SENTRY REVIEW FOR MUNICIPAL OPTIMIZATION OF DENITRIFICATION

11/9/2018

SENTRY DATA REVIEW: SECOND REPORT

1. Contents

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1. Executive Summary

The SENTRY system was installed on June 14th, 2018. This represents the interpretation of this data up till the end of October 2018. The sensor has shown the ability to recognize events which have significant effect on the biology. The sensor data correlates and complements the existing information collected on ammonia concentrations while providing required key BOD insights. Using the preliminary BOD correlations, the primary clarifier sensor has given additional insight into the changing organic load to the plant, as well as the important BOD/ammonia ratio (critical to denitrification efforts) throughout a day. This information will help the facility target and optimize their glycerol addition. The information that the SENTRY probe provides is unique as it provides data both on the relative organic strength (BOD) as well as biological response to known and unknown events. Typically, a separate, expensive and complicated sensor would be provided for BOD estimations and there is no probe available to receive instant updates to biological process upsets (ATP test kits are an example of a technology which is a snapshot of the biological health, but they are one off events and are expensive to run per event). Below we summarize key findings related to the sensor and suggestions on process optimization.

Key Process Insights and Findings:

- The facility's settled BOD/ammonia concentration ratio is 4.4, approximately 15% lower then the required 5.1. Micro C is being used to boost the BOD concentration. This would theoretically take ~5,000 gallons of Micro C per month. The treatment facility has been achieving sufficient denitrification with a maximum of 1,835 gallons/month (approximatley 33% of theoretical requirement).
- Micro C usage has increased steadily for bioreactors 3-6, with June (532 gallons) to October (1482 gallons). Except for August which 1249 gallons was dosed. The strategy has changed from only a total of 8 days (6.5%) where two doses of carbon where applied the same day (from June to September), to 13 days (42%) in October. The Dosing frequency and volume of Micro C added is nearly evenly distributed for Tuesday-Saturday with ~0.9 - 1.2 doses each day, while Sunday and Monday receive very little doses.
- The organic strength of the wastewater at the primary splitter box shows significant variabilty, showing up to 60% reduced metabolic activity from the hours of 8-10am. Tuesday - Friday all show reduced organic strength (down to -12%), while Saturday and Sunday show the highest organic strength (increase of 8 - 14%).
- The ammonia peak in influent lags only slightly behind the organic strength drop of the sensor. The anaerobic digestion's filtrate return continues to have a measureable impact on both the BOD/ammonia ratio, as well as significantly effecting the hours of the day that the plant is "light on carbon".
- BOD correlation to SENTRY MET showed a consistent response with the composite BOD samples. The plants daily BOD pattern can be seen, helping fill in the gaps of the composite sampling. Estimated influent BOD strength is between 150-250 mg/L.
- This BOD pattern was combined with ammonia data to understand the moving BOD/ammonia ratio entering the facility, data which should help to target glycerol dosing. Maximum BOD/ammonia ratio was observed around 12am, with the lowest occuring at 12pm. This shifted

back 1.5 hours after TOW01 was moved to the splitter box. The BOD/ammonia ratio fluctuates about 21% from the average per day.

Key Process Optimization Suggestions:

- Based on our sensor insights beginning Micro C dosing close to the sensor performance drop at 8am each day would be what is recommended from the data, with dosing to stop between 12 - 2 pm. Current primary dosing activities typically start at 9am and ends at 1pm. With additional data IWT can look to figure out what the optimal time period is for each day of the week, and look to implement suggestive alarms based on a specific drop in MET.
- Secondary dosing can also be matched up well with the sesnsor performance drop starting at 6-7pm, with dosing to stop around 11pm-12am. Due to this secondary drop being lower in magnitue (15% compared to 60%) then the primary drop, the dosing can be lower flow or shorter duration then the primary dosing.
- Micro C dosing is still considerably lower than the theoretical requirements (approx 33%). If improved removal rates are required incresaing dosing should be considered.

2. Site Information

2.1. Supplemental Carbon Addition

Glycerol addition (via Micro C) is being used for additional bioavailable carbon to drive the dentirifcation rates in the anoxic bioreactors. It is hypothesized that the influent bioavialable carbon is insufficient to drive the denitification process, especially on Wednesday and Thursdays. Initial estimates by the treatment facility of the cost for the addition of Micro C is between 100,000-200,000 USD/year at ~2.7USD/gallon micro C (37,000-74,000 gallons/year or 3,100-6,200 gallons/month). Dosing the Micro C as accurately as possible will minimize the financial burden of this dosing.

In correspondence with on-site personnel in March 2018, the plant appears to be set up similar to the Modified Ludzack-Ettinger (MLE) process, which entails primary treatment followed by an anoxic tank, followed by an aerobic tank, followed by clarification. The design is intended to allow bioavailable carbon entering the anoxic zone to come in contact with nitrate under anoxic conditions to allow denitrifcaiton to take place. This is accomplished by having a large internal recycle (typically 2-4 times the average wastewater influent flow (Metcalf & Eddy, 2004)), which carrys the nitrate produced in the aerobic tank back to the anoxic zone. The aerobic tank treats remaining available organic carbon, and then nitrifys the ammonia producing the nitrate. Inherently some of the nitrate produced will not be returned to the anoxic zone, and pass through to the effluent. Sludge is recycled from the secondary clarifiers back to the anoxic zone at a suggested rate of 50-100% of influent flow rate (Metcalf & Eddy, 2004).These type of plants can be designed to have effluent concentrations of TN at 4-10 mg/L (Metcalf & Eddy, 2004), with some references saying no better then 8 mg/L. These systems require a BOD/TKN ratio of 4:1 (Metcalf & Eddy, 2004). Ammonia can be used as a surrogate measurement, typically TKN/ammonia is 1.6 at raw or ~1.3 post primary clarifier (assuming 50% of organic nitrogen is settled out), meaning a BOD/ammonia ratio of >6.4 is optimal (non settled) or BOD/ammonia ratio of 5.1 (settled). Average influent BOD concentration:ammonia concentration (leaving the primary clarifier to go towards the bioreactors via the EQ tank, therefore settled) is 4.4 (137.7 mg/L BOD:31.6 mg/L ammonia), suggesting that additional carbon is required. Operators/designers need to be careful to not recycle too much D.O. back to the anoxic tank, as this will stop dentrification and encourage aerobic available carbon removal. Splitting the anxoic zones into 3 to 4 stages in series can increase kinetics, reducing overal retention time to 50-70% of a single stage design (Metcalf & Eddy, 2004).

In order to raise the settled BOD:ammonia ratio to 5.1 from 4.4, the average BOD concentration needs to be brought up to ~161 mg/L, an increase of ~24 mg/L. From June 6th to October 31st, 2018 the average flowrate into the plant was 7.72 MGD. This equates to:

$$7.72\ \text{MGD} * 3.78\frac{\text{L}}{\text{gal}} * 23.5\frac{\text{mg}}{\text{L}} BOD5 * \frac{1kg}{1000000mg} = 685\ kg\ BOD/day$$

According to Micro C's website, the Micro C solution provides COD at a rate of 1,100,000 mg/L. This equates to an average 165 gallons per day of Micro C, 5,008 gallons per month of Micro C and 60,096 gallons per year. At the 2.7$/gallon, this equates to an estimated 162,000 $/year. This assumes that 100% of the Micro C added to solution is bioavailable. Micro C product manual would need to be consulted to see if there was an additional safety factor of carbon addition.

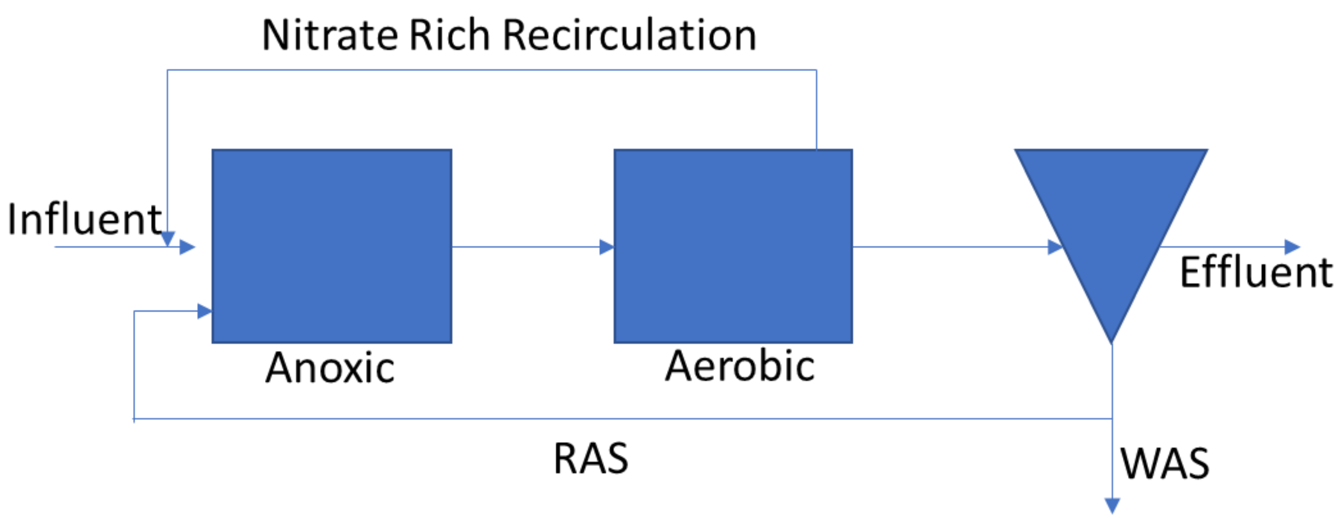


FIGURE 1 BLOCK DIAGRAM OF MLE PROCESS

The treatment facility is looking to add additional carbon to the anoxic tank to overcome assumed deficiencies in the BOD/TKN ratio of the plant. Ideally, the dosing would be intermittent as needed, so as to not pay for unneeded carbon and to not overdose the carbon (causing additional costs of carbon, as well as additional aeration costs to remove this carbon).

2.2. Existing On-site Data Provided

- Primary clarifier/influent ammonia concentrations;
- Flow rates through the system and estimated HRTs along the flow path;
- Filtrate pumping schedule and concentration;
- Influent 24 hour compositie BOD sampling;
- Bioreactor 4 nitrate and ammonia readings;
- Dosing schedule of glycerol (micro C) addition; and
- Aeration data.

Potential additional data that could provide additional insight:

- Remaining MET values from the panels – further bolster our correlations/observations;
- Nitrate data from the nitrate sensor closer to the effluent – Gives further clarity into iniatition of dosing cycles and their prolonged affect. Allows IWT to understand successful and unsuccesful dosing events;
- BOD/TKN/ammoina test of the plant filtrate – confirms that this loading back to the influent has a minimial effect, potentially understand options for keeping this return streams BOD/ammonia ratio in a better range;
- Grab samples of influent (TKN/BOD) – better correlations for instaneous MET/BOD and better correlations to TKN/ammonia ratio; and
- A log of the parameters/procedures that staff use to trigger a dosing event. Markup of times that staff noticed carbon getting into the aeration tank (aeration flow values were inconclusive).
- Additional BOD testing at the primary clarifier splitter box to further shore up BOD correlations at this area

3. Plant Parameters

Below is the Micro C dosing events combined with the influent ammonia concentrations.

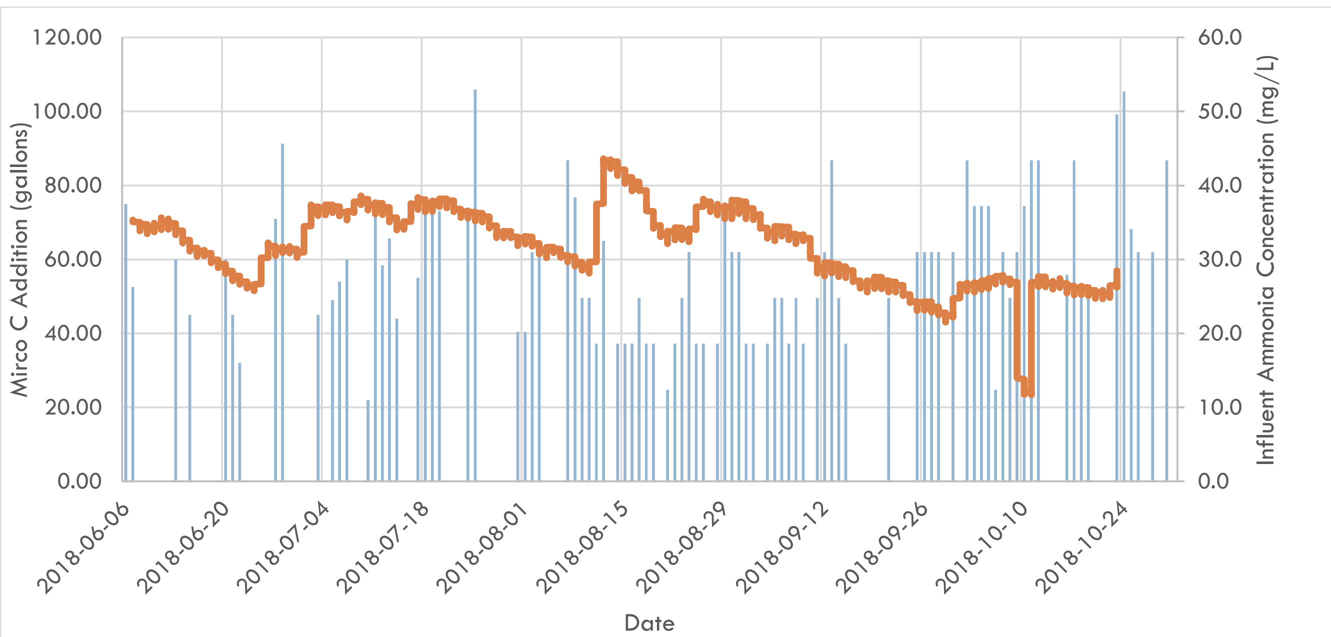


FIGURE 2 GLYCEROL DOSING SCHEDULE WITH NITROGEN DATA FOR BIOREACTORS 3-6. BLUE DATA IS MICRO C ADDITION, ORANGE DATA IS THE MOVING AVERAGE OF THE AMMONIA DATA

Total gallons dosed (532→1,482 gallons) and percentage of days dosed (30%→68%) has increased steadily from June to October. However, August's 1,249 gallons dosed with 81% of days receiving at least one dose was more consistent with the higher loading targeted in October. Days requiring two doses was relatively steady at 0-3/month, while October has increased to 13 days (42%) of days receiving two doses. Even at the highest usage rate of 1,835 gallons in October (total micro C added for basins 1,2,3-6, not shown) is only 30-60% of the original estimate of 3,100-6,200 gallons/month (~5,000 gallons/month as calculated above).

TABLE 1 DOSING SUMMATION OF BIOREACTORS 3-6

	June	July	August	September	October
days in month	30	31	31	30	31
# of days dosed	9	16	25	19	21
% of days dosed	30%	52%	81%	63%	68%
total gallons dosed	532	964	1249	980	1482
average gallons per day	59	60	50	52	71
# of two dose days	0	2	3	3	13

Maximum dosing of the carbon is done on the Wednesdays (averages of 61 gallons dosed/week, dosing 1.2 times per week). Tuesday/Thursday/Friday/Saturday are all similarly dosed with 45.8-52.7 gallons dosed/week and 0.9-1.2 doses per week for each. Sunday and Monday remain lower dosing days.

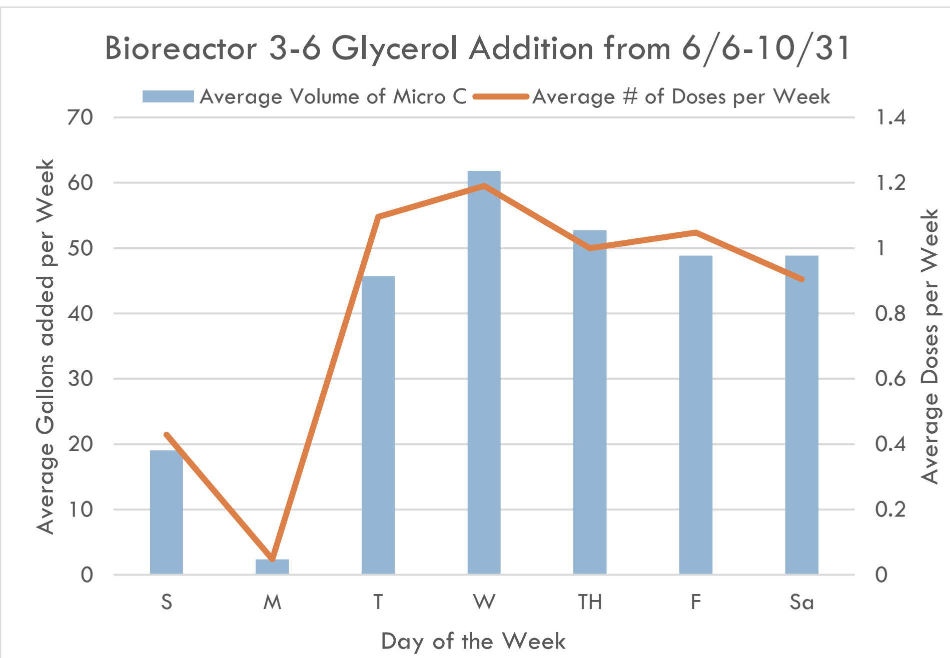


FIGURE 3 GLYCEROL DOSING BROKEN DOWN BY DAY OF WEEK

First dose on average started at 9:02 am and ended at 1:09 pm (4 hours 7 minutes). Second dose on average started at 6:33 pm and ended at 9:07 pm (2 hours 34 min)

4. SENTRY Data

4.1. Analysis on Filtrate Return

TOW01 sensor was installed in the Primary Clarifier from July 15th to October 2nd 2018. The previous report from IWT on August 31, 2018 “SENTRY DATA REVIEW” identified a repeatable shift in microbial response at specific time periods. Plant personnel were able to pinpoint this as the filtrate return flow from the treated anaerobic digesters. This lead to the analysis below, which has been updated to reflect the additional information provided to IWT for this report.

The 4:30pm to 7am trend which was previously picked up in the daily/weekly trend analysis. It was identified that this schedule matched quite similarly to the filtrate return that was scheduled at the plant. The summation of this can be seen in Table 2.

The anaerobic digester filtrate is collected (typically at 2% solids), sent through a screw press, an aerated liquid/solid separator (described as a DAF), and then returned to the front of the plant. During the Summer of 2018, the facility was also taking down one of its anaerobic digesters, during this time they slowly withdrew liquid from that anaerobic digester and sent it through the same process as their typical filtrate. They have been slowly releasing this anaerobic digestion reactor volume, only having to increase flows through the filtrate treatment system by ~15%.

The treated filtrate is transported to the primary clarifiers via a black 4-inch pipe, of which the last 150 feet of the pipe is in the sun. The first slug of this return flow could be at high temperatures. The mixture is also heavily aerated. Either of which could account for the initial large spike of data.

The filtrate return schedule is listed below. The facility pumps back the filtrate typically from 4 pm until either 7 am or 9 am the next day, providing a lot of the impact of this discharge over the off-peak hours, with flows between 210-240 GPM.

TABLE 2 SUMMATION OF FILTRATE DOSING SCHEDULE

start day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
finish day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
start hour	16	16	16	16	16	16	16
stop hour	7	7	7	7	7	9	9
total hours	15	15	15	15	15	17	17
flowrate (GPM)	240	210	210	210	240	240	240
total volume (million gallons)	0.22	0.19	0.19	0.19	0.22	0.25	0.25

The plant operators estimated that the filtrate return to the PC has an ammonia concentration of 200 mg/L, and an insignificant amount of organic carbon. Approximately 50-60% of the influent plant flow and approximately 50-55% of the mass of influent ammonia occurs from 4pm-7am every day. Using these assumptions, the below table was created. It shows that the additional ammonia during this time can have an effect on the total ammonia flowing through the system (15-19% increase), and subsequently the BOD/ammonia ratio dropping it as low as 3.66 (4.4 being the average for the facility). During the return period (typically 4pm-7am) this affect can be even greater, due to the lower flowrate and lower mass of ammonia during this time.

TABLE 3 POTENTIAL IMPACTS OF FILTRATE DOSING ON PLANT CHARACTERISTICS

start day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
finish day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
estimated ammonia in filtrate (mg/L)	200						
daily kg ammonia/discharge	163	143	143	143	163	185	185
average influent ammonia per day (kg/day)	974						
additional daily ammonia from filtrate	17%	15%	15%	15%	17%	19%	19%
new daily BOD/ammonia ratio	3.73	3.80	3.80	3.80	3.73	3.66	3.66
daily kg ammonia/discharge (from 4pm-7am)	497						
additional ammonia percentage (from 4pm-7am)	33%	29%	29%	29%	33%	37%	37%
new BOD/ammonia ratio (from 4pm-7am)	3.28	3.38	3.38	3.38	3.28	3.17	3.17

Recycle flow from anaerobic digesters can have significant ammonia concentrations (>1000 mg/L), BOD concentrations (100-3000 mg/L), and TSS (500-10,000 m/L) (Metcalf & Eddy, 2004). These high values are likely not the case for the facility due to their pretreatment steps, however, they have been included for reference. The higher the filtrate return BOD/ammonia ratio is, the better for the anoxic reactors. Depending on what each treatment step is removing, it might be helpful to provide less BOD removing treatment compared to ammonia removing treatment to the solution (i.e. potentially removing the solid/liquid separation or diverting some portion of the untreated from this to the headworks, if the plant can handle the additional solids as that should have higher BOD/ammonia ratio then the rest of the stream). A deeper understanding (i.e. grab or composite sampling) of this side stream, potentially at different locations of pretreatment might help understand why the SENTRY has such a strong response to the filtrate return.

4.2. Weekly and Daily Patterns at Primary Clarifier Splitting Box

TOW01 was installed at the Primary Effluent Splitter Box on October 2nd, 2018. This new location is just infront of the anoxic bioreactors and therefore should provide the most representative data for what is being fed to these bioreactors. They immediately reached steady state and began showing a repeatable trend. An example of these trends is shown below

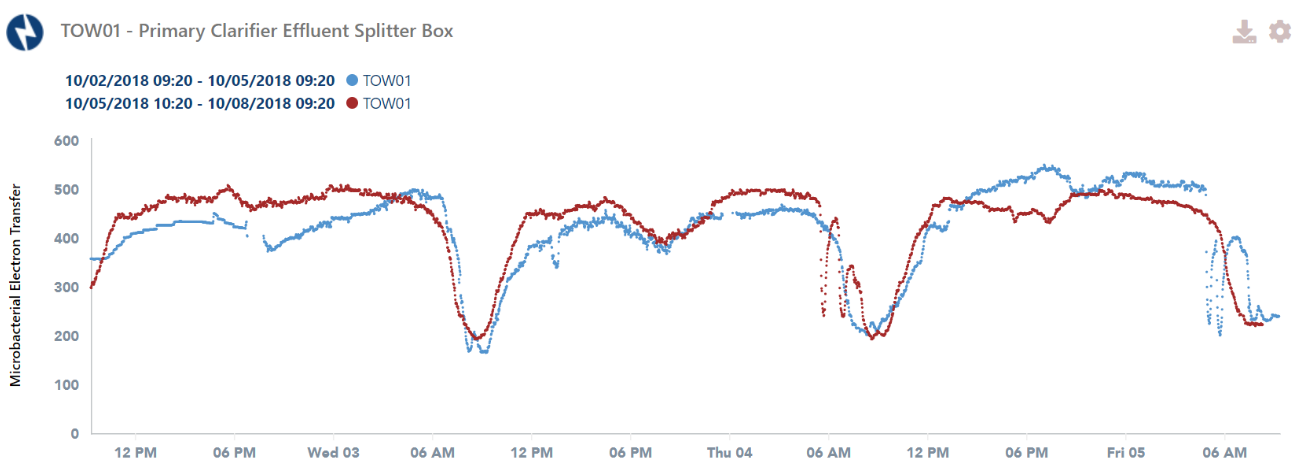


FIGURE 4 TOW01 TREND

- The signal showed that the sensor was reading reduced biological activity starting at 630-730am, with lowest activity at ~8-10am, with a return to full strength ~12-2pm.
- This reduced activity was approximately a 60% drop
- A secondary decrease in signal is observed starting around 6-7 pm with the lowest activity typically around 7:30-8pm. With a return to full strength by 11pm-12am.
- This drop reduces the MET value by 15%
- With additional data, IWT can look to figure out on average each day of the week that the organic concentration drops and could signal a dosing event. IWT can additionally look to implement an alert system to trigger during periods of significant drop.

A deviation from this pattern has been observed on three different days:

- October 5th (Friday) at 5:07 am and 5:45 am
- October 7th (Sunday) at 6:46 am and 7:54am
- October 22nd (Monday) at 00:59am and 1:37am

These are shown below:

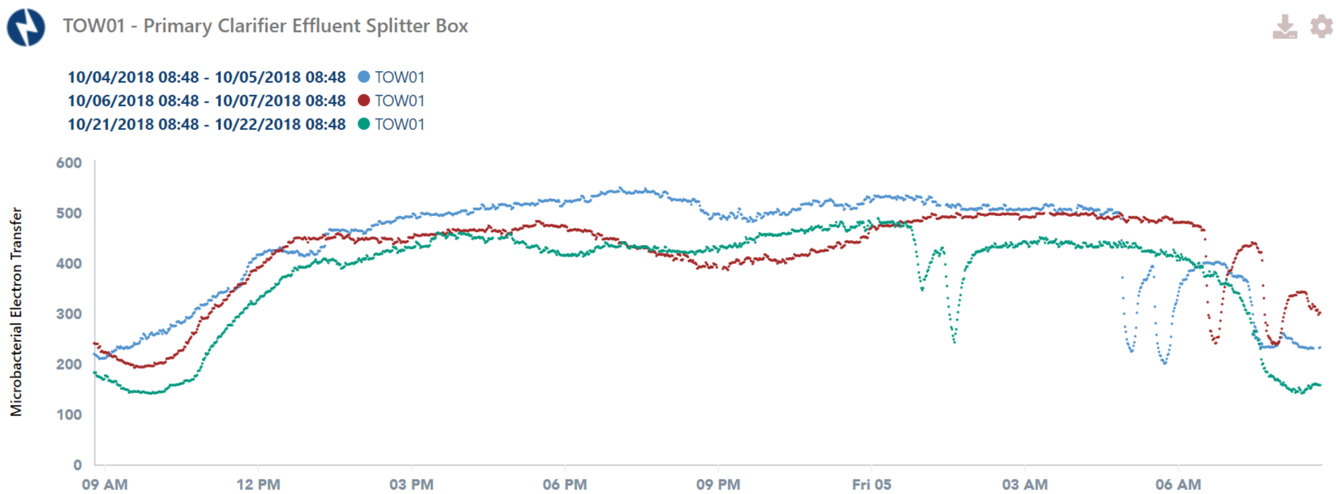


FIGURE 5 ANALYSIS OF ABNORMAL RESULTS

These time periods also corresponded to a dip in ammonia concentration in bioreactor 4-zone1.

- October 5th (Friday) at 5:07 am and 5:45 am-ammonia drops from 7.2→5.8 mg/L, nitrate rises 2→2.6mg/L
- October 7th (Sunday) at 6:46 am and 7:54am- ammonia drops from 9.2→7.8, nitrate rises from 2.1→2.3mg/L
- October 22nd (Monday) at 00:59am and 1:37am-no nitrogen data at this point

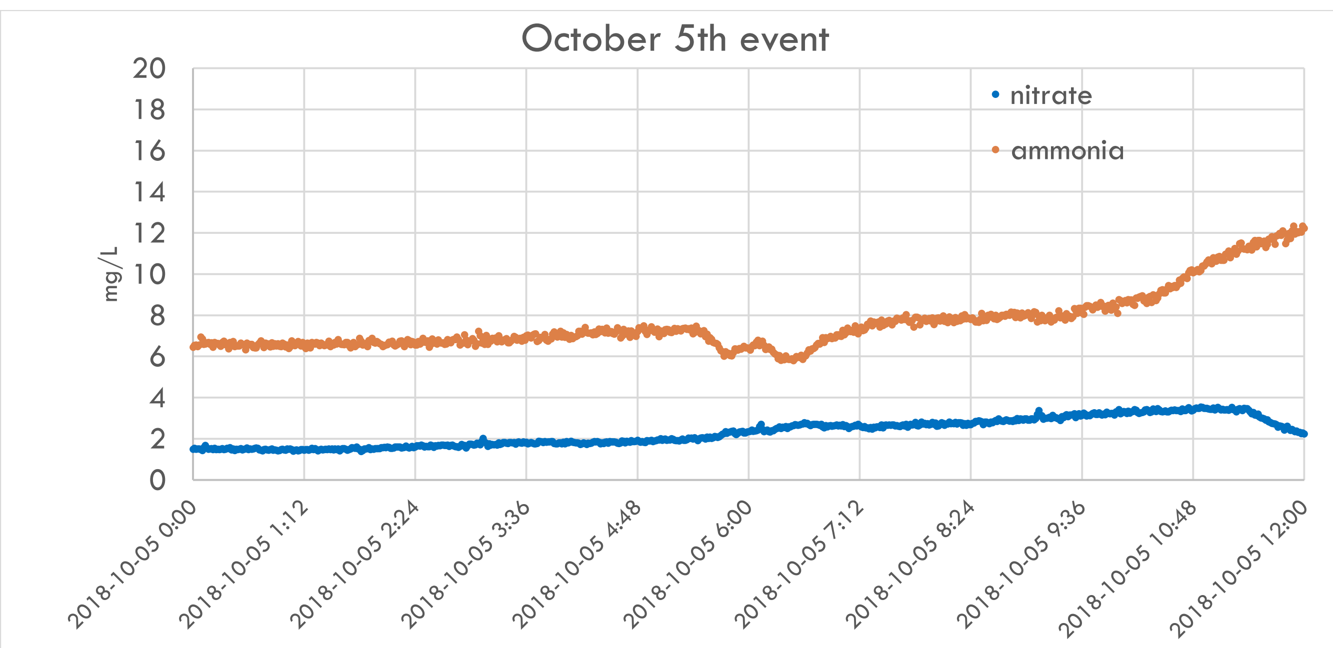


FIGURE 6 OCTOBER 5TH EVENT WITH AMMONIA DROP, NITRATE RISE.

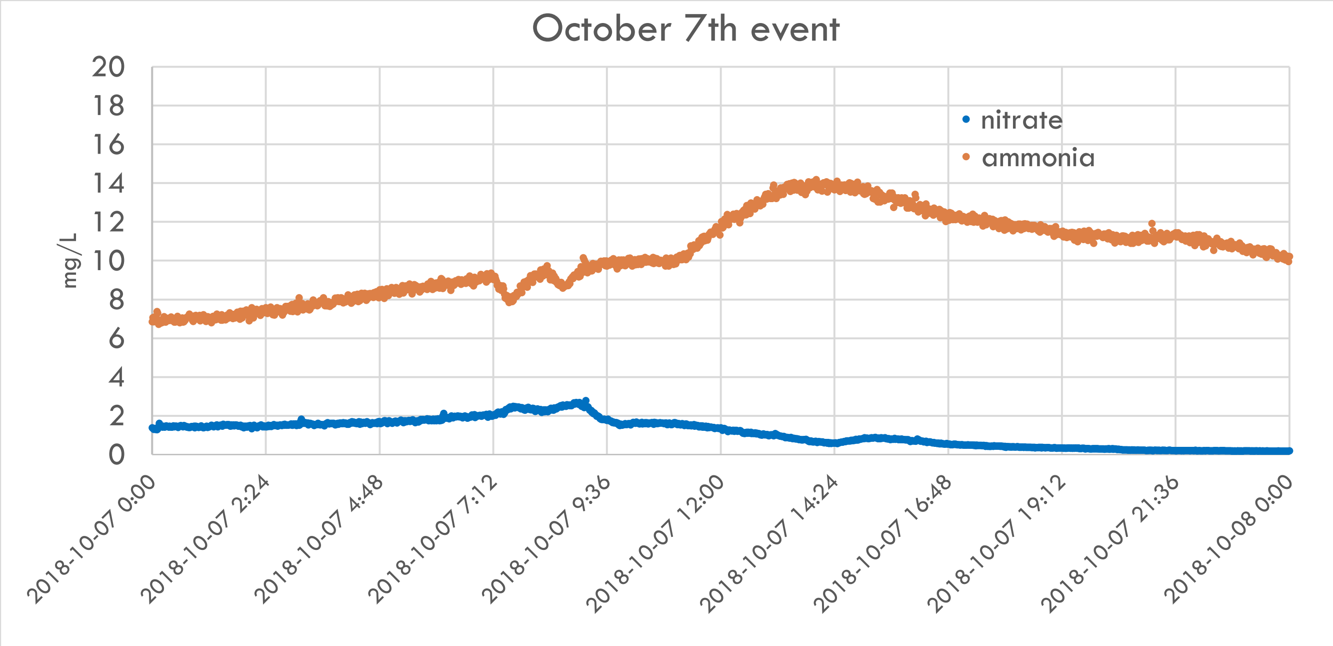
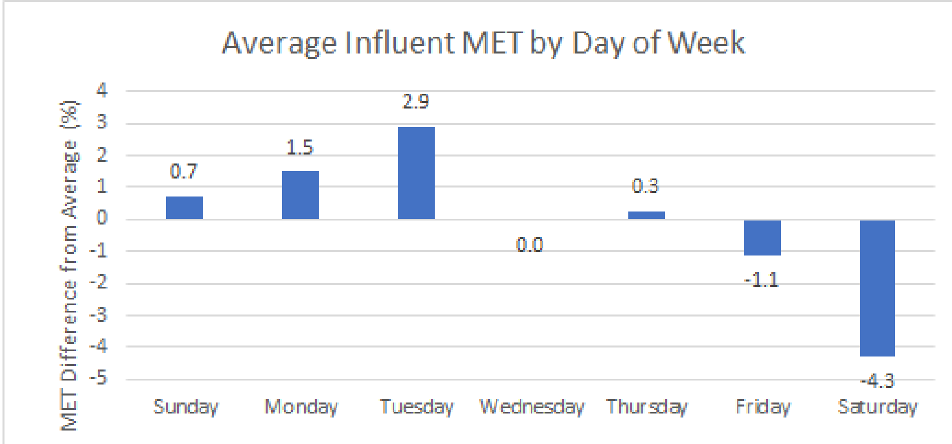


FIGURE 7 OCTOBER 7TH EVENT WITH AMMONIA DROP, NITRATE RISE.

Due to the infrequency of these events, this is not significantly affecting the biology of the system for extended periods of time. However, the source of these conditions should be investigated as this type of abnormality could mean a number of different things in regards to plant operation/conditions.

4.3. Average Influent MET by day of Week (Primary clarifier and Primary clarifier splitter box)

The days of the week average MET values were examined, to tabulate which day had the highest strength wastewaters. This was done for the sensor at the primary clarifier (July 18th to September 19th) and the Primary clarifier splitter box (Oct 2nd-Oct 24th). The primary clarifier splitter box has significantly less data, and as more data is collected at the location the more likely it is that the magnitude of the percent change is reduced. The results are shown below.



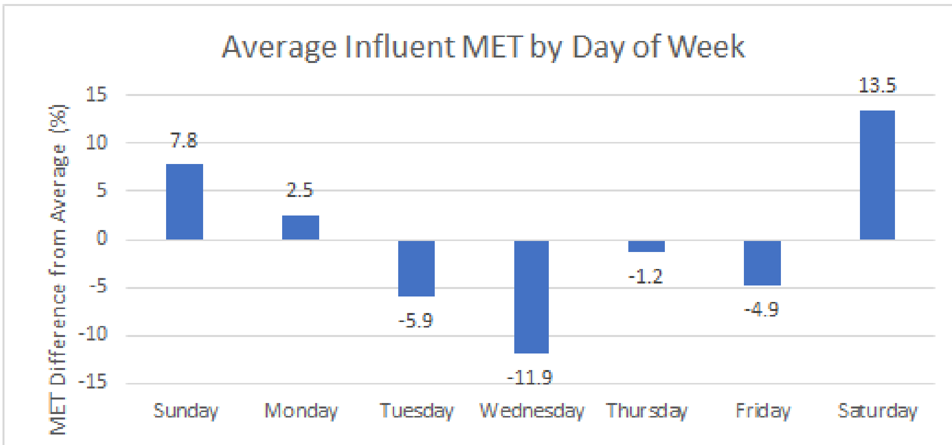


FIGURE 8: DAILY AVERAGE COMPARED TO WEEKLY AVERAGE TO DETERMINE HIGH/LOW INFLUENT DAYS OF THE WEEK. THE TOP GRAPH IS THE SENSOR LOCATED AT THE PRIMARY CLARIFER WHILE THE BOTTOM GRAPH IS THAT OF THE SENSOR INSTALLED IN THE PRIMARY CLARIFIER SPLITTER BOX

The data shows an interesting contrast between the two sensor locations. Showing that the high strength influent coming into the plant is primarily focused on Monday and Tuesday (1.5-2.9% increase), with minimal load coming on the Saturday.

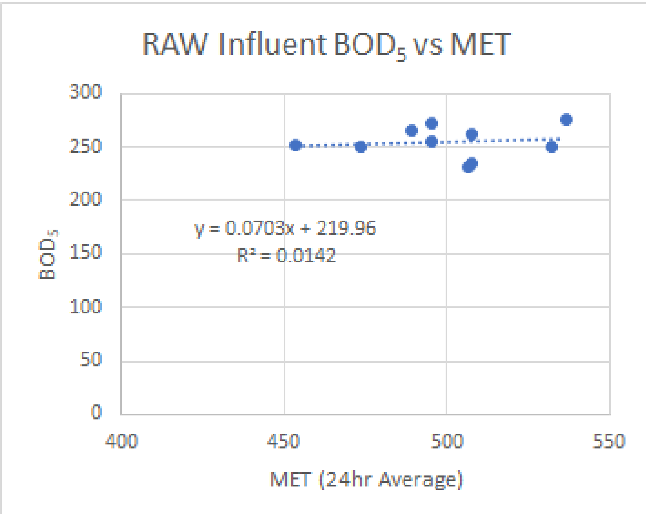
By the time the wastewater has moved through the equalization tank (located between the primary clarifier and primary clarifier splitting box), the time period of relative strength has changed dramatically.

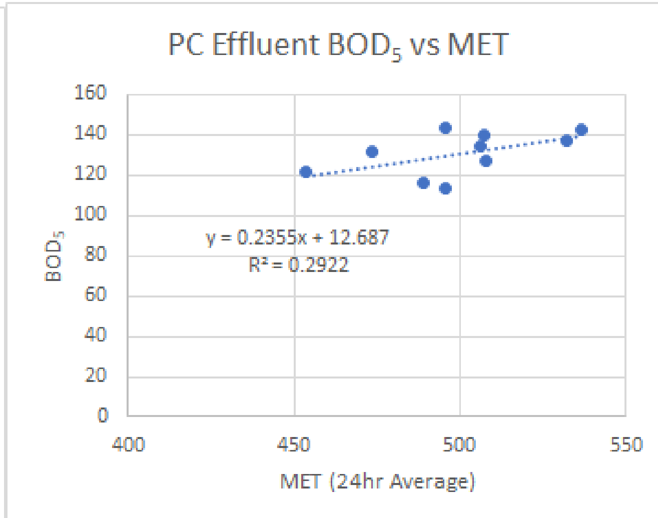
The primary clarifier effluent splitter box has considerably lower organic strength on Tuesday/Wednesday and Friday. This is consistent with the issues that the facility has had with high nitrate in the effluent later in the week. This also shows that the targeted application of the MicroC to days Tuesday-Friday make good sense (consistent with current dosing), however Saturday dosing may not be as important unless that day is specifically higher in nitrogen concentrations.

4.4. Full MET and BOD_5 Estimation at Primary Clarifier

The 24 hour composite sample results provided were compared to the 24 hour average MET signal during those collection periods. Results from the raw influent and a sample point just after the primary clarifiers were used. Staff estimated that the sensor was located approximately 80% of the way to the PC effluent sample and 20% close to the raw influent. The raw influent concentration does not appear to be well correlated to the sensor location, while the PC effluent and weighted BOD data shows a consistent upward slope on the data. Due to the changing nature of the waste throughout the day (both in absolute BOD_5, biodegradability and flow) it would be worth adding in a few grab samples to further increase the strength of these correlations.

Outlying data points from the last two weeks of September into early October were analyzed and interpreted to be invalid for the MET to BOD correlation. One BOD 24-hour composite sample from September 20th showed an abnormally low BOD reading in correspondence with the 24 hour average MET reading, raising concern if the sample location was changed.





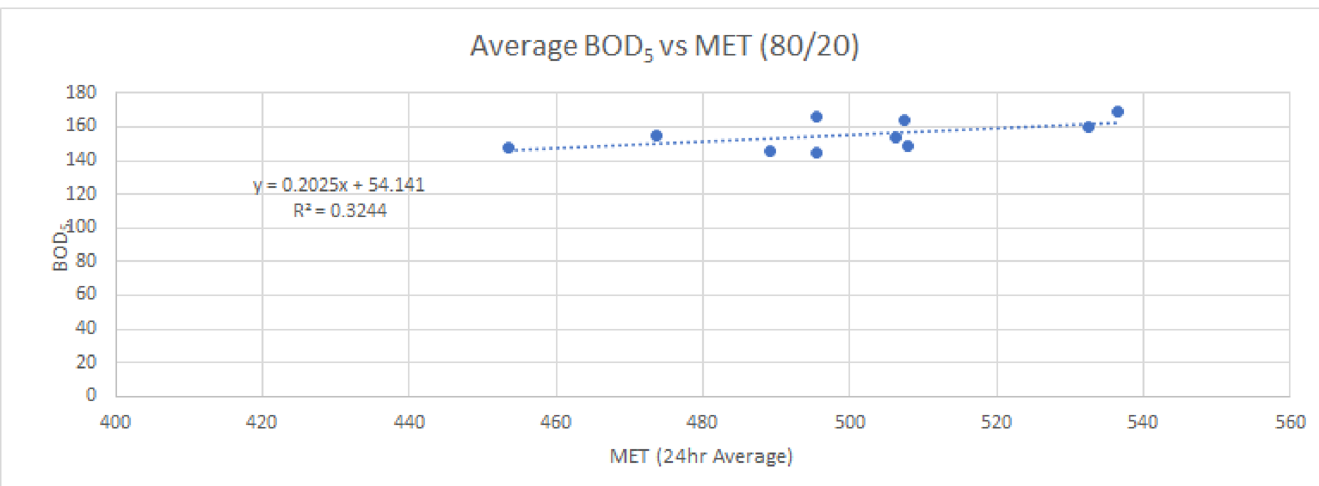
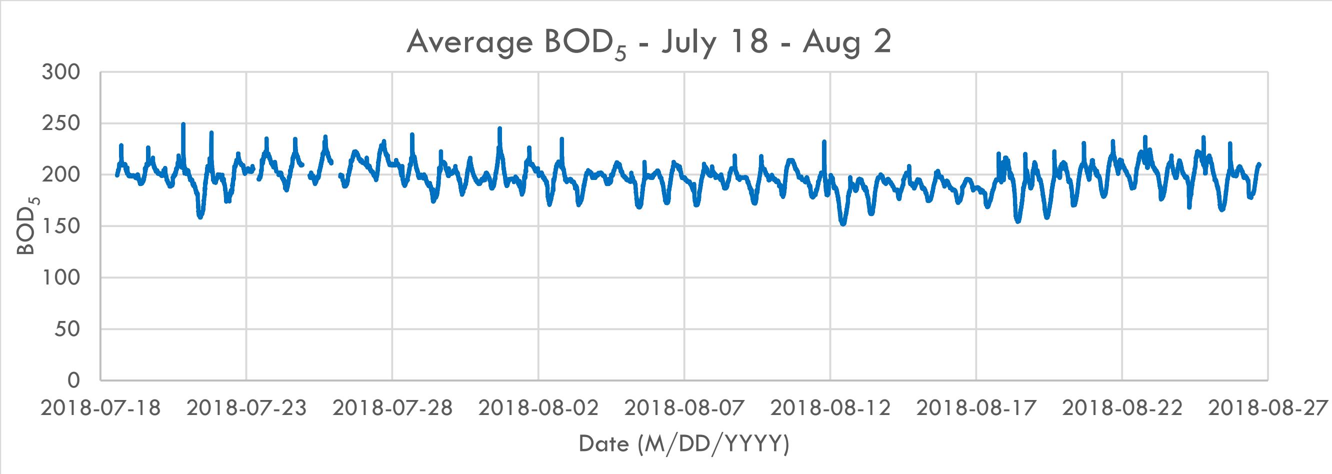


FIGURE 9 TOW01 (PRIMARY CLARIFIER) MET VS. BOD_5

IWT would recommend that correlations begin to be developed at the new location, the primary clarifier splitter box.

These correlations were used to provide an estimate of the available BOD concentrations during this test period. This data was used to fill in the gaps associated with only having a composite sample (1 test point per day), and to see the variance throughout a day, shown below.



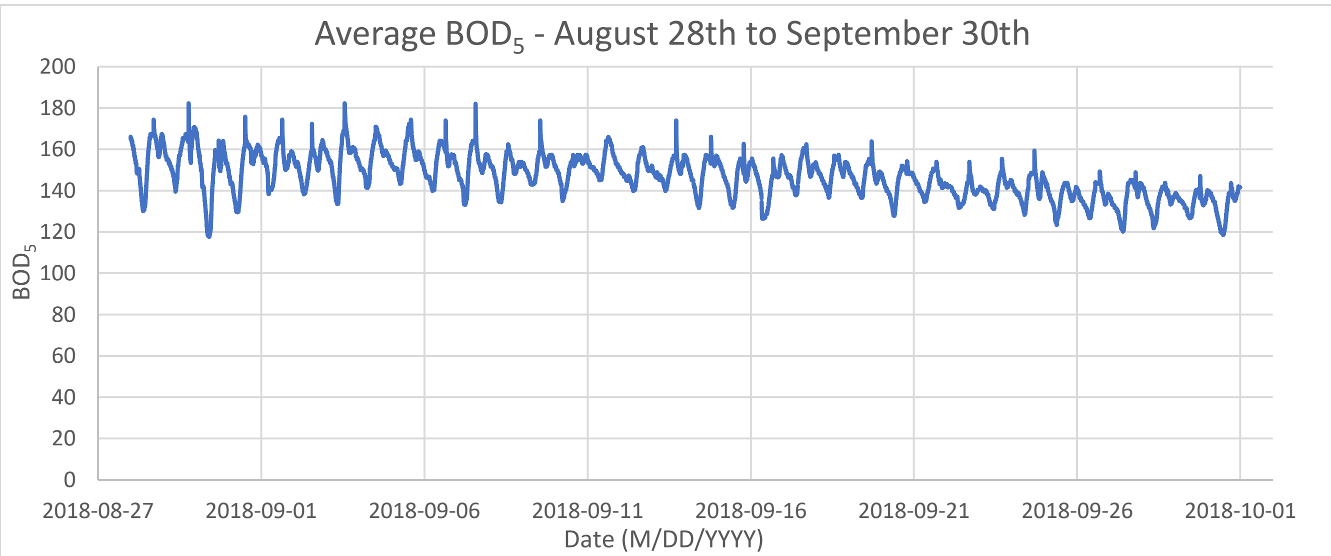
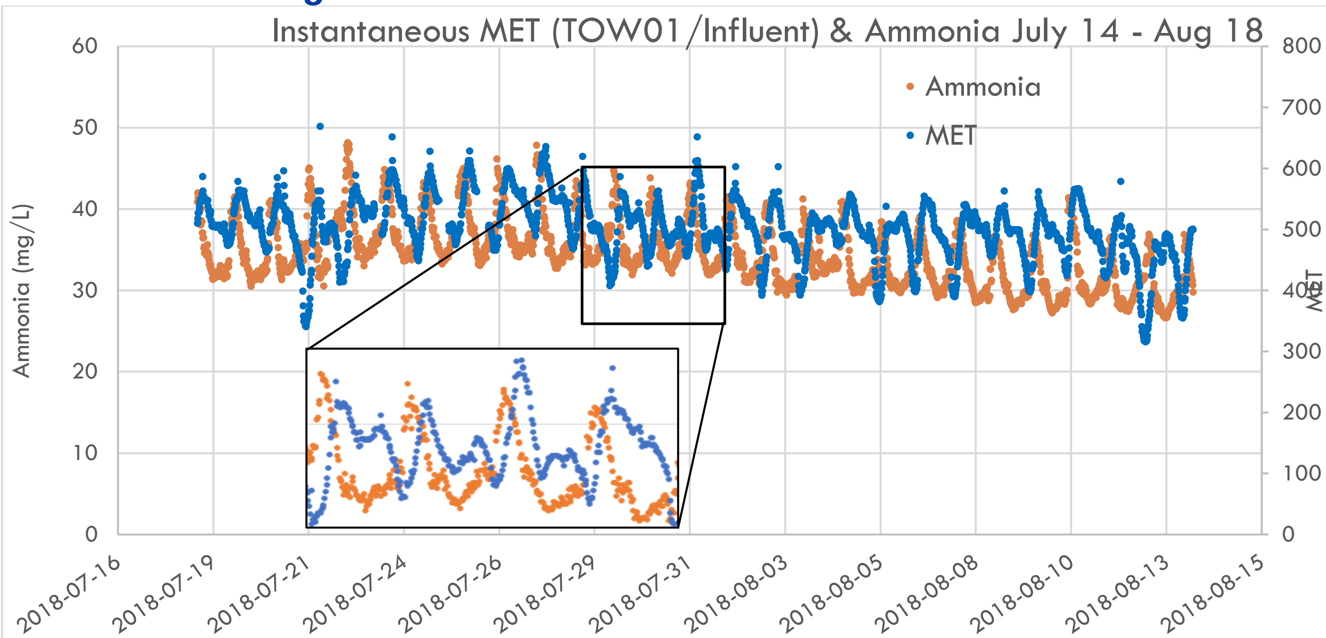


FIGURE 10 ESTIMATED BOD_5 CONCENTRATION (PRIMARY CLARIFIER) VS. TIME

- The average BOD ranges from 140-250 mg/L
- The BOD is generally highest between 4-6pm and lowest between 7-9am daily
- There is a downward trend in BOD concentrations as the data moves into the fall season
- The data from Aug 27th shows a shift down in BOD as compared to earlier data. This is due to the availability of more BOD sample data.
- Trend analysis of this data can be seen in Figures 6-8

4.5. MET Integration with Ammonia Data



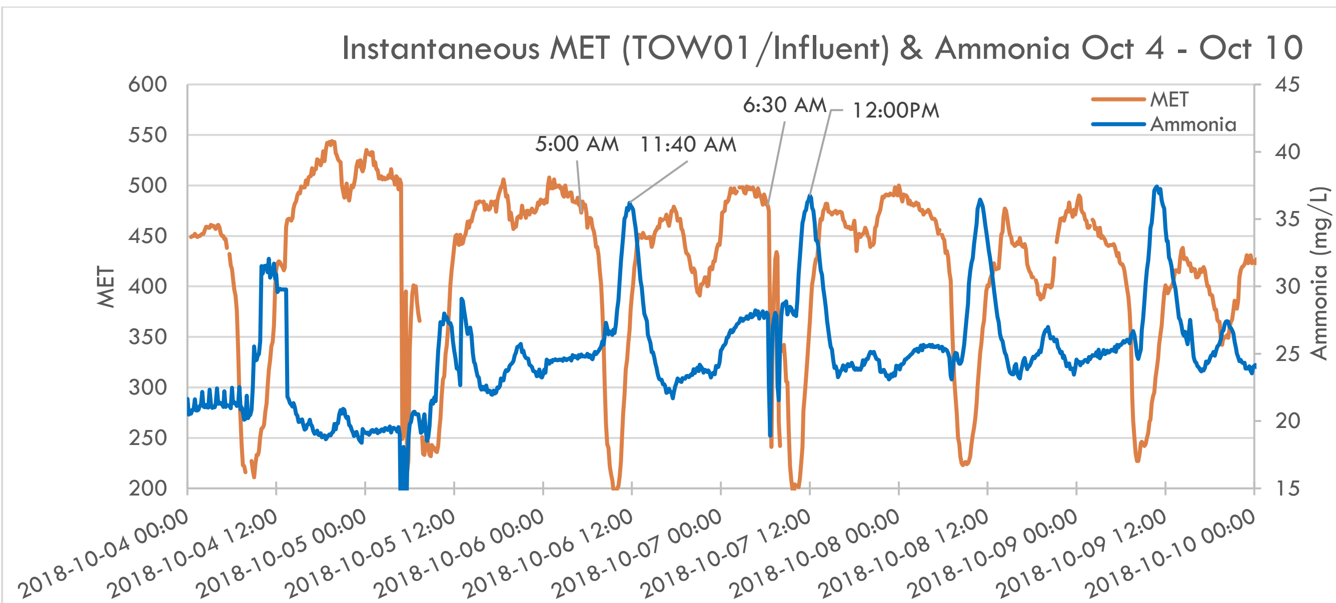
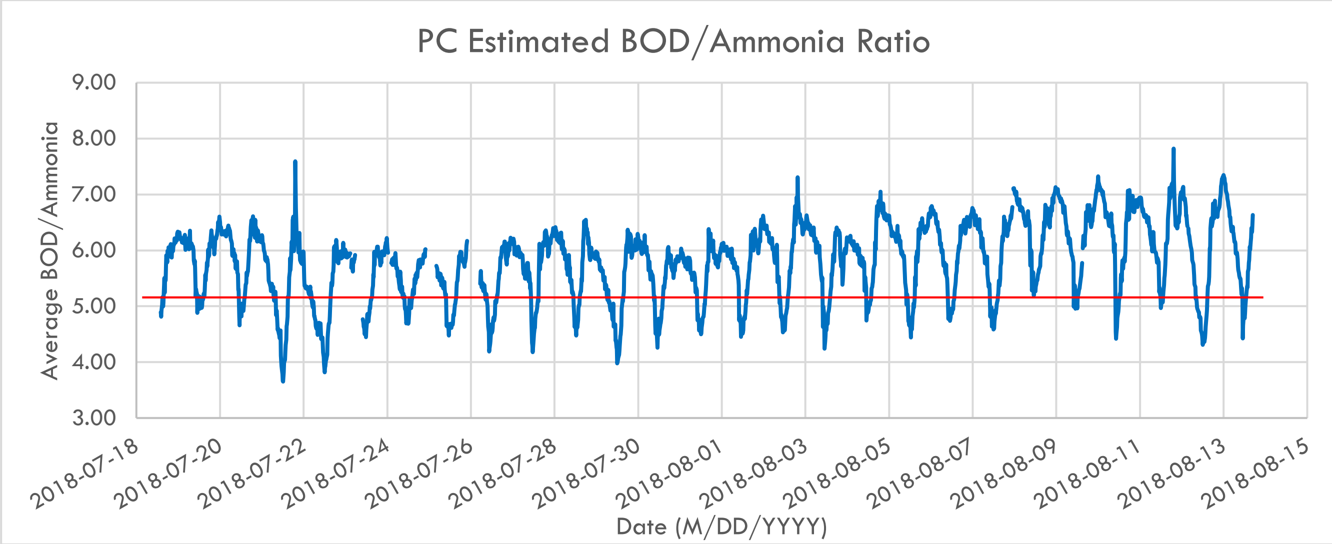


FIGURE 11 TOW01 MET AND AMMONIA VS. TIME

- During times the MET signal decreases, ammonia concentrations spike.
- Between the hours of 4:30-6:30am the MET begins to decrease rapidly, followed by ammonia concentrations beginning to increase at 8-9am and peaking between 11am-12pm.
- The first daily addition of glycerol takes place between the hours of 9-11am.
- It appears that the composition of the wastewater changes with the time of day as shown by the secondary smaller peaks in ammonia concentration. This also coincides with a decrease in MET.
- The magnitude of the peaks and troughs of MET are reflected in the ammonia concentration.



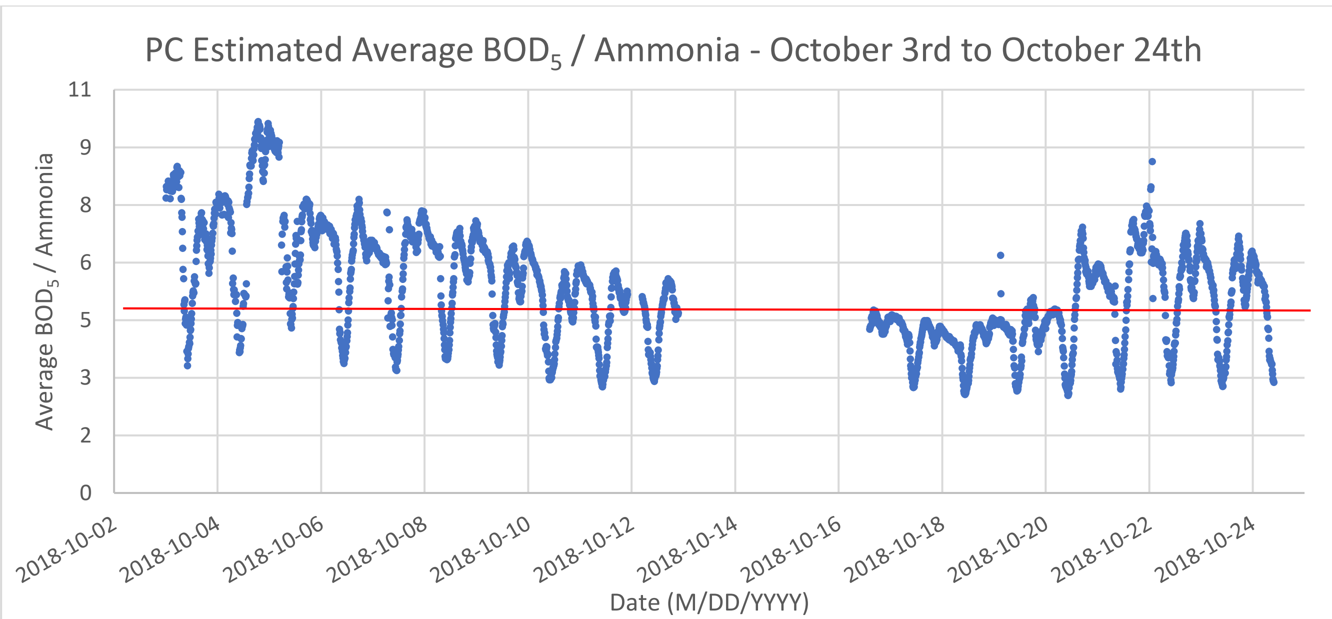


FIGURE 12 ESTIMATED BOD/AMMONIA IN PRIMARY CLARIFIER

- A BOD/ammonia ratio of 5.1 is added via the red line
- The BOD/Ammonia ratio is highest around 12am and lowest at 12pm prior to moving TOW01 to the splitter box.
- After moving TOW01 to the splitter box the BOD/ammonia ration is highest around 10:30pm and lowest at 10:30am.
- During the period of July 29th-Aug 2nd we see the daily BOD/Ammonia ratio peak begin earlier around 7:30pm and continue at this level over a 9-hour period before dropping.
- The BOD/Ammonia ratio fluctuates about 21% from the average daily.
- The data missing between Oct 12th – 16th is due to a power outage.

5. Conclusion

TOW01 has begun to show interesting correlations with available organic carbon entering the facility. This is helping to fill in influent organic data set around the BOD composite samples. Combining this information with the inline ammonia/nitrate sensors can greatly assist in understanding the plant's loading and changing loading throughout the day/week. The very clear correlations that exist with spiking ammonia concentration and the drop in the SENTRY readings demonstrate the sensitivity of the microbes to the lower BOD concentrations in the wastewater stream.

The facility has a low (4.4) BOD/ammonia ratio requiring supplemental carbon dosing for appropriate nitrate removal. Estimates of required Micro C dosing would require up to 5,000 gallons per month. Personnel are currently meeting their nitrate limits with a maximum of 1,835 gallons/month. A SENTRY sensor was installed at the primary clarifier splitter box and has shown a correlation to BOD5 testing done. The sensor's results show that the organic strength of the wastewater is significantly less (up to 60%) during 8-10 am (primary dosing window) and 15% lower around 8 pm (secondary dosing window). Personnel are currently primary dosing at approximately 9 am to 1 pm, with a second dose at 6:30 pm. The sentry data supports this dosing schedule, though it would suggest that typically the dosing could start at 8 am instead and would suggest that the secondary dosing could be pushed back an hour. The secondary dosing could be of a smaller size (duration or flowrate) then the primary dosing

TOW01 trend analysis was additionally used to recognize that the filtrate return was causing the MET of the sensor to change in a repeatable fashion. The constituents of that wastewater are affecting the biology on the sensor and may have further impacts on the biology downstream of the sensor. It does reconfirm the fact that this filtrate return is a critical piece of the nitrogen removal process. With additional analysis of BOD and TKN, there may be specific time periods that it may make sense to return that filtrate to maintain a healthy BOD/TKN ratio. For example, if it is indeed devoid of much bioavailable carbon then feeding it back to the plant during the highest BOD/ammonia periods may help normalize the performance of the system.

The longer the sensors are installed, the more IWT can improve these data sets and fine tune what events are background state and what are significant/impactful changes. The goal of this is to help the facility most efficiently use their resources and understand the effects that specific actions and events (known and unknown) have on the facility.