Soggy in Snohomish - Biofilm Media Improves Wet-Weather Lagoon Nitrification

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ABSTRACT

Lagoon systems are one of the oldest and most popular methods of wastewater treatment used today. They have remained appealing for both municipal and industrial treatment applications for their relatively low capital cost, low operating costs, and ease of maintenance. While aerated lagoons are typically well suited for carbonaceous biological oxygen demand (CBOD) removal, their susceptibility to inclement weather can make it difficult to maintain consistent biological nutrient removal. The City of Snohomish, Washington, located in the Puget Sound region, undertakes a unique set of challenges in maintaining treatment at its wastewater treatment facility, which primarily consists of four lagoon cells. While the plant's average month daily flow is 1.2 MGD, maximum month daily flows can reach up to 7.9 MGD due to heavy rainfall events. High flows through the plant can wash out the microbial populations responsible for ammonia transformation, making it difficult to maintain consistent nitrification. In early 2012, the City began construction on a facility upgrade which included retrofitting its three partial-mix lagoons with a total of fifty-four (54) submerged fixed-film (SFF) modules, to improve CBOD removal and nitrification performance. To date, the SFF media system has proven to be an effective solution to the treatment issues presented by wet weather flows at the facility, as it has quickly helped the plant meet or exceed its effluent criteria for CBOD and ammonia. In addition, the SFF system should result in significant cost savings for the City, as it required less additional footprint and lower operating costs compared to alternative solutions.

KEYWORDS: Lagoon, submerged fixed-film, wet-weather, nitrification

INTRODUCTION

The Snohomish WWTP is a 1.2 MGD facility consisting primarily of four aerated lagoon cells. The plant was originally constructed in 1958 as a facultative lagoon system and was upgraded to a multi-cellular aerated lagoon system in 1995. Figure 1 illustrates the typical process flow for the plant. The first cell (Lagoon 1) is a 10 million gallon (MG) completely mixed lagoon, and is followed by three 3.5 MG partially mixed lagoons (Lagoons 2, 3, and 4) in series. The 1995 upgrade also included a new headworks system, a tertiary sand filter, and dechlorination system.

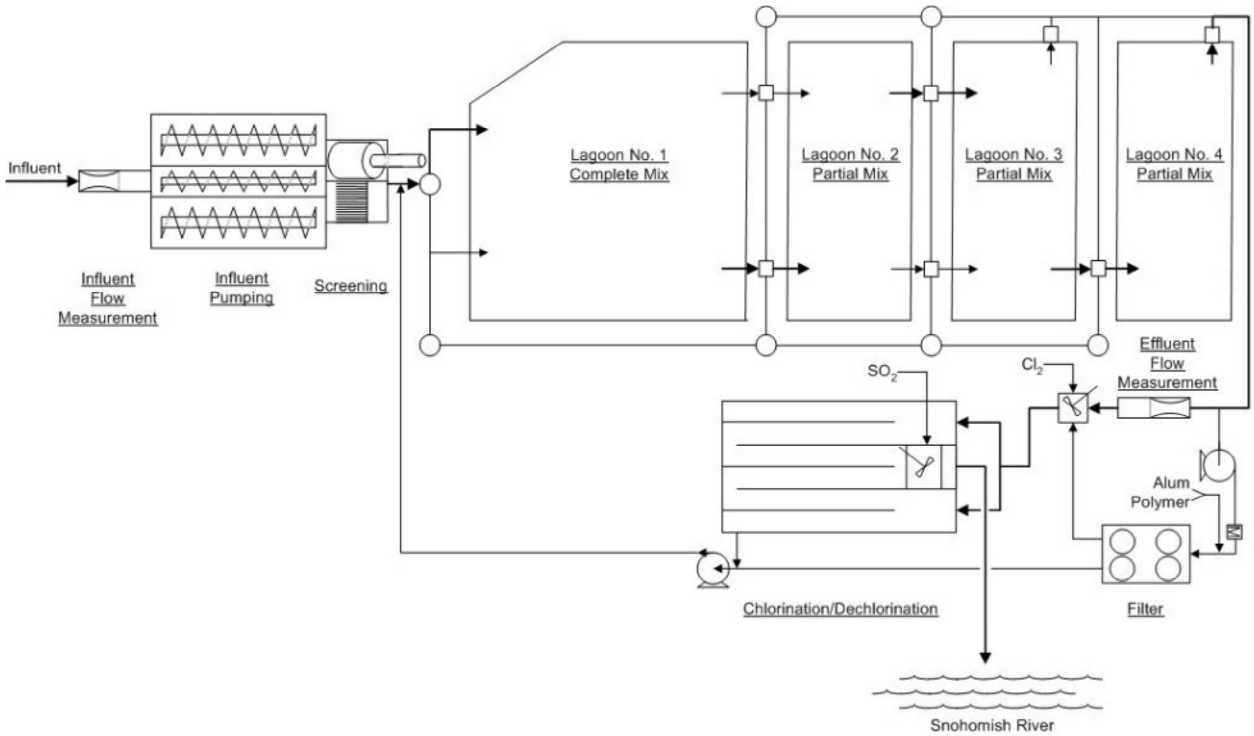

Figure 1. Wastewater flows by gravity from the headworks to the complete-mix 10 MG surface aerated lagoon, then through a series of three 3.5 MG partial-mix lagoons, before passing through the tertiary filter and disinfection system (McKone, 2012).

The City of Snohomish, located approximately 30 miles north of Seattle, lies in a prime location for the Puget Sound Convergence Zone (PSCZ), a meteorological phenomenon caused by large currents of air that split over the Olympic Mountains and converge over the Puget Sound. The PSCZ causes a number of heavy rainfall events in Snohomish throughout the year, but especially during the winter months. This, in turn, results in high flows at the wastewater treatment facility, as approximately 26% of the plant's service area operates as a combined sewer system (McKone, 2012). For example, Figure 2 shows the daily influent flows for the WWTP throughout 2010. Besides a relatively calm period between mid-June and December, flows frequently climb well above the yearly average of 1.27 MGD. Over the course of the year, the WWTP experienced 35 days of influent flows of 2 MG or greater, including 3 days of 4 MG or greater. While these flows tend to decrease in the summer as heavy rainfall subsides, they still affect how early in the year nitrification can be established. The increased flows result in shorter residence times in the lagoons, which in turn result in decreased biological treatment. In extreme cases, these high flows can cause washout of the slow growing nitrifiers, after which the reestablishment of nitrification can take as much as 8 weeks.

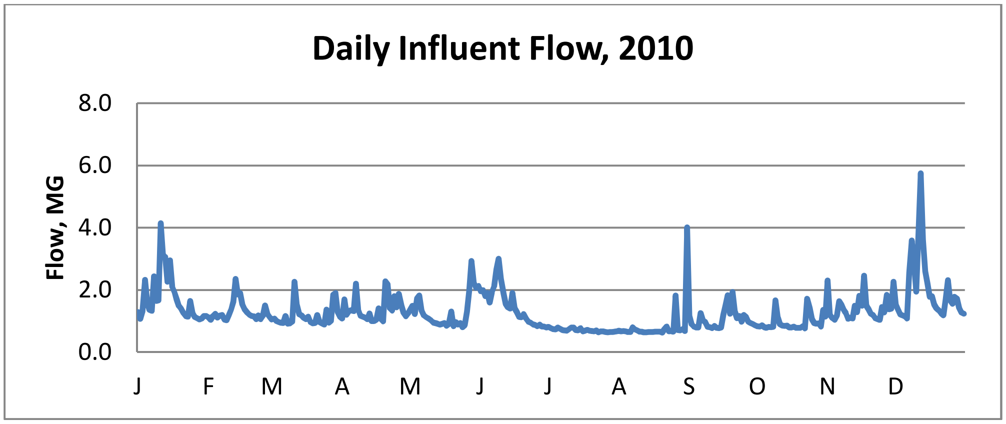

Figure 2. Daily influent flow in 2010 averaged 1.27 MG, although the plant experienced 35 days of flows over 2 million gallons.

For the purposes of comparison, Figure 3 shows the daily influent flows to date in 2013. This year, the plant recorded influent flows above 3 MG as late as April 7.

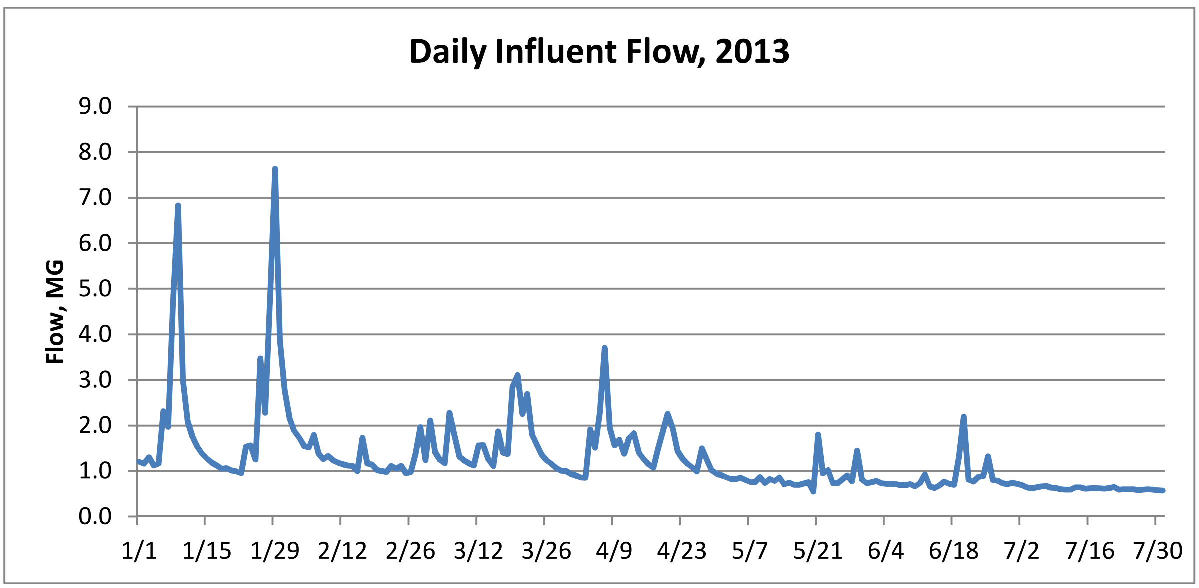

Figure 3. Daily influent flow to date in 2013.

In 2006, the Washington Department of Ecology (DOE) issued a new permit to the City of Snohomish which placed effluent limits on $CBOD_5$, TSS, pH, fecal coliform, and total residual chlorine. The permit also established total maximum daily load (TMDL) limits on $CBOD_5$ and ammonia from July to October. The TMDL limits were 93 pounds per day (ppd) and 99 ppd for $CBOD_5$ and ammonia, respectively. The system struggled to meet the new permit limits, especially the TMDL limits in the summer months. Between August 2006 and August 2010, the City reported 60 daily limit violations (44 $CBOD_5$, 16 ammonia) and 18 monthly average limit violations (9 $CBOD_5$, 9 ammonia) (McKone, 2012).

In 2007, in order to address ammonia permit violations, the plant began experimenting with bioaugmentation, in which nitrifying bacteria were added to the influent stream. While the bioaugmentation program was partially successful in reducing effluent ammonia levels, the nitrite oxidizing bacteria (NOB) population proved difficult to establish. Subsequently, effluent nitrite concentrations increased, a phenomenon commonly referred to as "nitrite lock" (Muirhead & Appleton, 2007). This significantly impacted the plant's disinfection system, which uses chlorine gas. As a result of the reaction between chlorine and nitrite, the plant saw poor disinfection and increased chlorine costs.

An agreed order between Snohomish and the Washington DOE required the City to implement necessary near-term improvements to its wastewater treatment facility in order to address the permit violations. The primary goal of the near-term improvements project was to maximize treatment performance of the facility while limiting construction costs. Though the improvements had to eliminate the effluent $CBOD_5$ and ammonia violations in the short term, the City also wanted to limit the utility rate increase seen by its citizens and save funds for its long-term improvement plan (McKone, 2012).

DESIGN APPROACH

Working in conjunction with Kennedy/Jenks Consultants, the City considered a number of integrated media solutions during the evaluation process, including both fixed and moving media systems. Ultimately, Entex Technologies Inc. (Chapel Hill, NC) was chosen to supply their Webitat^{TM} submerged fixed-film (SFF) system. In March 2012, the City began construction on a facility upgrade which included retrofitting each of the three partially mixed lagoons with 18 SFF media modules. Each Webitat module contains approximately 3,549 ft^2 of BioWeb^{TM} media, for a total of 191,646 ft^2 of biologically active surface area. In addition, each module is equipped with an integral diffuser system which allows for a thin, healthy biomass, enhanced mixing, and DO control. The upgrade also included a new chemical feed system for alkalinity addition and blowers to supply air to the SFF media system.

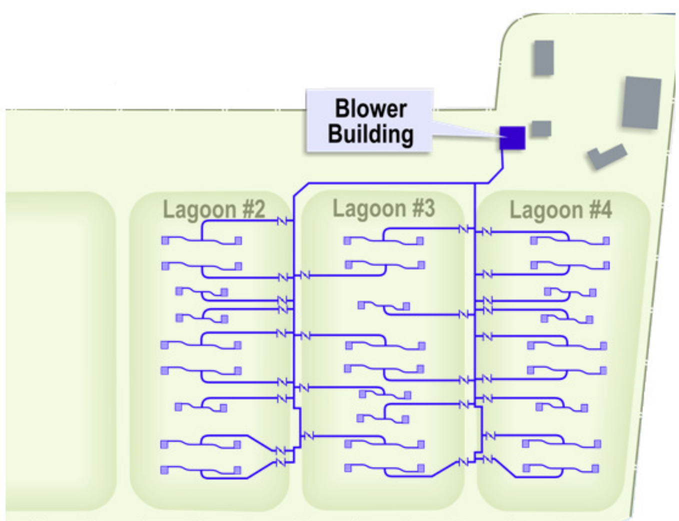

Figure 4. Plan view of the submerged fixed-film system. Modules closest to the surface aerators were placed nearer the edge of the lagoons. (Schuller & Giese, 2012)

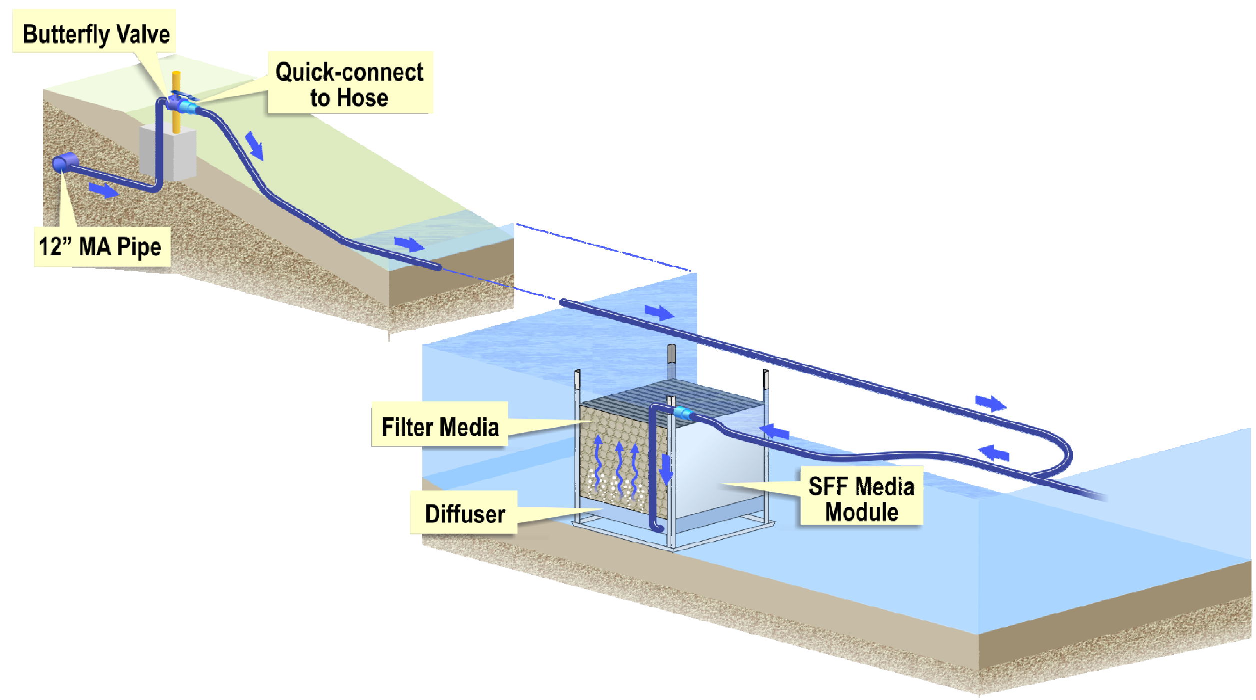

Figure 5. Each pair of SFF media modules receives air through a 3” air line extending from the lagoon shore. Air flow is controlled by an electrically actuated butterfly valve. (Schuller & Giese, 2012)

Through a dedicated programmable logic controller (PLC), the SFF system can run in one of two modes. Aerobic mode provides a continuous air supply of approximately 30 standard cubic feet per minute (SCFM) to each module via two positive displacement blowers, each discharging 800 SCFM. Alternating anoxic/aerobic mode is an energy savings mode in which a single blower runs at 800 SCFM and the actuated butterfly valves alternate between open and closed in one-hour durations. As such, only half of the modules are supplied with air at any one time. In both cases, the set points for desired blower air flow, actuated valve position, and time period between alternations are all user-adjustable at the PLC.

The effluent limits for $CBOD_5$ and ammonia enforced by the WWTP’s National Pollutant Discharge Elimination System (NPDES) permit vary by season. As such, the performance requirements of the SFF media system are different for the two time periods. “Dry weather” season begins on July 1 and ends on October 31. “Wet weather” season begins on November 1 and ends on June 30. Table 1 outlines the influent wastewater flow and quality data used for design of the SFF system. Table 2 specifies the performance requirements that must be met for the SFF system.

Table 1. Design influent wastewater flow and quality data.

Parameter	Units	Average Annual Flow	Max Month Dry Weather Flow (Jul – Oct)	Peak Day Dry Weather Flow (Jul – Oct)	Max Month Flow (Nov – Jun)
Influent Flow	MGD[a]	1.67	1.32	2.75	2.80
Influent $CBOD_5$[b]	ppd[c]	2,300	2,740	5,320	2,740
Influent $CBOD_5$	mg/L[d]	165	249	232	117
Influent filtered $CBOD_5$[e]	mg/L	83	124	77	59
Influent Ammonia-N	ppd	226	290	620	290
Influent Ammonia-N[f]	mg/L	16	26	27	13
Influent TKN[g][h]	mg/L	25	40	41	20
Influent TSS[i]	mg/L	216	348	338	164
Influent pH[j]		~7	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5
Minimum Temperature	°C	N/A	13	12	7
Average Temperature	°C	~15	20	20	13

Notes:
(a) Million gallons per day.
(b) Carbonaceous 5-day biochemical oxygen demand.
(c) pounds per day
(d) Milligrams per liter.
(e) Assumed typical range for filtered to total $CBOD_5$ ratio of 0.5 for max month and 0.33 for peak day.
(f) Based on historical loading from 2009.
(g) Total Kjeldahl nitrogen.
(h) Estimated by assuming a typical Ammonia-N to TKN ratio of 0.65.
(i) Total suspended solids.
(j) Sufficient supplemental alkalinity will be added to maintain influent pH within this range.

Table 2. SFF media system performance parameters. Effluent limits include both total loading limits (in pounds per day) and concentration limits.

Parameter	Units	Max Month Dry Weather Flow (Jul – Oct)	Peak Day Dry Weather Flow (Jul – Oct)	Max Month Flow (Nov – Jun)
Lagoon Cell No. 4 Effluent Filtered $CBOD_5$[a][b]	mg/L	< 3	< 3	< 15
Lagoon Cell No. 4 Effluent $CBOD_5$[b][c]	ppd	58	93	584
	mg/L	5.3	4.1	25
Plant Effluent Ammonia-N[c][d]	ppd	29	99	N/A
	mg/L	2.6	4.3	N/A

Notes:
(a) Assumed filtered to total $CBOD_5$ ratio of 0.5.
(b) The performance parameters for $CBOD_5$ are a design objective, but are not part of the process warranty. Although effluent filtration is available, it can only treat a portion of the effluent flow. For the design objective associated with $CBOD_5$ removal, assume there is no effluent filtration.
(c) $CBOD_5$ and ammonia-N are tested twice per week from a 24-hour composite sample.
(d) The performance parameter for ammonia-N is included in the process warranty.

RESULTS

The SFF modules were installed in September 2012, and startup activities for the system were completed in January 2013. The system switched to aerobic mode on May 1.

$CBOD_5$ Removal Performance

Tables 3 and 4 compare monthly averages of historical $CBOD_5$ removal efficiency at the Snohomish WWTP to its performance in 2013.

Table 3. $CBOD_5$ Removal Performance at Snohomish WWTP, 2007-2010. Samples were collected twice weekly, so each data point averages either 8 or 10 samples.

Month	Avg. Influent $CBOD_5$ (ppd), 2007-2010	Avg. Effluent $CBOD_5$ (ppd), 2007-2010	Removal Efficiency (%)
January	1710.5	172.7	89.9
February	1535.1	106.7	93.0
March	1531.0	121.6	92.1
April	1563.6	110.6	92.9
May	1611.1	82.9	94.9
June	1681.6	102.6	93.9
July	1509.1	44.6	97.0
August	1484.8	46.4	96.9
September	1579.7	58.7	96.3
October	1628.4	79.3	95.1
November	1670.0	143.9	91.4
December	1713.4	216.0	87.4

Table 4. $CBOD_5$ Removal Performance at Snohomish WWTP, 2013. While the influent $CBOD_5$ loads were 7.8% higher on average than in 2007-2010, the system achieved removal efficiencies 3.4% greater.

Month	Avg. Influent $CBOD_5$ (ppd), 2013	Avg. Effluent $CBOD_5$ (ppd), 2013	Removal Efficiency (%)
January	1936.5	134.6	93.0
February	1820.8	52.4	97.1
March	1655.5	64.6	96.1
April	1495.5	61.3	95.9
May	1685.6	32.1	98.1
June	1787.8	23.6	98.7
July	1634.2	19.9	98.8

Figure 6 compares the plant's historical average effluent $CBOD_5$ to its performance in 2013. By July 2013, the system produced effluent well below its max-month permitted load of 58 ppd.

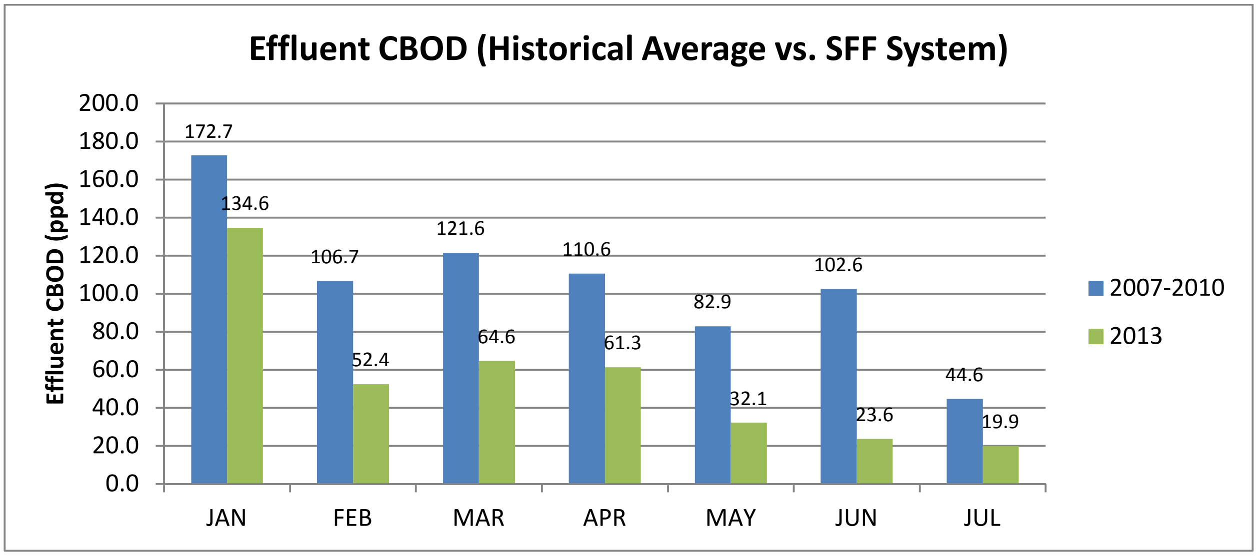

Figure 6. Comparison of 2013 (YTD) effluent $CBOD_5$ levels to monthly averages from 2007-2010.

Ammonia Removal Performance

Influent ammonia data is limited, as it was not required for reporting purposes until July 2013. However, one can assume that the influent ammonia load in pounds per day is fairly consistent throughout the year, given the fact that the plant receives mostly domestic sewage with minor industrial components. Figure 7 shows the influent ammonia loading for a typical year at Snohomish WWTP, from December 2008 to November 2009.

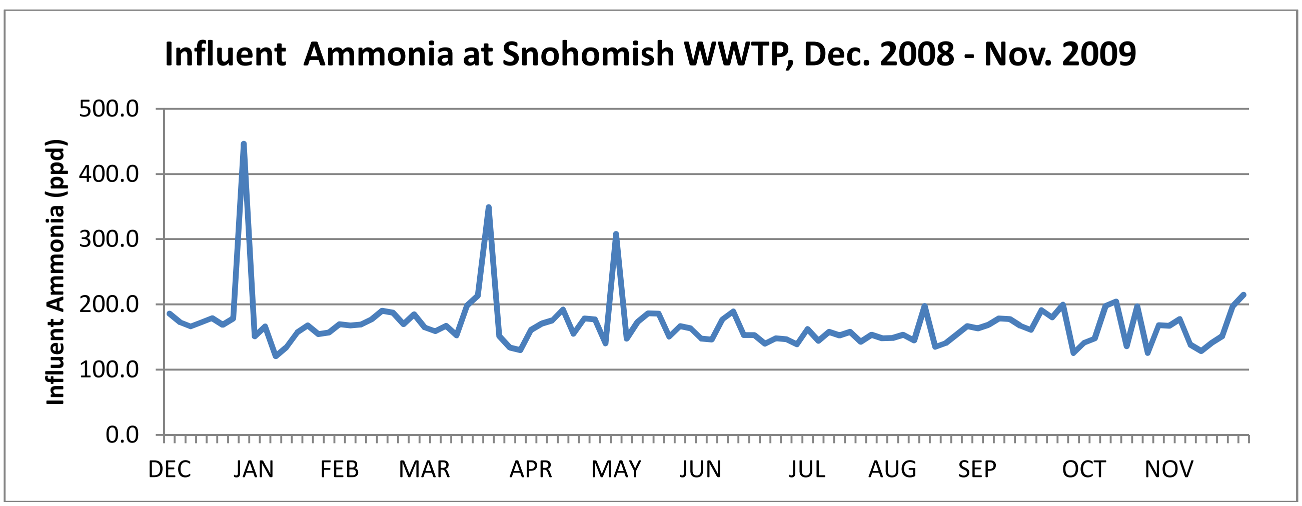

Figure 7. Influent ammonia loading at Snohomish WWTP over a one year period.

While plant experienced three days with influent loads over 300 ppd, the loading remained fairly consistent throughout the year, with an average of 169.5 ppd and a median of 165.4 ppd.

With this in mind, one can compare the plant's historical averages of effluent ammonia to its performance in 2013, after being upgraded to a submerged fixed-film system. While in general the autotrophic nitrifying bacteria take a longer time to establish than the heterotrophic populations responsible for BOD removal (WEF, 2007), the nitrification process was established much earlier with the SFF system, resulting in lower effluent ammonia levels earlier on in the year. Figure 8 compares the historical monthly averages (2007-2010) for effluent ammonia to the plant's performance to date in 2013, given in pounds per day. By the time the plant's dry weather permit came into effect on July 1, effluent ammonia had fallen well below the maximum month limit of 29 ppd.

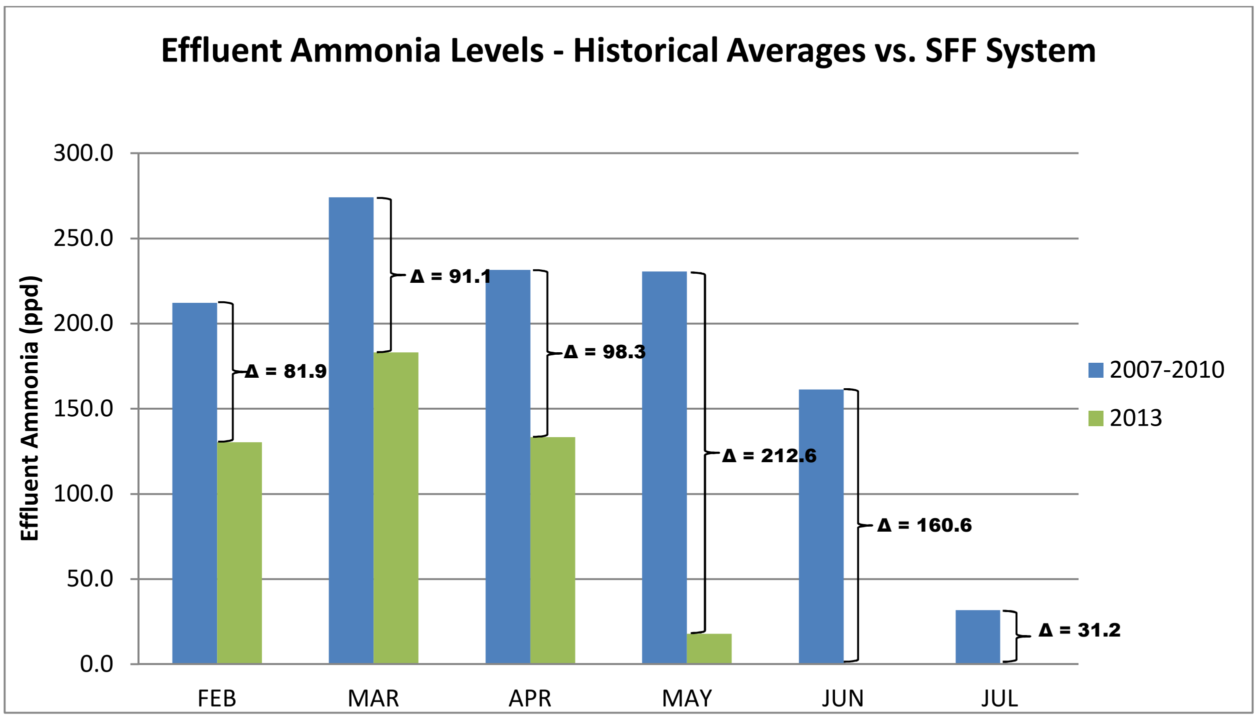

Figure 8. Comparison of effluent ammonia levels. In May 2012, the plant achieved an effluent ammonia load that was over 200 ppd less than what was typically expected.

Figure 9 provides a different perspective of the data used in Figure 8, showing the weekly averages of effluent ammonia concentrations in milligrams per liter (mg/L). Again, the submerged fixed-film system was able to help the plant achieve its maximum month concentration limit of 2.6 mg/L well before the dry weather permit came into effect on July 1.

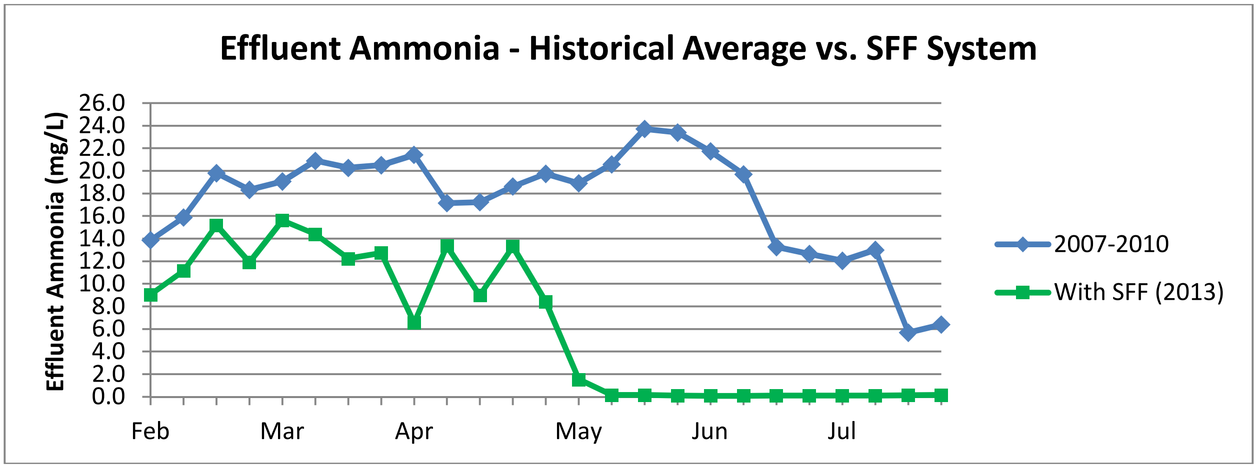

Figure 9. Effluent ammonia concentrations with the submerged fixed-film system fell below required levels (2.6 mg/L) well in advance of the permit's effective date.

SUMMARY AND CONCLUSIONS

Overall, the submerged fixed-film system has proven to be effective in helping the Snohomish WWTP meet its effluent $CBOD_5$ and ammonia permits. To date, the plant is achieving effluent levels far lower than what is typically expected at the plant for that time of year. The plant was able to establish nitrification in early May despite recording daily influent flows over 3 MG as late as April 7. Furthermore, effluent ammonia levels have remained consistently below 1 mg/L since mid-May. With the SFF system in place, the plant no longer has to continue their bioaugmentation program throughout the summer, as the nitrifying population is kept stable and healthy. Finally, the system has allowed for the growth of a stable NOB population, which has provided the added benefit of a stable and less costly chlorine disinfection process.

There are a number of ways in which further analysis can be helpful in understanding the benefits provided by the SFF system. For example, accounting for the influent wastewater temperatures at the plant in 2013 compared to historical averages would allow for a more definitive comparison of current performance to its historical performance. In addition, influent ammonia concentrations, both historical and current, would allow one to determine the removal efficiency of the SFF system as compared to the conventional aerated lagoon system. Lastly, a detailed cost analysis comparing the initial capital and operating costs to the current operating costs would provide a better idea of the long-term value added by the SFF system.

ACKNOWLEDGEMENTS

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