Water Quality Investigations

Date:	November 11, 2019
Client:	Heart of the Valley Metropolitan Sewerage District (HOVMSD) Strategic Municipal Services Inc. (SMS)
Project Description:	Corrosion Assessment – Wastewater Interceptor System

Sample Sources:	Wastewater Interceptor System
Sample Date:	September 9, 2019
Tests by WQI:	Biofilm Indication Test (BIT) and Biofilm Activity Test (BAT)

Sample Name:	**Area of System That Sample Represents:**
S6 Air	Concrete coupon suspended in the air above the wastewater stream at sewer location S6. Sample represents air/concrete surface conditions above the wastewater stream at location S6.
S6 Sewage	Concrete coupon submerged in the wastewater stream at sewer location S6. Sample represents conditions in wastewater at location at S6.
S9 Air	Concrete coupon suspended in the air above the wastewater stream at sewer location S9. Sample represents air/concrete surface conditions above the wastewater stream at location S9.
S9 Sewage	Concrete coupon submerged in the wastewater stream at sewer location S9. Sample represents conditions in wastewater at location at S9.
S16 Air	Concrete coupon suspended in the air above the wastewater stream at sewer location S16. Sample represents air/concrete surface conditions above the wastewater stream at location S16.
S16 Sewage	Concrete coupon submerged in the wastewater stream at sewer location S16. Sample represents conditions in wastewater at location S16.
S24 Air	Concrete coupon suspended in the air above the wastewater stream at sewer location S24. Sample represents air/concrete surface conditions above the wastewater stream at location S24.
S24 Sewage	Concrete coupon submerged in the wastewater stream at sewer location S24. Sample represents conditions in wastewater at location S24.
Damaged	Concrete coupon samples with this descriptor were completely corroded away. In lieu of testing the concrete coupon, the hardware holding the coupon was tested.

Summary

Eight concrete coupons were deployed at four sites for a period of ten weeks during the warm weather season. Four coupons were suspended in air above the sewage and four were submerged in sewage flow. At the end of the deployment period, all four coupons suspended in air at each site were present; two from each site were harvested for analysis. At Sites S6 and S24, all four coupons submerged in sewage were present; two from each site were harvested for analysis. At Sites S9 and S16, only one of the four coupons originally submerged in sewage was present and was harvested for analysis. The submerged coupon from S9 was severely corroded – this sample could only be analyzed in the soaking assay for BIT and BAT. The submerged coupon from S16 was corroded but was able to be split into two samples at a crack in the coupon to allow for full analysis.

The following factors appear to drive microbial induced corrosion (MIC) processes in HOVMSD's interceptor system:

- Off gassing of ammonia to the air/headspace of the interceptor system, which promotes the formation of an ammonia oxidation and production of nitric acid. Ammonia is a volatile like sulfide, but to a much lesser degree.
- Off gassing of ammonia and sulfide in the system assisted by turbulence at drop structures.
- A high ammonia concentration in the wastewater, which promotes an ammonia oxidizing biofilm above, at and below the normal waterline in the system.
- Protein degradation activity in the wastewater flow, particularly in anaerobic and/or slow-moving stretches, that supplements ammonia in the water and the transfer to the air/headspace. This would be particularly elevated in the siphon feeding Site S16.
- Excessive ammonia loading from anaerobic sources such as landfills and/or locations using ammonia-based products as cleaning agents.
- A deficit in metals relative to ammonia, which causes bacteria to secrete organic acids and other molecules to look for metals. These secretions create additional corrosion above, at and below the waterline.
- A deficit in phosphorous relative to ammonia above the waterline, which causes bacteria to secrete organic acids and other molecules to look for phosphorous. These secretions create additional corrosion above the waterline.

Background

Heart of the Valley Metropolitan Sewerage District (HOVMSD) is experiencing microbial induced corrosion (MIC) of concrete pipe and concrete sewer structures within its wastewater interceptor system. The MIC reportedly targets areas at and above the water level. Conventional wisdom suggests that hydrogen sulfide gas caused by sulfate reducing bacteria in the wastewater is the underlying cause of MIC. This gas feeds sulfide oxidizing bacteria that populate surfaces above the water line, which creates sulfuric acid and causes corrosion of concrete. However, chemical analysis and sensor data for HOVMSD's interceptor system do not fully support this assertion (data collected by HOVMSD and SMS not shown).

WQI assisted HOVMSD and SMS in a study to determine the role of biofilm in HOVMSD's MIC problem. The study involved analysis of biofilm that developed on concrete coupons that were suspended in the air or submerged in flowing wastewater for about ten weeks. The coupons were deployed in the interceptor system at four locations upstream of the wastewater treatment plant, which are identified/circled on the attached map prepared by SMS.

Sampling

Samples were analyzed to quantify the presence of biofilm and to assess biofilm related activities that likely contribute to or cause MIC in HOVMSD's system.

Biofilm is a general term used to describe common soil and water related microorganisms found growing on a wet surface. Biofilm typically attaches to a surface with a slime-like layer, and secretes components such as enzymes, acids, proteins and polysaccharides in response to stressful conditions, or to protect themselves from anti-microbial treatments. A thick biofilm can cause corrosion through secretions and/or created byproducts - sulfur oxidizing bacteria create sulfuric acid, ammonia oxidizing bacteria create nitric acid and starved biofilms secrete various organic acids.

Results

Condition of harvested concrete coupons is shown in **Figure 1** and **Figure 2**. Analysis results are shown in the attached BIT and BAT results summaries and summarized below. A summary of ammonia and sulfide loadings is shown in **Table 1**

BIT data are shown as two sets of results. **BIT Table 1** shows results of direct coupon analysis to quantify bacteria/biofilm that developed on the concrete coupon surfaces over their ten-week deployment period. **BIT Table 2** and individual BIT Sample Data show results of soaking each coupon in ultra-pure water for about 24 hours to assess secreted products and biological activity transferred to the water.

BAT data were generated by analyzing the water that was used to soak the harvested concrete coupons. These data generally correlate with data shown in **BIT Table 2**. BAT data shown in **BAT Table 1** show unitless raw data for relative comparison of biofilm related activity between the four sample locations and with control data.

The following is a brief assessment of the **BIT** and **BAT** results:

1. **Figure 1** and **Figure 2** generally shows the following:
    a. Concrete coupons *hung in air* show no apparent signs of MIC, though appearances differed.
        i. Site S6 shows normal colored concrete.
        ii. Sites S9 and S16 show slight browning of the concrete.
        iii. Site S24 shows a slightly darker colored concrete.
    b. Concrete coupons *submerged in sewage* showed variable results.
        i. Site S6 shows no sign of MIC damage
        ii. Sites S9 and S16 show severe MIC damage – about 70% of the coupons are corroded away or missing.
        iii. Site S24 shows moderate MIC damage – 10% to 30% of the coupons are corroded away or missing.
    c. Color patterns of the coupons *hung in air* show a correlation to corrosion seen on coupons *submerged in sewage*.
2. Data in **BIT Table 1** generally show that biofilms developed on concrete coupons that were hung in air and submerged in sewage.
    a. For the concrete coupons *hung in air*:
        i. Site S9 had the lowest microbial occurrence and Site S24 had the highest. Site S24 had about five times more biofilm than Site S9.
        ii. pH of reagents after being used to process the samples was lowest for Sites S9 and S16 and slightly depressed for Sites S6 and S24. All pH values decreased compared to unreacted reagent. The decrease in pH correlates with the presence of acid producing bacteria, which were in greater abundance at Sites S9 and S16.

b. For the concrete coupons *submerged in sewage*:

i. Site S6 had the lowest microbial occurrence and Sites S9 and S19 had the highest. Site S9 had about twenty times more biofilm than Site S6. Microbial occurrence on the coupon surfaces correlates with the magnitude of corrosion seen, which suggests damage to the submerged coupons was caused by MIC.
ii. pH of reagents after being used to process the samples was lowest for S6; all sample reagents showed depressed pH measurements. Acid producing bacteria were present at all sites.

3. Data in **BIT Table 2** generally show that active/corrosive biofilms developed on the concrete coupons that were hung in the air and submerged in the sewage. The following data show that corrosive biofilm secretions were added to ultra-pure water after incubation of the coupons in the water for about 24 hours.

a. For the concrete coupons *hung in air*:

i. Microbial occurrence was highest for Sites S16 and S24. Site S16 had about 35 times more biofilm than Site S6. Results for this set of coupons are similar to the direct lyse results shown in BIT Table 1.
ii. pH of the water that the coupons were soaked in was lowest for Sites S9 and S16 and slightly depressed for Sites S6 and S24. All pH values decreased compared to the control. The decrease in pH correlates with the presence of acid producing bacteria, which were in greater abundance at Sites S9 and S16. These data agree with the direct lyse results shown in BIT Table 1.
iii. Biofilm secretions were added to the ultra-pure water during the incubation period, which are represented in the EEM, ORP, FA DOC, Peptide and Protein results.

1. Trends for EEM correlate with microbial occurrence, which suggests biofilms present on the coupons were stressed and/or starved of nutrients. These conditions also create MIC. DP EEM was the highest for Site S16, which suggests this location had the most stressed and/or damaging biofilm present.
2. Oxidation Reduction Potential (ORP) measurements for the hung coupons showed a decrease at all sites. The smallest decreases were seen at Sites S9 and S16 and the largest were seen at Sites S24 and S6. A decrease in ORP represents the addition of energy to the water through bacteria secretions and/or byproducts of bacterial activity. Creation of organic acids on a coupon suspended in air would cause a decrease in ORP.
3. FA DOC measurements for the air hung coupons represent bacterial secretions generally caused by autotrophic bacteria. Bacteria in this classification include sulfur oxidizers and ammonia oxidizers. The data show the highest occurrence of these secretions at Sites S6 and S16.
4. Peptide measurements show the presence of short chain amino acids secreted by bacteria. Site S16 had the highest occurrence of these secretions.

iv. Combined data for microbial occurrence, EEM, pH, FA DOC and Peptides generally show the highest potential for pipe crown MIC at Site S16, followed by S24, and S9. Site S6 shows a low potential for MIC.
v. All sites generally look worse compared to Site S6.

b. For the concrete coupons *submerged in sewage*:

i. Microbial occurrence was highest for Sites S16 and S6. Site S16 had about 13 times more biofilm than Site S24. Results for these coupons show similar results compared to the direct lyse results shown in BIT Table 1 with the exception of Site S6. Visual inspection of the coupon for S6 showed the presence of fats, oil and grease (FOG), which may have allowed for biasing growth of bacteria during the incubation period.
ii. pH of the water that the coupons were soaked in was lowest for Site S6 and depressed for Sites S9, S16 and S24. All pH values decreased compared to the control. The decrease in pH correlates with the presence of acid producing bacteria. Results for Site S6 may have been biased by the presence of FOG. Because pH data could not be easily corrected, pH for Sites S9 and S16 would have likely been lower had a whole coupon been present.
iii. Biofilm secretions were added to the ultra-pure water during the incubation period, which are represented in the EEM, FA DOC, Peptide and Protein measurements.

1. Trends for EEM and microbial occurrence generally correlate with the presence of biofilm stressed and/or starved of nutrients. These conditions create MIC. DP EEM was the highest for Sites S9 and S16, which suggests these locations had the most stressed and/or damaging biofilm present. These results correlate with visible corrosion of the coupons.
2. FA DOC measurements generally increased with increasing distance from the treatment plant, which indicates changing biofilm conditions in the wastewater based on changes in wastewater composition. These results suggest one or more of the following: high nutrient conditions distant to the plant, nutrient depletion with travel to the plant and/or dilution of the flow with lower nutrient water closer to the plant.
3. ORP measurements for the submerged coupons show a decrease at all sites. The smallest decrease was seen at Site S24, which is most distant to the plant. Because ORP data could not be easily corrected, ORP for Sites S9 and S16 would have likely been lower had a whole coupon been present. A decrease in ORP represents the addition of energy to the water through bacteria secretions and/or byproducts of bacterial activity. Creation of organic acids, ammonia and/or sulfide by biofilm would cause a decrease in ORP.

c. Overall BIT data show a general correlation between the potential for MIC at and above the water line with biological activity and MIC below the waterline.
d. Sites S9 and S16 look noticeably worse with Site 24 looking moderately worse when compared to Site S6.

4. Data in **BAT Table 1** generally show that active biofilms developed on the concrete coupons that were hung in air and submerged in sewage. These data show activity of biofilm secretions added to ultra-pure water after incubation in the water for about 24 hours:

    a. The data provide much information that can be interpreted. The following is a brief summary of notable results for the concrete coupons *hung in air*:

        i. PO4:DSI is a general indicator of biofilm thickness and starvation. Results for this parameter show that biofilm was thickest at Sites S16 followed by S24 and S9. These results generally match BIT results.
        ii. Iron/Metal Deficit is a measure of bacteria secreting molecules to acquire needed metals from their surroundings. These molecules will pull metals from surfaces and minerals, including calcium and magnesium, which means their presence would be corrosive to concrete cements. Results for this parameter show that biofilm at Site S16 was the most metal starved followed by S9 and S24. These results generally match BIT results.
        iii. PO4:DSI and PO4:MSI data generally correspond with starved bacteria secreting organic materials to release phosphate from concrete cements, then utilizing the organic phosphorous that was created for growth/energy. This parameter shows that biofilm was thickest at Sites S16 followed by S24 and S9. These results generally match BIT results.
        iv. MSIs for Protein Degradation and Ammonia and/or Protein were generally elevated/increased for Sites S9, S16 and S24 compared to Site S6. The pattern for Protein Degradation relative to Ammonia and/or Protein correlates with the presence of an ammonia oxidizing biofilm at these locations searching for amino acids to satisfy an ammonia deficiency. This pattern would only occur if an ammonia oxidizing biofilm were present at these locations. An ammonia oxidizing biofilm would create nitric acid, which is highly corrosive to cement and steel.
        v. Data for Site S6 generally show the presence of biofilm that is starting to form and/or on the verge of becoming corrosive. This is seen in the high DSI values for organic acids and protein degradation, indicating the presence of biofilm trying to change its environment to find nutrients. The low MSI values for these parameters and for PO4 show that biofilm/MIC has not yet been successful.

    b. The following is a brief summary of notable results for the concrete coupons *submerged in sewage*:

        i. PO4:DSI is a general indicator of biofilm thickness and starvation. Results for this parameter show that biofilm was the thickest at Sites S16 and S9. These results generally match BIT results if you exclude the microbial growth that occurred for Site S6 caused by the presence of FOG.
        ii. Iron/Metal Deficit is a measure of bacteria secreting molecules to acquire needed metals from their surroundings. These molecules will pull metals from surfaces and minerals, including calcium and magnesium, which means their presence would be corrosive to concrete cements. Results for this parameter show that biofilm at Site S9 was the most metal starved; there was no difference between the remaining sites. Site S9 had the worst visual corrosion – only 30% of a single concrete coupon remained of the four that

were deployed. This parameter strongly correlates with MIC experienced on submerged coupons except for Site S6, which was likely biased by the presence of FOG.

iii. Results for PO4:MSI show no correlation or trend, which makes sense given that bacteria present would not be looking for phosphorous from a surface because phosphorous is typically ample in sewage.

iv. DSIs and MSIs for simple organic acids, complex organic acids and protein degradation generally correspond with the presence of starved biofilm secreting acids to release needed nutrients and/or degrading complex matter to obtain ammonia. These parameters show that biofilm was thickest and/or most starved at Sites S9 and S16 followed by S24. These results match with visible corrosion in Figure 1.

v. Sulfur:DSI data show the potential for sulfate reducing bacteria to be present at Sites S9 and S16. However, the presence of elevated organic acid activity could indicate this result is more indicative of bacteria seeking a sulfate ester as a food source, not sulfate.

c. All data were elevated or excessive compared to the Control Coupon and were very different than Ultra-Pure Water.

5. **Table 1** summarizes flow, sulfide and ammonia loadings contributed to the wastewater treatment plant by HOVMSD member communities. Flow data and sulfide data were obtained from SMS. Ammonia data were obtained from projected member community loadings shown in the 2019 budget. The data generally show the following:
   a. Ammonia is present in the water at an average concentration that is about 100 times higher than that of sulfide.
   b. Combined Locks and Darboy contribute water with a higher percentage of sulfide compared to their average flow contribution at the wastewater treatment plant (highest concentrations of sulfide).
   c. Darboy and Little Chute contribute water with a higher percentage of ammonia compared to their average flow contribution at the wastewater treatment plant (highest concentrations of ammonia).
   d. The highest ammonia concentrations are located further from the plant, which correlates with the part of the interceptor system that has the greatest potential for MIC damage.

Figure 1. Appearance of harvested concrete coupons subjected to direct lyse (BIT Table 1 data). No sample was available from S9 sewage for analysis. Sample from S16 sewage was split at a crack to create two samples for analysis.

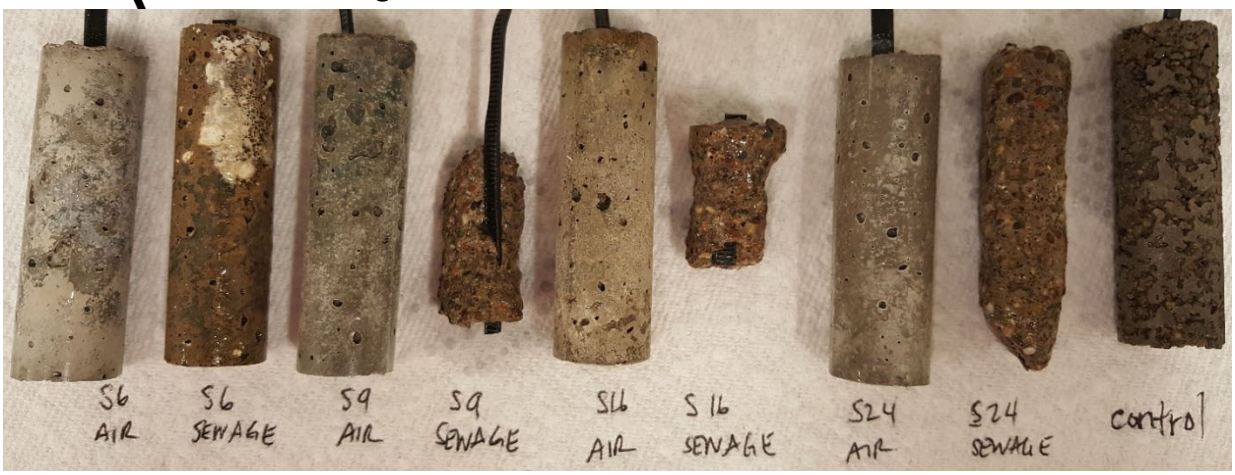


Figure 2. Appearance of harvested concrete coupons subjected to soaking in ultra-pure water for analysis of products excreted by biofilm present on the coupon surfaces (BIT Table 2 and BAT Table 1 data) . Sample from S16 sewage was split at a crack to create two samples for analysis. Sample S6 shows the presence of fats, olis and grease (FOG) on the surface of the coupon. Photo was taken three days after analysis and does not necessarily represent condition of the coupons immediately after analysis.

Table 1. Summary of Flow, Sulfide and Ammonia Loadings

Member Community	Average Gallon per Day Flow	% Plant Flow	Plant Sulfide (lb/d)	% Plant Sulfide Load	Sulfide (mg/L)	Plant NH_3 (lb/d)	% Plant NH_3 Load	NH_3 (mg/L)	Sewage Mass Ratio NH_3:S	Air Mass Ratio NH_3:S
Combined Locks	337,000	5.9%	3.0	23%	1.07	83.1	6%	29.6	27.7	0.09
Darboy	923,900	16.3%	2.4	18%	0.31	270.3	20%	35.1	112.6	0.37
Kaukauna	2,166,200	38.1%	3.5	27%	0.19	404.9	31%	22.4	115.7	0.38
Kimberly	749,200	13.2%	1.1	8%	0.18	133.8	10%	21.4	121.6	0.40
Little Chute	1,505,500	26.5%	3.1	24%	0.25	427.1	32%	34.1	137.8	0.45
total per day	5,681,800	100%	13.1	100%	0.28	1,319.2	100%	27.9	100.7	0.33

Conclusions and Recommendations

Trends in the data suggest the potential for severe microbial induced corrosion (MIC) in the wastewater interceptor system above, at and below the water line caused by ammonia in the wastewater. The study shows the most impacted areas to be at Sites S9 and S16. Site S24 appears to be impacted by MIC but to a lesser degree.

The attached map prepared by SMS shows the location of each structure that contained concrete coupons and the sewage strength/flow proportion at each location. The map shows that S24 is the furthest upstream structure in this study; this structure contains a vertical drop. S16 is downstream of S24 and has a vertical drop and a siphon connection. Site S9 is downstream of S16 and has a flow direction change within the structure. S6 is the closest to the plant and conveys the largest flow rate. In general, the concrete coupon locations with the highest MIC potential correlate with the highest mass loading for ammonia.

The following factors appear to drive corrosion processes in HOVMSD's interceptor system:

- Off gassing of ammonia to the air/headspace of the interceptor system, which promotes the formation of an ammonia oxidation and production of nitric acid. Ammonia is a volatile like sulfide, but to a much lesser degree.
- Off gassing of ammonia in the system assisted by turbulence at drop structures.

- A high ammonia concentration in the wastewater, which promotes ammonia oxidation above and below the normal waterline.
- Protein degradation activity in the wastewater stream, particularly in anaerobic and/or slow-moving stretches, that supplements ammonia in the water and the transfer to the air/headspace. This would be particularly elevated in the siphon feeding Site S16.
- Excessive ammonia loading from anaerobic sources such as landfills and/or locations using ammonia-based products as cleaning agents.
- A deficit in metals relative to ammonia, which causes bacteria to secrete organic acids and other molecules to look for metals. These secretions create additional corrosion above and below the waterline.
- A deficit in phosphorous relative to ammonia above the waterline, which causes bacteria to secrete organic acids and other molecules to look for phosphorous. These secretions create additional corrosion above the waterline.

If sulfide is part of the corrosion issue in HOVMSD's system, it appears to be a minor component. Patterns in the sulfate related BAT data do not support the presence of sulfate reducing bacteria looking for nutrients in the flow stream. The reported gray/black color to the wastewater nearest the plant suggests that metals present in the flow stream may help bind sulfide present/generated to keep it from becoming an issue.

MIC in HOVMSD's system could be minimized/controlled in the following manner:

- Identify and remove point sources of ammonia or require pretreatment of these sources.
- Addition of an iron salt such as ferric sulfate at Site S24 to reduce the metal deficit seen in the water.
- Modification of drop structures to minimize/prevent off gassing of ammonia and/or sulfide.
- Periodic purging of stagnant regions with river water at low flow times to reduce off gassing caused by stagnancy.
- Filling of redundant siphons with river water after use to minimize off gassing and anaerobic activity between periods of use.

Water Quality Investigations

Sample Date:	**9/9/2019**
Analysis Date:	**9/10/2019**

Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) TABLE 1 - Direct Lyse Summary

Sample Description	ME/coupon	pH (s.u.)	Notes
S6 Air	8,886,000	10.93	Low ME, Low MIC
S9 Air	4,772,000	8.57	Low ME for sewage, acid producing bacteria present
S16 Air	8,552,000	8.44	Low ME, high presence of acid producing bacteria
S24 Air	22,720,000	10.77	Moderate ME for sewage
S6 Sewage	50,050,000	8.95	Low ME, high presence of acid producing bacteria
S9 Sewage (0.3 coupon)	1,033,202,923	NT	Moderate ME for sewage, low acid producing bacteria present
S16 Sewage (0.3 coupon)	923,200,000	9.67	Moderate ME, Low MIC
S24 Sewage (0.84 coupon)	427,100,000	9.66	Moderate ME for sewage, acid producing bacteria present
Control	144,415	11.76	Control coupon exposed to office air for 10 weeks

Notes:

ME = equivalent microbial occurrence.

Concrete coupons were placed directly in a lysing agent to quantify bacteria present on each surface.

pH of lysing agent for each coupon was analyzed after reaction.

A drop from initial pH of 11.76 indicates presence of acid producing bacteria.

Acid producing bacteria were present on coupons hung in the air at S9 and S16.

Acid producing bacteria were present on all coupons submerged in sewage.

Water Quality Investigations

Sample Date:	9/9/2019
Analysis Date:	9/10/2019

Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) TABLE 2 - Coupon Soaking Data Summary

Sample Description	ME/coupon	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	Peptide Est (mg/L)	Protein Est (mg/L)
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S9 Air	9,163,000	827,774	767,130	1,594,903	17.2	11	10.08	1,534	3.36	0.068	0.001
S16 Air	262,620,000	2,212,343	3,128,444	5,340,787	37.8	20	9.14	3,110	6.32	0.179	0.100
S24 Air	183,600,000	2,151,216	896,017	3,047,233	73.2	-67	10.18	582	1.74	0.025	0.036
S6 Sewage	2,589,300,000	3,276,611	3,832,968	7,109,578	60.8	-216	8.51	802	11.29	0.001	0.130
S9 Sewage (0.3 coupon)	1,033,202,923	6,513,302	8,435,004	14,948,307	34.6	-218	9.21	2,410	45.73	0.064	0.439
S16 Sewage (0.3 coupon)	4,776,875,288	4,889,389	6,603,406	11,492,795	25.5	-242	8.86	2,370	80.41	0.003	0.003
S24 Sewage (0.7 coupon)	356,026,700	2,471,059	4,084,620	6,555,679	27.8	-11	10.58	1,963	61.58	0.338	0.184
Control	144,415	86,212	16,280	102,492	5.4	387	11.76	2,820	0.00	0.000	0.000

NOTE: Data except for pH and ORP were corrected to an equivalent coupon basis, correcting for coupon lost to corrosion.

BIT DATA COMPARISON TABLE

Sample Description	ME/coupon	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	Peptide Est (mg/L)	Protein Est (mg/L)
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
% Change	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*#DIV/0!*
S9 Air	9,163,000	827,774	767,130	1,594,903	17.2	11	10.08	1,534	3.36	0.068	0.001
S9 Air	9,163,000	827,774	767,130	1,594,903	17.2	11	10.08	1,534	3.36	0.068	0.001
% Change	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
S16 Air	262,620,000	2,212,343	3,128,444	5,340,787	37.8	20	9.14	3,110	6.32	0.179	0.100
S16 Air	262,620,000	2,212,343	3,128,444	5,340,787	37.8	20	9.14	3,110	6.32	0.179	0.100
% Change	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
S16 Sewage (0.3 coupon)	4,776,875,288	4,889,389	6,603,406	11,492,795	25.5	-242	8.86	2,370	80.41	0.003	0.003
S24 Sewage (0.7 coupon)	356,026,700	2,471,059	4,084,620	6,555,679	27.8	-11	10.58	1,963	61.58	0.338	0.184
% Change	*-93%*	*-49%*	*-38%*	*-43%*	*9%*	*96%*	*19%*	*-17%*	*-23%*	*10032%*	*5411%*
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S9 Air	9,163,000	827,774	767,130	1,594,903	17.2	11	10.08	1,534	3.36	0.068	0.001
% Change	*21%*	*444%*	*108%*	*206%*	*701%*	*128%*	*-9%*	*-26%*	*-62%*	*646%*	*#DIV/0!*
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S16 Air	262,620,000	2,212,343	3,128,444	5,340,787	37.8	20	9.14	3,110	6.32	0.179	0.100
% Change	*3377%*	*1353%*	*746%*	*923%*	*1657%*	*153%*	*-17%*	*50%*	*-29%*	*1864%*	*#DIV/0!*
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S16 Sewage (0.3 coupon)	4,776,875,288	4,889,389	6,603,406	11,492,795	25.5	-242	8.86	2,370	80.41	0.003	0.003
% Change	*63151%*	*3112%*	*1686%*	*2102%*	*1088%*	*-545%*	*-20%*	*14%*	*809%*	*-63%*	*#DIV/0!*
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S9 Air	9,163,000	827,774	767,130	1,594,903	17.2	11	10.08	1,534	3.36	0.068	0.001
% Change	*21%*	*444%*	*108%*	*206%*	*701%*	*128%*	*-9%*	*-26%*	*-62%*	*646%*	*#DIV/0!*
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S16 Air	262,620,000	2,212,343	3,128,444	5,340,787	37.8	20	9.14	3,110	6.32	0.179	0.100
% Change	*3377%*	*1353%*	*746%*	*923%*	*1657%*	*153%*	*-17%*	*50%*	*-29%*	*1864%*	*#DIV/0!*
S6 Air	7,552,250	152,228	369,656	521,883	2.1	-38	11.05	2,070	8.85	0.009	0.000
S24 Sewage (0.7 coupon)	356,026,700	2,471,059	4,084,620	6,555,679	27.8	-11	10.58	1,963	61.58	0.338	0.184
% Change	*4614%*	*1523%*	*1005%*	*1156%*	*1192%*	*72%*	*-4%*	*-5%*	*596%*	*3608%*	*#DIV/0!*

Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

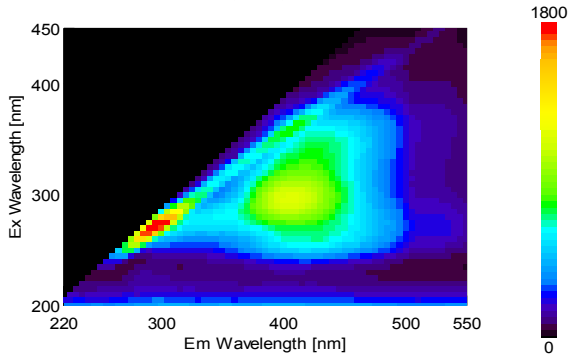
Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) SAMPLE DATA

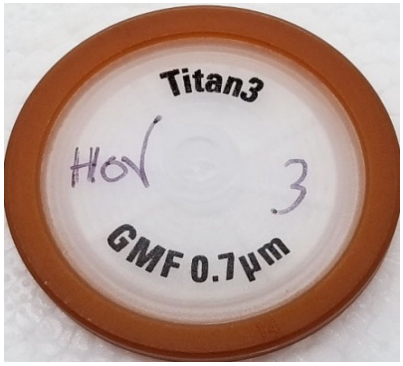
Sample ID: 2019-09-11_A-03-01 **Name:** S6 Air

	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	7,552,250	-38	11.05	2070	8.85	152,228	369,656	521,883	2.1	none

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE



Notes:

Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

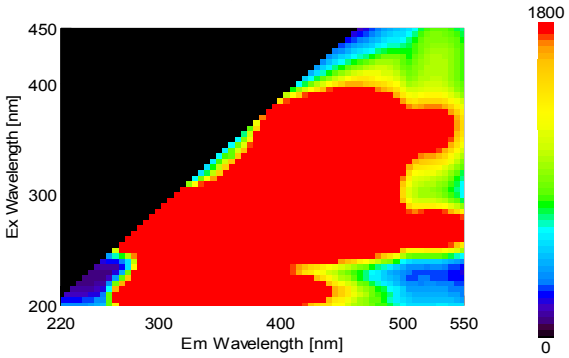
Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) SAMPLE DATA

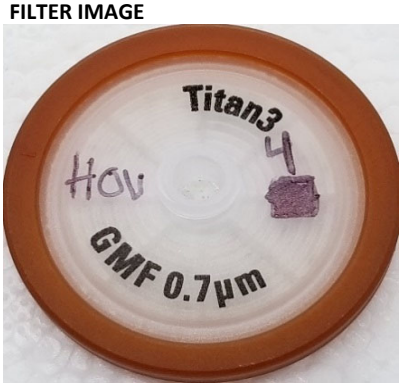
Sample ID: 2019-09-11_A-04-01 **Name:** S6 Sewage

	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	2,589,300,000	-216	8.51	802	11.29	3,276,611	3,832,968	7,109,578	60.8	none

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE



Notes:

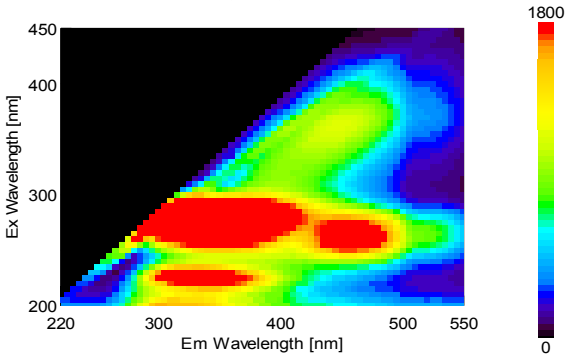
Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

Client/Project: Heart of the Valley Coupons

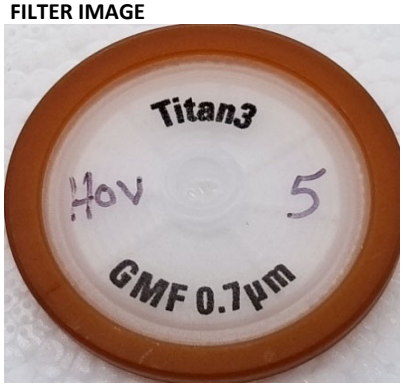
BIOFILM INDICATION TEST (BIT) SAMPLE DATA

Sample ID:	2019-09-11_A-05-01				Name:	S9 Air				
	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	9,163,000	11	10.08	1534	3.36	827,774	767,130	1,594,903	17.2	none

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE



Notes:

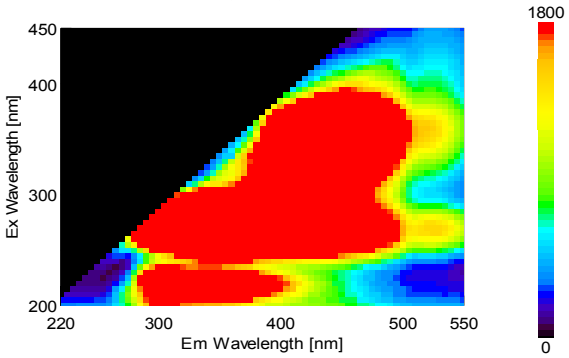
Sample Date:	9/9/2019
Date of Analysis:	9/11/2019

Client/Project: Heart of the Valley Coupons

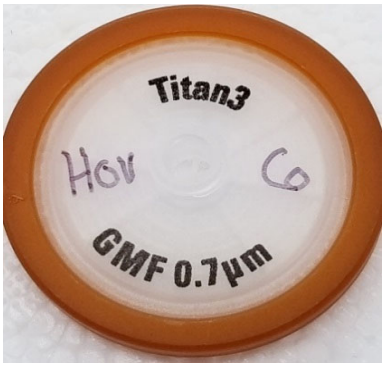
BIOFILM INDICATION TEST (BIT) SAMPLE DATA

Sample ID:	2019-09-11_A-06-01				Name:	S9 Sewage (0.3 coupon)			
	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	1,033,202,923	-218	9.21	723	13.72	1,953,991	2,530,501	4,484,492	34.6	none

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE



Notes:

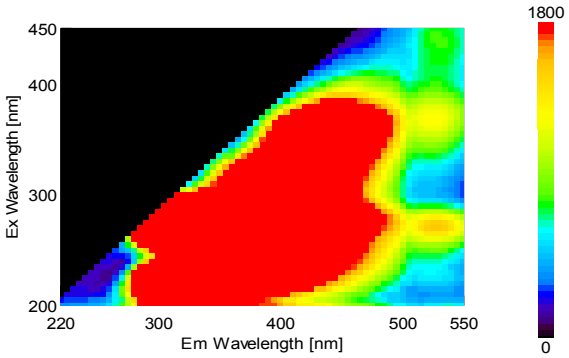
Sample Date:	9/9/2019
Date of Analysis:	9/11/2019

Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) SAMPLE DATA

Sample ID:	2019-09-11_A-07-01				Name:	S9 Sewage (damaged)				
	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	2,502,900,000	112	7.06	432	21.28	2,044,204	1,827,472	3,871,676	43.3	none

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE

Notes:

Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

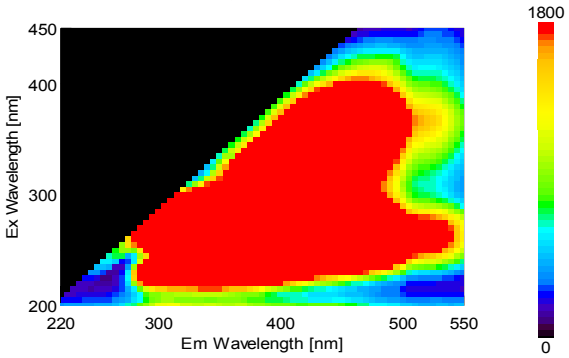
Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) SAMPLE DATA

Sample ID: 2019-09-11_A-08-01 **Name:** S16 Air

	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	262,620,000	20	9.14	3110	6.32	2,212,343	3,128,444	5,340,787	37.8	none

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE

Notes:

Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

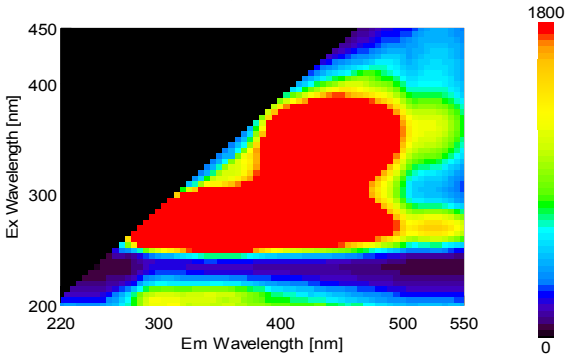
Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) SAMPLE DATA

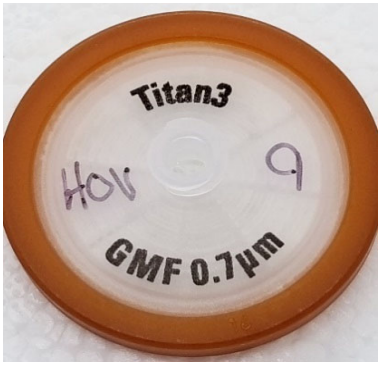
Sample ID: 2019-09-11_A-09-01 **Name:** S16 Sewage (0.3 coupon)

	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	4,776,875,288	-242	8.86	711	24.12	1,466,817	1,981,022	3,447,839	25.5	dark

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE



Notes:

Sample Date:	9/9/2019
Date of Analysis:	9/11/2019

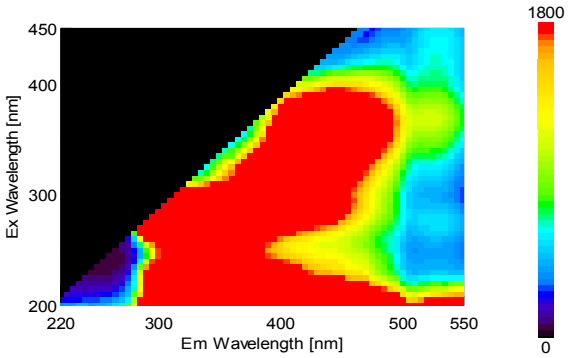
Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) SAMPLE DATA

Sample ID: 2019-09-11_A-10-01 **Name:** S16 Sewage (damaged)

	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	3,016,800,000	32	6.94	726	88.29	2,072,793	1,890,450	3,963,243	43.5	dark

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE

Notes:

Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

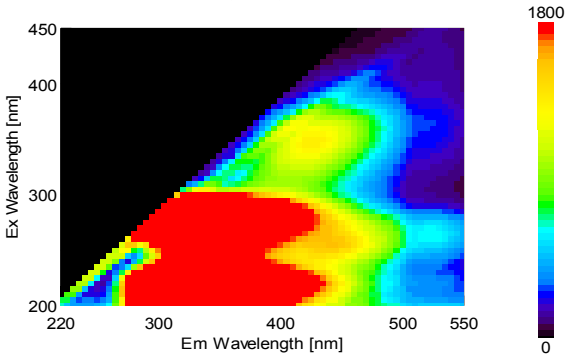
Client/Project: Heart of the Valley Coupons

BIOFILM INDICATION TEST (BIT) SAMPLE DATA

Sample ID: 2019-09-11_A-11-01 **Name:** S24 Air

	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	183,600,000	-67	10.18	582	1.74	2,151,216	896,017	3,047,233	73.2	none

TOTAL PRODUCTS DATA (EEM)



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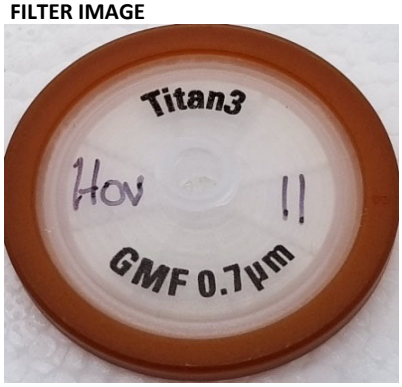


Notes:

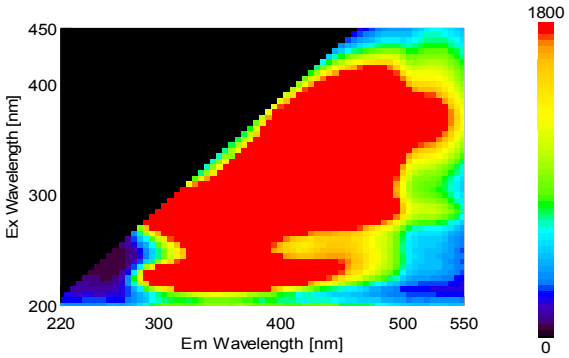
Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

Client/Project: Heart of the Valley Coupons

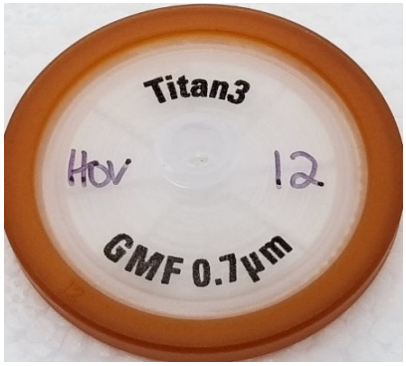
BIOFILM INDICATION TEST (BIT) SAMPLE DATA

Sample ID:	2019-09-11_A-12-01				Name:	S24 Sewage (0.7 coupon)				
	ME/coupon	ORP (mV)	pH (s.u.)	Specific Conduct (uS/cm)	FA DOC (mg/L)	MBP EEM (FI)	DP EEM (FI)	TP EEM (FI)	BCI	Filter Color
Result:	356,026,700	-11	10.58	1374	43.10	1,729,741	2,859,234	4,588,975	27.8	dark

TOTAL PRODUCTS DATA (EEM)



FILTER IMAGE



Notes:

Water Quality Investigations

2581 State Road 92, Suite 2
Mount Horeb, WI 53572
Phone: (888) 499-2507

Biofilm Indication Testing Report Explanation Page

- BIT = Biofilm Indication Test
- SI = Severity Index on a scale of 0 (good) to 10 (poor)
- Biofilm: A layer of diverse bacteria on a surface that has grown to form a colony. Biofilm attaches to a surface with a slime layer that protects the bacteria/colony. Biofilm grows inside of water distribution system piping, water/wastewater treatment systems, plumbing, hot water heaters, softeners, process piping, fountains, groundwater wells, and more. Bacteria found in biofilms are typically harmless (but not always). Biofilm in a water system becomes a problem when conditions allow it to grow so thick that the bacteria can change the quality of the water or cause corrosion. Thick biofilm can corrode plumbing fixture to increase metals in the water (such as lead and copper), cause and increase in disinfection byproducts, cause taste and odor complaints, and corrode sewage works. Thick biofilms can also harbor pathogens such as Legionella.
- ME = Microbial Equivalents: Estimate of total microbial occurrence in sample volume based on measurement of ATP present. Does not estimate biofilm related ME. Samples from a drinking water system with greater than 500 ME/mL have elevated microbial occurrence and are likely to be affected by microbial biofilms. In certain waters, low ME could indicate the presence of an excessively thick biofilm.
- ORP = Oxidation Reduction Potential: A relative measure of the concentration of dissolved energy-bearing nutrients in the water, and/or is an indicator of an adequate chlorine residual.
- pH = measure of acidity: pH of sample is highly dependent on geology, aquifer/sediment/mineral chemistry, the type of chemical/disinfectant used, and the type of microbial activity present.
- Specific conductance: Estimate of the concentration of dissolved ions in the water.
- FA DOC: An estimate of the fulvic acid portion of dissolved organic carbon content of the water, which is a subset of total organic carbon. Can be used to assess the presence of biofilm and biofilm-produced fulvic acid type molecules.
- EEM = Excitation Emmission Matrix: Provides information on the type of fluorescing organic carbons present in water (food for microbial growth and/or microbial created products) and/or exposure of water to biofilm. In general, the greater the EEM, the greater the biofilm presence was in the system sampled, with the proportion of each type of EEM indicating the underlying cause of biofilm.
- MBP = Microbial By Products EEM: Metabolic by products excreted by actively respiring microorganisms in water and biofilm. High levels create the potential for microbial induced corrosion. Units = FI (fluorescence intensity)
- DP = Decay Products EEM: Products caused by the decay of organic matter and/or biofilm. High levels indicate the presence of decaying organic matter and/or biofilm attempting to cause decay. Units = FI (fluorescence intensity)
- TP = Total Products EEM: Total of microbial produced compounds and fluorescing organic matter in water. Units = FI (fluorescence intensity)
- BCI = Biofilm Corrosivity Index: Assessment of biofilm's ability to cause corrosion of aquifer, equipment and/or plumbing materials. As BCI increases, the potential for micrbial induced corrosion increases. A biofilm sloughing event could cause a spike in ME and BCI.
- BDL = Below Detection Limit.
- Filter Color: Color of filters used to process the samples is used to gauge the presence of biofilm and/or sloughed material in the water samples. All filters begin as white.
- Iron/Metal Limitation: Assesses the presence of bacterial molecules searching for needed metals for activiation of metabolism related processes.

WQI

Sample Date:	9/9/2019
Date of Analysis:	9/10/2019

Client/Project: Heart of the Valley

BAT TABLE 1 - SUMMARY OF RESULTS

	Decay Severity Index (D		Decay Severity Index (DSI)							Metabolism Severity Index (MSI)							
Sample Description	PO4: DSI	Sulfur: DSI	Complex Organic Acid: DSI	Simple Organic Acid: DSI	Protein Degrade: DSI	Simple Sugar: DSI	Ammonia and/or Protein: DSI	Biofilm Degrade: DSI	Iron/Metal Deficit	PO4 : MSI	Sulfur : MSI	Complex Organic Acid : MSI	Simple Organic Acid : MSI	Protein Degrade: MSI	Simple Sugar: MSI	Ammonia and/or Protein: MSI	Biofilm Degrade: MSI
S6 Air	2,007	3,674	12,108	15,028	13,247	-486	-5,600	-361	3	0.0	0.5	-4.1	5.6	18.5	0.4	0.4	0.2
S9 Air	5,252	2,847	7,461	9,909	8,830	-463	-4,569	-344	41	60.3	-13.7	33.6	11.4	35.7	0.1	5.4	0.1
S16 Air	11,407	2,658	6,452	8,778	6,010	-387	-5,068	-303	87	101.4	-56.8	53.8	37.0	51.5	0.9	-30.9	-0.1
S24 Air	8,760	3,079	6,890	9,813	8,855	-435	-4,736	-329	14	75.2	-24.2	40.4	17.9	42.8	0.2	16.4	0.2
S6 Sewage	2,600	3,449	3,966	8,415	5,999	3,159	-4,147	-247	96	6.4	-14.1	97.5	130.4	111.3	112.9	17.9	-0.2
S9 Sewage (0.3 coupon)	7,401	11,705	17,684	36,688	29,646	10,272	-17,727	-1,013	247	-6.6	-69.6	305.1	332.9	375.3	355.6	47.4	0.4
S16 Sewage (0.3 coupon)	7,934	11,842	18,512	37,606	28,759	13,749	-17,594	-1,027	110	1.5	-62.3	350.3	359.8	477.8	450.2	27.2	0.7
S24 Sewage (0.7 coupon)	3,011	4,179	15,076	21,352	17,453	1,955	-7,903	-458	108	10.4	-40.7	-27.5	-26.8	51.3	96.2	6.4	0.5
Ultra Pure Water	-90	748	20	-8	-29	-172	-2,045	-99	1	-0.1	-3.0	0.1	0.9	0.5	0.1	-5.4	-0.1
Control Coupon Office Air	1,308	2,512	9,887	14,388	11,573	-481	808	-379	2	-2.9	-12.1	-44.9	-41.9	-56.1	0.1	33.5	0.1

NOTE: Data were corrected to an equivalent coupon basis, correcting for coupon lost to corrosion.

Water Quality Investigations

2581 State Road 92, Suite 2
Mount Horeb, WI 53572
Phone: (888) 499-2507

Biofilm Activity Testing Report Explanation Page

- BAT = Biofilm Activity Test
- Severity Index (SI) results for the BAT highlight the likely cause(s) of microbial induced corrosion, taste and odor issues, disinfection byproduct formation, and excess microbial occurrence in drinking water samples, source water or a water-related system.
- BAT assesses the presence of microbial related products in water, which are generally created by starved or stressed bacteria located in biofilm. Decay generally represents the presence of proteins, enzymes, soluble microbial produced byproducts and cofactors caused by the presence of decaying and/or dying biofilm. Metabolism generally represents the presence of metabolically active biofilm searching for nutrients.
- BAT DSI = BAT Decay Severity Index
- BAT MSI = BAT Metabolism Severity Index
- BAT results are ranked against a database of sample results and corrosive condition correlations to calculate the severity index (SI), with 0.0 (zero) being the best and 10.0 being the most severe. A color code is assigned to each calculated SI with a color transition between the following colors: green for SI = 0, yellow for SI = 5 and red for SI = 10.
- Preventative action is recommended for a BAT SI of greater than 6.0.
- Phosphate metabolism data generally represent a phosphorous starvation response from biofilm.
- Sulfur metabolism data generally represent utilization of organic sulfur compounds for energy and/or sulfate by sulfate reducing bacteria.
- Organic acid data generally represent the utilization/searching for organic acids for growth. Complex organic acid data typically represent anaerobic metabolism and/or thick biofilm.
- Protein degradation data typically represent an environment with organic carbon limitation, ammonia limitation, thick biofilm and/or severe nutrient starvation.
- Simple sugar and biofilm degradation data typically represent the presence of fermentation and/or thick biofilm.
- Ammonia data typically represent active attack/digestion of amino acids and/or biofilm related compounds for energy.
- Iron or Metal Deficit represents bacterial secretion of siderophores in search of metals. These compounds have been shown to correlate with corrosion of metals including steel, copper, brass and lead, and can mobilize radium and arsenic from aquifer minerals. This signal is often associated with biofilm thickness in a water system or source with low iron content.
- Corrosion potentials are based on analysis of proprietary data collected from numerous corrosion assessment and correlation with BAT results.

Client/Project: Heart of the Valley

Notes:

D VERTICAL DROP
G STEEPER GRADE
H ——
L ——
R RISERS – REPLACE w BARREL
T ——
REHABILITATE INTERIOR SURFACES
REHABILITATE EXTERIOR SURFACES
EXTERIOR SURFACES SEALED
INTERIOR SURFACES COATED
INTERCEPTOR – PVC
INTERCEPTOR – CIPP
INTERCEPTOR – MIC DAMAGE

VANDENBROEK SANITARY DISTRICT

LITTLE CHUTE

Q 45%
S+ 35
S- 40
NH3 50

Q 5%
S+ 10
S- 5
NH3 5

Q 25%
S+ 30
S- 20
NH3 15

Q 20%
S+ 20
S- 20
NH3 25

RIVERSIDE PARK
950'
MS10
DAM
RACEWAY
CENTRAL PARK
MS5N
MS5S
KAUKAUNA
LOCKS 1–5
MS6
WWTF
THILMANY MILL
POWER PLANT
HEESAKKER PARK
SANITORIUM
MS3
ISLAND PARK
DOYLE PARK
MS2
CANAL and LOCKS
DAM
DROP
MS1
COMBINED LOCKS
MS4–7
KIMBERLY
DARBOY SANITARY DISTRICT

GRAPHIC SCALE
0 600 1200
(in FEET)
1 INCH = 600 FEET

REVIEW

NONE

ORTHOPHOTO:

SMS
MUNICIPAL • INFRASTRUCTURE • PLANNING
TRANSPORTATION • FINANCE
STRATEGIC MUNICIPAL SERVICES, INC.
1180 NAUBUCK AVENUE, PLYMOUTH, WI 53073
(920) 893-3147

NO.	DATE	REVISION	BY
1	—	—	—
2	—	—	—

PROJECT NO. 10060
DATE FEB 2019
SCALE 1"=600' (22"X34")
F.B. S 01
DRAWN BY SMS
CHECKED BY SMS
CADD FILE NO. E.2e
PLOT DATE 02/06/19
PLOT TIME 10:25 AM

INTERCEPTOR CONVEYANCE SYSTEM
PRIORITY ACTION PLAN
HEART of the VALLEY METROPOLITAN SEWERAGE DISTRICT, OUTAGAMIE COUNTY

FILE NO.
10060–2

SHEET
1 OF 1