

Evaluation of the Primary Filtration Process at the Lancaster Water Reclamation Plant

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ABSTRACT

Primary Filtration (PF) using a pile cloth-depth filter (PCDF) is an emerging treatment process that may provide significant benefits to the wastewater treatment industry. Rather than using a primary clarifier, a PCDF is used after screening and grit removal prior to the activated sludge process. To evaluate this technology as a potential option for replacement of the existing primary clarifiers at the Lancaster Water Reclamation Plant (WRP), a one year pilot-scale study was conducted. During the study, over ten million gallons of screened and de-gritted raw sewage was treated without any significant operational or maintenance issues. The results from this study demonstrate some of the key reported benefits of PF including enhanced removal of particulates and organics and a related reduction in activated sludge process aeration energy requirements. This manuscript summarizes the pilot study, including the testing objectives, methodology, and results.

KEYWORDS: Carbon Diversion, Primary Filtration, Cloth-Depth Filtration, Advanced Primary Treatment, Aeration Energy Savings

BACKGROUND

Process Description

Primary Filtration (PF) using a pile cloth-depth filter (PCDF) is an emerging treatment process that may provide significant benefits to the wastewater treatment industry. Rather than using a primary clarifier, a PCDF is used after screening and grit removal prior to the activated sludge process (Figure 1). Filter backwash water, containing the solids captured by the PCDF, is thickened and diverted to anaerobic digestion. Potential advantages of using the PF process in place of primary clarifiers include: (1) improved removal of organics resulting in lower aeration energy requirements for the activated sludge process; (2) improved removal of particulates resulting in increased gas production in the anaerobic digestion process; (3) smaller primary treatment footprint requirements; (4) smaller footprint for the activated sludge process; and (5) increased treatment capacity for existing activated sludge processes where primary clarifiers are retrofitted or replaced by the PF process (Caliskaner *et al.*, 2017).

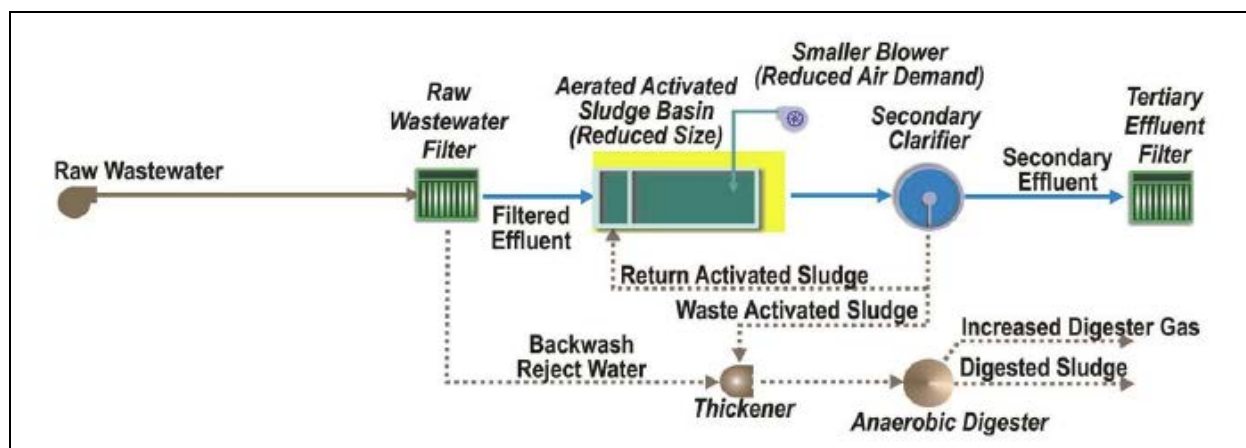


Figure 1. Wastewater Treatment Flow Diagram with Primary Filtration Process (Caliskaner *et al.*, 2016).

California Energy Commission Research Project

Kennedy/Jenks Consultants (KJ) in collaboration with Aqua-Aerobic Systems, Inc. (AASI) conducted the first PF process pilot test at the Rock River Water Reclamation District in Rockford, Illinois (Caliskaner *et al.*, 2016). Based on the success of this seven-month pilot study, KJ received funding from the California Energy Commission (CEC) to demonstrate that the PF process is a technically viable and commercially attractive approach for achieving significant aeration energy savings at wastewater treatment plants. The CEC project includes the first full-scale study of the PF process, which is being conducted over a three-year period at the Linda County Water District (Linda) Wastewater Treatment Plant (WWTP) (Caliskaner *et al.*, 2017). In addition to the full-scale study, two pilot-scale studies were planned at sites that differ in wastewater composition, treatment process type, and capacity to confirm the Linda WWTP results. The sites selected for testing include the City of Manteca WWTP and the Los Angeles County Sanitation Districts' (Districts) Lancaster Water Reclamation Plant (WRP).

LANCASTER WRP PILOT STUDY OBJECTIVES

The Lancaster WRP was selected for testing because the Districts are potentially interested in replacing the existing primary clarifiers at the facility with the PF process. In July 2012, the Stage V expansion of the plant was completed, during which time the treatment capacity was increased from 16 to 18 million gallons per day (MGD). In addition, the treatment process was upgraded from oxidation ponds to conventional activated sludge with step-feed nitrification-denitrification (NDN), followed by granular media filtration and chloramination for disinfection (Figure 2). The original plan was to also replace the existing preliminary and primary treatment systems, including the addition of new primary clarifiers that would have been designed with increased treatment capacity. However, due to budget constraints, these upgrades were not included in the expansion project. With the emerging development of the PF process as a viable technology, the Districts are interested in the potential to provide the needed additional primary treatment capacity with a lower cost and better performing system.

The objectives for the pilot-scale study at the Lancaster WRP were to: (1) evaluate removal of particulates and organics; (2) quantify backwash water volumes; (3) document process reliability/operational and maintenance issues; and (4) generate input water quality data for use in a BioWin simulation model of the step-feed NDN activated sludge process to assess the impact of PF on aeration requirements and nitrogen removal.

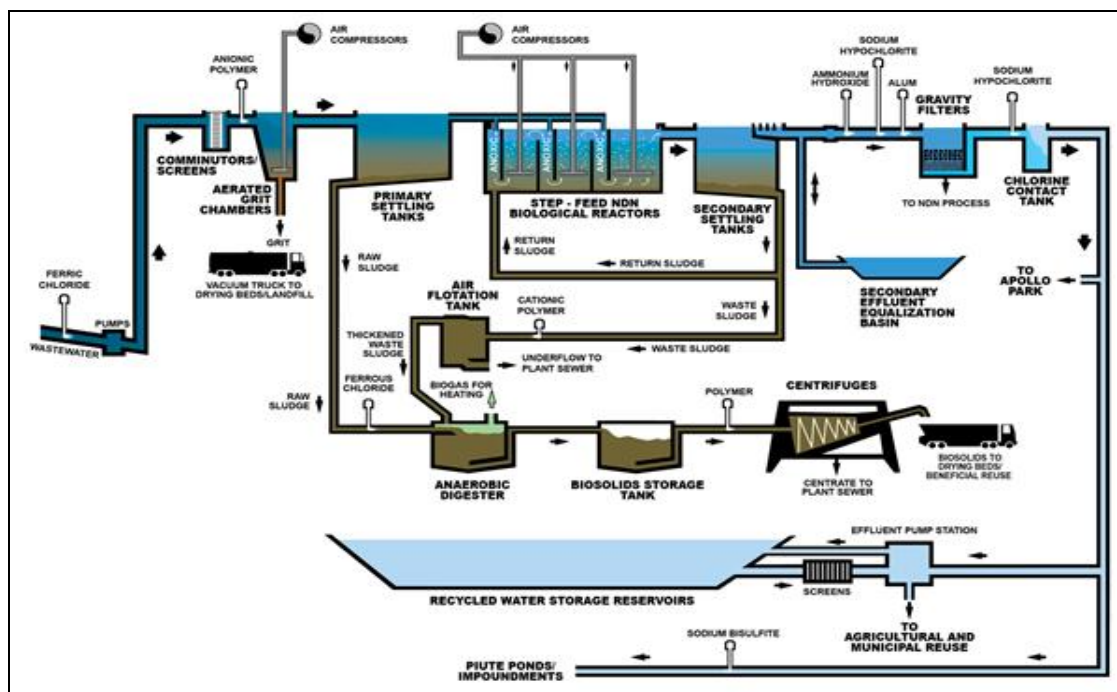


Figure 2. Lancaster WRP Process Flow Diagram.

METHODOLOGY

Pilot-Scale System

AASI provided a PCDF pilot system (Figures 3 and 4) that included the following major components: (1) submersible feed pump; (2) filtration tank; (3) backwash/solids waste pump; (4) process control valves; (5) influent and backwash/solids waste flowmeters; (6) filtration basin level sensors; and (7) influent and effluent turbidity/TSS sensors. The pilot system also included flocculation basins for chemical pretreatment. However, these basins were bypassed as chemical pretreatment was not used at any time during the study.

The influent pump was submerged in the primary clarifier influent channel. Screened and de-gritted raw sewage was pumped to the pilot unit, which was located near the primary clarifier effluent channel. The filtration basin contained a single Aqua MiniDisk® filter. The MiniDisk® had an available filtration area of 10.8 ft² and was fitted with OptiFiber® PF-14 ultra-fine pile cloth media with a 5 µm nominal pore size. The pilot system had a maximum treatment capacity

of 78,000 gallons per day or a maximum hydraulic loading rate of 5 gpm/ft². The pilot system had five modes of operation, which were automatically controlled by a programmable logic controller (PLC), and included filtration, backwash, solids removal, scum removal, and solids conditioning. Each of these modes of operation is described in Table 1.

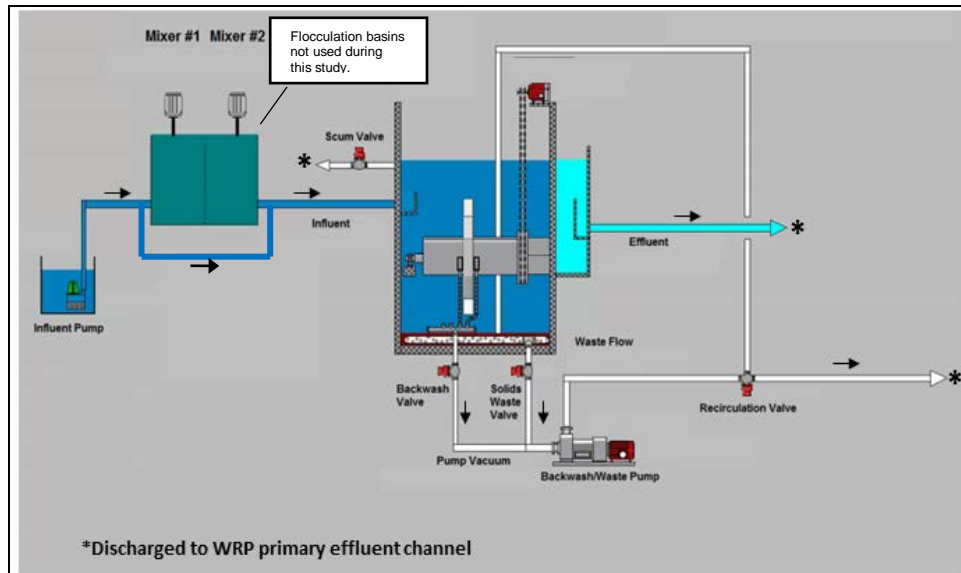


Figure 3. PCDF Pilot System Process Flow Diagram.



Figure 4. PCDF Pilot System and Aqua MiniDisk® Filter.

Table 1. PCDF Pilot System Modes of Operation.

Operation Mode	Description
Filtration	During filtration, an influent pump feeds raw sewage to the filtration basin. As water passes through the MiniDisk® via an outside-in flow path, particulates are removed and stored within the pile cloth media as well as on the media surface. Filtered water is collected in a centertube and flows by gravity over an effluent weir into an effluent chamber prior to discharge. During filtration, the MiniDisk® is completely submerged and does not rotate.
Backwash	As particulates are deposited on and within the pile cloth media, the headloss across the media increases. Upon reaching a preset water level, or preset time interval, a backwash is initiated. A backwash consists of removing particulates from the media by liquid suction through backwash shoes that are positioned to be in contact with the media on each side of the MiniDisk®. During a backwash, the MiniDisk® rotates slowly while a backwash pump draws filtered water from the centertube through the pile cloth media in an inside-out flow path. Filtration continues while the system is in backwash mode.
Solids Removal	A quiescent environment during filtration, combined with the outside-in filtration flow path, allows heavier particulates to settle to the bottom of the filtration basin. Upon reaching a specific number of backwash cycles performed, or an elapsed time period, the solids removal mode is initiated. Solids removal is achieved by using the backwash pump to provide suction of the settled solids through a perforated collection manifold positioned at the bottom of the filtration basin. Solids removal occurs immediately after a backwash and filtration continues while in this mode of operation.
Scum Removal	Upon reaching a specific number of backwash cycles performed, or an elapsed time period, scum that accumulates on the surface of the filtration basin is removed via a scum removal weir.
Solids Conditioning	Upon reaching a specific number of backwash cycles performed, or an elapsed time period, solids accumulated at the bottom of the filtration basin are mixed by recirculation with the backwash pump to prevent anaerobic conditions from developing.

Pilot Study Duration and Operating Conditions

The PCDF pilot system was operated for one year at the Lancaster WRP, from November 2016 to November 2017. The primary operating set-point impacting system performance was the hydraulic loading rate. The system was initially operated, for approximately two months, at a hydraulic loading rate set-point of 3.2 gpm/ft² (Phase 1). The hydraulic loading rate set-point was subsequently reduced to 2.1 gpm/ft² for the remainder of the study (Phase 2). Throughout the study, minor adjustments were also made to solids waste and scum removal set-points in response to observations of PCDF performance and conditions at the Lancaster WRP.

Data Collection

To evaluate system performance throughout the pilot study, PCDF pilot system operating parameters were continuously monitored. These parameters included flowrates, backwash and solids waste volumes, and filtration basin water level. The PCDF pilot system was also equipped with Hach SOLITAX turbidity/TSS sensors in the influent and effluent chambers to continuously monitor filter solids loading rate and particulate removal.

To evaluate removals of particulates and organics, a sampling and analyses program was initiated in January 2017 (Phase 2) in which filter influent and effluent 24-hour composite samples were collected and analyzed for the parameters shown in Table 2. Filter influent and effluent samples for chemical oxygen demand (COD), Total Kjeldahl Nitrogen (TKN), ammonia, TSS, and settleable solids were collected and analyzed twice per week. To facilitate a comparison with the PCDF pilot system, 24-hour composite treatment plant monitoring data (COD and TSS) for the existing primary clarifiers were recorded throughout the sampling program. Periodic grab samples of backwash water and solids removed from the bottom of the filtration basin were also collected and analyzed for TSS, volatile suspended solids (VSS), and settleable solids to characterize the solids content of the waste streams produced by the pilot system.

Monthly filter effluent samples for VSS, BOD₅, flocculated and filtered COD, acetate, pH, alkalinity, total phosphorus, and orthophosphate were also collected. These samples were required to generate input data to develop a BioWin simulation model of the step-feed NDN activated sludge process to assess the impact of PF on aeration requirements and nitrogen removal.

An important objective of this study was to evaluate process reliability and potential operational and maintenance issues. This was achieved by documenting any operational challenges/incidents that occurred and the corrective actions taken.

Table 2. Primary Filtration Pilot Study Sampling and Analyses Program.

Parameters	Sample Location	
	Filter Influent	Filter Effluent
(collected twice per week)		
COD	√	√
Soluble COD	√	√
TKN	√	√
Ammonia	√	√
TSS	√	√
Settleable Solids	√	√
(collected once per month)		
VSS		√
BOD ₅		√
Soluble BOD ₅		√
Flocculated and Filtered COD		√
Acetate		√
pH		√
Alkalinity		√
Total Phosphorus		√
Orthophosphate		√

RESULTS

Operations

The PCDF pilot system was operated for one year from November 2016 to November 2017. Daily flow totals for influent, effluent, total waste, backwash waste, and solids waste are shown in Figure 5. These data only include full 24-hour operational days (275 days) and exclude data from days with partial operation due to planned and unplanned shutdowns. These data also exclude several days of operation in which the pilot system was running but operations data was unavailable due to lost communication with the remote data logging system. Cumulative flows are summarized in Table 3. Over the 275 days of operation, the PCDF pilot system treated approximately ten million gallons of screened and de-gritted raw sewage. The total waste produced was 13.9% of the influent flow, resulting in a net effluent production of 86.1%. Backwash and solids waste flows were 9.3% and 4.6% of the influent flow, respectively. If the PF process were to be implemented at full-scale at the Lancaster WRP, facilities would be designed to thicken the waste flows. Thickened solids would be sent to the digesters and the return flow would be sent to the headworks. Thickening technologies are being evaluated at the Linda WWTP full-scale PF study and include a Volute Thickener (mechanical thickening system) and Phase Separator (gravity thickening system) (Caliskaner *et al.*, 2017). Information generated from this study can be used to inform the design of a full-scale facility at the Lancaster WRP.

The cumulative flows in Table 3 represent average conditions over the entire study. Specific operations results from each phase of the study are discussed in more detail below.

Table 3. PCDF Pilot System Cumulative Flows¹.

Location	Flow Total (gallons)	% of Influent Flow
Influent	9,939,737	--
Effluent	8,557,651	86.1
Total Waste	1,382,086	13.9
(Backwash Waste)	(919,603)	(9.3)
(Solids Waste)	(462,502)	(4.6)

1. Data only includes full 24-hour operational days (275 days).

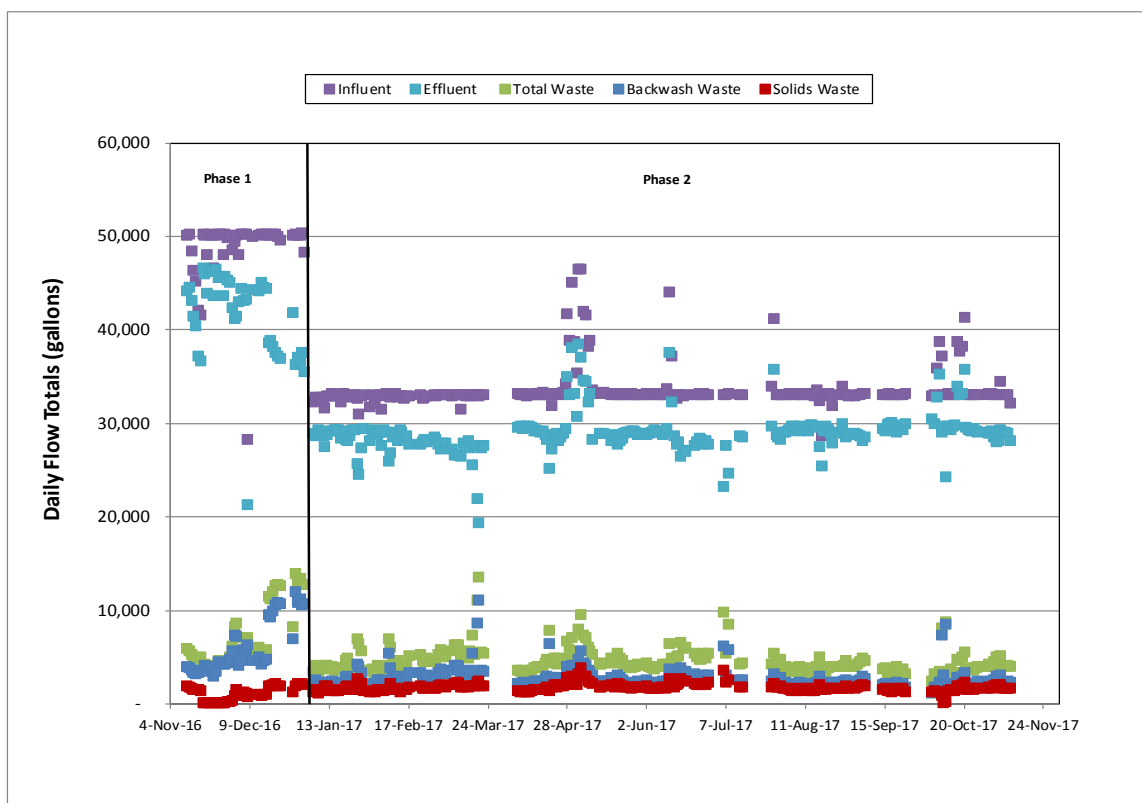


Figure 5. PCDF Pilot System Daily Flow Totals.

Phase 1

The PCDF pilot system was initially operated, for approximately two months, at a hydraulic loading rate set-point of 3.2 gpm/ft². The actual hydraulic loading rates as well as other operations parameters including solids loading rate (lb TSS/ft²-day), effluent and waste flows (as a percentage of influent flow), and filtration basin water level are shown in Figures 6 through 9. These parameters are also summarized in Table 5 along with notes for specific periods of operation. The total waste produced during Phase 1 was 14.6% of the influent flow (12.3% backwash and 2.3% solids), resulting in a net effluent production of 85.4%. As summarized in Table 5, the results from Phase 1 operation illustrate the importance of filter solids loading rate on PF process performance.

Phase 2

Because of the increasing solids loading rates observed during Phase 1, the hydraulic loading rate set-point was reduced to 2.1 gpm/ft² during Phase 2. Phase 2 operations results are shown in Figures 6 through 9 and are also summarized in Table 6. The total waste produced during Phase 2 was 13.7% of the influent flow (8.4% backwash and 5.3% solids), resulting in a net effluent production of 86.3%. Similar to Phase 1, the results from Phase 2 operation illustrate the importance of filter solids loading rate on PF process performance.

Table 5. PCDF Pilot System Phase 1 Operations Results Summary.

Date (s)	Average Results for Period	Notes
11/10/16 - 11/17/16	Hydraulic Loading Rate = 2.9 gpm/ft ² Solids Loading Rate = 8 lb TSS/ft ² - day Effluent Flow = 88.7% of Influent Flow Total Waste Flow = 11.3% of Influent Flow Backwash Waste Flow = 7.6% of Influent Flow Solids Waste Flow = 3.7% of Influent Flow Filtration Basin Water Level = 5.3 ft	Start-up, first week of operation.
11/18/16 - 12/1/16	Hydraulic Loading Rate = 3.2 gpm/ft ² Solids Loading Rate = 10 lb TSS/ft ² - day Effluent Flow = 91.3% of Influent Flow Total Waste Flow = 8.7% of Influent Flow Backwash Waste Flow = 8.4% of Influent Flow Solids Waste Flow = 0.30% of Influent Flow Filtration Basin Water Level = 5.5 ft	On 11/18, the solids waste set-point for number of backwashes between solids waste events was unintentionally increased from 3 to 30. This resulted in significantly reduced solids waste flows and increased effluent flows until the set-point was corrected on 12/1.
12/2/16 - 12/7/16	Hydraulic Loading Rate = 3.2 gpm/ft ² Solids Loading Rate = 12 lb TSS/ft ² - day Effluent Flow = 86.0% of Influent Flow Total Waste Flow = 14.0% of Influent Flow Backwash Waste Flow = 11.7% of Influent Flow Solids Waste Flow = 2.3% of Influent Flow Filtration Basin Water Level = 5.5 ft	Noticeable increase in waste flows and corresponding reduction in effluent flows. While the hydraulic loading rate remained stable, the solids loading rate began to steadily increase and was consistently >10 lb TSS/ft ² - day. The increasing solids loading rate resulted in increased backwash frequency and higher waste flows.
12/8/16	Hydraulic Loading Rate = 1.8 gpm/ft ² Solids Loading Rate = 13 lb TSS/ft ² - day Effluent Flow = 75.2% of Influent Flow Total Waste Flow = 24.9% of Influent Flow Backwash Waste Flow = 22.1% of Influent Flow Solids Waste Flow = 2.8% of Influent Flow Filtration Basin Water Level = 5.6 ft	On 12/8, a significant reduction in overall system performance was observed. This was caused by a sustained loading event due to cleaning of the influent pump station wet-well (grease and grit removal) by Lancaster WRP Operations staff. The influent pump became obstructed with debris, which reduced influent flow capacity. The waste flow for the day increased significantly resulting in reduced effluent production. Despite the significant loading placed on the filter, the filter continued to operate and did not overflow. The filtration basin water level remained below 7ft, which was the high water level alarm set-point.
12/9/16 - 12/16/16	Hydraulic Loading Rate = 3.2 gpm/ft ² Solids Loading Rate = 13 lb TSS/ft ² - day Effluent Flow = 88.7% of Influent Flow Total Waste Flow = 11.3% of Influent Flow Backwash Waste Flow = 9.3% of Influent Flow Solids Waste Flow = 2.0% of Influent Flow Filtration Basin Water Level = 5.5 ft	Over the week following the wet-well cleaning event, PCDF filter performance recovered without any special cleaning (e.g., chorine) other than removing debris from the influent pump.
12/17/16 - 1/2/17	Hydraulic Loading Rate = 3.2 gpm/ft ² Solids Loading Rate = 20 lb TSS/ft ² - day Effluent Flow = 75.5% of Influent Flow Total Waste Flow = 24.5% of Influent Flow Backwash Waste Flow = 20.5% of Influent Flow Solids Waste Flow = 4.0% of Influent Flow Filtration Basin Water Level = 5.7 ft	For the balance of Phase 1, PCDF performance steadily declined due to increasing solids loading rates that peaked at 24 lb TSS/ft ² - day. However, the filter continued to operate and did not overflow. The filtration basin water level remained below 7ft. On 12/28, which was the day that the peak solids loading first occurred, the water level was > 5.8ft, which was the set-point to initiate backwashes. This indicates that the filter was in continuous backwash mode for most of the day.

Table 6. PCDF Pilot System Phase 2 Operations Results Summary.

Date (s)	Average Results for Period	Notes
1/4/17 - 1/24/17	Hydraulic Loading Rate = 2.1 gpm/ft ² Solids Loading Rate = 6 lb TSS/ft ² - day Effluent Flow = 88.1% of Influent Flow Total Waste Flow = 12.0% of Influent Flow Backwash Waste Flow = 7.2% of Influent Flow Solids Waste Flow = 4.8% of Influent Flow Filtration Basin Water Level = 5.4 ft	First three weeks of operation. Stable hydraulic and solids loading rates.
1/25/17 - 4/5/17	Hydraulic Loading Rate = 2.1 gpm/ft ² Solids Loading Rate = 12 lb TSS/ft ² - day Effluent Flow = 83.8% of Influent Flow Total Waste Flow = 16.2% of Influent Flow Backwash Waste Flow = 10.7% of Influent Flow Solids Waste Flow = 5.5% of Influent Flow Filtration Basin Water Level = 5.4 ft	Noticeable increase in waste flows and corresponding reduction in effluent flows. The hydraulic loading rate remained stable, however the solids loading rate began to steadily increase, with a maximum of 18 lb TSS/ft ² - day. The maximum total waste flow over the entire study (41.1%) occurred during this period on 3/20. The backwash, solids wastes, and effluent flows on this day were 33.7%, 7.4%, and 58.9%, respectively. A 24-hour composite sample result (discussed below) indicated that the TSS was >1,000 mg/L, which explains the significant reduction in performance. Despite the significant loading placed on the filter, the filter continued to operate and did not overflow. The filtration basin water level was 5.6 ft. No data from 3/23 to 4/5. Lost remote communication with pilot system on 3/23. Pilot system down on 3/27 due to backwash valve malfunction. AASI on site to replace valve on 4/4.
4/6/17 - 5/9/17	Hydraulic Loading Rate = 2.3 gpm/ft ² Solids Loading Rate = 11 lb TSS/ft ² - day Effluent Flow = 86.0% of Influent Flow Total Waste Flow = 14.0% of Influent Flow Backwash Waste Flow = 8.5% of Influent Flow Solids Waste Flow = 5.5% of Influent Flow Filtration Basin Water Level = 5.5 ft	Noticeable increase in waste flows and corresponding reduction in effluent flows due to increasing solids loading rate, with a maximum of 19 lb TSS/ft ² - day. The hydraulic loading rate was variable, for unknown reasons, over the last few weeks of the period, which may have contributed to the increasing solids loading rate.
5/10/17 - 7/26/17	Hydraulic Loading Rate = 2.2 gpm/ft ² Solids Loading Rate = 10 lb TSS/ft ² - day Effluent Flow = 85.5% of Influent Flow Total Waste Flow = 14.5% of Influent Flow Backwash Waste Flow = 8.5% of Influent Flow Solids Waste Flow = 6.0% of Influent Flow Filtration Basin Water Level = 5.5 ft	Relatively stable operating conditions. The solids loading rate exhibited a decreasing trend over the period. There were two days in July (7/6 and 7/8) in which performance declined significantly (effluent production < 75%) even though the solids loading rates on these days were not unusually high (< 8 lb TSS/ft ² - day). There were periodic shutdowns during this period due to influent pump clogging and the system was also shutdown in June for a few days to prevent issues related to a planned influent pump station wet-well cleaning event by Lancaster WRP Operations staff. No data from 7/16 to 7/26. Substantial clogging of influent pump on 7/16. System down for several days. AASI on site on 7/26 to clear debris, restart system.
7/27/17 - 11/9/17	Hydraulic Loading Rate = 2.2 gpm/ft ² Solids Loading Rate = 11 lb TSS/ft ² - day Effluent Flow = 88% of Influent Flow Total Waste Flow = 12% of Influent Flow Backwash Waste Flow = 7.2% of Influent Flow Solids Waste Flow = 4.8% of Influent Flow Filtration Basin Water Level = 5.5 ft	Relatively stable operating conditions. There were two days in October (10/10 and 10/12) in which performance declined significantly (effluent production < 78%). Solids loading rates on these days were at or slightly higher than average for the period, 11 and 12 lb TSS/ft ² - day. The filtration basin water level on these days was >5.8ft, indicating that the filter was in continuous backwash mode for most of the day. There were two additional days in October where the filtration basin water level was > 5.8ft (10/6 and 10/11), however, this did not correlate with observed performance (effluent production > 90%). There were periodic shutdowns during this period due to influent pump clogging.

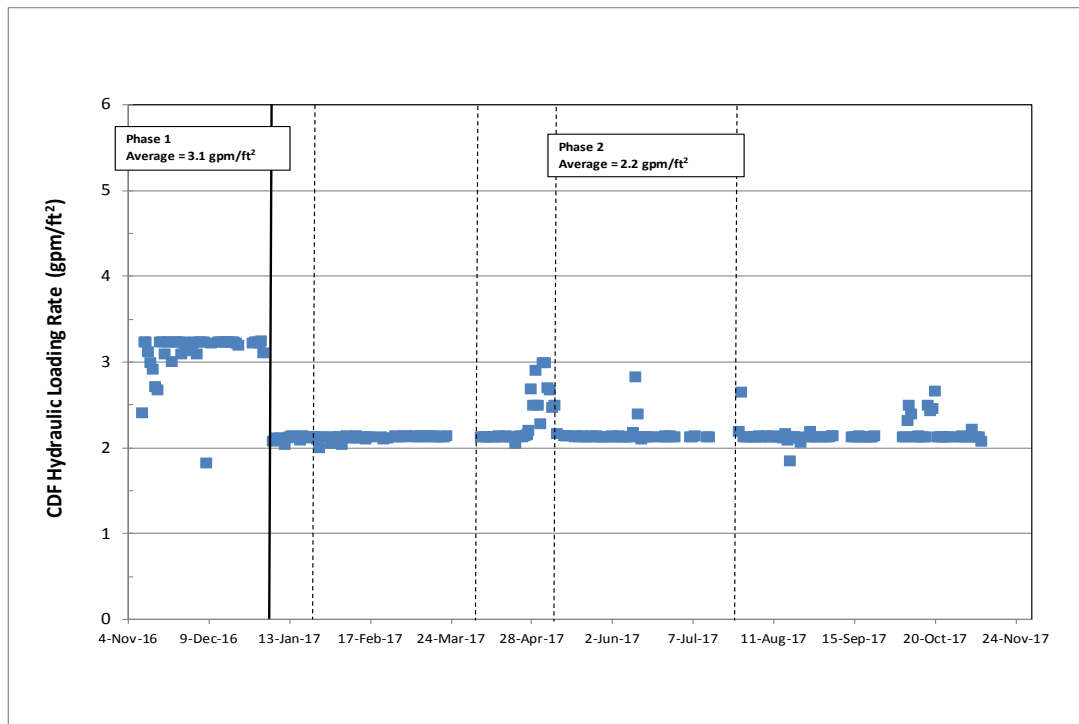


Figure 6. PCDF Pilot System Hydraulic Loading Rate.

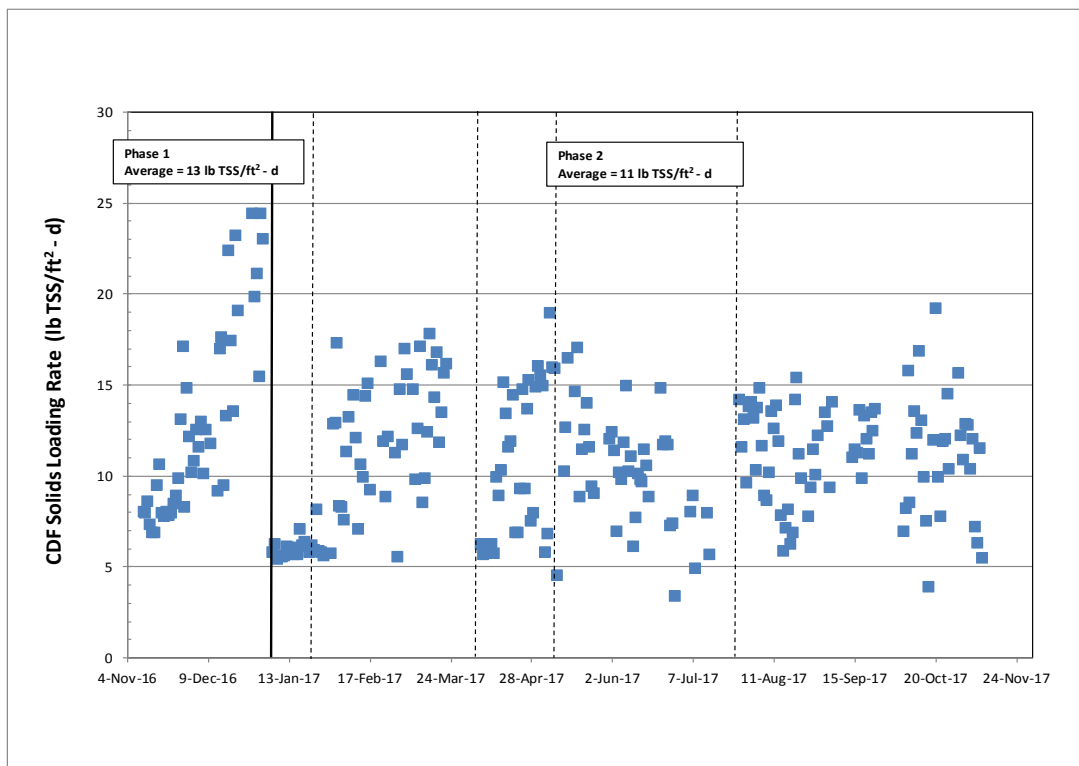


Figure 7. PCDF Pilot System Solids Loading Rate.

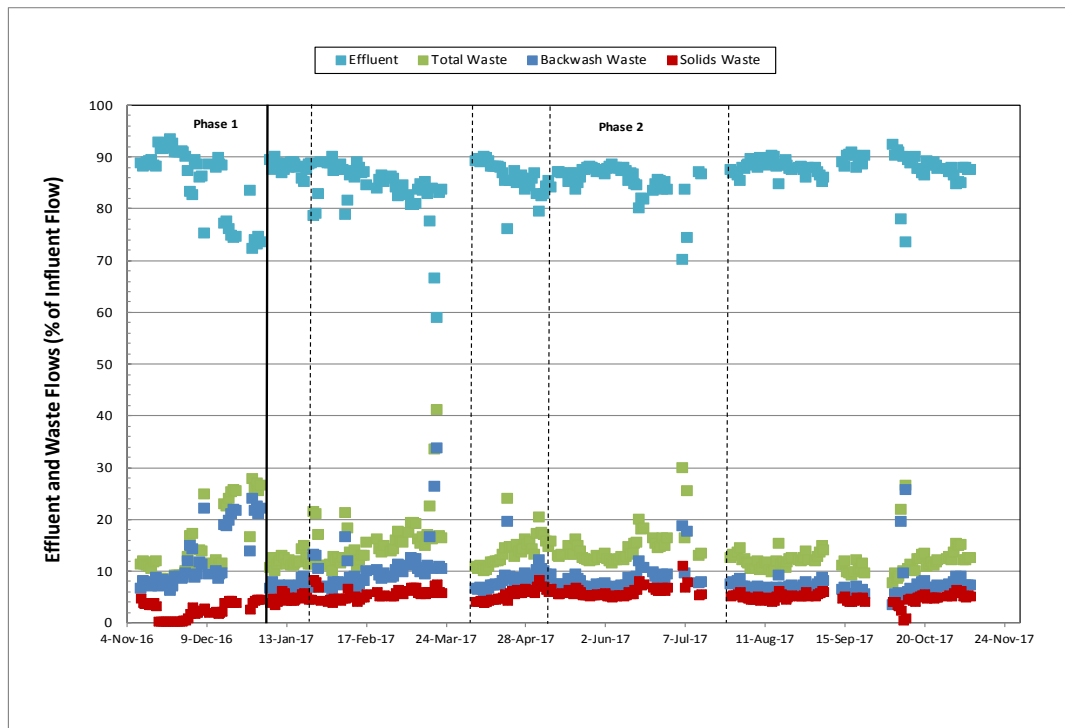


Figure 8. PCDF Pilot System Effluent and Waste Flows as a Percentage of Influent Flow.

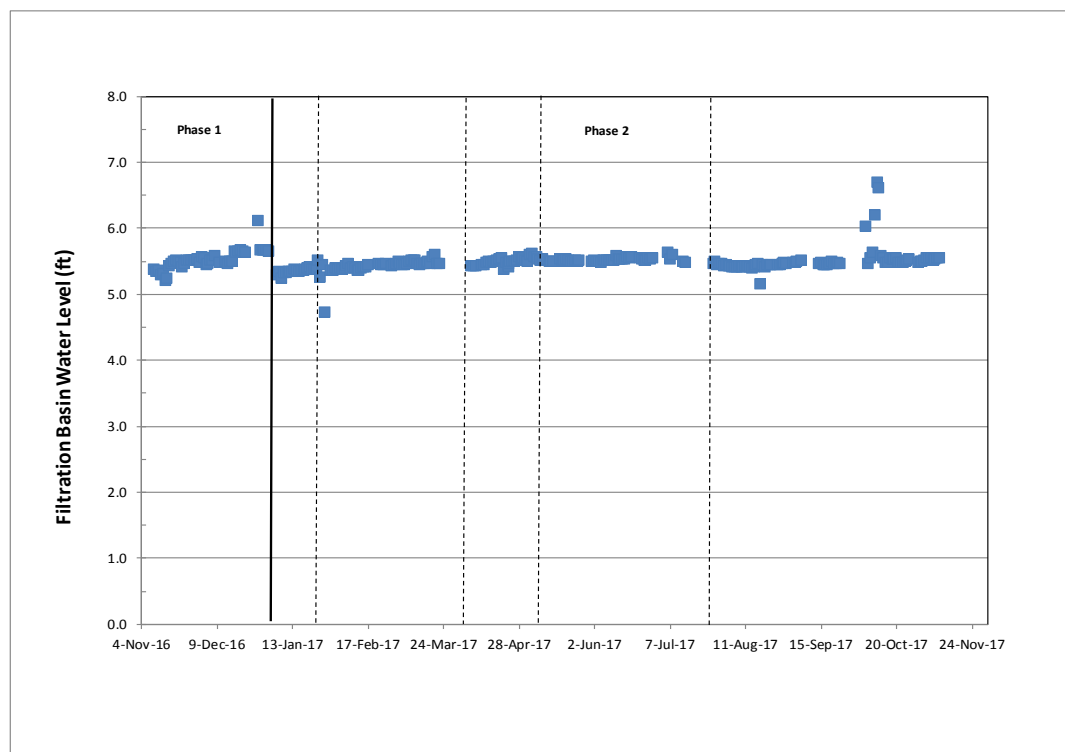


Figure 9. PCDF Pilot System Filtration Basin Water Level.

Process Reliability

To evaluate process reliability, any operational challenges/incidents that occurred and the corrective actions taken were documented. Of the twenty incidences recorded, none were specifically related to the PCDF itself. There were periodic issues with ancillary equipment (valves and low level pressure transducer) and occasional losses of power. However, the major challenge during the study was the significant amount of grit and debris that passed through preliminary treatment and into the primary clarifier influent channel where the PCDF pilot system feed pump was located. On several occasions, the feed pump, backwash pump, or lines connected to the pumps were clogged causing system shutdowns. If the PF process were to be implemented at full-scale at the Lancaster WRP, improvements to the preliminary treatment systems would be needed (e.g., 10 mm perforated fine screen followed by grit removal).

Water Quality

To evaluate removals of particulates and organics, a sampling and analyses program was initiated in January 2017 in which filter influent and effluent 24-hour composite samples were collected and analyzed for TSS, settleable solids, COD, soluble COD, TKN, and ammonia. TSS removal was also monitored continuously with the Hach SOLITAX sensors located in the influent and effluent chambers of the PCDF pilot system. To facilitate a comparison with the PCDF pilot system, 24-hour composite treatment plant monitoring data (COD and TSS) for the existing primary clarifiers were recorded throughout the sampling program. Periodic grab samples of backwash water and solids removed from the bottom of the filtration basin were also collected and analyzed for TSS, VSS, and settleable solids to characterize the solids content of the waste streams produced by the pilot system. Representative images of the PCDF pilot system sample locations are shown in Figure 10.

PCDF sampling results are shown in Figures 11 - 16, and comparative sampling results for the primary clarifiers are shown in Figures 17 and 18. All results are summarized in Table 7. The PCDF achieved average TSS, on-line TSS, settleable solids, COD, soluble COD, TKN, and ammonia removals of 83.6%, 86%, 99.4%, 56.3%, 9.6%, 15.7%, and 0%, respectively. The effluent water quality, with respect to TSS and COD, produced by the PCDF was very consistent. Even during an extreme loading event that occurred on 3/20 (feed TSS = 1,140 mg/L and feed COD = 1,920 mg/L), the effluent TSS and COD values were not significantly higher than the averages for the entire study (effluent TSS = 88 mg/L on 3/20 vs. 65 mg/L average; effluent COD = 434 mg/L on 3/20 vs. 325 mg/L average).

Removal of soluble COD (COD measured after filtration through a 1.5 μm nominal pore size glass fiber filter) illustrates the ability of the PCDF to remove particulates and colloidal material smaller than the nominal pore size of the cloth media (5 μm). This can likely be attributed to the formation of a mat of rejected larger particles that forms on the surface of the media, which then functions as a secondary filter to remove smaller particles. The TKN and ammonia results illustrate the ability of the PCDF to remove particulate organic nitrogen.

Over the same operating period, the primary clarifiers achieved average TSS and COD removals of 53.5% and 36.9%, respectively. The PCDF average effluent TSS and COD concentrations were 56% (65 mg/L vs. 147 mg/L) and 31% (325 mg/L vs. 471 mg/L) lower than those produced by the primary clarifiers. These results clearly illustrate the potential for enhanced removal of TSS and COD if PF with a PCDF were implemented as a replacement for the existing primary clarifiers at the Lancaster WRP.

Results from the waste stream sampling events are shown in Table 8. The average backwash and solids waste TSS concentrations were 1,070 mg/L and 10,060 mg/L, respectively. These results illustrate the need for thickening of these waste streams prior to digestion for full-scale application.

Table 7. PCDF Pilot System and Primary Clarifiers Sampling Results Summary.

System	Parameter	No. Samples	Feed			Effluent			Avg. % Removal
			Avg.	Min	Max	Avg.	Min	Max	
PCDF Pilot System	TSS (mg/L)	48	396	132	1,140	65	34	118	83.6
	Hach SOLITAX TSS (mg/L)	264 ¹	400	130	693	56	46	82	86.0
	Settleable Solids (mL/L)	30	28	13	75	0.18	0.10	0.50	99.4
	COD (mg/L)	48	744	440	1,920	325	268	437	56.3
	Soluble COD (mg/L)	30	188	118	367	170	102	307	9.6
	TKN (mg N/L)	48	51	38	79	43	35	72	15.7
	Ammonia (mg N/L)	30	34	30	38	34	29	40	0.0
Primary Clarifiers	TSS (mg/L)	39	316	220	552	147	101	240	53.5
	COD (mg/L)	42	747	561	2,333	471	374	565	36.9

1. Daily average values.

Table 8. PCDF Pilot System Waste Stream Sampling Results.

Sample Date	Sample Location					
	Backwash Water			Filtration Basin Solids		
	TSS (mg/L)	VSS (mg/L)	Settleable Solids (mL/L)	TSS (mg/L)	VSS (mg/L)	Settleable Solids (mL/L)
1/31/2017	1,690	1,500	120	5,540	5,040	750
3/1/2017	733	650	46	17,500	14,900	420
4/27/2017	568	560	60	10,400	9,640	550
5/25/2017	1,290	1,280	100	6,800	6,720	350
Avg.	1,070	998	82	10,060	9,075	518

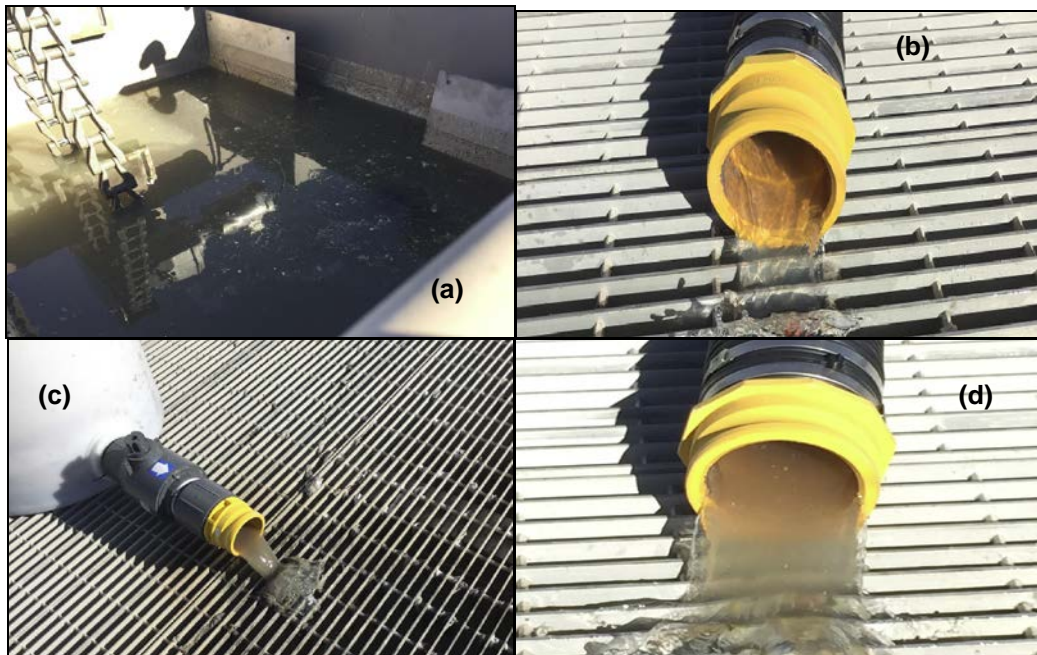


Figure 10. PCDF Pilot System Sample Locations: (a) Feed; (b) Effluent; (c) Solids Waste; (d) Backwash Waste.

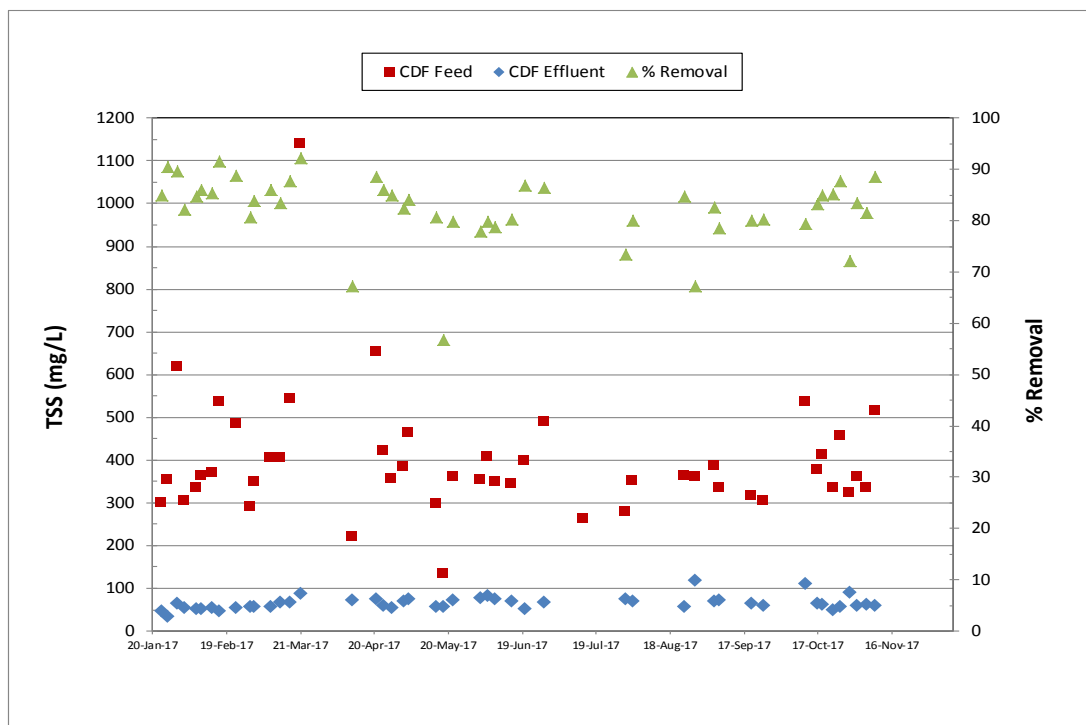


Figure 11. PCDF Pilot System TSS Sampling Results.

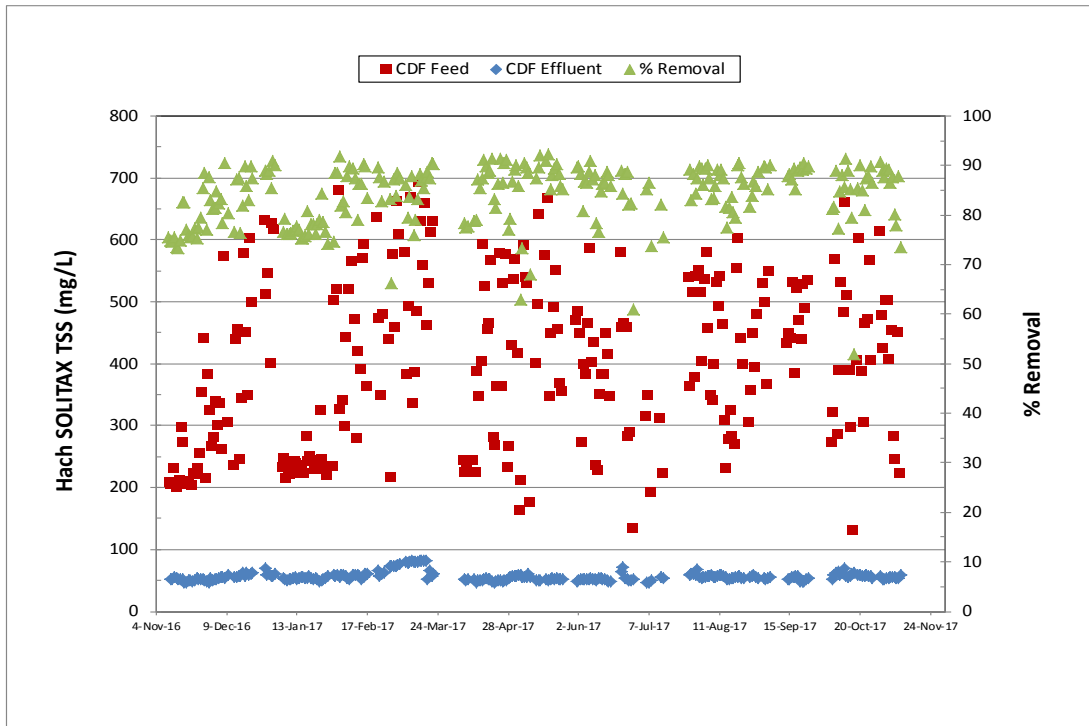


Figure 12. PCDF Pilot System Hach SOLITAX TSS Results.

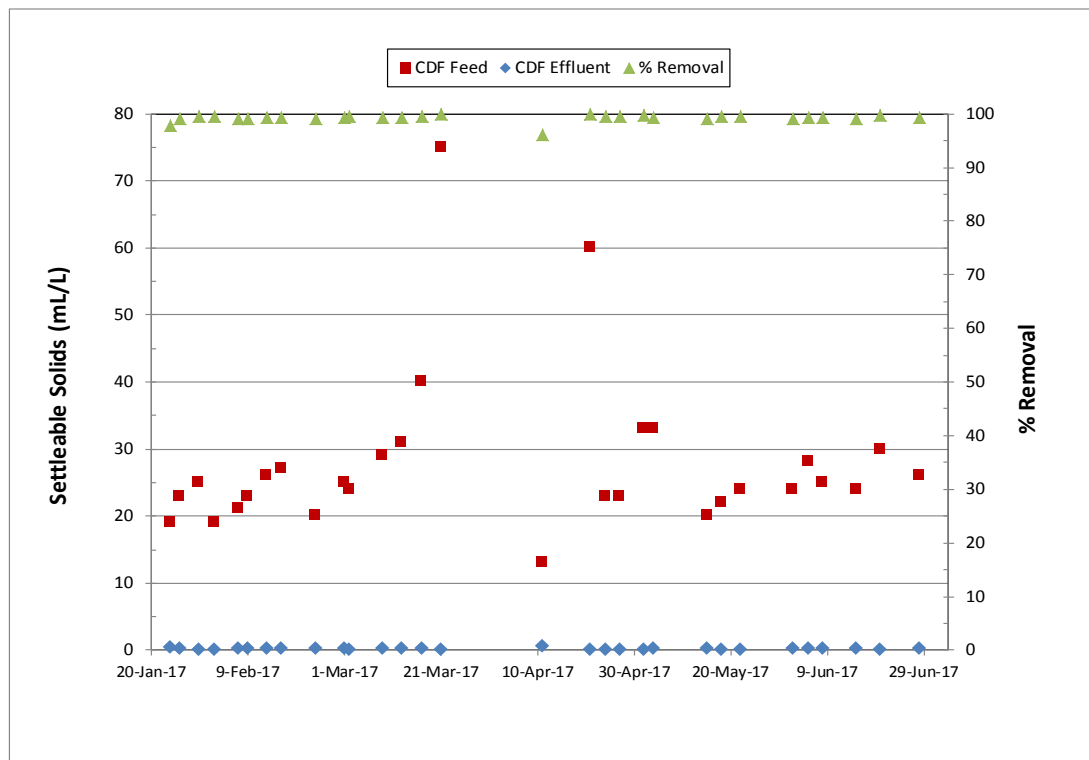


Figure 13. PCDF Pilot System Settleable Solids Sampling Results.

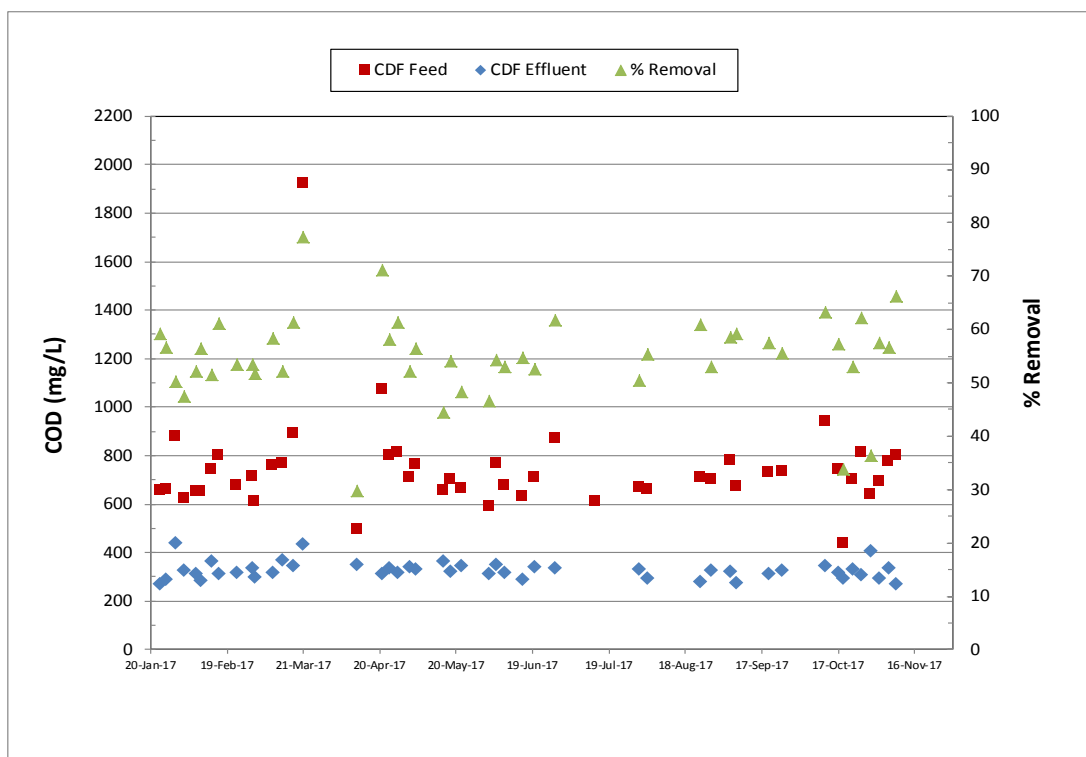


Figure 14. PCDF Pilot System COD Sampling Results.

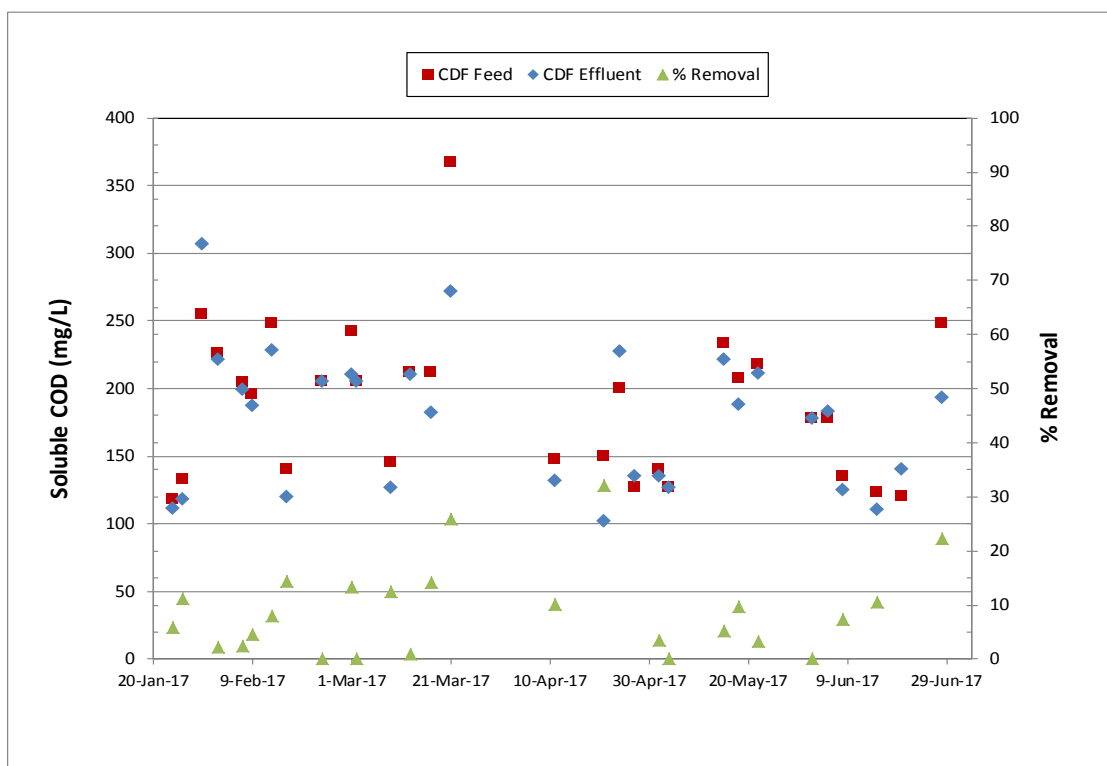


Figure 15. PCDF Pilot System Soluble COD Sampling Results.

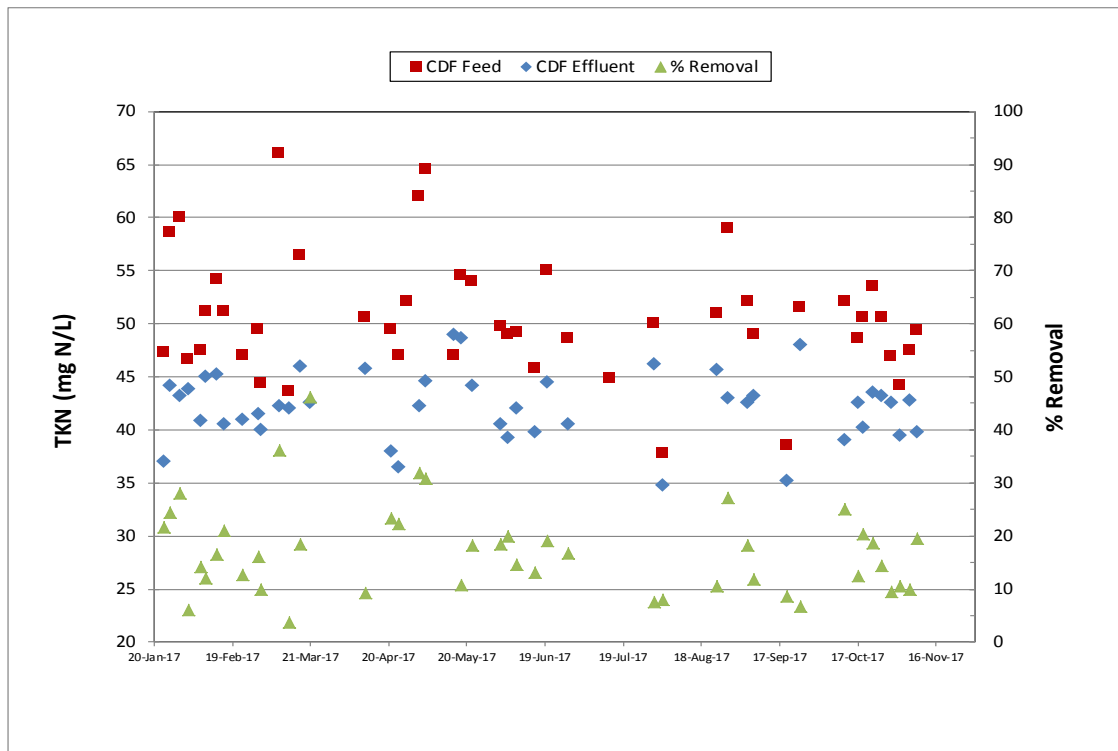


Figure 16. PCDF Pilot System TKN Sampling Results.

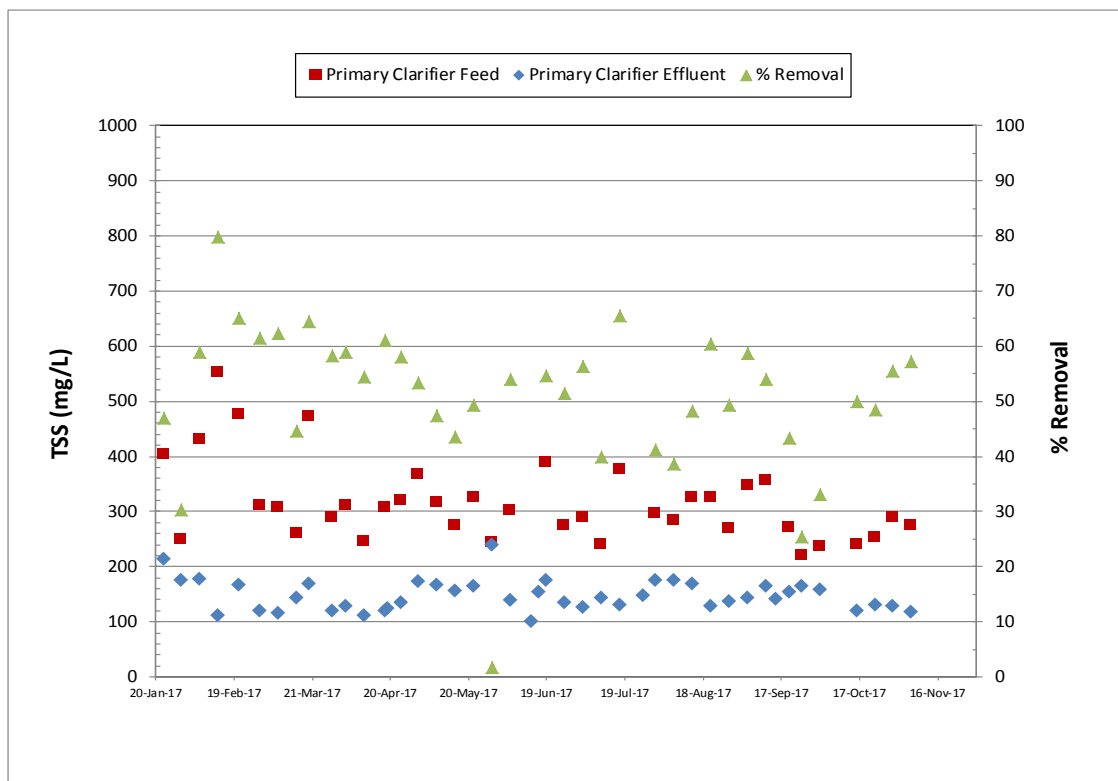


Figure 17. Primary Clarifiers TSS Sampling Results.

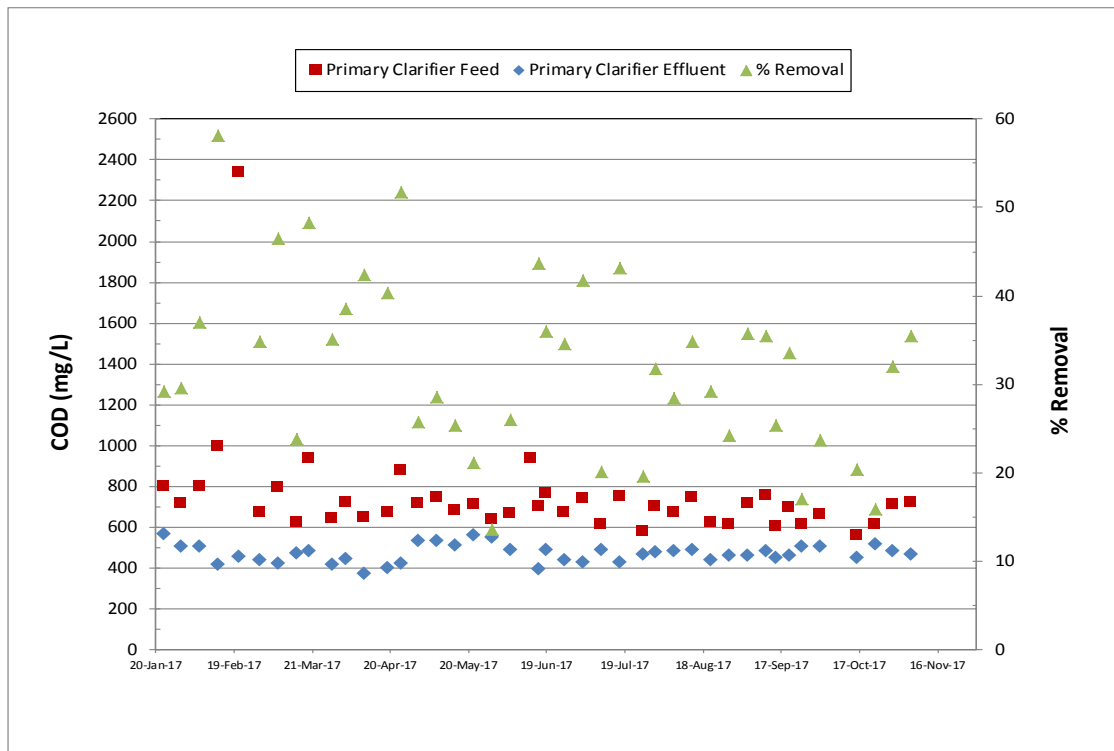


Figure 18. Primary Clarifiers COD Sampling Results.

BioWin Modelling

A BioWin simulation model of the step-feed NDN activated sludge process at the Lancaster WRP was used to assess the impact of PF on aeration requirements and associated electrical energy requirements. In addition, the impact of PF on nitrogen removal performance was evaluated. The following sections include a brief description of the activated sludge process and a summary of modelling results.

Activated Sludge Process

The step-feed NDN activated sludge process at the Lancaster WRP has a design capacity of 18 MGD. The process was designed to produce effluent with annual average total nitrogen concentrations ≤ 10 mg N/L. The process consists of three units operated in parallel. Each unit has three passes, with each pass being divided into three sequential zones including anoxic, swing, and aerobic (Figure 19). Return activated sludge (RAS) from the secondary clarifiers (14 total) is fed to the anoxic zones in Pass 1 of each unit, while primary effluent is fed to the Pass 1, Pass 2, and Pass 3 anoxic zones. The middle zone of each pass is a swing zone that can be operated in either aeration or anoxic mode; swing zones are currently operated in anoxic mode.

Each unit has two aeration headers that distribute air to thirteen diffuser grids. Four single-stage centrifugal process air compressors (PAC) provide air for the aeration system (each rated at 25,000 standard cubic feet per minute, scfm). Currently, only one PAC is required to meet aeration demands.

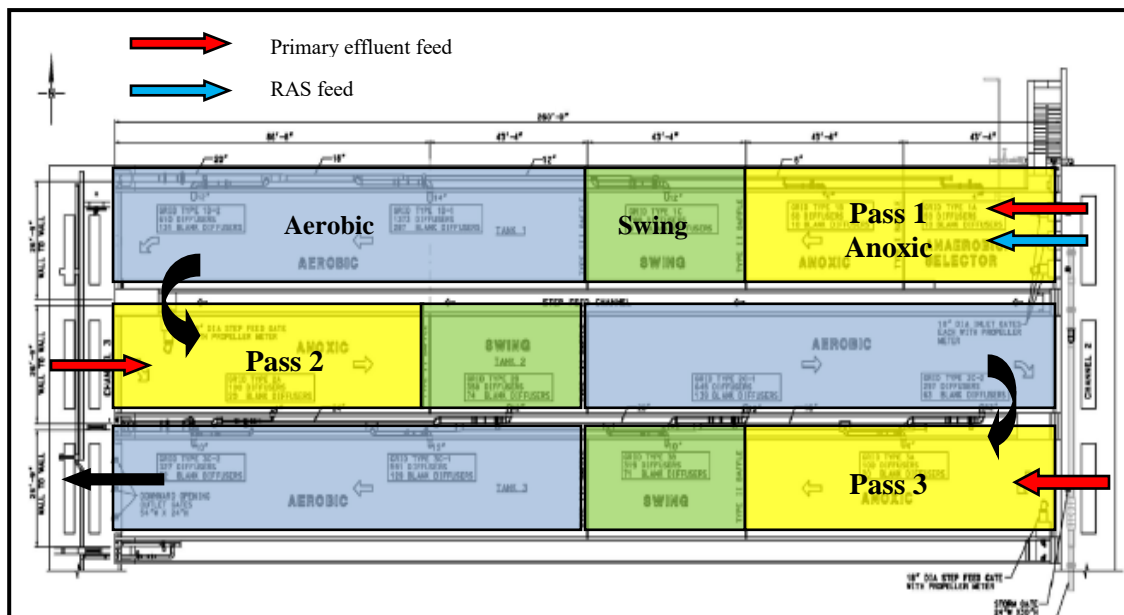


Figure 19. Step-Feed Activated Sludge Unit Layout at Lancaster WRP.

Modelling Results

The BioWin model was developed to represent a single activated sludge unit and associated secondary clarifiers (Figure 20), and was calibrated against plant operations and monitoring data from November 2017. To assess the impact of PF on aeration requirements and nitrogen removal performance, the calibrated model was run with feed water quality data developed specifically for this purpose (Table 9). The water quality data were developed based on average results from the PCDF study sampling program, primary effluent plant monitoring data collected during the study period, and from primary effluent sampling data and plant monitoring data collected for development and calibration of the model.

The major difference between the primary effluent and PF effluent water quality that impacted model projected performance of the activated sludge process was COD (471 vs. 325 mg/L), due to enhanced removal by the PCDF. COD fractionation data for primary effluent and PF effluent are shown in Figures 21 and 22, respectively. The data illustrate that the PF effluent had an equivalent amount of readily biodegradable COD. However, the slowly biodegradable COD fraction was significantly lower; approximately 48% for particulate and 43% for colloidal. The PF effluent total biodegradable COD was approximately 32% lower than that of the primary effluent. As will be discussed below, this difference resulted in a model projected reduction in process air requirements, but increased effluent nitrogen concentrations.

It was assumed during development of the feed water quality data that the TKN and ammonia concentrations were the same for primary effluent and PF effluent. Pilot study sampling results (Table 7) illustrate that the PCDF did not remove ammonia, but did remove TKN and thus particulate organic nitrogen. Enhanced removal of organic nitrogen by the PF process would lead to an additional reduction in process air requirements. However, it is expected that a significant fraction of this nitrogen load would be returned to the activated sludge process in the centrate sidestream. Therefore, for conservatism, the PF effluent TKN and ammonia concentrations were assumed to be equal to that of the primary effluent.

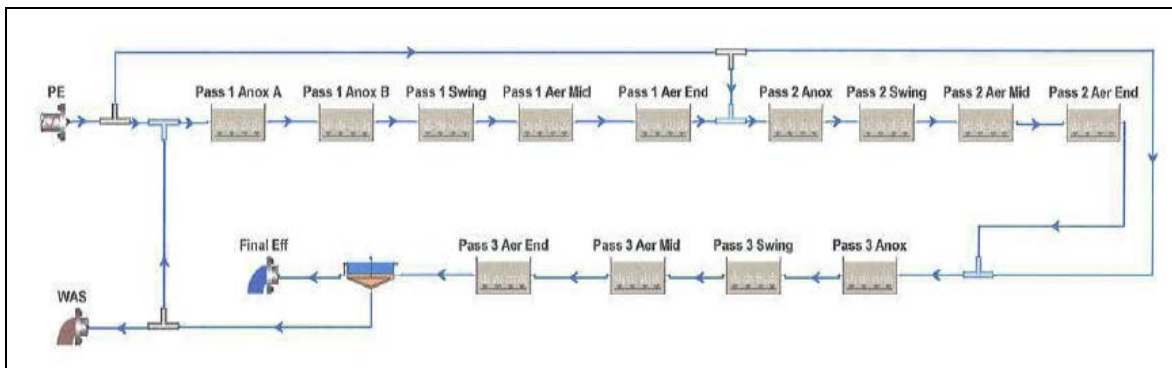


Figure 20. BioWin Model Configuration of One Lancaster WRP Activated Sludge Process Unit.

Table 9. Activated Sludge Process Feed Water Quality Data used for BioWin Modelling Simulations.

Parameter	Primary Effluent	PF Effluent
Temperature (°C)	25	25
pH	7.5	7.5
Alkalinity (mg/L CaCO ₃)	222	222
TKN (mg N/L)	45	45
Ammonia (mg N/L)	36	36
TSS (mg/L)	147	66
VSS (mg/L)	125	56
COD (mg/L)	471	325

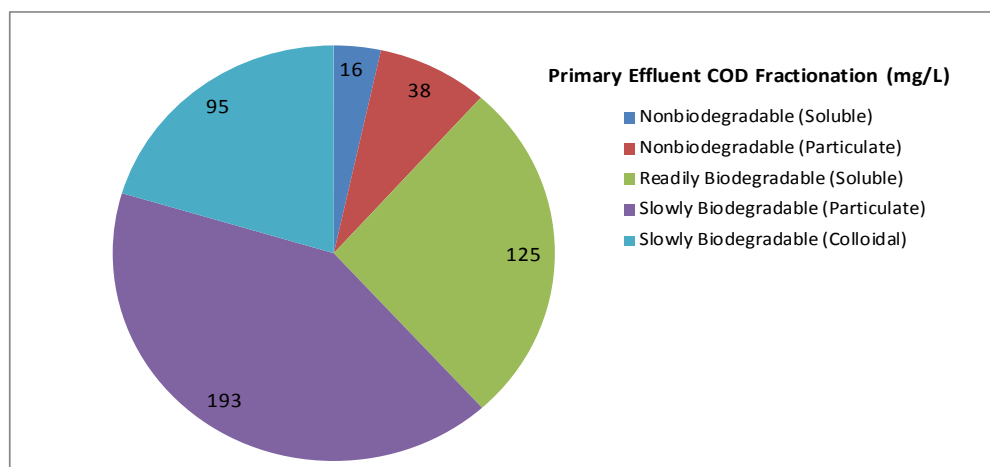


Figure 21. Primary Effluent COD Fractionation.

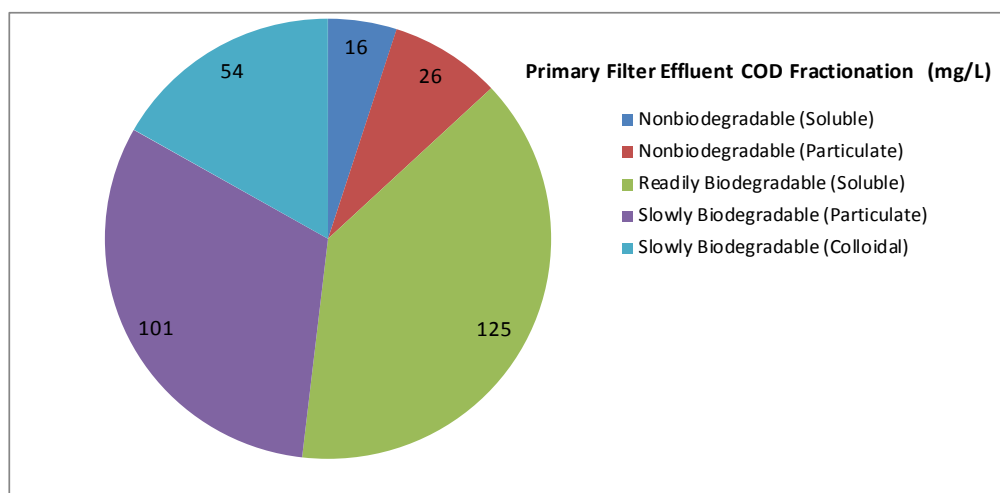


Figure 22. Primary Filter Effluent COD Fractionation.

Two modelling scenarios were run, under steady-state conditions with default stoichiometric and kinetic coefficients, to evaluate the impact of PF effluent on the activated sludge process (Table 10). Scenario 1 was run with primary effluent feed water quality data, while Scenario 2 was run with PF effluent feed water quality data. For each scenario, estimated aeration energy costs were calculated by first determining the total required PAC discharge air flow, which included projected process air requirements plus an additional 1,800 scfm for channel air and filter backwash air. PAC power consumption was then determined based on performance data (power consumption vs. discharge air flow) from November 2017. Annual costs were subsequently calculated assuming \$0.107/kWh, which was the Districts' average electricity rate for Fiscal Year 2016/2017. Major observations/conclusions that can be drawn from the modelling projections are as follows:

1. Implementation of the PF process could potentially reduce activated sludge process aeration energy costs by approximately 20%, compared to operation with the current primary clarifiers. This is a result of the enhanced removal of COD that would be achieved by the PF process.
2. Implementation of the PF process could potentially result in higher secondary effluent nitrate concentrations, compared to operation with the current primary clarifiers. This is a result of the reduced amount of biodegradable COD that would be available for denitrification. However, the projected nitrate levels were below 10 mg N/L.

Table 10. BioWin Model Simulation Results and Estimated Aeration Energy Costs.

Parameter	Scenario	
	1	2
Feed	Primary Effluent	PF Effluent
Feed Split	65-35-0 ¹	65-35-0
Aeration Control	D.O. ²	D.O.
Feed Flow (MGD)	18.0 ³	18.0
RAS Flow (MGD)	17.7	17.7
WAS ⁴ Flow (MGD)	0.24	0.24
WAS Production (lb/day)	19,941	15,120
MCRT ⁵ (days)	17	17
Pass 3 MLSS ⁶ (mg/L)	5,071	3,846
RAS TSS (mg/L)	9,935	7,638
Process Air (scfm)	13,233	10,005
Aeration Energy Cost (\$/year)	425,500	341,600
Secondary Effluent COD (mg/L)	24	17
Secondary Effluent TSS (mg/L)	3	2
Secondary Effluent Ammonia (mg N/L)	< 0.1	< 0.1
Secondary Effluent Nitrite (mg N/L)	< 0.1	< 0.1
Secondary Effluent Nitrate (mg N/L)	2.9	8.5

1. Current feed split at Lancaster WRP = 65% Pass 1, 35% Pass 2, 0% Pass 3.

2. Set point = 1.5 mg/L.

3. Design capacity = 18 MGD. Current flow at Lancaster WRP is ~ 14 MGD.

4. WAS = waste activated sludge

5. MCRT = mean cell residence time

6. MLSS = mixed liquor suspended solids

SUMMARY AND CONCLUSIONS

A pilot-scale PCDF PF system was operated at the Lancaster WRP from November 2016 to November 2017 to: 1) evaluate removal of particulates and organics; 2) quantify backwash water volumes; 3) evaluate process reliability and potential operational and maintenance issues; 4) generate input water quality data for use in a BioWin simulation model of the step-feed NDN activated sludge process. The major results/conclusions from this study are summarized below.

1. Removal of Particulates and Organics: The PF process is capable of achieving enhanced removal of particulates and organics compared to primary clarification. During the study, the PF process achieved average TSS and COD removals of 83.6% and 56.3%, respectively. Over the same operating period, the Lancaster WRP primary clarifiers achieved average TSS and COD removals of 53.5% and 36.9%, respectively.

2. Backwash Water Volumes: Over 275 full 24-hour operational days, the PF pilot system treated approximately ten million gallons of screened and de-gritted raw sewage. The total waste produced was 13.9% of the influent flow, resulting in a net effluent production of 86.1%. Backwash and solids waste flows were 9.3% and 4.6% of the influent flow, respectively.
3. Process Reliability: Operational challenges/incidents that occurred and the corrective actions taken were documented throughout the study. Of the twenty issues recorded, none were specifically related to the PCDF itself. There were only periodic issues with ancillary equipment and occasional losses of power.
4. BioWin Simulation Model: A BioWin simulation model of the step-feed NDN activated sludge process at the Lancaster WRP was used to assess the impact of PF on aeration requirements and associated electrical energy requirements. In addition, the impact of PF on nitrogen removal performance was evaluated. BioWin modelling indicates that implementation of the PF process could potentially reduce activated sludge process aeration energy costs by approximately 20%, compared to operation with the current primary clarifiers. BioWin modelling also indicates that implementation of the PF process could potentially result in higher secondary effluent nitrate concentrations, compared to operation with the current primary clarifiers. However, the projected nitrate levels were below 10 mg N/L. It should be noted that the impact of PF on denitrification is currently being studied as part of the first full-scale PF installation and demonstration project mentioned above (Caliskaner *et al.*, 2017).

REFERENCES

Caliskaner, O., Tchobanoglous, G., Reid, T., Young, R., Downey, M., Kunzman, B. (2016) “Advanced Primary Treatment *via* Filtration to Increase Energy Savings and Plant Capacity”, Proceedings of the 2016 Water Environment Federation Technical Exhibition and Conference, New Orleans, Louisiana.

Caliskaner, O., Tchobanoglous, G., Reid, T., Davis, B., Young, R., Downey, M. (2017) “First Full-Scale Installation of Primary Filtration for Advanced Primary Treatment to Save Energy and Increase Capacity”, Proceedings of the 2017 Water Environment Federation Technical Exhibition and Conference, Chicago, Illinois.