Madison Water Utility
Summary of Findings
Unit Well #8 Water Quality and Microbial Occurrence Investigation
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Introduction

This report summarizes the water quality and microbial occurrence investigation of the Madison Water Utility's Unit Well #8, which was performed from June 29 through September 9, 2009. This investigation was initiated based on the results of a preliminary investigation in 2008, which indicated iron related microbial activity was occurring within the well and/or aquifer. It was hypothesized that these microbes could be causing of the elevated iron and manganese levels in water pumped from this well when comparing initial water samples with samples obtained after an extended period of pumping. In this current investigation, water quality parameters and microbial occurrence were determined upon initial startup of the well after a nine month shutdown (seasonal well), and again after aggressive treatment of the well, which was performed to inactivate microbes that were assumed to be present within the well and/or geologic formation.

Objectives of Investigation

There were three objectives for this investigation. The first objective was to investigate the stability of water quality parameters for water pumped from the well over an extended period of pumping prior to any treatment of the well. This objective also included an investigation for the presence of common soil microbes in water pumped from the well via microscopy (morphological identification, if possible), and an estimate of the extent of microbial influence within the well. Work for this objective occurred immediately after startup of the well after a nine-month period of stagnancy.

The second objective was to develop a treatment plan based on analysis of results for the first objective. The treatment plan was developed prior to the sampling for Objective 1, based on previous sampling results, to allow for expedited treatment and placement online for summer use.

The third objective was to investigate the stability of water quality parameters for water pumped from the well over an extended period of pumping following treatment and a two-month period of daily use. This objective also included an investigation for the presence of common soil microbes in water pumped from the well via microscopy (morphological identification, if possible), and an estimate of the extent of microbial influence within the well.

Definition of Terms

Borehole volume: Volume of water in the well borehole that was continuously changed over during pumping, which was replenished by flow from the aquifer to the well.

Borehole volumes pumped: Ratio that was determined by dividing the total gallons pumped by the volume of the borehole. This calculation was based on the pump setting, well diameter and well depth, and considered the initial water volume drop above pump at initiation of pumping. A

ratio of greater than one suggests that the water that was pumped from the well was located outside of the well borehole (in the aquifer) at the start of pumping.

Results and Discussion

A portion of the inorganic chemical analysis results are summarized in **Figure 1** through **Figure 5**, with a table of all data gathered included in the appendix. In general, comparing analytical results obtained after treatment of the well with those obtained prior to treatment, the concentrations of iron (total, ferrous and ferric), sulfate, phosphate and silica were generally found to be lower. Microscopy analysis of filtered samples confirmed these results, based on qualitative comparison of the color of the filtered samples; however the magnitude of the difference could not be quantified.

Results for total iron concentration are shown in **Figure 1**. The data suggest there was a reduction in total iron concentration after treatment of the well; however the statistical difference between all correlated sampling times was not significant (two sample t-test, p=0.62). Results for analysis of ferrous iron (Fe^{+2}) also indicated a reduction in concentration following treatment of the well, and statistical analysis of all correlated sampling times indicated a marginally significant difference (two sample t-test, p=0.11). If the 0-minute thru 2-minute samples are excluded from the two sample t-test analysis, which tests the statistical difference between water that originated from the aquifer at start of pumping (borehole volume pumped of approximately 1 and larger), the reduction in total iron concentration following treatment of the well was statistically significant (p=0.008).

Qualitative microscopic analysis of the 0-minute filtered sample, before and after treatment of the well, indicated the presence of a large microbial population in the first flush samples. However, there appeared to be a reduction in total microbial population in the first flush sample following treatment of the well. Prior to treatment, iron oxidizing bacteria such as *Gallionella* sp. and *Crenothrix* sp. were present, as well as the fungal species *Aspergillus*. After treatment of the well, *Aspergillus* appeared to increase in occurrence; whereas *Gallionella* was not identified (other unidentified morphologies were present). The initial water pumped from the well was oxygenated for both analyses (see appendix), which suggests conditions were present to support iron oxidizing bacteria and Aspergilla. The reduction in *Gallionella* sp. and *Crenothrix* sp. following suggests treatment of the well reduced microbial occurrence, so the significant reduction in total iron concentration from the aquifer suggests a positive relationship between total iron concentration and microbial occurrence.

Microscopy analyses of water pumped from the well, particularly after long periods of continuous pumping, suggest the presence of disperse bacilli-form bacteria of 1μm diameter. These bacilli are numerous, and appear to be coated in iron due to their orange iron-oxide color. The literature indicates that organic polymers and polysaccharides secreted by microorganism can be negatively charged, which may allow them to chelate iron from geologic formations and cause the release of iron and other inorganic constituents into solution. In addition, *Aspergillus* is known to secrete a number of secondary metabolites, including organic acids, which also act as chelating agents (Ward et al., 2006; Diano et al., 2009), causing dissolution of aquifer materials and release of metals into solution. The presence of these organisms, and their

association with metals in the environment, suggests their presence is resulting in an increased level of iron in the water pumped from Unit Well No. 8.

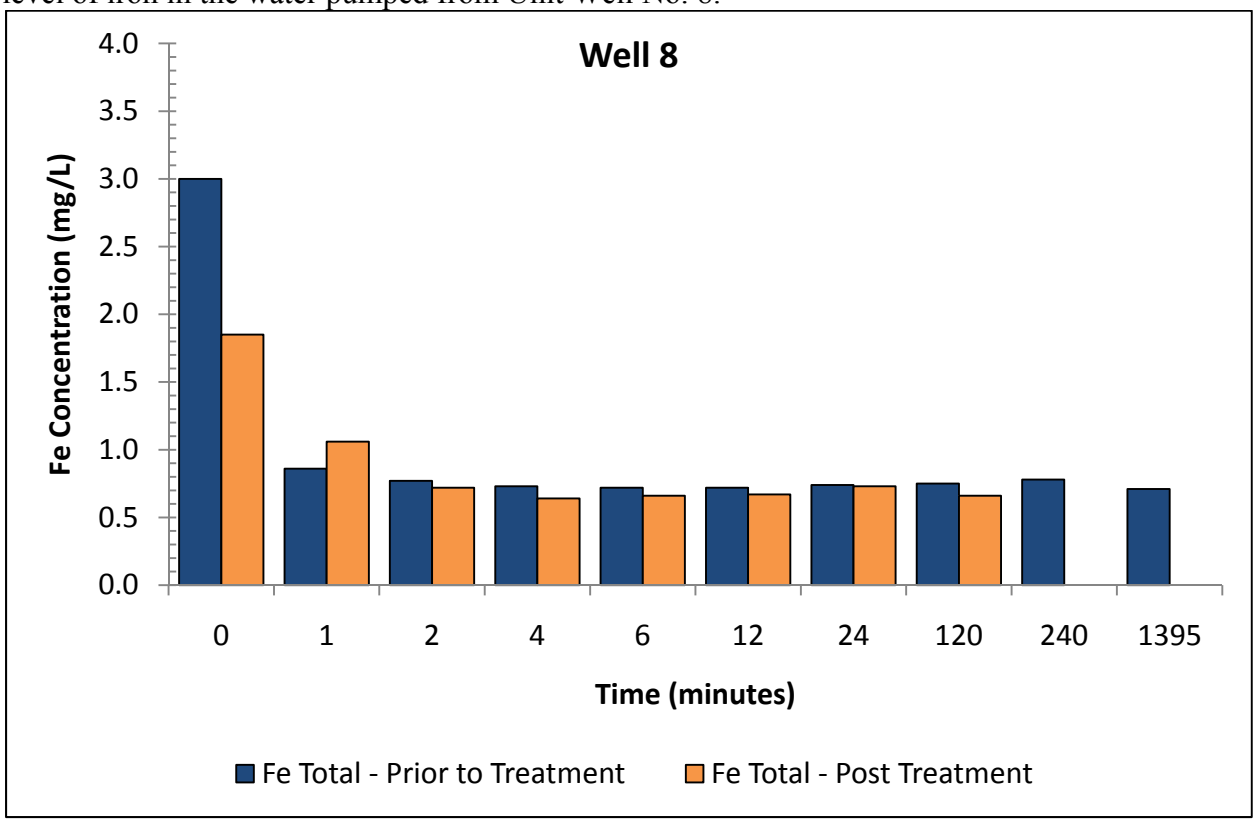

Figure 1. Total iron concentration comparison prior to and post treatment.

The 0-minute sulfate concentration in the well prior to treatment was considerably lower that the background concentration of sulfate after 24 hours of pumping, and was lower than the 0-minute sample from the well after treatment (**Figure 2**). For this sample time, the oxidation reduction potential (ORP) was not determined due to the flow cell just starting to fill, however shortly after filling (approximately 20 seconds) the ORP was -225 mV (**Figure 5**), which indicates a reducing environment was present. The microscopy pictures obtained from this time frame clearly indicate the presence of microbes. Considering this data in combination (a low sulfate level, negative ORP, and microbial occurrence) suggests sulfate reducing bacteria could have been present in this sample to consume sulfate. The significant difference in sulfate concentration at late pumping times for post treatment compared to prior to treatment ($p<0.001$) suggests that treatment of the well may have reduced the occurrence of sulfide oxidizing bacteria, which convert sulfide to sulfate via oxidation to obtain energy for growth and respiration.

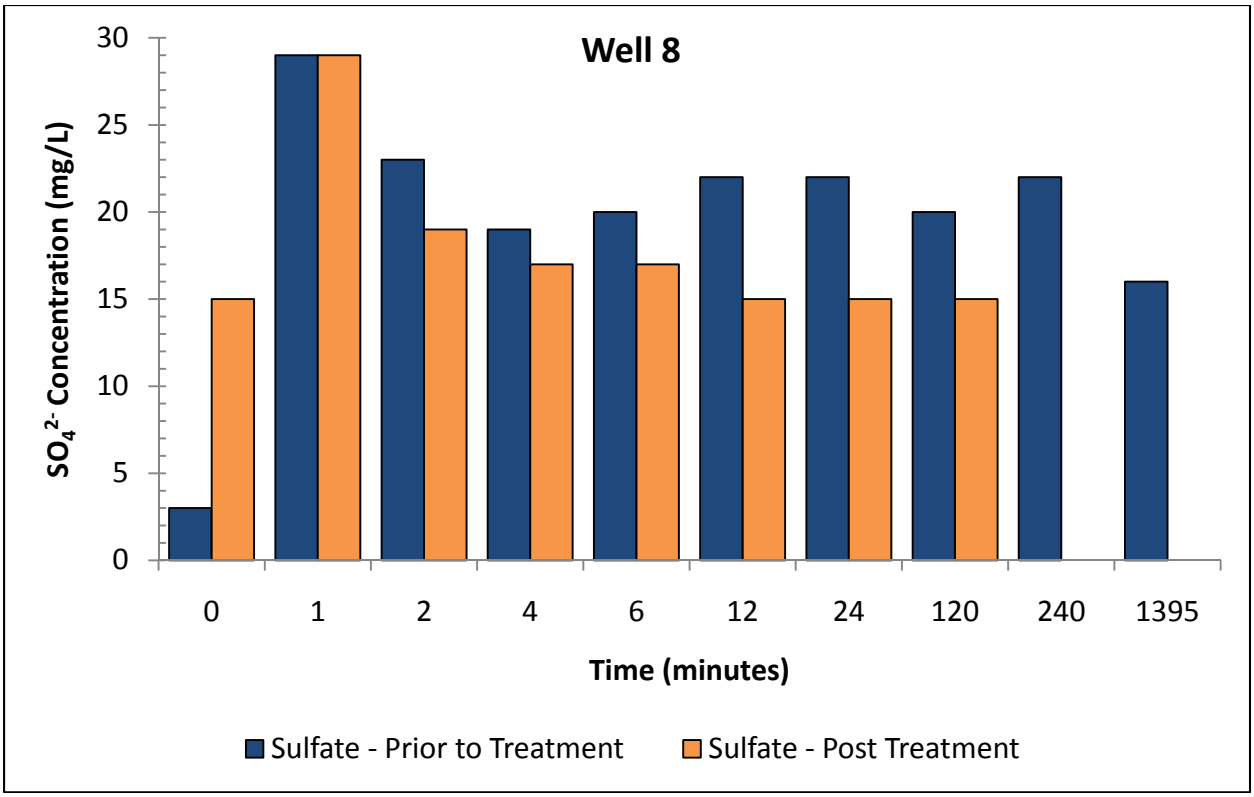

Figure 2. Sulfate concentration comparison prior to and post treatment.

Phosphate results are shown in **Figure 3**, and silica results are shown in **Figure 4**. The concentration of each of these compounds generally declined after treatment of the well. When considering water that originated in the aquifer prior to start of pumping (borehole volumes of greater than 1), phosphate and silica levels were significantly lower after treatment of the well based on a two-sample statistical t-test ($p=0.013$ and $p=0.011$ respectively).

As indicated above, microbial occurrence was visually evident in water pumped from the well at all pumping times, though the microbial consortia appeared to change over time. In a nutrient poor environment, such as a groundwater well, it has been shown that microorganisms utilize the ABC transport system to acquire nutrients from their environment and transport them into the cell through the cell membrane (facilitated transport versus passive diffusion). A primary use for this mechanism is the transport of phosphate in a phosphate poor environment. It has been shown that groundwater microbes will preferentially colonize iron and phosphorous bearing materials to acquire these nutrients (Rogers et al., 1998; Bennett et al., 2001), and in the process release silica from the geologic formation. This observation was subsequently confirmed in laboratory microcosm tests which subjected microbes to glass plates made with and without supplements of iron and phosphorous (Rogers et al., 2004). In this referenced experiment, the groundwater microbial consortium colonized and etched the surface of the iron and phosphorous bearing glass plates, releasing silica from the matrix to put it into solution, but left the glass plates lacking iron and phosphorous supplements untouched. This referenced experiment, when taken into consideration along with the inorganic testing results for Well 8 (unfiltered samples), suggests that the significant reduction in phosphate and silica from Well 8 after treatment may be the result of inactivation of microbes that were living within the borehole prior to treatment. The

fact that silica was detected after treatment suggests that microbes continue to be present in the aquifer, which is consistent with visual observation of microbial morphologies in water that originated in the aquifer. In addition, there could be residual effect of silica release by microbes prior to treatment that may be flowing back toward the well during pumping.

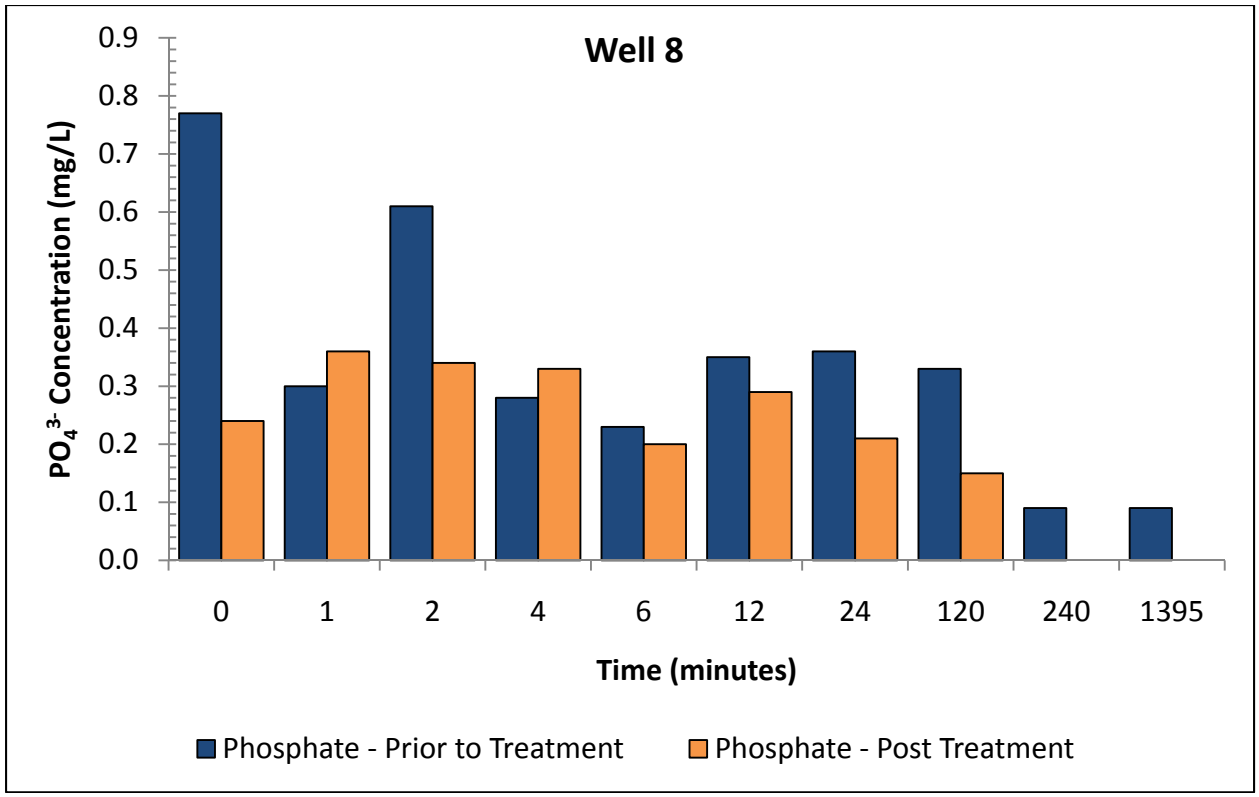

Figure 3. Phosphate concentration comparison prior to and post treatment.

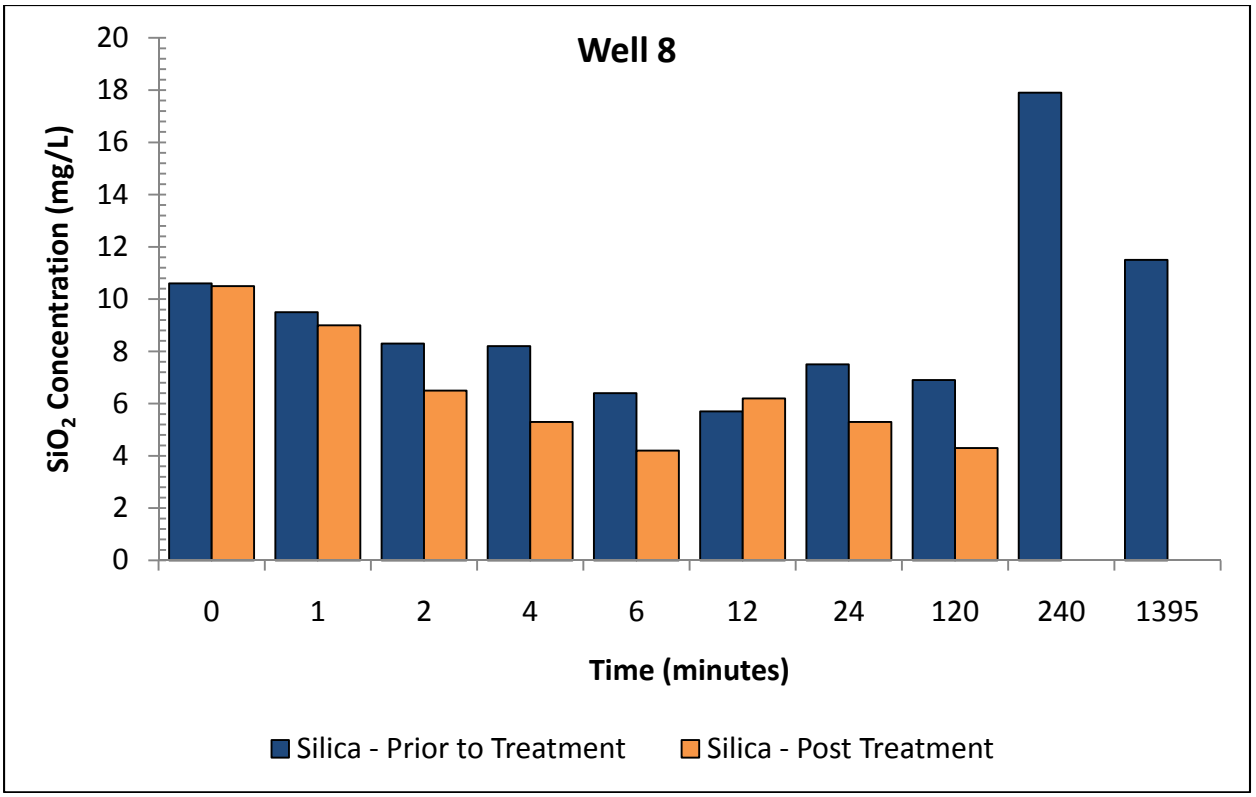

Figure 4. Silica concentration comparison prior to and post treatment.

The results for continuous monitoring of ORP are shown in **Figure 5**. Prior to treatment of the well, the water pumped from the aquifer was characterized as "reducing", with a negative ORP value. The initial water pumped from the well, which originated in the column pipe prior to start of pumping, had a more negative ORP value, suggesting the presence of reducing microorganisms in the borehole. After treatment, the initial water had a slight negative ORP, however the ORP did gradually decline over time suggesting that reduced compounds continues to dominate the water supply and aquifer feeding the well.

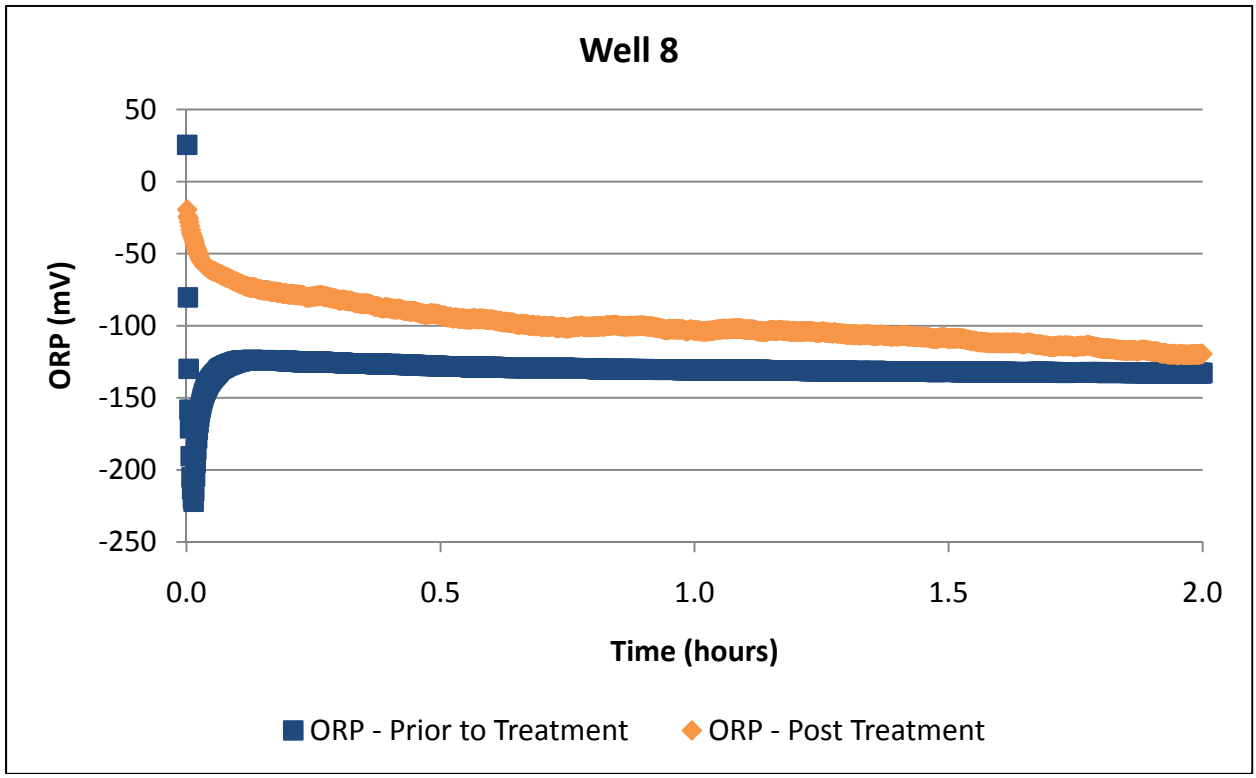

Figure 5. Comparison of oxidation-reduction potential (ORP) prior to and post treatment.

The following pictures were acquired through a microscope mounted camera. These pictures were taken before and after treatment of Well 8 at the times indicated under each picture.

Figure 6 through **Figure 24** generally depict conditions observed under the microscope for each time frame visualized. In general, microbial occurrence was greater in the initial and early pumping times, with only bacilli-form organism identified at late pumping times. This observation suggests that a majority of the first flush microbial population that inhabits the well may in fact inhabit the discharge side of the pump and the pipe leading to the reservoir from the well, which is probably made of uncoated cast iron pipe. At pump shutdown, the pipe from the well to the reservoir drains back to the well as no check valve is located on this line, effectively transporting biofilm related organisms into the well for potential growth and colonization within the well. In addition, this pipe was not effectively disinfected as part of the treatment of the well since the pipe was not able to hold water (drained back to the well). At pump start up, the momentum of the water rushing over the surface-associated biofilm in this pipe may dislodge some of the biofilm and transport it to the reservoir. This action would result in visual microbe detection in samples obtained from the well, with greater microbe occurrence detected in the first flush sample. At some point during pumping of the well, the amount of biofilm loss diminished and water quality representative of the aquifer and borehole dominated the samples. The spike in sample color for the initial time samples, as seen in the pictures, and the relative stabilization of iron, phosphate and sulfate concentration after about two minutes of pumping supports this observation. In addition, the presence of only bacilli-like microorganisms in microscopic examination at late pumping time suggests that these first-flush occurrences may be random biofilm losses from the piping and not organisms from the aquifer and/or borehole. Finally, the

lack of *Gallionella* after treatment suggests that the treatment was effective at impacting microbial occurrence, and that *Gallionella* may be reliant on Aspergilla to obtain nitrate from the complex organic polymers seen in the visualized samples.

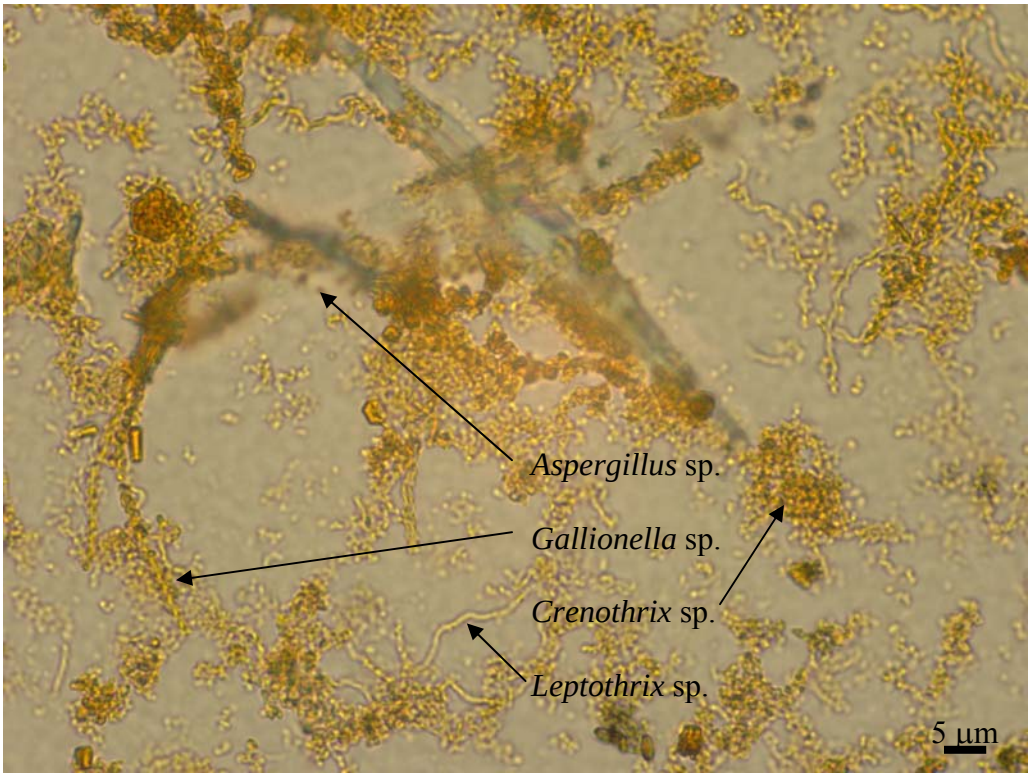

Figure 6. Unit Well No. 8 prior to treatment. Initial sample from sample tap (Time 0).

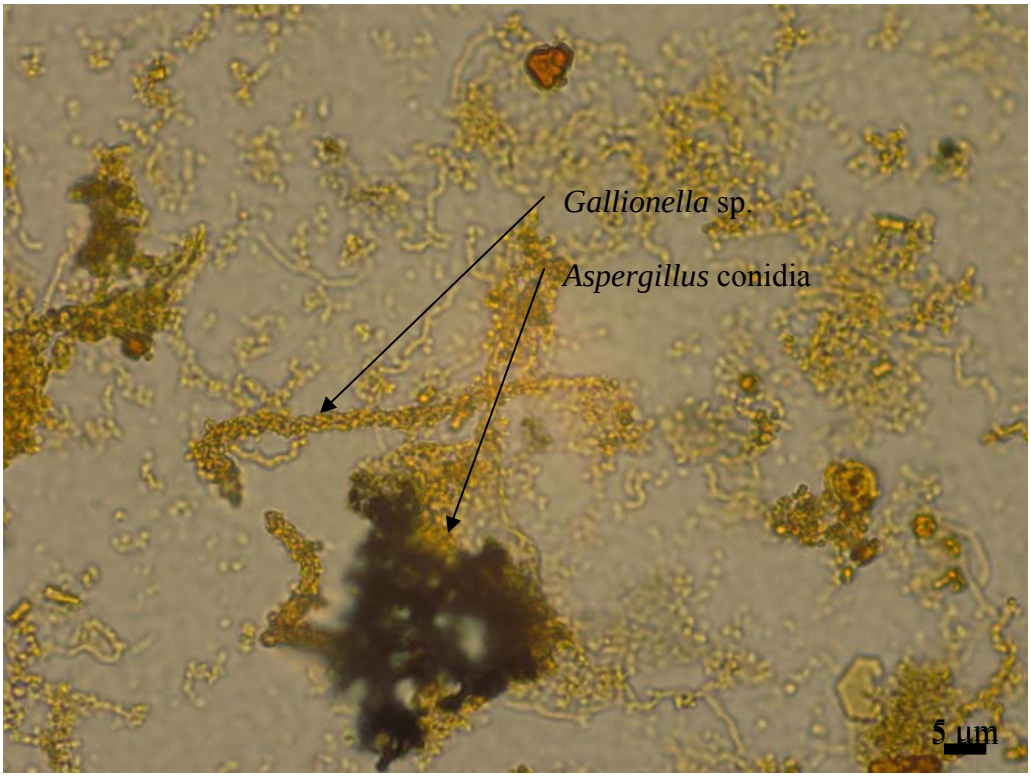

Figure 7. Unit Well No. 8 prior to treatment. Initial sample from sample tap (Time 0).

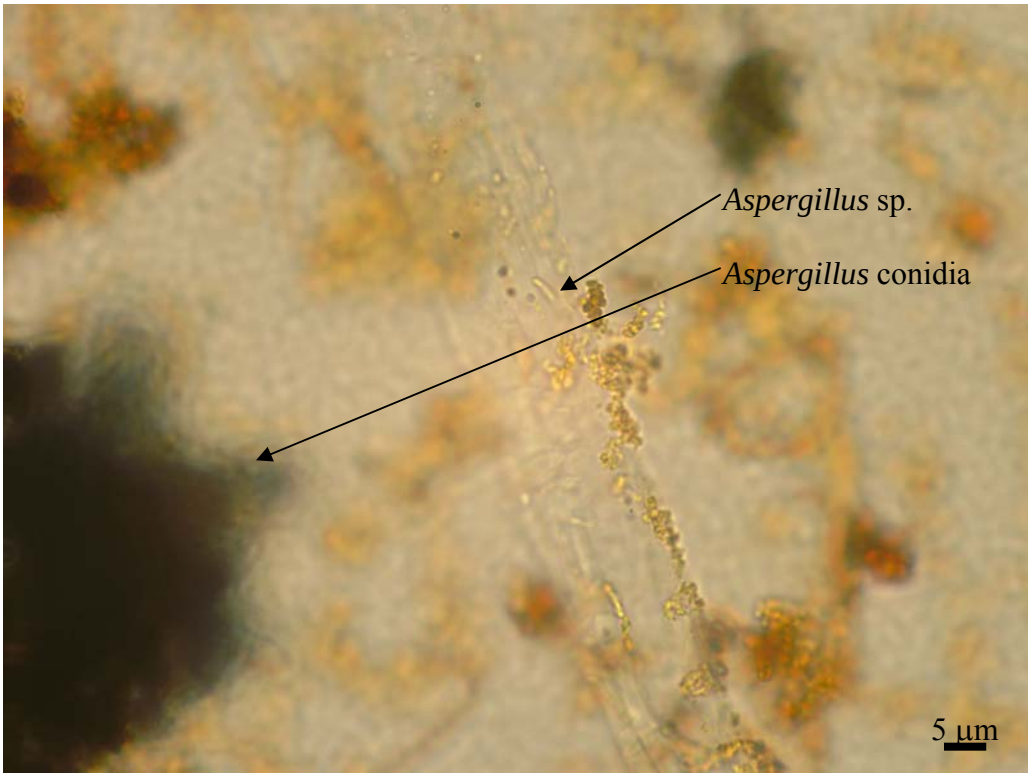

Figure 8. Unit Well No. 8 prior to treatment. Initial sample from sample tap (Time 0).

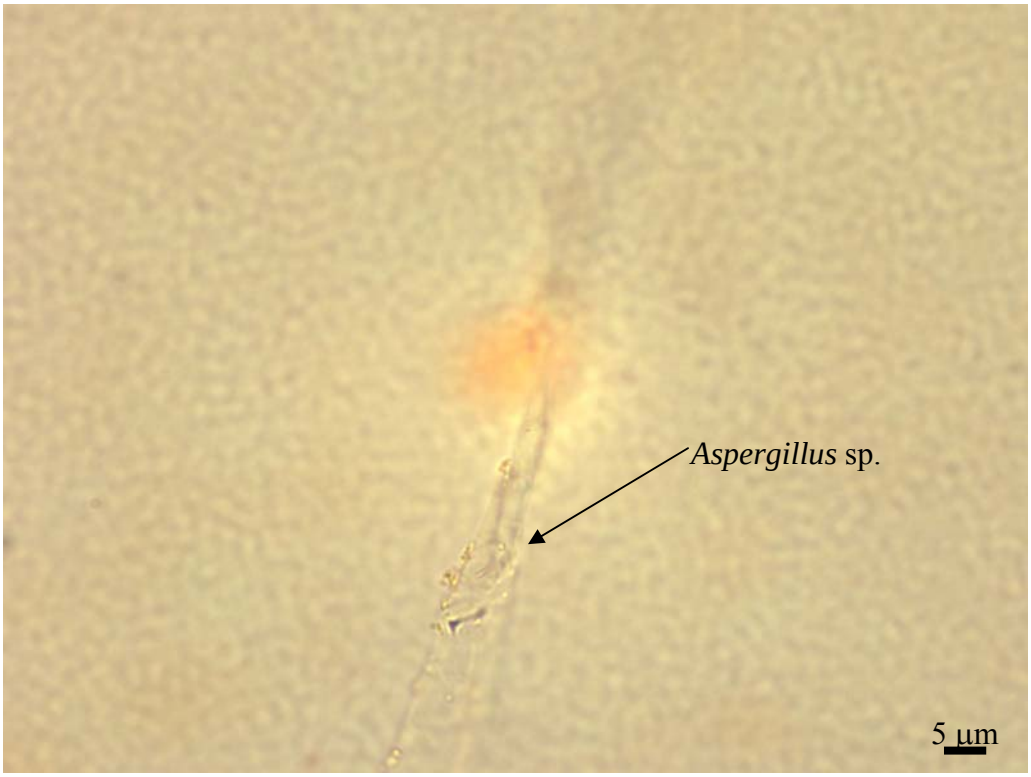

Figure 9. Unit Well No. 8 prior to treatment. Sample obtained after 4 minutes of pumping.

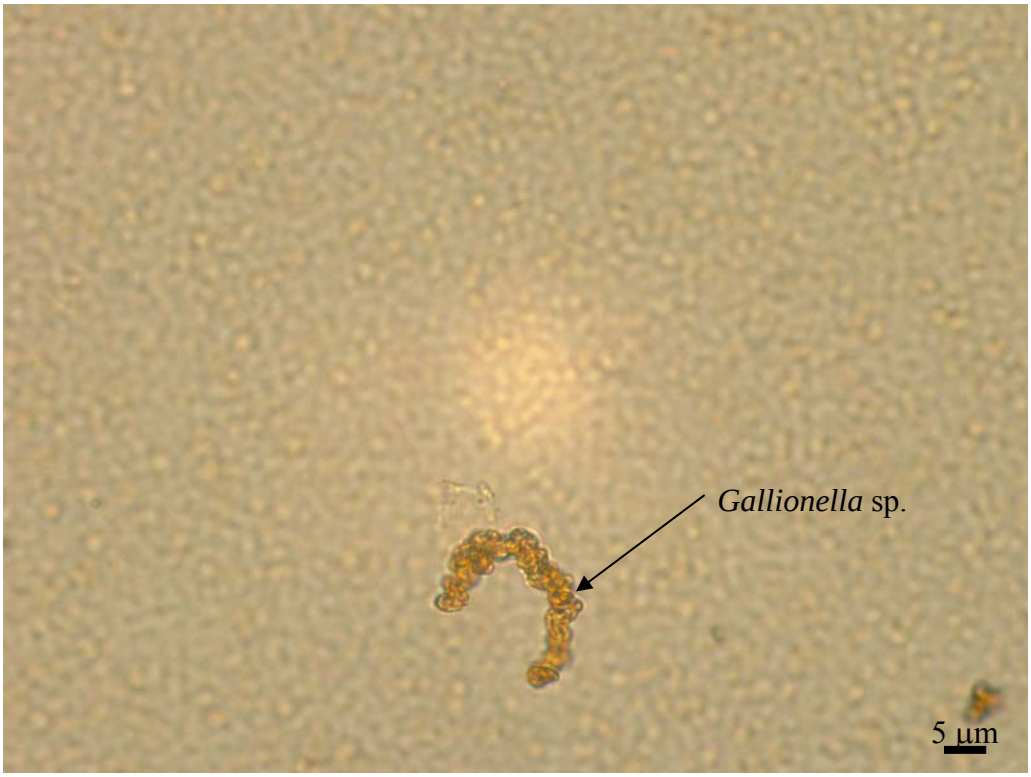

Figure 10. Unit Well No. 8 prior to treatment. Sample obtained after 4 minutes of pumping.

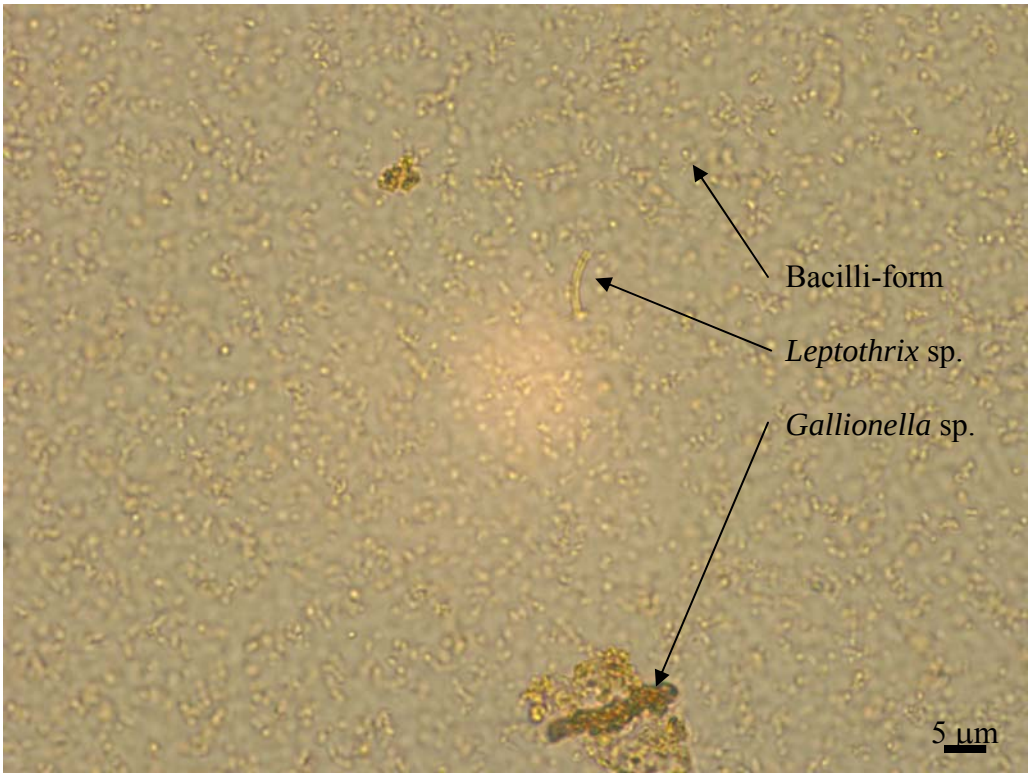

Figure 11. Unit Well No. 8 prior to treatment. Sample obtained after 4 minutes of pumping.

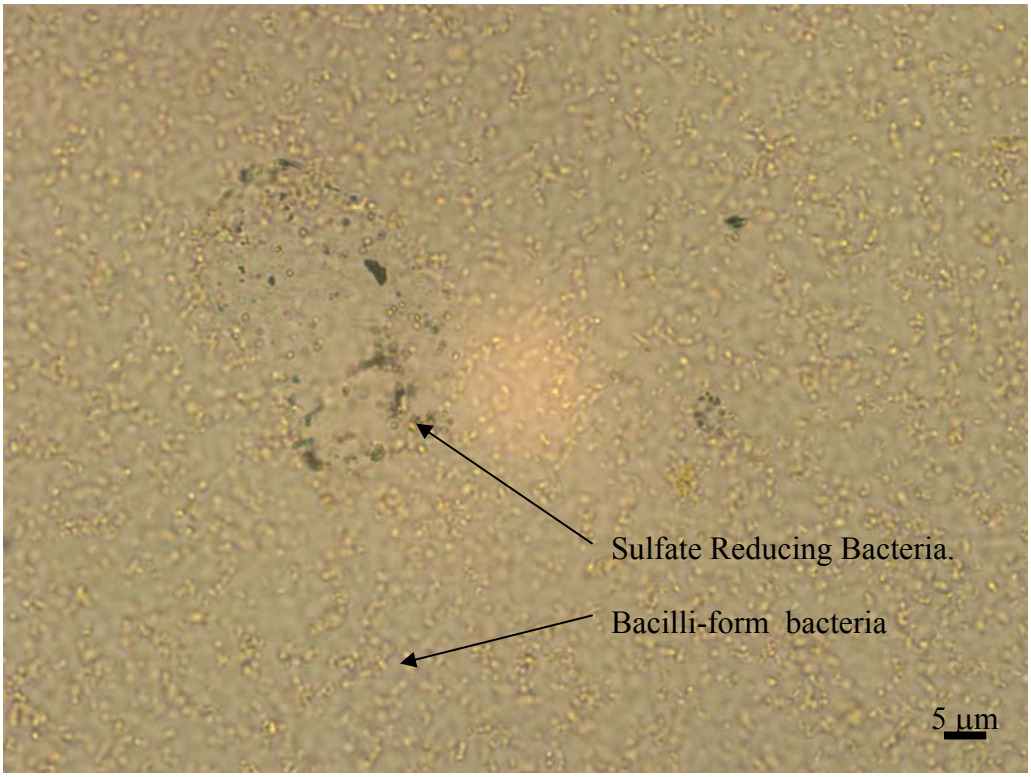

Figure 12. Unit Well No. 8 prior to treatment. Sample obtained after 4 minutes of pumping.

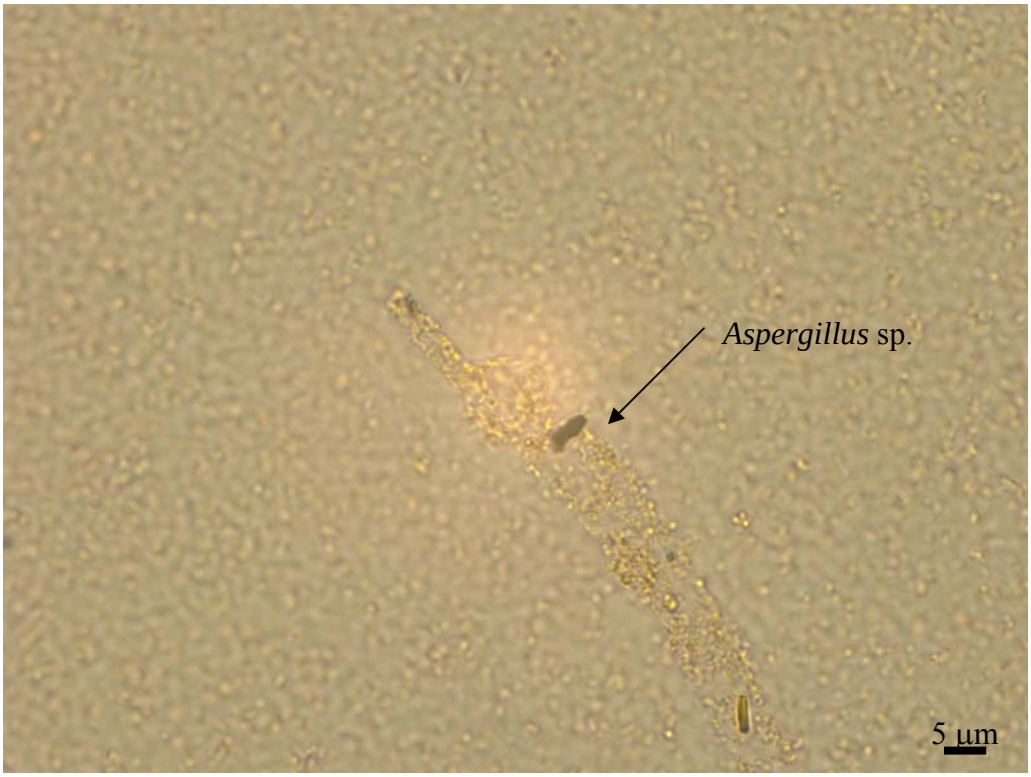

Figure 13. Unit Well No. 8 prior to treatment. Sample obtained after 12 minutes of pumping.

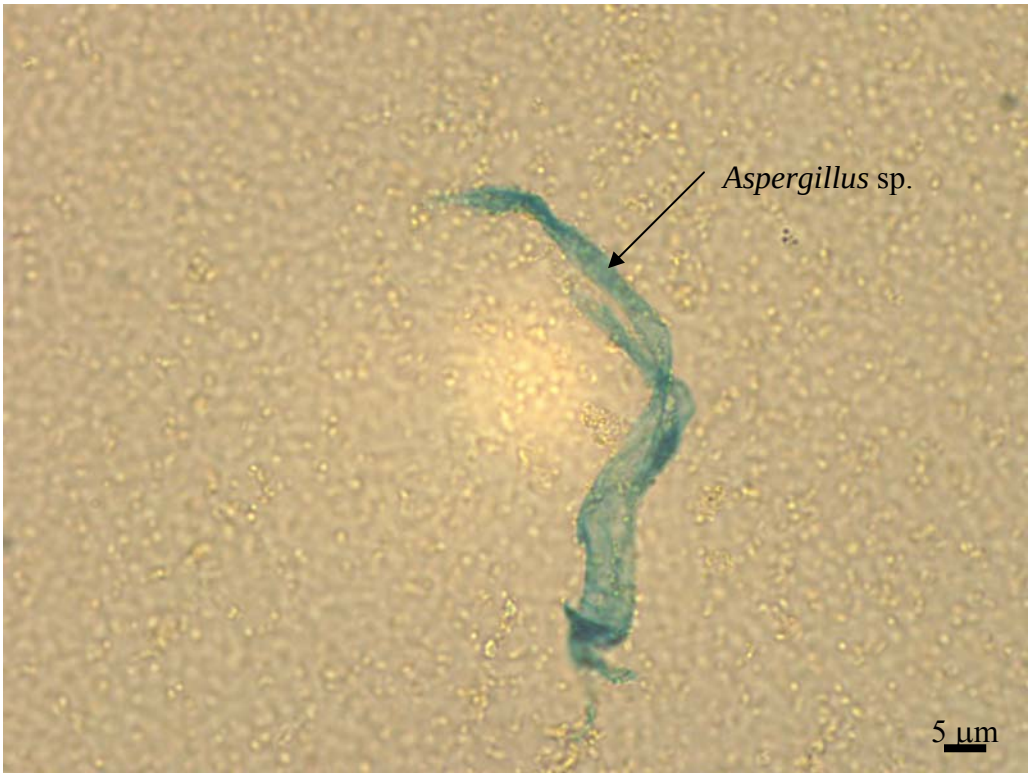

Figure 14. Unit Well No. 8 prior to treatment. Sample obtained after 12 minutes of pumping.

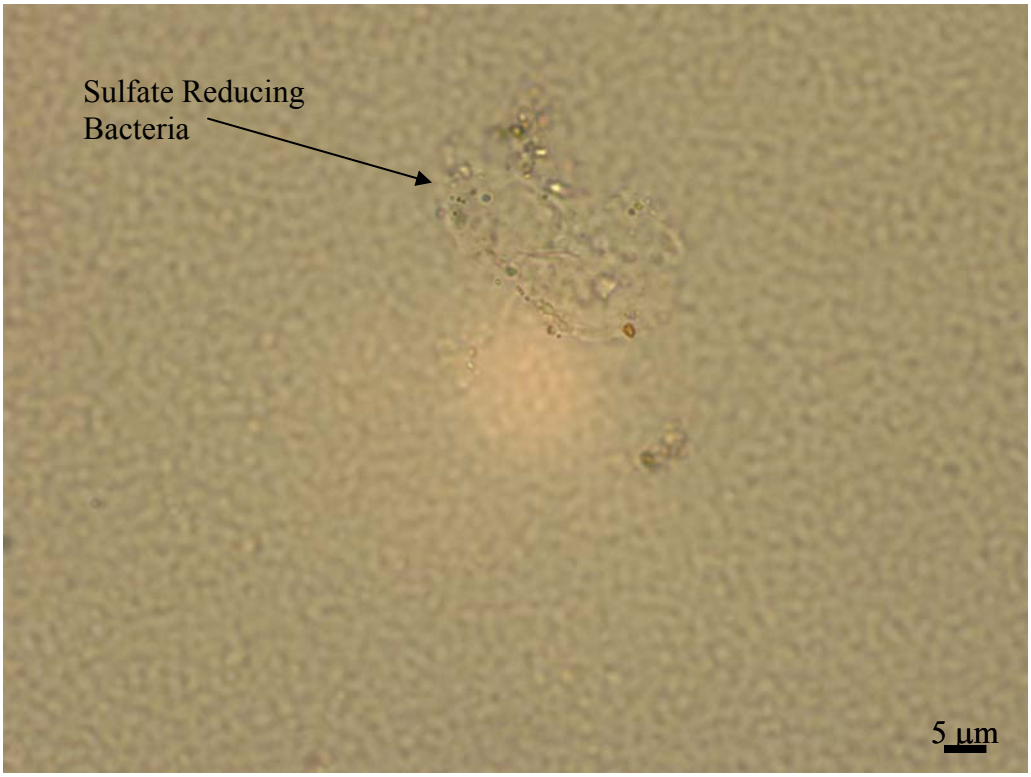

Figure 15. Unit Well No. 8 prior to treatment. Sample obtained after 120 minutes of pumping.

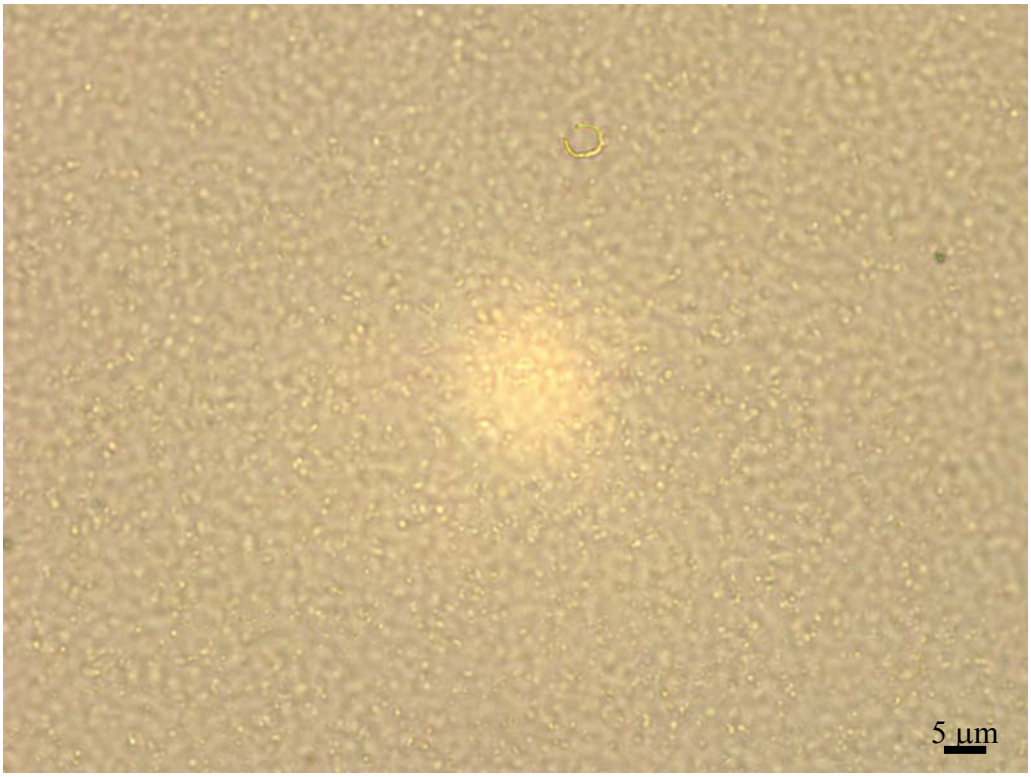

Figure 16. Unit Well No. 8 prior to treatment. Sample obtained after 120 minutes of pumping.

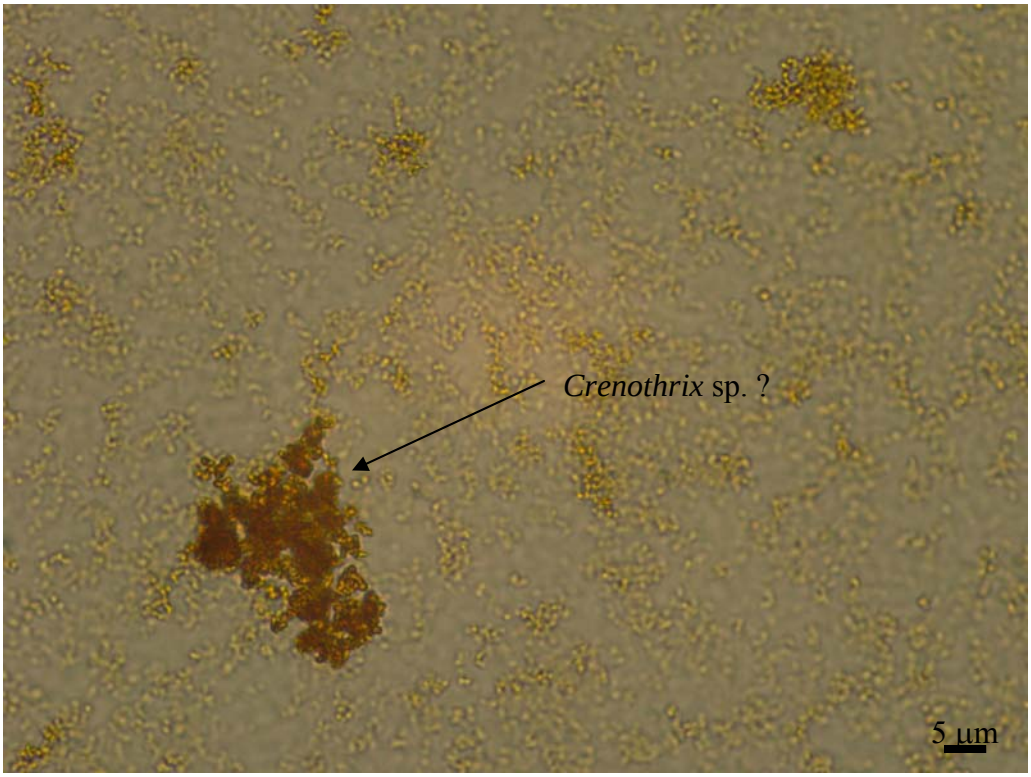

Figure 17. Unit Well No. 8 after treatment. Initial sample from sample tap (Time 0)

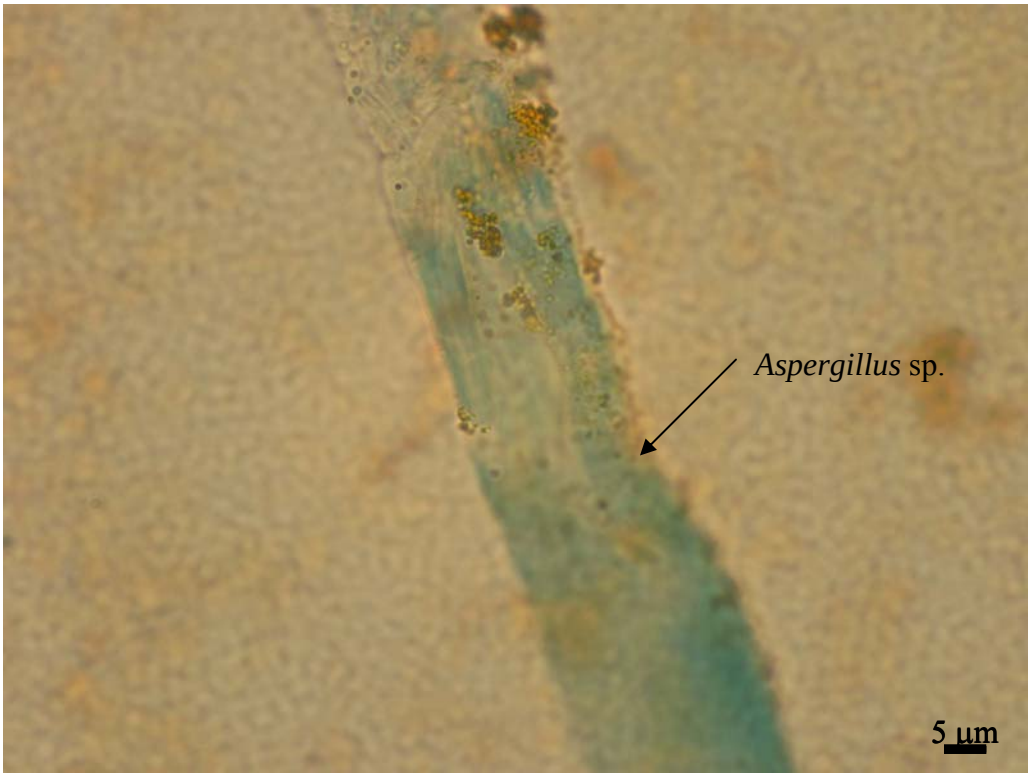

Figure 18. Unit Well No. 8 after treatment. Initial sample from sample tap (Time 0)

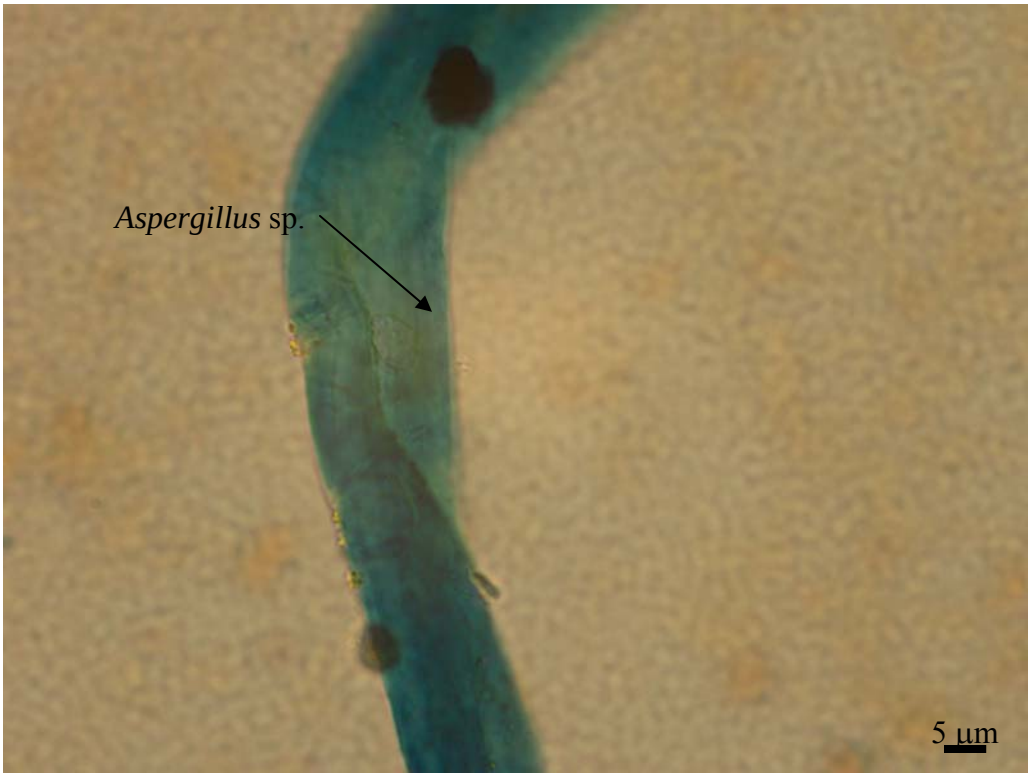

Figure 19. Unit Well No. 8 after treatment. Initial sample from sample tap (Time 0)

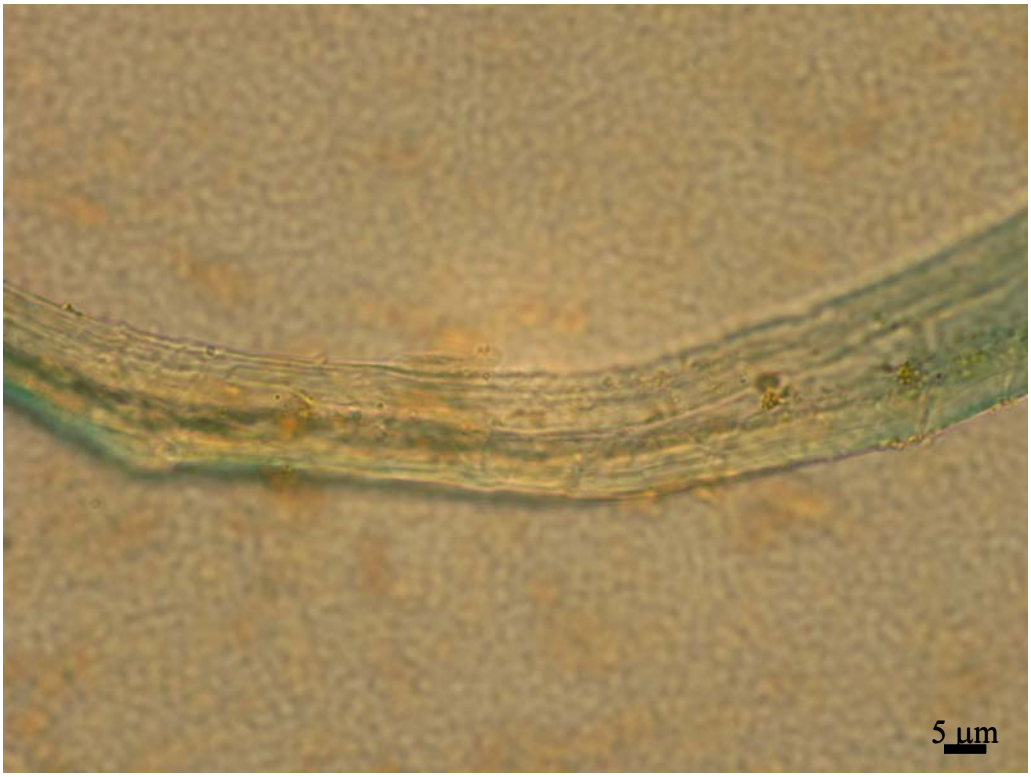

Figure 20. Unit Well No. 8 after treatment. Initial sample from sample tap (Time 0)

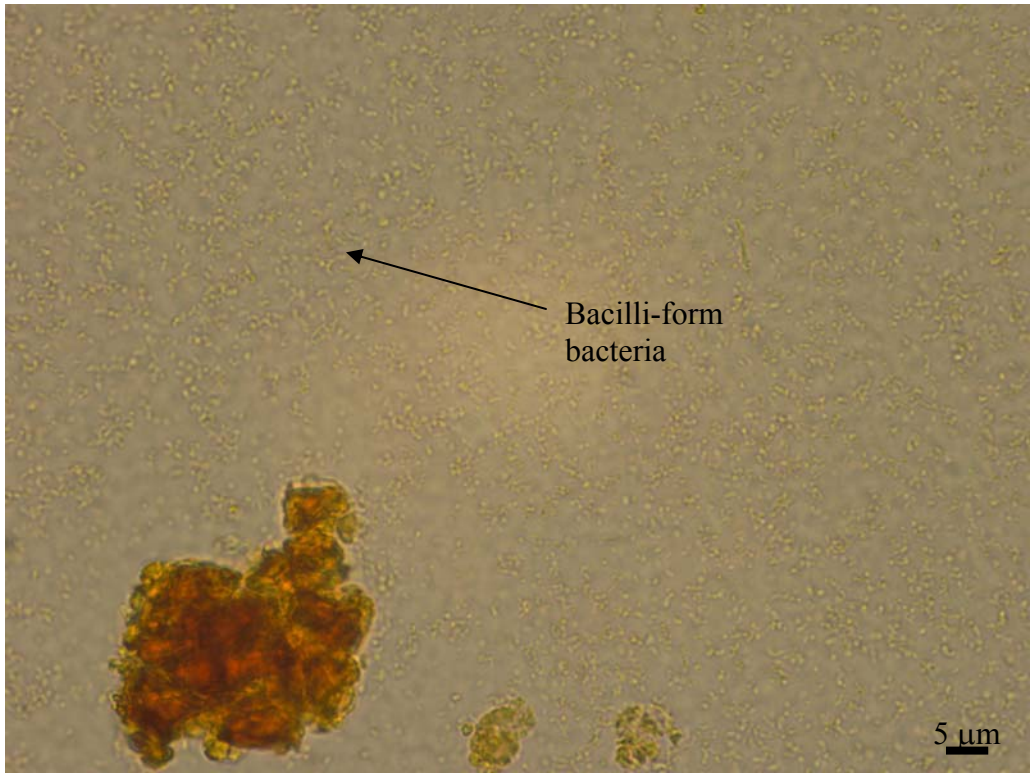

Figure 21. Unit Well No. 8 prior to treatment. Sample obtained after 6 minutes of pumping.

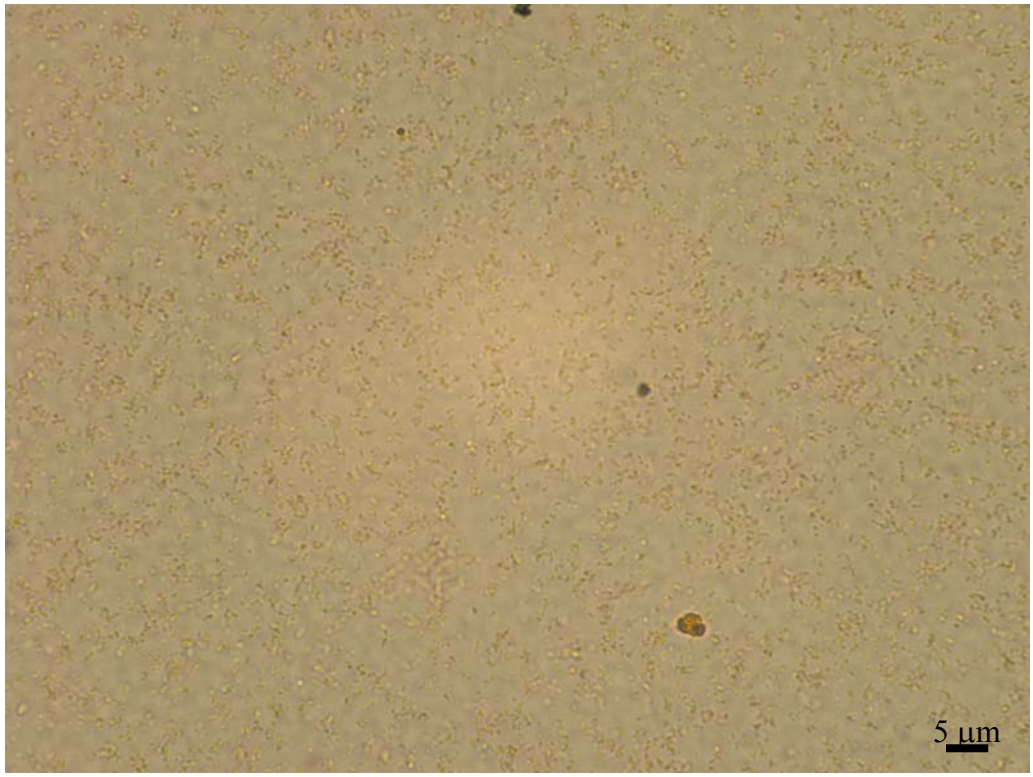

Figure 22. Unit Well No. 8 prior to treatment. Sample obtained after 6 minutes of pumping.

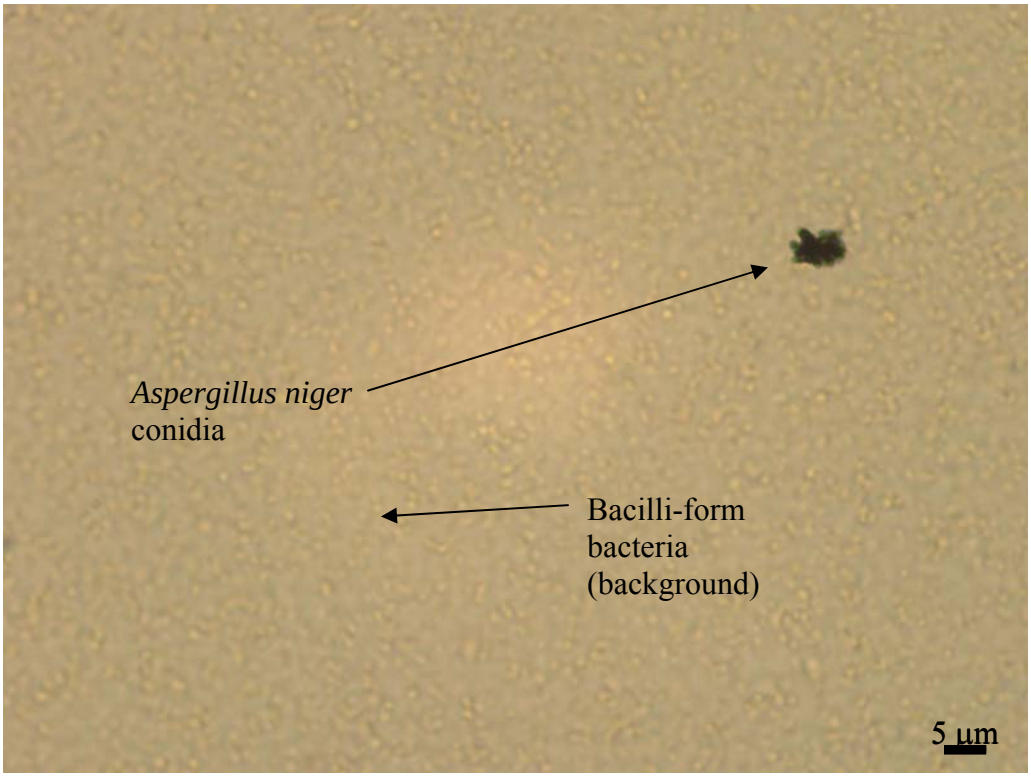

Figure 23. Unit Well No. 8 prior to treatment. Sample obtained after 60 minutes of pumping.

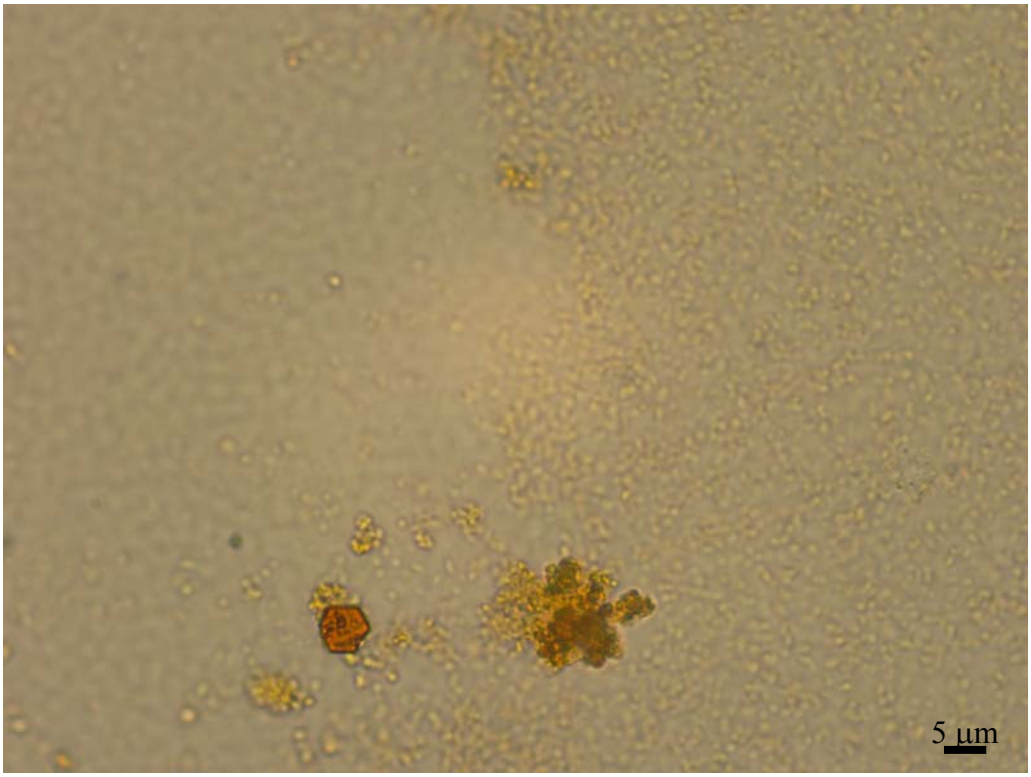

Figure 24. Unit Well No. 8 prior to treatment. Sample obtained after 60 minutes of pumping.

Conclusions

There was a positive association between the concentration of total iron and the occurrence of microbes in water samples analyzed from the well, though the nature of the relationship could not be determined from the analyses performed. Microbes were microscopically visualized at all sampling times. In addition, it appeared that treatment of the well reduced the initial iron concentration of the first flush sample from the well, with visual analysis indicating the absence of *Gallionella* and the increased presence of *Aspergillus*. Aggressive treatment of the well significantly reduced the concentrations of iron, sulfate, silica and phosphate for water that originated in the aquifer prior to pumping. These results indicate that treatment of the well did inactivate microbes that inhabited the well, and impacted some of the microbial activity occurring within the aquifer, however continued presence of bacilli-like microorganisms may indicate that the problem may not be solved by treatment of the well alone.

The background level of total iron associated with late pumping times, which was assumed to represent water acquired from the aquifer, still contained an iron concentration above the aesthetic limit of 0.5 mg/L following treatment of the well. This water also appeared to contain bacilli form bacteria. This result may suggest that the well is drawing induced recharge water that originated from Lake Monona, with the detected bacilli-like bacteria utilizing remnant nutrients obtained from the sediment layer of the lake. Further investigation is needed to determine whether induced recharge is occurring. If it is, and treatment alone cannot control the bacilli, then the only recourse to maintain Unit Well No. 8 as a supply location may be the construction of a filtration plant for removal of metals and microorganisms.

Recommendations

The following is a list of recommendations for the operation of Unit Well No. 8, and for consideration at other facilities operated by the Madison Water Utility:

1. While Unit Well No. 8 is shutdown from September through June, application of a weekly to monthly dosing by direct liquid chlorine addition through the well vent to achieve a chlorine concentration of approximately 10 mg/L may reduce the potential for microbial re-growth within the well(s) during this period of non-use and stagnancy. The benefits of this action may also include inactivation of microorganism within the aquifer formation via extended contact with chlorine, which was not possible during the short duration of treatment that occurred at the well as part of this investigation. Re-sampling of the well in spring may indicate the usefulness of this action, comparing the results with the results obtained during startup of the well in 2009.

2. Piping between the well and the reservoir empties back to the well when the well is not in use. This construction arrangement may support the existence of a surface associated biofilm above the water line inside the pump column, which may include large numbers of *Aspergillus* species. This hypothesis could be investigated by obtaining a biofilm sample from the inside of the discharge piping in the pump room. Potential sampling locations include any tap in the pipe, where the tap could be removed to gain access to the pipe interior. If an *Aspergillus* dominated biofilm is detected, water quality may be improved by aggressive cleaning of this pipe section and modification of the pipe arrangement to keep the pipe full of water at all times.

3. The presence of bacilli form bacteria in late pumping time samples may indicate that the well is pumping induced recharge water obtained from Lake Monona. Investigating oxygen isotope data for the water pumped from the well may confirm this hypothesis.

4. In general, water quality from a seasonal well may be improved by instituting changes in operational practice, disinfection, and shutdown of the wells similar to those discussed herein for Unit Well No. 8. The benefit of these changes may include improved quality of water pumped from the wells (reduced metal concentrations and biological activity), which may translate to improved distribution system water quality.

Methods

To determine the presence and extent of microbes within a groundwater well, and evaluate the potential for these microbes to influence water quality, water samples were gathered for analysis at specific time points after startup of the well pump. Prior to treatment, the following samples were gathered: initial, 1, 2, 4, 6, 12, 24, 120, 240 and 1395 minutes after pump startup. After treatment, the following samples were gathered: initial, 1, 2, 4, 6, 12, 24, 60 and 120 minutes after pump startup. Prior to each sampling event, the well was stagnant for a minimum of 24-hours. Samples were collected from the first sample tap downstream of the wellhead. Each sample was collected in a 500 ml pre-sterilized Whirl Pak bag, and analyzed onsite for sulfate, sulfide, orthophosphate, phosphonate, silica, ferrous iron and ferric iron using a HACH spectrophotometer. Alkalinity was also determined onsite by a HACH digital titration kit. At the time of sample collection, parameters of temperature, pH, oxidation-reduction potential (ORP), dissolved oxygen (DO) and conductivity were gathered using a YSI 6920-2 multi-parameter sonde with a flow cell.

Samples were analyzed for chemical composition as follows:

1. Alkalinity: unfiltered sample; titration HACH Method 8203.
2. Sulfate: unfiltered sample and blank; processed using HACH Method 8051 (Sulfa Ver 4 Method adapted from Standard Methods for the examination of Water and Wastewater). Limit of detection 0.1 mg/L SO_4^{2-}.
3. Sulfide: unfiltered sample and blank; processed using HACH Method 8131 (Methylene Blue Method, adapted from Standard Methods for the examination of Water and Wastewater). Used for detection of total sulfides, H_2S, HS^-, and certain metal sulfides in groundwater. Limit of detection 1 μg/L S^{2-}.
4. Phosphorous, reactive (orthophosphate): unfiltered sample and blank; processed using HACH Method 8048 (Phos Ver 3 Ascorbic Acid Method, adapted from Standard Methods for the examination of Water and Wastewater). Low end detection limit of 0.045 mg/L PO_4^{3-}.
5. Phosphonate: unfiltered sample and blank; processed using HACH Method 8007 (Persulfate UV oxidation method). Detection limit of 0.045 mg/L PO_4^{3-}.
6. Ferrous iron: unfiltered sample and blank; processed using HACH Method 8146 (1, 10 Phenanthroline Method adapted from Standard Methods for the examination of Water and Wastewater 1980). Detection limit of 0.008 mg/L Fe^{2+}.
7. Total iron: unfiltered water for sample, prepared blank; processed using HACH Method 8365 (FerroMo Method). Detection limit of 0.025 mg/L Fe^{3+}.
8. Silica: unfiltered sample and blank; processed using HACH Method 8185 (Silicomolybdate Method, adapted from Standard Methods for the examination of Water and Wastewater). Lower detection limit of 0.3 mg/L SiO_2.
9. Microscopy examination. 10 ml of each sample was filtered (Millipore HAWP, 0.22 μm pore size, 25 mm diameter filter paper) for microscopy examination, with the exception of the initial sample time prior to treatment, which was 5 ml. Filters were air dried, adhered to slides using immersion oil, covered with glass cover slips, and randomly viewed. Pictures were acquired through a microscope mounted digital camera to document findings and depict representative results for sample times visually analyzed. A consistent sample size was attempted to allow qualitative comparison of visual analyses. At 100X magnification and 10 ml of sample volume, each picture represents 0.0055% of sample volume (0.55 μl), with 100 pictures representative of one drop of water. For the sample volume of 5 ml, 200 pictures represent one drop of water.

To assist in interpretation of data, sample source within the well prior to start of pumping was estimated for each sample obtained. The initial sample obtained at time zero, the time when water reached the sample tap after start of pumping, was considered representative of water that was in the well discharge column above the pump just prior to starting the well. Each subsequent sample was either representative of water that was in the well borehole just prior to pumping or a combination of borehole and aquifer water. The last sample was considered representative of the aquifer flowing toward the well with minimal influence from the well borehole. Water pumping rate, and static and dynamic water levels within the well borehole were recorded to estimate original source location for each sampling time (or estimated based on previous measurements). By comparing changes in chemical composition of the water, analysis of microscopy results, and estimating source location of water tested, influence of microbial activity was characterized and extent of activity was estimated.

A summary of the treatment plan is included in the appendix.

Treatment plan and chemical requirement for Unit Well #8, with notations from treatment Madison Water Utility

Monday June 29th

1) begin sampling of well at approximately 9:00 am
2) Sample times of 0, 1, 2, 4, 6, 12, and 24 minutes, and 2, 4 and 24 hours.

Tuesday June 30th

1) Take 24 hour sample and shutdown well
2) Add Carus 8100 (phosphate, NSF approved)) through well vent at 2.5 gallons/1000 gallon borehole volume (20 gallons)
3) Surge well 5 times to mix (6 second run time for water to hit sample tap)
4) Add Carus 8100 at 3.75 gallons/1000 gallon borehole volume (30 gallons)
5) Surge well 5 times to mix
6) Add IntelliClor (acid, NSF approved) at approx. 1 gallon/150 gallon borehole volume (50 gallons)
7) Surge well 5 times to mix
8) Let sit for a minimum of 8 hours.

Wednesday July 1st

1) 9:00 am, Flush well to reservoir, pump reservoir to sanitary sewer.
    a) First flush surprisingly clear
    b) At 1 minute into flush, pH was 5.5.
    c) First color appeared at about 45 seconds, suggesting color came from deep in the hole.
    d) Greenish color from 45 seconds to 5 minutes.
    e) Flushed 11 minutes, running clear.
2) Surged 5 times at five minute runtime each surge to dislodge loose biofilm.
    a) Total runtime of 36 minutes.
    b) At 1 minute into 5th surge:
        i) pH was 6.7,
        ii) Fe total was 0.1 mg/L (compared to 0.86 prior to treatment)
        iii) Phosphate was > 6 mg/L.
3) Add IntelliClor at approx. 1 gallon/150 gallon borehole volume (50 gallons)
4) Surge well 5 times to mix
5) Add 12.5% NaOCl to achieve 1000 ppm (61 gallons)
6) Surge well 5 times to mix
7) Final treatment pH was 7.00
8) Let well sit stagnant

Friday July 3rd

1) Flush well to waste 9 minutes, followed by one 6 minute runtime surge.
    a) Again, first flush surprisingly clear, with mild yellow/green color from 45 seconds to 5 minutes.
    b) Chlorine residual approximately 200 ppm.
    c) 1 minute sample, pH = 6.1

d) 5 minute sample
    i) pH = 6.5
    ii) Fe total = 0.67 mg/L (compared to 0.86 prior to treatment)
e) Total runtime of 15 minutes, running clear.
f) Flow diverted to reservoir for pumping to sanitary.
g) Phosphate level in reservoir at end of flushing was approximately 21 mg/L.

2) Add IntelliClor at approx. 1 gallon/150 gallon borehole volume (50 gallons)
3) Surge well 5 times to mix
4) Add 12.5% NaOCl to achieve 1000 ppm (60 gallons)
5) Surge well 5 times to mix
6) After 2nd treatment, pH = 6.7
7) Let well sit stagnant over the weekend

Tuesday July 7th

1) Flush well to waste, diverting to reservoir for de-chlorination, 60 minute runtime.
    a) First color present in flush at 20 seconds
        i) Greenish yellow in color
        ii) Microscopic examination indicates significant iron related debris
    b) 1 minute, pH = 6.35
    c) 30 minute
        i) pH = 6.63
        ii) alkalinity = 322 mg/L
    d) 60 minute
        i) pH = 6.86
        ii) alkalinity = 311 mg/L
        iii) total iron = 1.3 mg/L
        iv) phosphate = 1.4 mg/L
        v) microscopic examination:
            (1) Significant reduction in organic polymers.
            (2) Oxide particles present, both black and brown in color, suggesting manganese and iron precipitate caused by treatment.
2) Add IntelliClor at approx. 1 gallon/150 gallon borehole volume (50 gallons)
3) Surge well 5 times to mix
4) Check pH
5) Add 12.5% NaOCl to achieve 1000 ppm (60 gallons)
6) Surge well 5 times to mix
7) After 3rd treatment, pH = 6.73
8) Let well sit stagnant until Thursday July 9th

Table 1. Inorganic analysis prior to treatment

Prior to treatment

Time (min)	Bicarbonate Alkalinity as CaCO3 (mg/L)	Fe^{2+} (mg/L)	Fe^{3+} (mg/L)	Fe_{Total} (mg/L)	Fe^{2+}/Fe_{Total}	ortho PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	sulfide (ug/L)	silica as SiO_2 (mg/L)	pump rate (gpm)	approx. aquifer radius (ft)	gallons pumped	borehole volumes pumped	microscope volume (ml)
0	233	0.46	2.54	3.00	0.15	0.77	3	68	10.6	1840	0	0	0.00	5.00
1	298	0.54	0.32	0.86	0.63	0.30	29	4	9.5	1840	2	1,840	0.24	
2	307	0.44	0.33	0.77	0.57	0.61	23	4	8.3	1840	2	3,680	0.48	
4	320	0.47	0.26	0.73	0.64	0.28	19	2	8.2	1840	3	7,360	0.96	10.00
6		0.50	0.22	0.72	0.69	0.23	20	3	6.4	1840	4	11,040	1.4	
12	323	0.55	0.17	0.72	0.76	0.35	22	0	5.7	1840	6	22,080	2.9	10.00
24	308	0.57	0.17	0.74	0.77	0.36	22	2	7.5	1840	8	44,160	5.8	
120	306	0.70	0.05	0.75	0.93	0.33	20	10	6.9	1840	18	220,800	29	10.00
240	304	0.67	0.11	0.78	0.86	0.09	22	1	17.9	1840	26	441,600	58	
1395	310	0.62	0.09	0.71	0.87	0.09	16	0	11.5	1840	62	2,566,800	336	

Table 2. Inorganic analysis post treatment

Post treatment

Time (min)	Bicarbonate Alkalinity as CaCO3 (mg/L)	Fe^{2+} (mg/L)	Fe^{3+} (mg/L)	Fe_{Total} (mg/L)	Fe^{2+}/Fe_{Total}	ortho PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	sulfide (ug/L)	silica as SiO_2 (mg/L)	pump rate (gpm)	approx. aquifer radius (ft)	gallons pumped	borehole volumes pumped	microscope volume (ml)
0	304	0.31	1.54	1.85	0.17	0.24	15	0	10.5	1840	0	0	0.00	10.00
1	312	0.61	0.45	1.06	0.58	0.36	29	7	9	1840	2	1,840	0.24	
2	306	0.43	0.29	0.72	0.60	0.34	19	12	6.5	1840	2	3,680	0.48	
4	312	0.37	0.27	0.64	0.58	0.33	17	1	5.3	1840	3	7,360	0.96	10.00
6	307	0.41	0.25	0.66	0.62	0.20	17	0	4.2	1840	4	11,040	1.4	
12	309	0.45	0.22	0.67	0.67	0.29	15	1	6.2	1840	6	22,080	2.9	10.00
24	307	0.47	0.26	0.73	0.64	0.21	15	5	5.3	1840	8	44,160	5.8	
60	310	0.57	0.09	0.66	0.86	0.15	15	4	4.3	1840	13	110,400	14	10.00
120						0.10				1840	18	220,800	29	

Table 3. Meter data prior to treatment

Prior to treatment meter data

Time (min)	pH	Temp (deg-C)	Adjusted Dissolved Oxygen (mg/L)	ORP (mV)	Conductivity (mS/cm)	Turbidity (NTU)	TDS (mg/L)
0	8.0	22.2	8.7	26	0.00	4	0.00
1	8.1	12.0	2.1	-195	0.54	10	0.47
2	7.6	11.7	0.8	-147	0.55	2	0.48
4	7.4	11.4	0.3	-130	0.50	0	0.44
6	7.4	11.3	0.2	-125	0.49	0.1	0.43
12	7.4	11.3	0.1	-125	0.50	0.1	0.44
24	7.4	11.4	0.1	-127	0.50	0.2	0.44
120	7.3	11.4	0.0	-133	0.50	0.0	0.44
240	7.3	11.5	0.0	-136	0.50	0.0	0.44
1395	7.3	11.5	0.0	-132	0.49	0.3	0.43

Table 4. Meter data post treatment

Post treatment meter data

Time (min)	pH	Temp (deg-C)	Adjusted Dissolved Oxygen (mg/L)	ORP (mV)	Conductivity (mS/cm)	Turbidity (NTU)	TDS (mg/L)
0	8.3	15.4	8.6	-19	0.49	166	0.39
1	7.4	11.8	2.2	-45	0.55	1123	0.48
2	7.2	11.6	0.8	-58	0.49	1122	0.43
4	7.5	11.4	0.4	-65	0.46	1120	0.40
6	7.2	11.4	0.3	-70	0.46	0.4	0.40
12	7.2	11.4	0.2	-78	0.45	0.6	0.40
24	7.1	11.4	0.2	-88	0.45	0.7	0.40
60	7.2	11.5	0.1	-103	0.45	0.6	0.40
120	7.4	11.5	0.1	-119	0.45	0.6	0.39