A TALE OF TWO FILAMENTS:
BNR System Recovery from a Major Process Upset

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The Glendale Wastewater Treatment Plant in the city of Lakeland was constructed in 1926 as a primary treatment facility. Trickling filters for secondary treatment were added in 1939, and an extended aeration activated sludge system (Carrousel® Process) was added in 1987. In 1998, the trickling filters were removed and the Carrousel® system was modified to provide denitrification.

Designed to treat a combination of domestic and industrial waste; the Glendale Plant receives industrial waste primarily from several local food processing industries. The facility has a treatment capacity of 13.7 million gallons per day and consists of grit removal, screening, primary clarification, the activated sludge process configured for nitrification and denitrification, and secondary clarification. Treated effluent is discharged into a pond/wetland system where it proceeds into the north prong of the Alafia River.

Thickened primary sludge is sent to anaerobic digestion. Thickened Waste Activated Sludge is mixed with digested primary sludge prior to dewatering on the belt filter presses. The dewatered sludge cake is land applied. The facility includes several holding tanks for thickening the waste activated sludge before it is sent to the gravity belt thickeners. All decant and filtrate is returned to the head of the plant.

The design capacity of the facility is 40,904 pounds per day (ppd) of carbonaceous biochemical oxygen demand (CBOD). At design flow, the influent CBOD concentration equals 408 milligrams per liter (mg/L). The average CBOD load from the largest of the food processing industries is about 12,000 ppd, or about 30 percent of the design load.

It is important to note that the industrial waste has a low suspended BOD fraction and that the soluble BOD will pass through primary clarification. Any significant increase in the load from this industry has a big impact on the oxygen demand in the activated sludge basins.

At 3 p.m. on Saturday, January 21, 2006, the Edgewood electrical substation serving the Glendale Wastewater Treatment Plant malfunctioned, causing a power outage at the plant. All electrical systems were restarted, except the lag blower of the activated sludge aeration process unit, which failed to automatically restart because of a surge condition. The failure was not noticed until the arrival of the chief operator on the morning of Monday, January 23, when the lag blower was manually restarted at 7:57 a.m.

In the meantime, the dissolved oxygen concentrations in the aeration basins had dropped very low. The plant influent BOD loading was not measured over the weekend, but it must have risen drastically to call for the lag blower to energize.

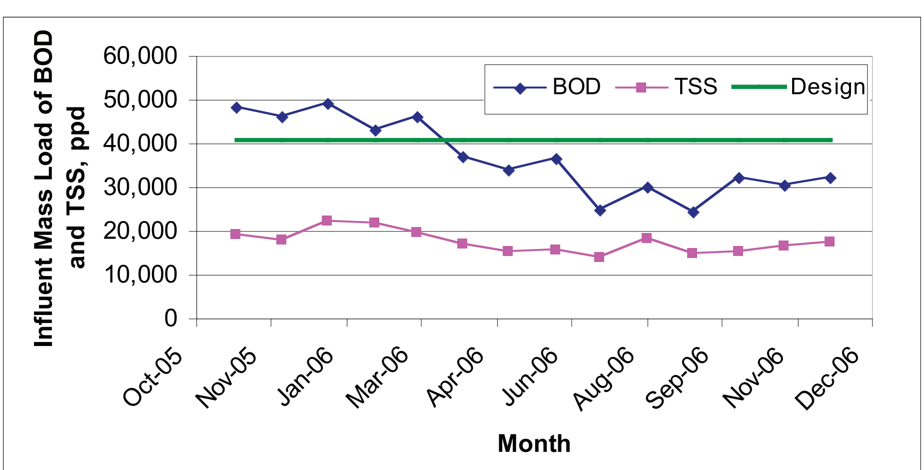

Figure 1. 2006 Historical BOD Loads

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Monday, January 23, when the CBOD load was measured, marks the first day in a pattern of record-high influent CBOD mass loads. From January 25 through February 9, the influent CBOD loading exceeded 45,000 ppd, having reached a peak day loading of 103,016 ppd on January 31.

Since the average loading to the treatment plant for this period was 62,360 ppd and the design capacity of the facility is 40,904 ppd, it was being loaded at 152 percent of its design capacity. The previous maximum short-term maximum CBOD loading event, which occurred in November 2004, had been 53,000 ppd.

The BOD load history for 2006 is shown in Figure 1. The influent mass load of BOD exceeded the design load from January through March but remained at normal values through the rest of the year. The influent total suspended solids (TSS) load did not undergo as large a fluctuation as the BOD; it declined over the first three months of 2006 and reached a maximum month value only 28 percent higher than the annual average, a variation that is typical for domestic wastewater.

The daily mass load of BOD into and out of the primary clarifiers through February 2006 is indicated in Figure 2. The daily loads ranged from 75,929 ppd to 10,680 ppd. While the primary clarifier might be expected to provide some protection for the activated sludge process, this assumption is based on a normal ratio of soluble BOD to suspended BOD. The data in

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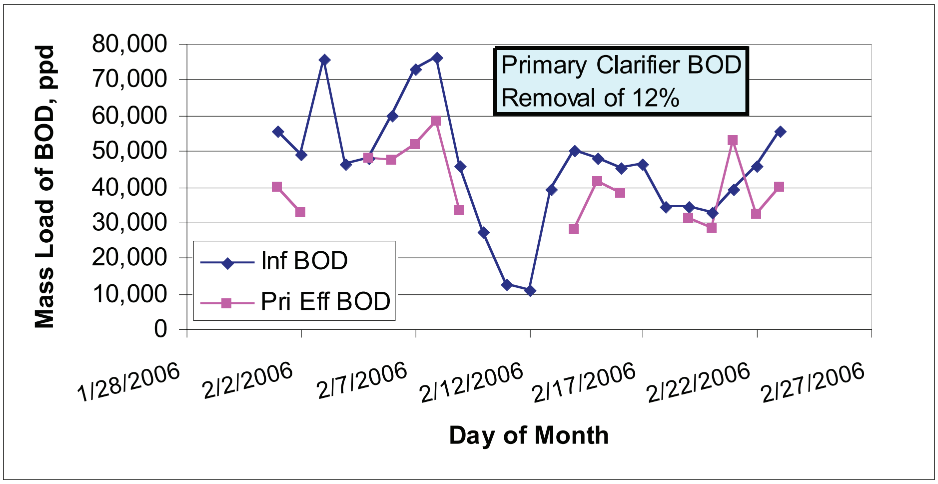

Figure 2. Comparison of Influent and Primary Effluent BOD Mass Loads

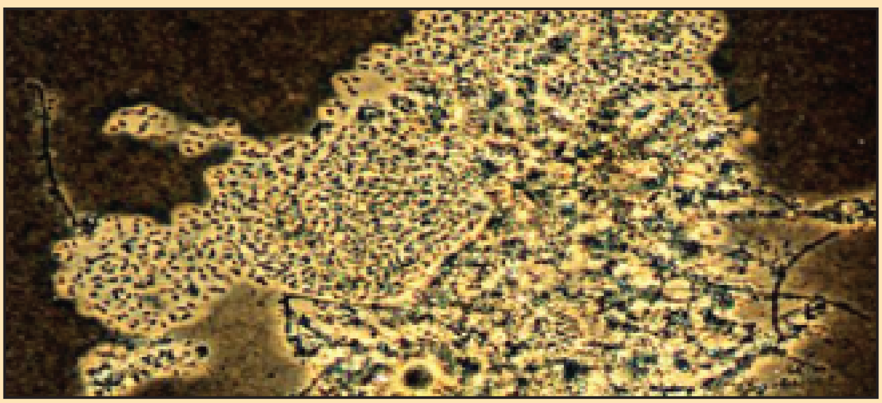

Figure 3. Healthy Floc

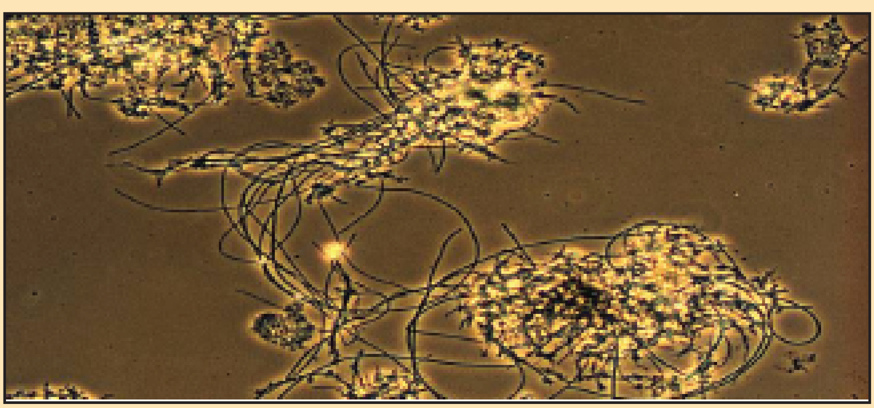

Figure 4. Floc Overtaken with Filaments

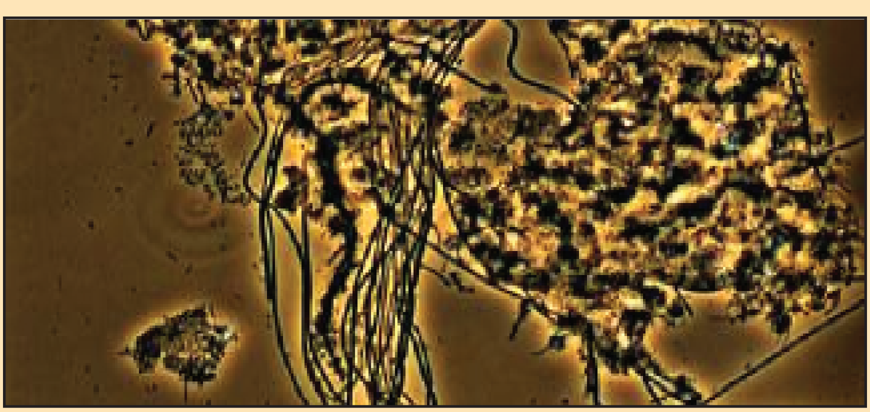

Figure 5. Chlorinated Floc

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Figure 2 show only a 12 percent BOD removal across the primary clarifier instead of the more typical 25 to 30 percent, which means that a higher percentage of the influent BOD load is passing through to secondary treatment.

The plant staff monitored the CBOD, dissolved oxygen (DO), and solids settling rates throughout the week. By Friday, January 27, the solids settling rates had decreased significantly while the filamentous bacteria population within the biomass had increased. On Saturday, January 28, to combat the low DO concentrations in the aeration basins, plant staff began feeding calcium nitrate (Bioxide) at the inlet of the aeration system.

On Sunday, January 29, with the advent of very slow solids settling rates, a standby secondary clarifier (No. 2) was placed into service. On Tuesday, January 31, in addition to the measures implemented during the previous week, staff began to add a polymer product at the inlet of the secondary clarifiers. This is a normal last resort aid employed by plant staff during extremely poor settling conditions in an attempt to keep the activated sludge solids contained within the treatment plant.

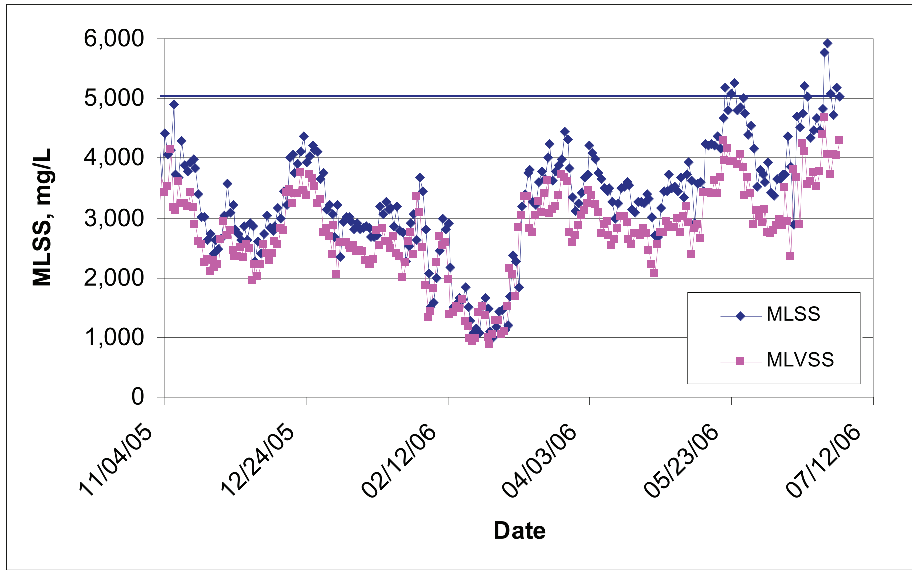
On Friday, February 3, nearly four inches of rain fell on the city, causing the flow into the Glendale Plant to peak at 18.5 mgd. The additional hydraulic loading to the secondary clarifiers caused a major loss of solids over the weirs into the effluent stream. In an effort to reduce this solids discharge, the drain valve on Secondary Clarifier No. 3 was opened to return the excess activated sludge to the primary clarifiers.

During the week of February 6-12, efforts to minimize solids loss over secondary clarifier weirs continued, as did the application of Bioxide. The excess flow was stored in the mid-plant flow surge tank. Plant staff requested operating advice and assistance from a Black & Veatch operations specialist.

To combat the filamentous bacteria, plant staff began feeding dry chlorite (HTH) at the inlet of each aeration basin. The nine pounds of chlorine added daily at the basin inlet is equivalent to approximately 0.65 mg/L, which was the highest chlorine dosage ever used until then. Also, hydrogen peroxide was used to control filamentous growth when it was noticed chlorine was not working effectively. Both chlorine and hydrogen peroxide failed to control the filamentous growth over the long term.

During the first few days of the over-

Figure 6. MLSS Concentrations from November 2005 to July 2006



loading event, the settling rates were high. Even with the addition of Bioxide and with all blowers in operation, the DO profile was poor, creating an environment favorable to the formation of filaments. As a result, by the end of the week (February 27) the 60-minute settling volume had increased to more than 600 milliliters. The mixed liquor suspended solids (MLSS) were being overtaken by filaments.

Figure 3 is a picture of a healthy MLSS floc with a low filament population. In contrast, Figure 4 is a picture of the MLSS floc at the Glendale Plant with a high filament population. Figure 5 is a picture of the MLSS after oxidant adding. Note the dead filament mass accumulated in the MLSS.

These initial attempts at recovery met with minimal success. There was some improvement in the 60-minute settling volume, but not enough to prevent the loss of excessive amounts of MLSS.

The variations in MLSS loading during November 2005 through July 2006 are shown graphically in Figure 6, and the normal settling rates typical for this facility are shown on Figure 7. The upset period began in early February and lasted through the end of March 2006.

The calculated Sludge Volume Index (SVI) values for this same period are shown in Figure 8. While they usually varied from less than 100 to slightly over 200, the upset resulted in values ranging from 300 to 900. When they are compared with the MLSS profile and the effluent TSS mass discharged (Figure 9), it is obvious that most of the biomass was lost into the effluent.

An operations specialist's review of the preceding two months' laboratory results, settlometer data, and microscopic examination of the primary clarifier sludge, primary clarifier effluent, secondary clarifier effluent, and contents of oxic basins resulted in the following conclusions and observations:

- Settlometer readings were consistently poor from January 25 to February 26,

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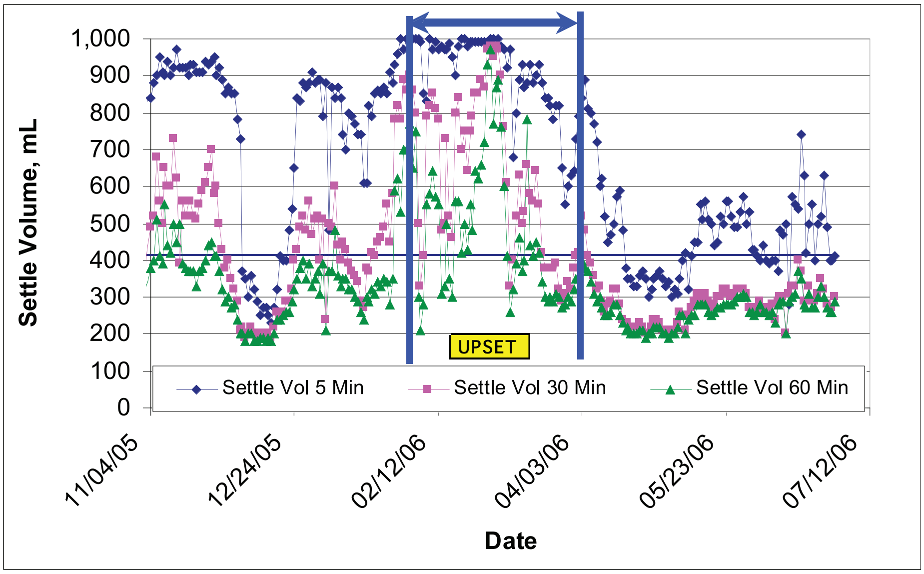

Figure 7. Typical Settling Rates from November 2005 to July 2006

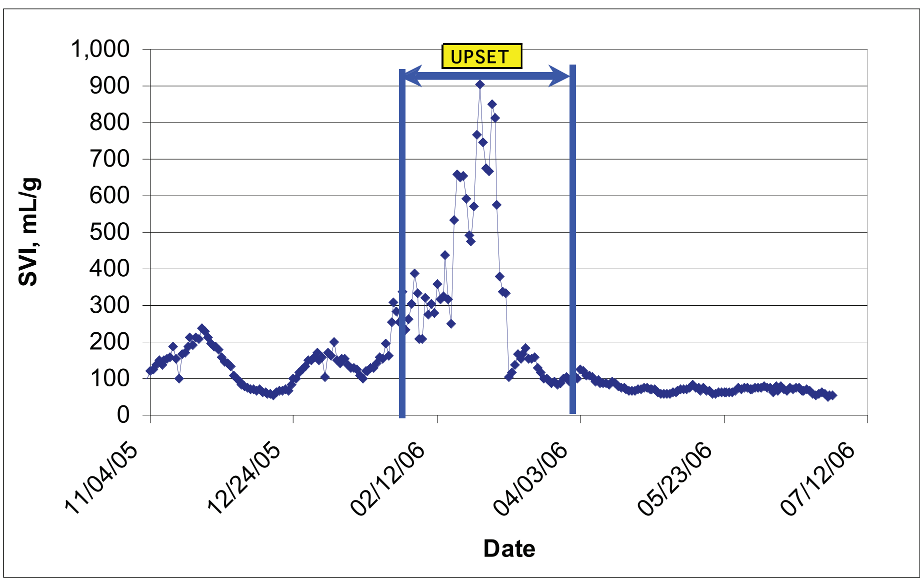

Figure 8. Typical Sludge Volume Index from November 2005 to July 2006

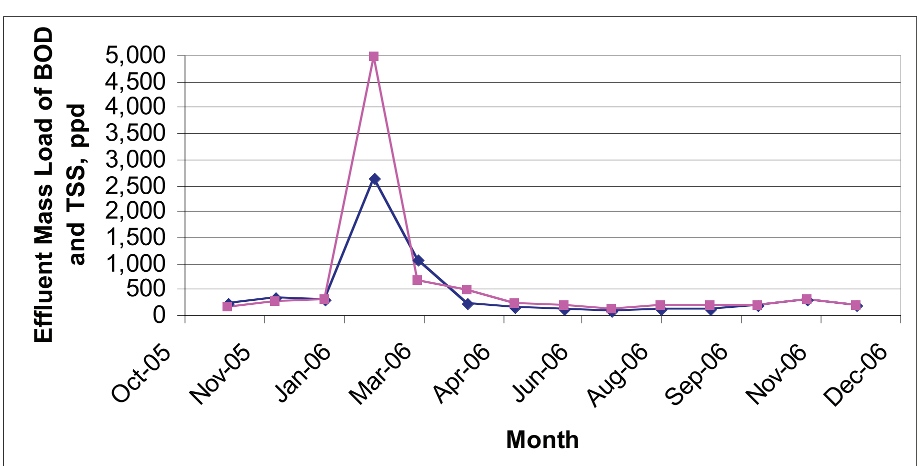

Figure 9. Historical Effluent Quality

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Figure 7.

- The solids inventory continued to decline from January 25 through the end of February, with the majority of the solids floating over the secondary clarifier effluent weir as opposed to a case of over-wasting sludge. The impact of solids loss is evident from the MLSS concentrations shown in Figure 6.
- Microscopic examination revealed that the sludge contained a large amount of filaments; the floc morphology was open, dispersed; and the numbers of indicator organisms were significantly reduced.
- The oxidant dosage was increased from 15 mg/L to 30 mg/L.
- The DO concentration and oxidation-reduction potential values of the overall facility are within the normal operating range.
- The solids inventory sheet indicates the facility is operating at a 3.5-day sludge retention time, yet the actual recorded values indicate the facility is wasting sludge at a rate producing a 10-day sludge retention time.
- The changing settlometer data reflects the effects of decanting waste sludge from the holding tanks back to the primary clarifiers. Microscopic examination of the decant liquor indicated that significant amounts of filaments and "old" activated sludge were returned to the primary clarifiers.

Solids loss continued and became so severe during February 2006 that nitrification was lost. As indicated in Figure 10, when the plant was nitrifying, it nitrified completely. There was some ammonia breakthrough in January, but that was attributed to the lack of DO caused by organic overload. The loss of nitrification marks the end of the first recovery effort.

Conventional methods of recovery from the filament bloom had failed. It was obvious that additional help was needed. A sample of MLSS was shipped to Dr. Michael Richard in Fort Collins, Colorado, who is a national expert in organism identification. During a follow-up telephone conversation, Dr. Richard clarified the term "septicity" or "septic conditions" in his report.

In many instances, septicity is used to describe a low concentration or complete absence of DO that can be corrected simply by increasing aeration to maintain a DO residual. This condition can be confused with an organic overload or a blower failure; however, as defined by Dr. Richard, septicity is also a condition of high concentrations of organic acids. The septicity produced by the high concentration of organic acids would have occurred in the collection system or in the primary clarifier and would persist into the activated sludge basin.

O21N, N. limicola II, and Thiothrix I all thrive on organic acids. Under aerobic conditions and with an abundance of organic acids, the filaments identified by Dr. Richard can out-compete the desirable floc-forming bacteria for organic acids. This explains why the recovery attempts after the failure of nitrification did not succeed.

The organic acids in the aeration basin influent enable the unwanted filaments to thrive and out-compete the other bacteria for food, and until the concentration of the organic acids is reduced, the system can not recover. Without nitrification to produce nitrate, the biological activity in the anoxic zone will not remove the organic acids, which then carry over into the aerobic zone.

Given the observations and recommendations by Dr. Richard, several evaluations were conducted to assess system status. Regular microscopic examinations of the primary sludge that were started at the end of February revealed filaments in both the primary sludge and the primary clarifier effluent. Primary effluent was chlorinated to prevent filaments from entering the activated sludge basins.

Both the sludge and the effluent in the primary clarifier were monitored for volatile fatty acids (VFA). The first evidence of septicity in the primary sludge was the low pH (around 5), which indicated active fermentation. The primary sludge blanket was being kept at four feet deep in an effort to thicken the sludge and thus minimize the hydraulic load on the anaerobic digesters. The solids capture by gravity belt thickeners and the belt filter press was still poor at the beginning of February because of the high SVI of the MLSS, and the solids were returned to the primary clarifier.

Samples of primary sludge and primary effluent were analyzed for VFA. On March 2 the VFA concentration was 360 mg/L in the primary sludge and 65 mg/L in the primary effluent; on March 3 it was 470 mg/L in the primary sludge and 50 mg/L in the primary effluent; and on March 4 the VFA concentration in the primary sludge was 410 mg/L and in the primary effluent it was 80 mg/L.

Since nitrification in the activated sludge basin had stopped, there was no nitrate for recycling to the anoxic zone. In fact, the anoxic zones were functioning more like anaerobic zones and were possibly causing the formation of more VFA. The high concentration of VFA in the primary clarifier effluent was providing the substrate for O21N to thrive in the activated sludge basins.

If the anoxic zone could be re-established, VFA could be consumed by nitrate reduction, making the environment in the aerobic zones more favorable for the growth of floc-forming organisms. A search was begun for a local source of nitrate.

Once the filaments had been identified, a new operating strategy was implemented. Chlorine dosage of primary effluent and returned activated sludge (RAS) was increased, and the addition of calcium nitrate to the anoxic zone was started at the beginning of March. The combination of nitrate and chlorine caused the sludge settling characteristics to improve rapidly.

Figure 11 is a repeat of the daily settling data shown on Figure 7; however, the time scale was reduced to 90 days to focus on the recovery period in early March, which reflects the rapid improvement in the MLSS settling volumes. Figures 12 and 13, which focus on the same 90-day period as Figures 6 and 8, show the rapid improvement in the MLSS SVI and the corresponding increase in the basin MLSS concentration, demonstrating that the system was recovering rapidly.

The true measure of system recovery, besides the improving SVI, was the re-establishment of nitrification in the activated sludge basin. Over the six-day period from March 13 to 19, the effluent ammonia concentration decreased from 30 mg/L to less than 2 mg/L as shown on Figure 14. Nitrification continued to improve through the rest of the month. Plant staff declared the upset ended on March 22, after the effluent BOD, TSS, and ammonia concentrations had returned to normal.

The upset at the Glendale Wastewater Treatment Plant appears to have been a single event; however, it occurred in two phases. The first phase was probably an ordinary low-DO

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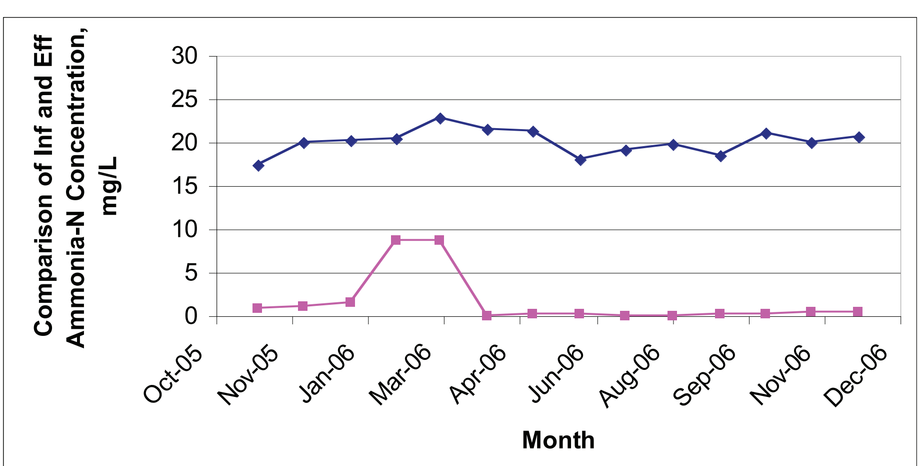

Figure 10. Ammonia Profile through the Glendale Plant During 2006

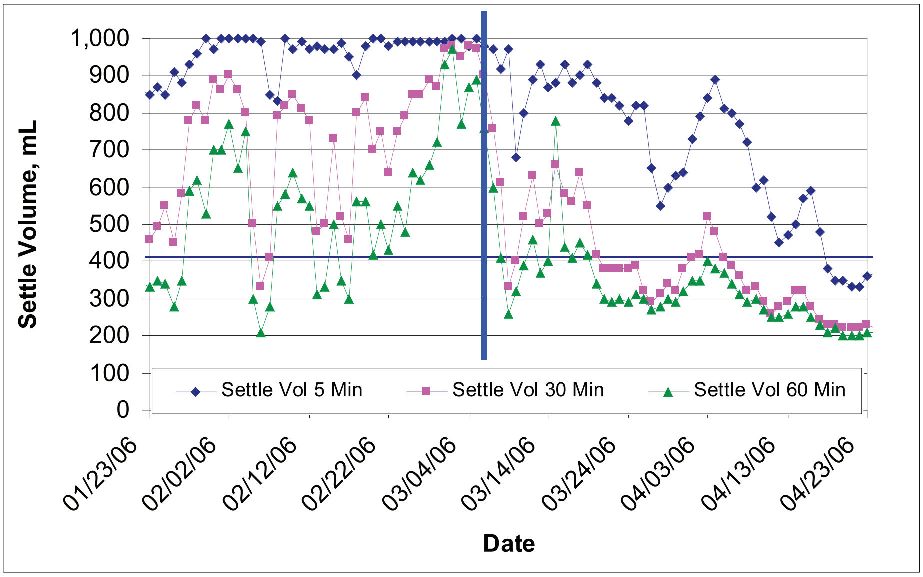

Figure 11. Daily MLSS Settling Volumes during the Recovery Period

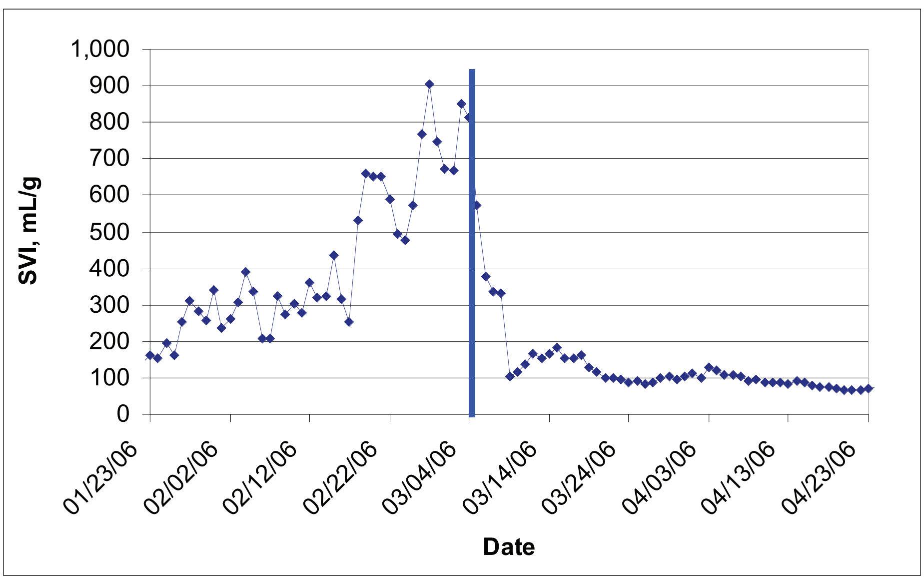

Figure 12. Daily SVIs during the Recovery Period

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filament bloom caused by the loss of DO control and the low DO in the activated sludge basin that resulted in a high SVI. Prompt action to increase the basin DO concentration and add oxidant to reduce the filament concentration should have resulted in rapid recovery, but in this case it did not work and the upset transitioned into the second phase.

The second phase of the upset involved a number of additional treatment units. Poor solids capture on both the gravity belt thickener and the belt filter press resulted in a large mass of active microbes being recycled to the primary clarifiers. Poor thickening led to a higher hydraulic load being sent to the anaerobic digesters. To reduce the impacts of this load, the depth of the primary sludge blanket was increased to thicken the feed sludge to the anaerobic digesters.

The result of these measures was increased fermentation in the primary clarifier and production of more VFA, so at this point, it did not matter if the organic load in the industry's discharge was still higher than usual because the primary clarifier particulate BOD in the influent flow was being fermented into VFA.

Continued high SVIs resulted in the loss of biomass (MLSS) from the activated sludge system and led to the failure of nitrification, which, in turn, led to loss of nitrate formation and thus the means to remove VFA in the anoxic zones because the oxygen source (nitrate) was no longer available. In fact, the anoxic zones became anaerobic and VFA formation in the activated sludge basin increased.

O21N thrives on VFA under aerobic conditions because these conditions enable it to out-compete other organisms for soluble BOD, specifically VFA, which is its favorite substrate. The result is an out-of-control filament bloom. Attempts to kill O21N with chlorine were unsuccessful because new filaments grew more rapidly than they could be destroyed.

One possible approach in such situations would be to increase the chlorine dose to get ahead of the filament growth rate, but this approach is very risky. Chlorine is an indiscriminant oxidant that kills any organism it comes into contact with, so applying it in high dosages might have also killed more desirable bacteria which would prevent recovery and keep the SVI high.

There are only three possible recovery approaches for such an upset. The first is to promptly correct the low DO concentration and to minimize filament formation before it gets out of control. The second approach also relies on rapid identification of the problem to reduce the filament population to a manageable level by adding an oxidant. Both of these approaches assume that the filament problem can be promptly identified and that it was caused by low DO. The third solution involves the use of nitrate to reestablish the anoxic zone, complete with soluble BOD (VFA) removal, and to add oxidant to kill the accumulated filaments.

Recommendations

The personnel of every wastewater treatment plant should develop a Standard Operating Procedure (SOP) or Process Upset Plan to be used in the event an activated sludge system or other major process is upset. System upsets start by appearing to be only minor malfunctions, but they can blossom into major events if left uncorrected.

A key issue is how to recognize non-ideal or abnormal performance. One of the first indicators for physical processes is a shift in BOD and TSS removal, but in the case of the activated sludge process, it can be a change in the SVI, in the basin DO concentration, or in the final clarifier effluent TSS concentration or turbidity; an increase in the final clarifier sludge blanket; a decrease in the RAS concentration; or a sudden shift in sludge age.

Maintaining an ongoing plot of these characteristics is essential. Watching the trends and using the data graphs to define "normal" conditions can often provide early warning that something is going wrong. The trend charts should be set up at least for 30, 90, and 180 days. Plotting daily data and superimposing a floating 30-day average line on the graph is very useful, as is establishing ranges for the characteristics and when they stray outside the normal range.

Track your historical raw influent and

activated sludge basin influent BOD mass and nutrient loads. Seasonal variations in domestic and industrial contributions can be tracked and anticipated. For example, utilities serving population centers that include colleges experience large seasonal shifts in user population, as do communities with seasonal migrations in population, such as resorts and tourism centers. Seasonal changes in industrial production schedules can seriously shift the normal mass load almost overnight.

Follow the trends, rather than a single data point. Refer to the last week of historical data to see if the data trend indicates that you are headed into dangerous territory. With one day of "bad" data, wait a day to see if the poor results persist. Do not panic over one day's data, unless it is effluent TSS. If you study the historical data, very few process upsets should come as a surprise.

Microscopic examination of the MLSS to look for an increase in filament population is essential. If practical, purchase a microscope that will accept a camera attachment to get pictures of the floc being examined. Developing a library of pictures of both good floc and excessive filaments will provide a yardstick for making judgmental decisions about excessive filament populations.

A rapid response by chlorinating RAS and restoring the normal oxygen concentration in the activated sludge basins may head off major upsets; however, this rapid response was not good enough to avert the upset at the Glendale Plant. During upset, adding COD analyses to the list of characteristics to be monitored will help identify the makeup of the organic loading. Another valuable tool is the oxygen uptake rates. Develop a standard procedure for including the activated sludge basin influent into an MLSS sample to determine the strength of the wastewater. This information can be used independently or in conjunction with COD and BOD data to confirm the organic strength of the influent.

Many people may think such a situation would never happen at their plant. With the regulatory push for nutrient control, many more facilities will be susceptible to VFA overloads. If your plant includes primary clarifiers or fermenters, it will produce VFA, and if the VFA concentration is too high, the result may be a bloom of O21N. If the influent is highly septic from industrial contributions, VFA will be formed in the sewer and too much of it will wind up in your plant.

While biological phosphorus removal plants need VFA, it is possible to get too much of a good thing. The real danger period is when nitrification is incomplete or when it stops altogether. In either case, there is not enough nitrate to trigger the removal of VFA in the anoxic zone, so the VFA concentration in the aerated section of the basin may get too high, as it did at Glendale.

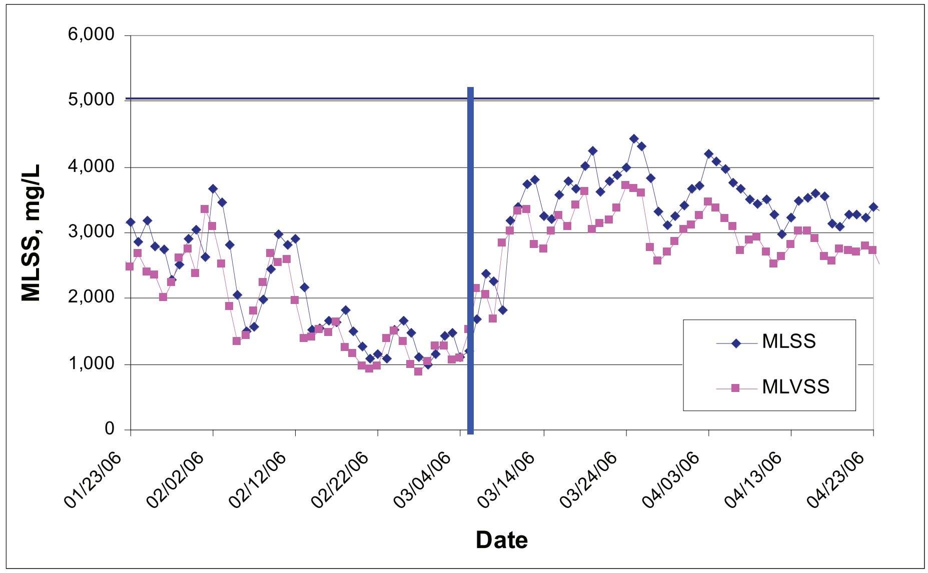

Figure 13. Daily MLSS Concentrations during the Recovery Period

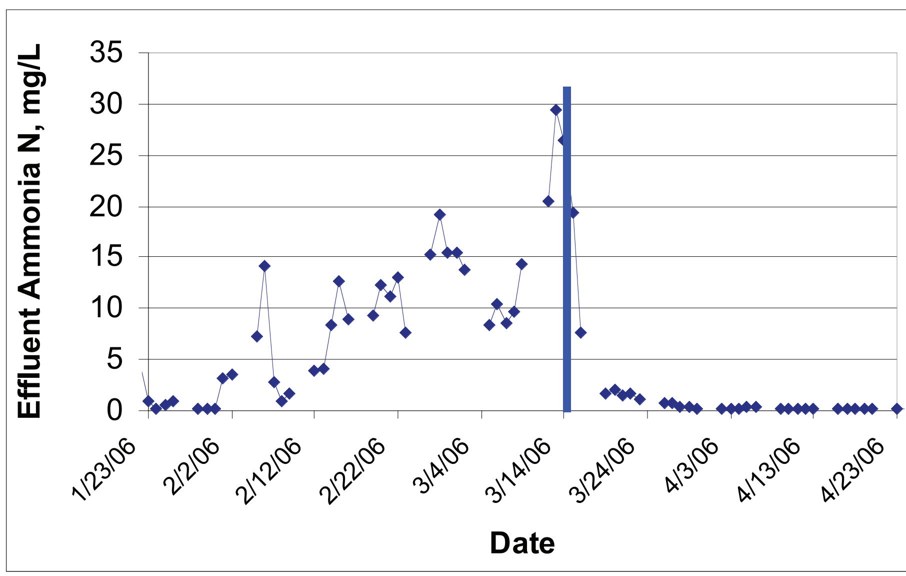

Figure 14. Daily Effluent Ammonia-N Concentrations during the Recovery Period

Finally, do not be afraid to seek outside help. For most plant upsets, it is assumed that staff members know the type of organism causing the poor SVI. Assumptions are dangerous because they can lead to a false sense of security. Sending samples to someone like Dr. Michael Richard at Fort Collins will help identify the filaments that are causing the problem.

More important, recognizing the type of filament and what stimulates its growth or understanding the conditions that are ideal for it will enable you develop an effective control strategy. For the Glendale Plant, this was essential. Understanding the conditions that allowed O21N to thrive enabled us to develop a multiple-prong strategy to remove VFA, the favorite substrate of O21N, and by applying chlorine to the RAS, O21N was rapidly purged from the system.

It sounds like a military operation, but these principles apply. If you know your enemy, you can beat it, so make sure that if your initial attempts at recovering the system fails, identify the filament and talk to microbiology experts to develop an effective strategy to remove the it.

After the crisis has passed, document what happened, what was done, what worked, and what didn't work. Describe the conditions that started the chain of events. Include pictures of the floc and a chronology of the chemical doses used. Put this report with your SOP or Process Upset Plan. Living through a major upset once is stressful. Having it happen a second time, and being unprepared, is painful.