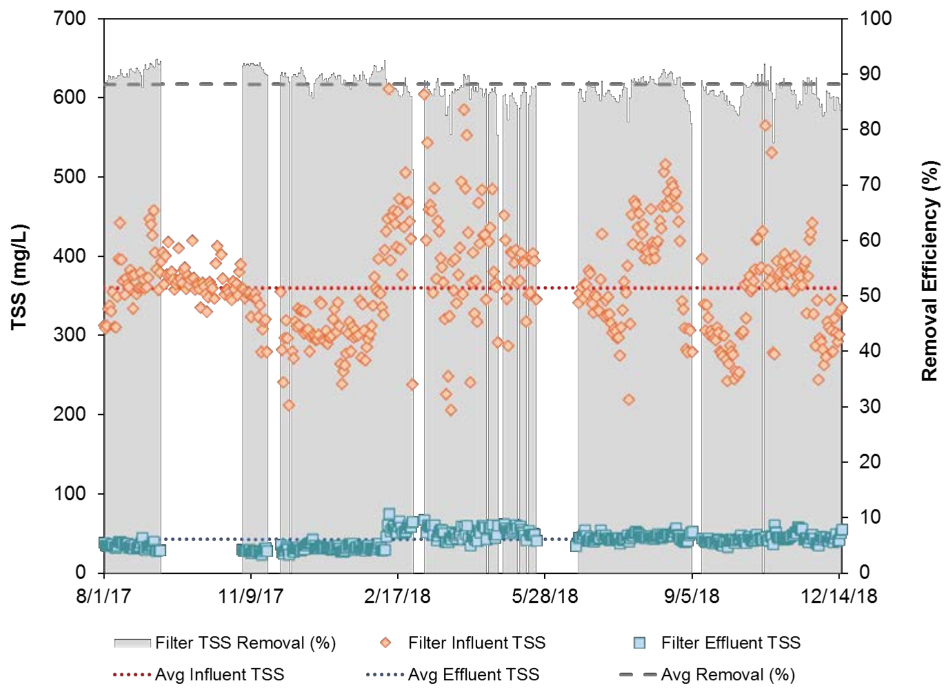

Figure 7. Primary Filter TSS Removal Efficiency at the Linda County Water District Water Resource Recovery Facility

Performance Based on 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 composite sampling conducted from August 2017 to December 2018 are summarized in Table 1.

Table 1. Concentration Ranges and Average Removal Performances for Key Constituents for the Primary Filter Installation at the Linda County Water District Water Resource Recovery Facility[a]

Constituent	Constituent concentrations, mg/L				Average removal efficiency, %
	Filter influent		Filter effluent		
	Range	Average	Range	Average	
TSS	210-560	316	24-99	54	82
COD	410-940	619	170-380	257	57
BOD_5	210-500	316	76-160	120	60
TKN	41-56	48	29-51	40	17

[a]Based on composite samples taken over 24 hours

Process 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 to 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 values are shown in Figure 8. Influent flow for the primary filter system ranged between 20 and 50 percent of the total Linda WRRF flow since the start-up. The filter system has eight filter disks, with a total filtration area of 430.4 ft^2. Daily average filter influent flow mostly ranged from 200 to 300 gpm (0.3 to 0.45 mgd), which corresponds to HLR of 0.45 to 0.7 gpm/ft^2. The filter was also operated at higher flow rates with HLR values up to 4 gpm/ft^2. Primary filter flow rates reached approximately 2.5 mgd during storm events.

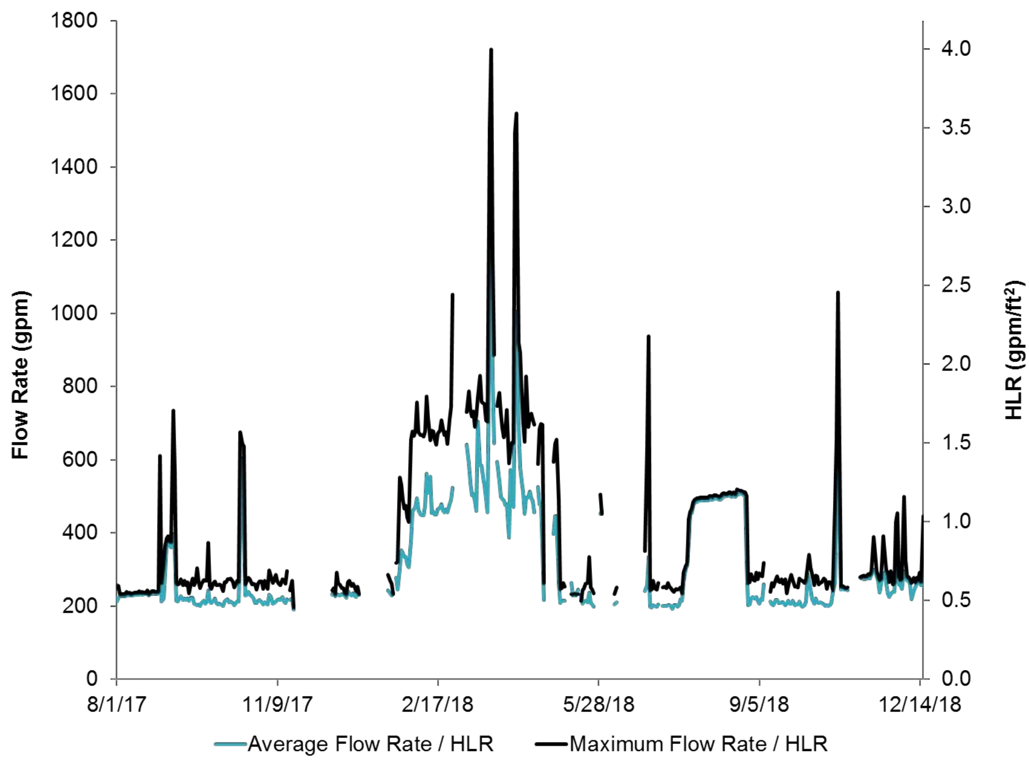

Figure 8. Daily Average Primary Filter Influent Flow and Hydraulic Loading Rate (at the Linda County Water District Water Resource Recovery Facility)

Solids Loading Rates

SLR for the primary filter at the Linda WRRF system is shown in Figure 9. SLR was strongly dependent on HLR. At setpoint of 20 percent of total WRRF plant flow, filter SLR ranged typically between 2 and 3 lbs/day-ft^2, with a noticeable increase after the plant started receiving wastewater from City of Marysville in November 2018. At higher operational flow rates, filter SLR typically ranged from 6 to 8 lbs/day-ft^2, with a maximum of 8-10 lbs/day-ft^2 reached during storm events.

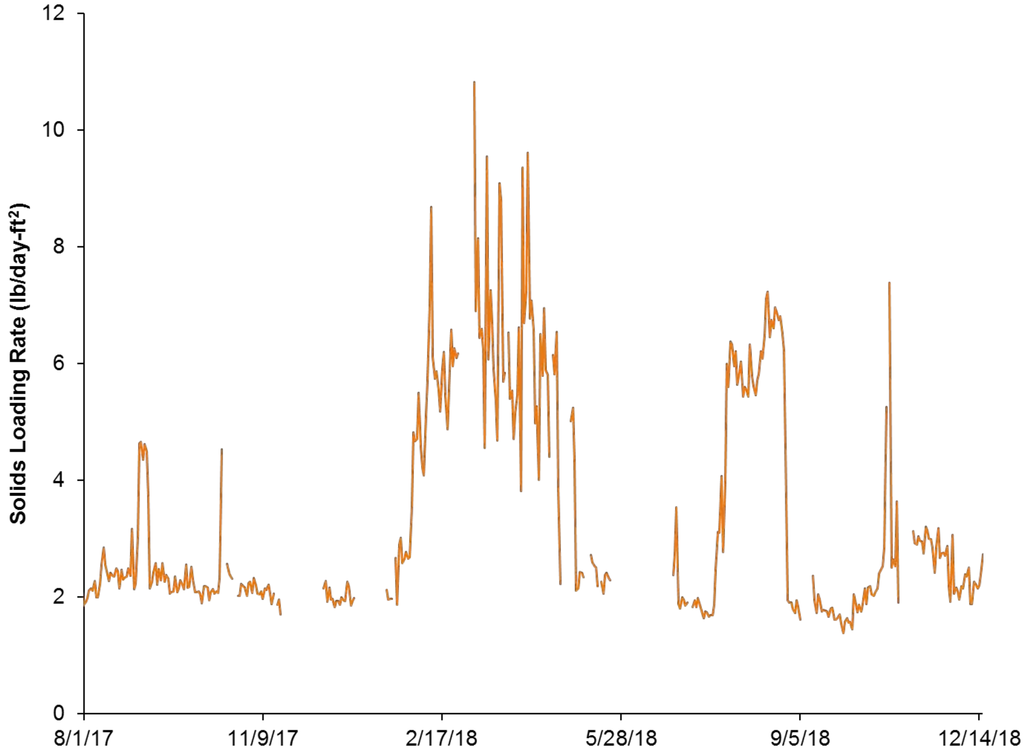

Figure 9. Daily Average Primary Filter Solids Loading Rate (at the Linda County Water District Water Resource Recovery Facility)

Production and Reject Rates

Backwash is typically set to initiate when water in the filter basin reaches a certain level due to head loss build-up across the filter media. The daily filter reject ratios are shown in Figure 10. Combined daily flow reject ratios were below 10 percent under normal operating conditions, where the filter was backwashing based on head loss build-up through the filter media.

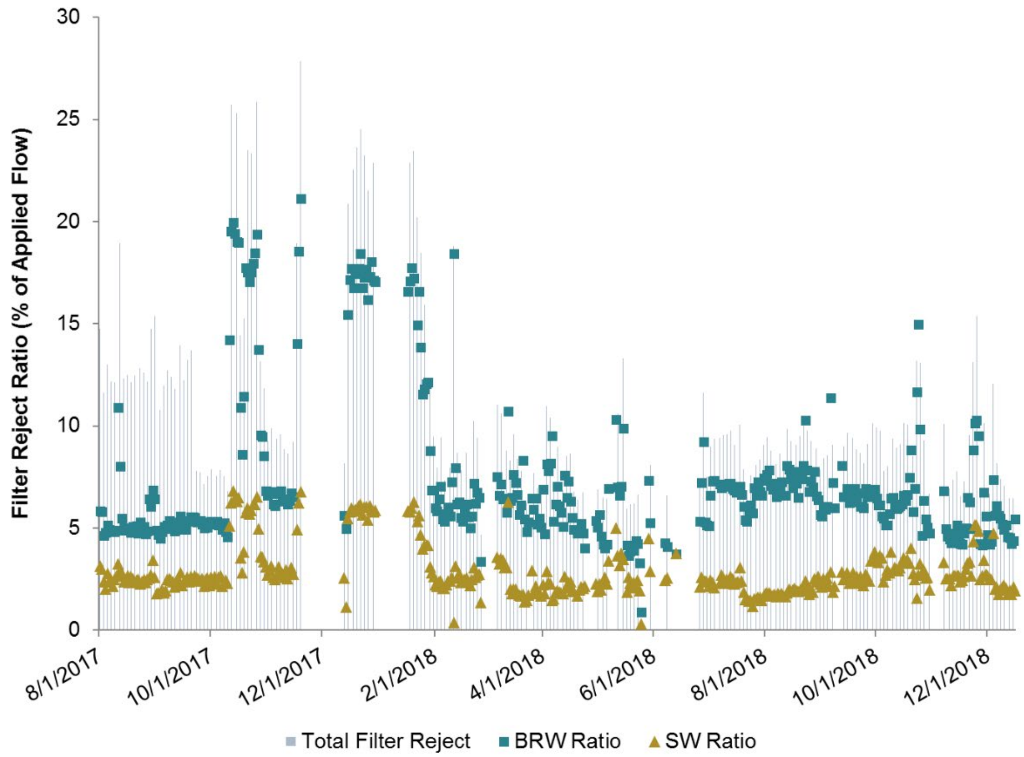

Figure 10. Daily Average Primary Filter Reject Flows

VERIFICATION OF PF PERFORMANCE

To validate the performance of the PF system achieved at the Linda WRRF, the results were compared to those archived at the demonstration-scale deployments at the Lancaster WRP from November 2016 to December 2017 and at the City of 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.

Treatment Performance

The average removal efficiencies of the three deployments based on laboratory analyses are shown in Figure 11. Overall, primary filtration demonstrated very consistent performance across the deployments, regardless of variations in filter capacity and influent characteristics and 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. These removal rates are higher than typical removal rates of 50 to 60 percent of TSS and 20 to 30 percent of BOD_5 by a conventional primary treatment system (*i.e.*, primary clarifier).

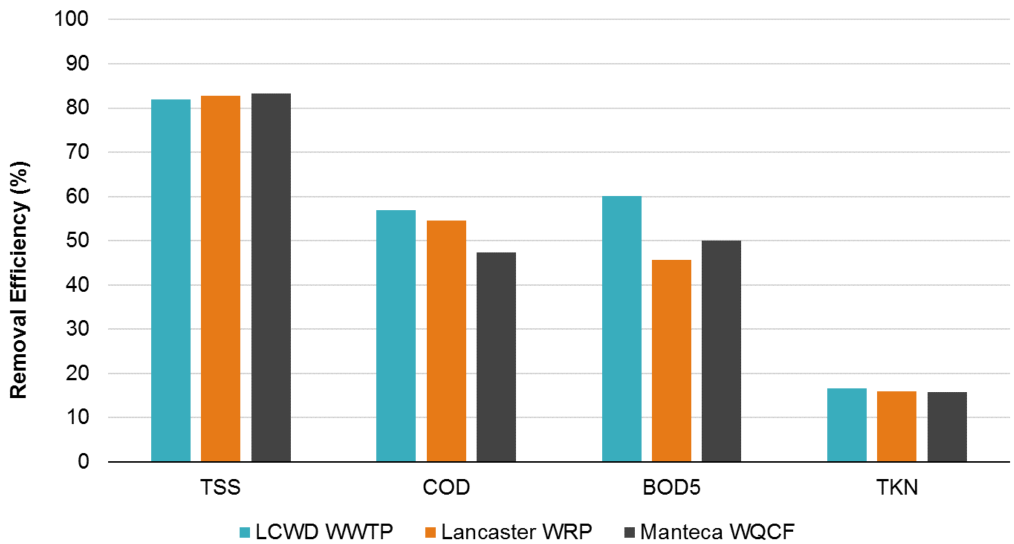

Figure 11. Average Removal Efficiencies of the Primary Filtration Deployments

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 the Linda WRRF 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 2. The demonstration-scale filters at the Lancaster WRP and the Manteca WQCF were found to have an average reject ratio of approximately 16 percent, while the full-scale filter at the Linda WRRF had an average reject ratio of 10 percent.

Table 2. Hydraulic Performance Summary for the Primary Filtration Deployment Systems

Parameter	Deployment Site		
	Linda WRRF	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.

EVALUATION OF ENERGY SAVINGS

Using the treatment and hydraulic performance results obtained from the deployment systems, computer process simulation and third-party energy measurement and verification were conducted 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 water resource recovery facilities. The additional six representative WRRFs were selected to cover a spectrum of sizes and treatment processes.

Third Party Validation

A third-party energy audit firm, BASE Energy, Inc., conducted a measurement and verification (M&V) study for all three primary filtration deployments discussed in this paper. 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 M&V study was conducted by directly logging power consumption of the demonstration filters and associated equipment. At each deployment site, 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 WRRF. 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.

Estimated Power Reduction

The baseline line aeration power consumption, as described above, 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 the Linda WRRF to evaluate power consumption of all plant equipment. Secondary treatment aeration savings estimated from M&V are summarized in Table 3. 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 3. M&V Aeration Power Reduction Estimates for the Deployment Sites

Parameter	Deployment Site		
	Linda WRRF	Lancaster WRP	Manteca WQCF
Required Aeration Power, Normalized to Flow (hp/mgd of wastewater treated)			
for conventional primary treatment	20	46	38
for primary filtration system	12	31	28
Potential Aeration Power Reduction (%)	39	32	25

Other Energy Impacts

Additional ways in which PF impacts WRRF'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 while maintaining the same MLSS as with a primary clarifier. The smaller secondary treatment basin reduces the mixing volume of the anoxic portion, thereby reducing the mixing power requirement by 20 to 35 percent based on process simulation findings.
- *Increase in Digester Gas Production:* Plants which has co-generation may benefit from the diversion of greater amount of high gas value primary solids during primary treatment. Based on process simulation findings (using the observed performances of the PF systems) digester gas production at the deployment sites is expected to increase by 36 to 48 percent.

EVALUATION OF COST SAVINGS

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

Cost Estimate Methodology

Primary filtration reduces the footprint of conventional primary treatment by approximately 60 to 70 percent, which translates to significant cost savings, particularly for water resource recovery facilities with limited land availability. The improved primary effluent quality coupled with reduced organics loading (upstream of the secondary biological treatment process) also either increases existing secondary treatment capacity or decreases required secondary treatment footprint. Based on the performance data cited above, planning-level opinions of probable cost were prepared for primary filtration and primary clarification projects. These conceptual level estimates include various WRRF design scenarios, have an expected accuracy range of +50 to -30 percent.

Energy Cost Savings

The corresponding estimated annual energy savings range from $22,000 to $35,000 per mgd of average WRRF flow capacity. The basis for the energy savings is as follows:

- As a result of the higher removal efficiency for organic material achieved with primary treatment, electrical energy requirement for aeration in activated sludge basin is estimated to be reduced by 15 to 30 percent. The corresponding annual aeration power savings is between $9,000 to $17,000 per mgd of average WRRF flow capacity.
- 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 40 percent. The corresponding annual digester gas power recovery increase is between $13,000 to $18,000 per mgd of average WRRF flow capacity.

Overall Cost Savings

Primary filtration is estimated to save an average $1.6 million per mgd of average WRRF flow capacity over a 30-year period. Minimum savings over a 30-year period were estimated to be $830,000 per mgd and maximum savings were estimated to be $2.2 million per mgd (of average WRRF flow capacity) depending on influent wastewater characteristics and specific site and system requirements. A cost comparison summary is provided in Table 4 with the breakdown for capital, energy, and overall annual O&M cost savings. As reported in Table 4, the estimated

Table 4. Cost Savings of Primary Filtration Replacing Primary Clarification

Cost Item	Estimated Range of Savings (per mgd of average WRRF flow capacity)
Construction Cost	$640,000 to $1.1 million
Overall Annual O&M	$6,000 to $35,000
Total Net Present Value (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

Capital cost savings range from $640,000 to $1.1 million per mgd of average WRRF flow capacity, depending on influent wastewater characteristics and system specific requirements. The net present value cost analysis is based on the benefits of primary filtration on a 30-year life cycle cost (using 3 percent discount rate) compared to primary clarification.

CONCLUSIONS AND SUMMARY

The results of the project demonstrated successfully that primary filtration is a technically viable and cost-effective approach to reduce energy use at water resource recovery facilities. 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 the Linda WRRF, over a consecutive period of 24 months. The estimated benefits in terms of energy and cost savings are compelling.

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REFERENCES

Caliskaner, Onder; Tchobanoglous, George; Reid, Terry; Kunzman, Bill; Young, Ryan; Ramos, Nick. (2015). "Evaluation and Demonstration of Five Different Filtration Technologies as an Advanced Primary Treatment Method for Carbon Diversion," *Proceedings of the 88th Annual Water Environment Federation Technical Exposition and Conference*: 795-818.

Caliskaner, Onder; Tchobanoglous, George; Reid, Terry; Young, Ryan; Downey, Mike; Kunzman Bill. (2016). "Advanced Primary Treatment via Filtration to Increase Energy Savings and Plant Capacity," *Proceedings of the 89th Annual Water Environment Federation Technical Exposition and Conference*: 782-794.

Caliskaner, Onder; Tchobanoglous, George; Wu, Zoe; Young, Ryan; Paez, Catrina; Davis, Brian; Mansell, Bruce; Ackman, Phil; Reid, Terry; Dyson. (2018) "Performance of Full Scale and Demonstration-Scale Primary Filtration Projects." *Proceedings of the 91th Annual Water Environment Federation Technical Exposition and Conference*: 70-84.

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

Ma, Jia; K Reid, Terence; Caliskaner, Onder; J Binder, Daniel; Castillo, Matthew. (2015). "Cloth Depth Filtration of Primary Domestic Wastewater." *Proceedings of the 88th Annual Water Environment Federation Technical Exposition and Conference*: 3429-3438.

Mansell, B., Song, W., Ackman, P., Melitas, N., Tremblay, M., Caliskaner, O., Paez, C., Dyson, J., Reid, T. (2018) “Evaluation of the Primary Filtration Process at the Lancaster Water Reclamation Plant” *Proceedings of the 91st Annual Water Environment Federation Technical Exposition and Conference*.

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

Tchobanoglous, G., H.D. Stensel, R. Tsuchihashi, and F.L. Burton (2014) *Wastewater Engineering: Treatment and Resource Recovery*, 5th ed., Metcalf and Eddy I AECOM, McGraw-Hill Book Company, New York.

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