Reduction of iron and hydrogen sulfide from a well system using oxidation and filtration

Walkerton Clean Water Centre

Research & Technology Institute

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Acknowledgments

Executive Summary

Background

A year-round residential well system that serves 21 residences, consisted of one 280 foot drilled well that has not been confirmed as true groundwater by a hydrogeological study. Although samples have not indicated any microbiological contamination, the well was assumed to be groundwater under the direct influence of surface water (GUDI) due to elevated turbidity. After some analysis, it was found to contain elevated iron, hydrogen sulfide, sulfate, and ammonia.

Objectives

The purpose of this study was to reduce iron and hydrogen sulfide below the aesthetic objectives using economical treatments and determine an appropriate secondary disinfection strategy.

Approach

The water quality was monitored for iron, sulfide, sulfate, disinfection by-product formation, ammonia, turbidity, pH, chlorine residual, UV transmittance, and manganese to assess the efficacy of the proposed treatment.

Key Findings

A 1 µm cartridge filter was necessary to reduce iron below Ontario's aesthetic objective (AO), while a 3 - 5 µm mono-media sand filter was not successful. A series of 50 - 5 µm and 25 - 1 µm dual gradient nominal depth filters followed by a 0.35 µm surface pleated nominal filter reduced the concentration of iron near or below the detection limit for the duration of treatment.

The sulfide odour was detected at ~ 0.08 mg/L in the untreated well water. Passive aeration and ventilation were not effective at reducing the odour, while oxidation using chlorination and ventilation qualitatively reduced the sulfide odour in the finished water.

Two doses of sodium hypochlorite were tested due to the presence of ammonia. An average of ~ 4 mg/L represented the chloramination dose and an average of ~ 7 mg/L represented the free chlorination dose. Haloacetic acids (HAAs) were not detected while trihalomethanes (THMs) and N-nitrosodimethylamine (NDMA) were detected, but below the maximum acceptable concentration in Ontario for both chlorine doses used.

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1. Introduction

The water supply is a year-round residential system that serves 21 residences each with their own private septic. The system consisted of one 280 foot drilled well that has not been confirmed as true groundwater by a hydrogeological study. Although samples have not indicated any microbiological contamination, the well was assumed to be groundwater under the direct influence of surface water (GUDI) until proven otherwise. The concentration of iron found in the well was ~ 1.5 mg/L, above the aesthetic objective (AO) of 0.3 mg/L (Ontario, 2006), in addition to an offensive sulfide (hydrogen sulfide) odour. No analytical data was previously collected on the level of sulfate or sulfide concentration so it was investigated in this pilot. It was reported by the community Water Association that the turbidity was < 0.1 NTU immediately after sampling from the well; however, if the sample was allowed to sit or was taken near the end of the distribution system, the turbidity was recorded ~ 13 NTU.

The Municipality was investigating the potential of implementing a treatment system for the community. They expressed interest to conduct a pilot experiment to collect information that may assist in determining the most practical and efficient way to remove iron and the sulfide gas odour from the source. The proposed treatments include a combination of aeration and/or chlorine (sodium hypochlorite) oxidation followed by various filtration options.

2. Rationale

Turbidity is an important parameter that represents the clarity of water and measures the suspended particulate and colloidal matter of a water sample, expressed as nephelometric turbidity units (NTU). An instrument that measures this parameter sends a beam of incandescent light through the water sample and measures the amount of light scattered at 90˚ from the light source. Turbidity readings with a low NTU have a low amount of scattered light, meaning they have fewer suspended particles and are clearer. The Province of Ontario's AO for turbidity in the distribution system is 5 NTU (Ontario, 2006). AOs are established for parameters that may impair the taste, odour and/or colour but will not produce adverse health effects.

Iron was measured at ~ 1.5 mg/L which is above the AO of 0.3 mg/L (Ontario, 2006). Iron is common in groundwater due to the natural mineral deposits found in aquifers. The iron ion usually exists in a soluble state as Fe^{2+} in aquifers due to the low level of oxygen deep in the ground (Dvorak et al, 2007). Iron that is dissolved in water cannot be seen, does not produce any colour, and won't scatter light when measuring turbidity. As iron approaches the surface it readily combines and precipitates with oxygen and sulfur compounds to form oxides, hydroxides, carbonates, and sulfides (WHO, 2008). In concentrations above the AO, iron visually produces a brown or rust colour (Dvorak et al, 2007), and will scatter light on a turbidity meter. This explains why the water is initially low in turbidity and increases with time in the distribution system. It is common for elevated levels of iron to impart colour and unpleasant tastes in the water, stain fixtures and laundered materials, and precipitate in the distribution system which may promote the growth of iron bacteria in pipes. Based on the level of iron (< 10 mg/L) and pH (> 7.5), weak oxidants such as air and chlorine are effective at precipitating iron prior to filtration with the appropriate contact time (Dvorak et al, 2007).

Sulfur was reported at the well head as hydrogen sulfide gas, as the gas is volatile and produces offensive odours. Sulfide gas can be present naturally in the ground but can also be a metabolic byproduct of sulfur reducing bacteria. Sulfates are comprised of sulfur and oxygen and occur naturally in soil and rock formations that contain groundwater (WRC 2014). Sulfur reducing bacteria use sulfates as an energy source and are the main producers of hydrogen sulfide gas, a byproduct of its metabolism and is the cause of the offensive rotten egg or sulfur smell (WRC, 2014). These bacteria are found living in low oxygen environments such as deep wells and often thrive in hot water plumbing and heaters (WRC, 2014). Samples of sulfate and sulfide from the well revealed the average sulfate concentration was 1300 mg/L which is above the AO of 500 mg/L; and sulfide was detected in one sample at 0.08 mg/L which is above the AO of 0.05 mg/L. Sulfide results were mostly non-detected but was likely underestimated due to the volatility of sulfide gas.

There are a few options to address elevated concentrations of iron and sulfur. Sulfide can be treated using the same aeration and chlorination approach as used for iron (WSC & EPA, 2007). Sulfate, which in high concentrations can impart a bitter or astringent taste

and have a laxative effect on some individuals, cannot be addressed using oxidation and filtration (Ontario, 2006; MDH, 2018). It is likely that regular consumers develop a tolerance to the laxative effect, but visitors, new residents or people with sensitivities may experience some symptoms. Although the concentration of sulfates cannot be treated using the identified approach, sulfates can be addressed by controlling sulfur reducing bacteria with the maintenance of a chlorine residual to prevent the metabolism and conversion of sulfate to hydrogen sulfide in the distribution system (WSC & EPA, 2007). Additionally, high levels of sulfate may also corrode metallic plumbing such as copper; therefore, plastic polyvinylchloride (PVC) or cross-linked polyethylene (PEX) pipe is often used because it is more resistant to corrosion. Methods that can be used to remove sulfate from water include reverse osmosis, distillation, and ion exchange; however, these methods are not economical in most cases (MDH, 2018) and outside the scope of this project

3. Objectives

The overall purpose of this study is to reduce iron below the aesthetic objective and reduce the unpleasant sulfide gas odour. Specific objectives to be investigated are listed as follows:

3.1   Bench Scale

1. Conduct water quality analysis of untreated well water
2. a) Determine dose(s) and contact time(s) for effective chlorine oxidation of iron
   b) Monitor pH variation for operational guideline
3. Determine appropriate chlorine dose(s) to establish a typical chlorine residual
4. Sample for potential disinfection byproduct formation (specifically THMs, HAAs, and NDMA)

3.2　Pilot Scale

1. a) Reduce iron below the AO using cartridge and media filters

    b) Provide filtered particle size exclusion analysis
2. Monitor filter pressure performance for operation and maintenance
3. Reduce sulfide gas odour in finished water
4. Maintain a free chlorine or chloramine residual after filtration
5. Monitor water quality parameters:
    a) UV transmittance
    b) pH
    c) Turbidity

<u>Note</u>- Items outside the scope of this project are listed as follows:

- Treatment technologies necessary for the proper disinfection of water.
- The calculation of the CT (concentration x time)
- Chlorine residuals of the actual distribution system
    - Values will be underestimated due to distribution material, detention time, maintenance and other pre-existing conditions in comparison to that of the pilot system.
- Treatment necessary for the removal of sulfate
- This pilot project does not address primary disinfection. If the community is interested in chloramination it is important to note that primary disinfection must be met prior to establishing a combined chlorine residual.

4. Methods

4.1   Bench Scale

The purpose of objective 1 was to better understand the source water and identify parameters that could affect the finished quality and the proposed treatment (Table 4.1). The analysis was completed on-site at the well, off-site at the WCWC lab, or sent to an external lab dependent on the parameter being analyzed. Sulfide can be measured with Method 8131 using a spectrophotometer in the range of 0.005 to 0.80 mg/L. Sulfates can be measured with Method 8051 between 2 to 70 mg/L SO_4^{2-} and both methods that measure forms of sulfur have hazardous reagents which must be collected from reacted samples and disposed of according to local, state and federal regulations (APHA, 2012). Sulfate and sulfide samples were shipped to an external lab to limit the risk of handling and storing hazardous chemicals on-site due to facility limitations. Ammonia can be measured with Method 8155 using a benchtop spectrophotometer or a portable handheld 'key' instrument; however, iron at any level and sulfate at levels above the AO are interferences that could impact the results. Ammonia samples were shipped to an external lab and Method 4500-NH3 G was used to compare the results to determine if interferences impacted the results.

The experiment for objective 2 examined the iron composition (dissolved and precipitated) in the well immediately and over time as it would appear in the distribution system with no chlorination; followed by the addition of chlorine doses of 1, 2, 3 and 4 mg/L. The sample containers were amber glass bottles that were treated to be chlorine demand free to eliminate external sources of demand. Five samples were prepared with their corresponding chlorine doses. Samples were filtered with a 0.45 µm (micron) polyethersulfone (PES) membrane filter prior to iron analysis. Method 8008 measured total iron, including both dissolved and precipitated iron, using a spectrophotometer; therefore, filtration with a 0.45 µm filter was used to differentiate between dissolved and precipitated iron. It is widely accepted that iron particles smaller than 0.45 µm are considered dissolved (APHA et al, 2012). This information was used to gauge the most appropriate chlorine dose and contact time for the pilot. Samples that met the iron

minimum detection limit (MDL) at the chlorine dose and contact time were sampled once more to verify the analyzed MDL value. The pH was analyzed once per chlorine dose to ensure it was within the operational guideline of 6.5 - 8.5 (Ontario, 2006).

The experiment that addressed objective 3 showed how the well water reacted with chlorine immediately and over time for the respective chlorine dosages. The doses were chosen based on the level of ammonia found in the raw water and the amount of measured free and total chlorine residual needed to demonstrate a breakpoint curve. Chlorine residuals were measured immediately after dosing, after 30 minutes, and after 24 hours of contact time.

Objective 4 was completed to gauge potential disinfection by-product formation of N-nitrosodimethylamine (NDMA), trihalomethanes (THMs) and haloacetic acids (HAAs) using a simulated distribution system method. A chloramination dose, and chlorination dose were selected for testing, relative to the source water quality at the time to achieve a typical target residual. This test confirmed if the concentrations of disinfection by-products formed meet the Ontario Regulation 169/03, Ontario Drinking Water Quality Standards. Samples were taken in duplicate for quality assurance and control.

Table 4.1. Bench Scale: Sampling and Laboratory Analysis

Objective	No. of Samples	No. of Parameters	Sampling Conditions	In-House Parameters	Out-Sourced Parameters
1	1	41	Untreated	- Turbidity (nephelometric) - Iron (Method 8008) - Filtered iron (Method 8008) - Alkalinity (Method 8203) - pH (Method 8156) - UV transmittance (Method 10054) - Dissolved organic carbon (persulphate-UV oxidation) - Manganese (Method 8149) - Ammonia (Method 8155)	- Manganese (Method 200.8 ICP-MS) - Sulfate (Method 300.1 Ion chromatography) - Sulfide (Method SM 4500-S2 segmented flow colourimetry) - Ammonia (Method 4500-NH3 G)
2	5	35	Chlorinated	- Filtered iron (Method 8008) - pH (Method 8156)	
3	8	36	Chlorinated	- Free chlorine (Method 8201) - Total chlorine (Method 8201)	
4	4	28	Chlorinated	- Free chlorine (Method 8201) - Total chlorine (Method 8201)	- THMs (Method SW-846, SM 8260C) - HAAs (Method EPA 552.3) - NDMA (Method SM 6410B)

4.2   Pilot Scale

From the utility line, a backflow prevention device was installed to protect the residents from experiencing water quality changes during experimental testing (Figure 4.1). Phase 1 included a passive aeration venturi and hydro-pneumatic tank to oxidize and purge sulfide. Following the tank, a peristaltic pump dosed chlorine with an injector prior to a static mixer. A sample port located immediately following chlorination measured iron and chlorine residuals to either confirm bench scale results or allow for adjustments in the process. A chlorination dose of ~ 6.5 - 7 mg/L was used to run the system with a free chlorination residual of ~ 1.2 - 1.5 mg/L following the filters. Sample ports and pressure gauges followed each filter to monitor performance over time. The two proposed methods for the removal of precipitated iron were mono-media sand filtration, housed in a pressure vessel with a nominal rating of 3 - 5 μm and as series of surface pleated cartridge filtration with nominal ratings of 50, 20, 10, 5, and 1 μm.

Phase 2 omitted aeration from the process and chlorination was added upstream of the hydro-pneumatic tank to increase the chlorine contact time (Figure 4.2). This was done to determine if the sulfide odour could be reduced and if the size of the iron particles increased with time under the same filtration conditions.

Phase 3 experimented with a different configuration of cartridge filters and removed the mono-media sand filter due to the results from the first two phases (Figure 4.3). A configuration of a 50 - 5 μm and 25 - 1 μm dual gradient depth nominal filters and a 0.35 μm surface pleated nominal filter were used in series for iron removal with a chlorine dose of ~ 4 mg/L to achieve a combined chlorine residual.

Online analyzers were connected to continuously monitor the quality of water throughout the pilot and measured turbidity, pH, UV transmittance and free chlorine residuals.

Backflow
Preventer

Utility
Line

Hydro-
pneumatic
Tank

Chlorine
Pump

Legend

Check Valve

Ball Valve

Flow Control Valve

Pressure Gauge

Flowmeter

Sample Port

Air Relief Valve

Static Mixer

Venturi

3- 5 um

Monomedia
Sand Filter

50 um

5 um

20 um

1 um

10 um

Cartridge
Filtration
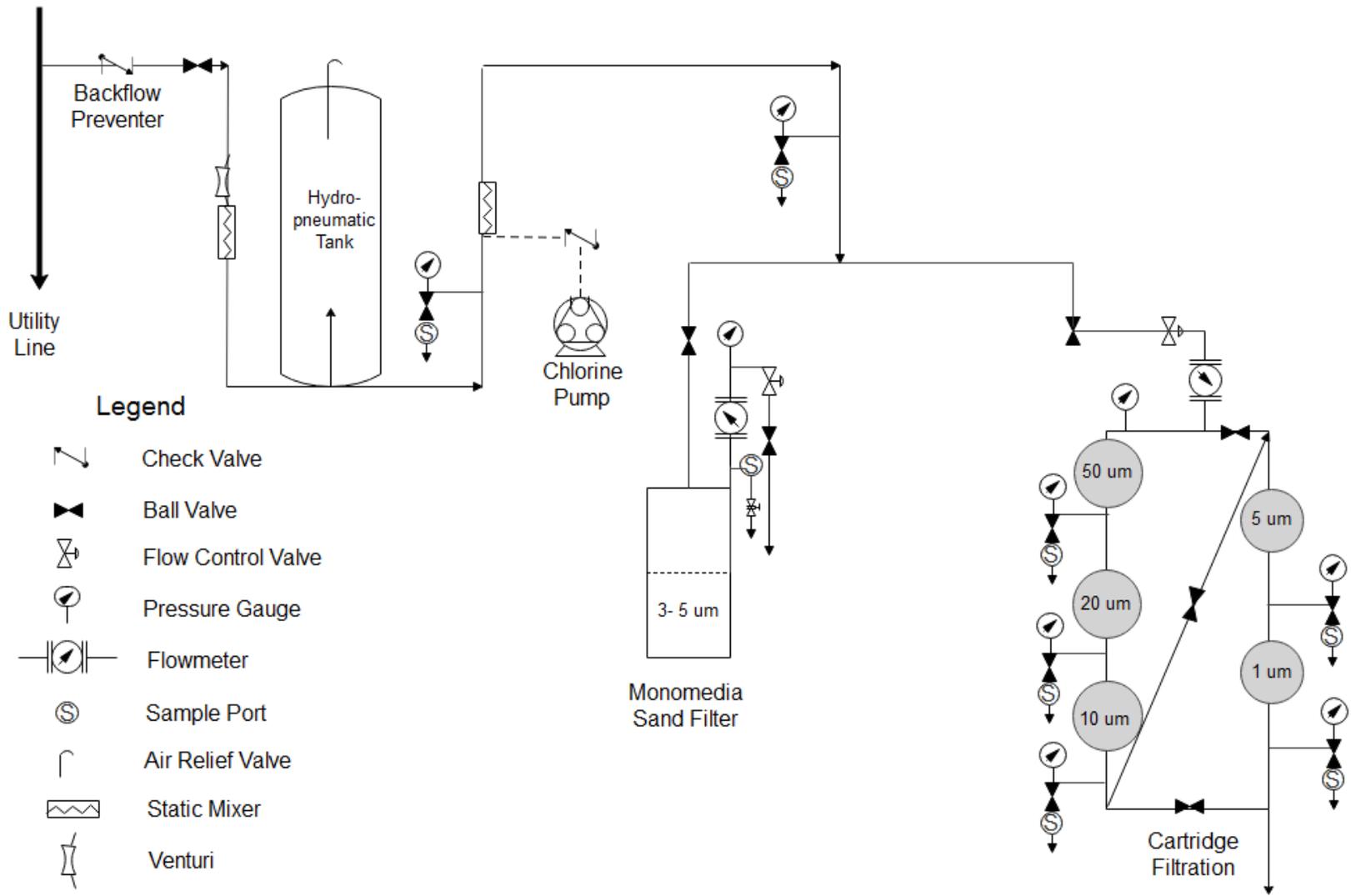
Figure 4.1. Pilot: Phase 1 Process Flow

16
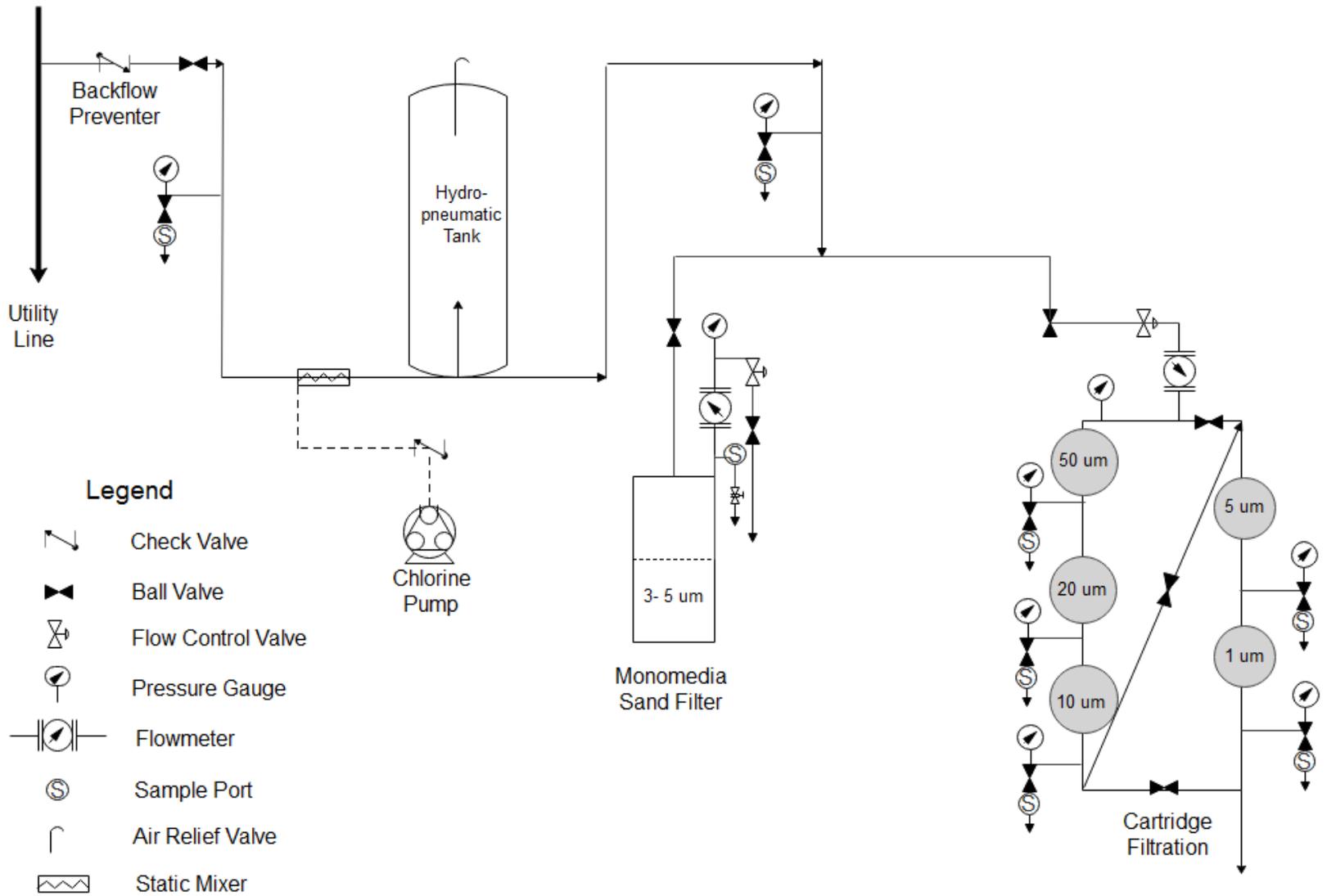
Figure 4.2. Pilot: Phase 2 Process Flow

Backflow
Preventer

Utility
Line

Hydro-
pneumatic
Tank

Chlorine
Pump

Legend

↘ Check Valve

▶◀ Ball Valve

⋈ Flow Control Valve

⌀ Pressure Gauge

⊣⌀⊢ Flowmeter

Ⓢ Sample Port

⌐ Air Relief Valve

〜〜 Static Mixer

3- 5 um

Monomedia
Sand Filter

50 um

20 um

10 um

5 um

1 um

Cartridge
Filtration

17

Figure 4.3. Pilot: Phase 3 Process Flow

Backflow Preventer

Utility Line

Hydro-pneumatic Tank

Chlorine Pump

Legend

Check Valve	
Ball Valve	
Flow Control Valve	
Pressure Gauge	
Flowmeter	
Sample Port	
Air Relief Valve	
Static Mixer	

50-5 um

25-1 um

0.35 um

Cartridge Filtration

4.2.1 Oxidation

Passive aeration is a term used for an air injection system that does not require energy, such as a blower or compressor. Instead, water flows in line where the diameter of the pipe narrows abruptly, increasing the velocity, known as a venturi (Figure 4.1). The increase in velocity creates a vacuum adjacent to a check valve that allows air to be drawn into the pipe but does not let air or water out. The amount of air being d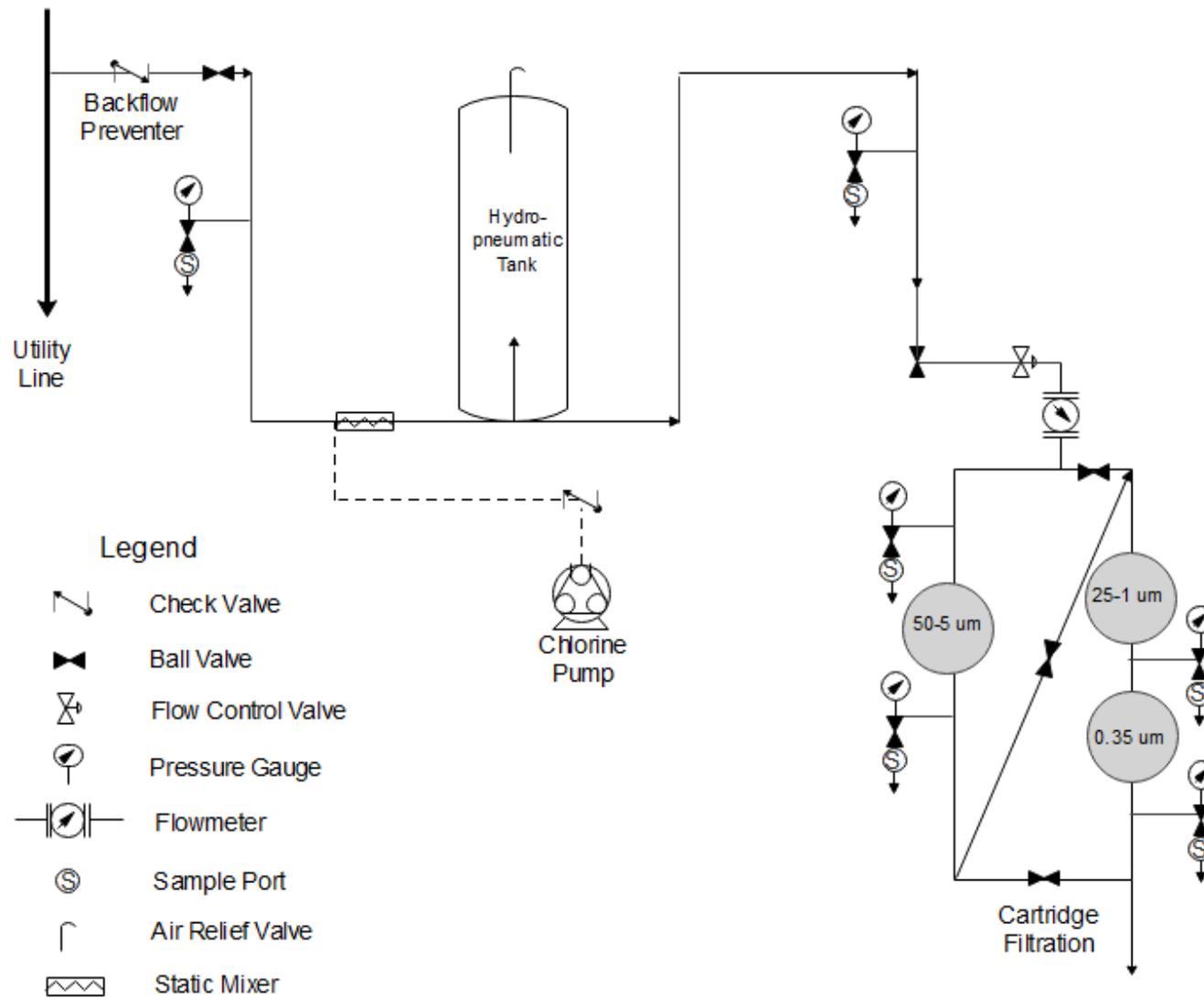rawn into the pipe varies and is controlled by the water flow, pressure, the pipe diameter, and a bypass valve. The system only injects air when water is flowing so there is no need for automation and controls. The system passively injects air because there is no additional energy to the amount of air being applied. Flow meters are available to quantify the air being drawn into the system and specifications are available for sizing units during design. A bypass valve can be used to control the water flow through or around the venturi, thereby allowing the adjustment of air flow through the suction.

Figure 4.4. Pilot: Phase 1 Passive (Venturi) Aeration
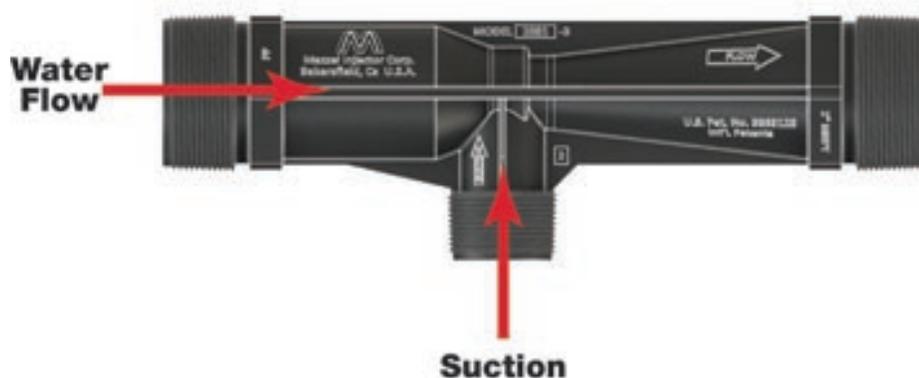
(Source: http://mazzei.net/venturi_injectors/)

The operation and maintenance of this technology is simple, inexpensive, and can be effective; however, the flexibility of the aeration dose is limited. Since aeration is a weak oxidant, conditions such as temperature, contact time, and pH are important for the successful use of aeration as an oxidant. For small applications where chlorine will also be applied as an oxidant, passive aeration is an option. Passive aeration occurs in a closed and pressurized application followed by a hydro-pneumatic tank that controls the amount of air in the system using a float and air relief valve.

Chlorine is a commonly used oxidant for iron precipitation and is favourable since this system will likely be dosing chlorine for secondary disinfection. This simplifies the design, operation, and maintenance of the system with relatively low capital, operation, and maintenance expenses. Chorine is a stronger oxidant than air and can precipitate iron and sulfide with less contact time. In certain cases, chlorine will oxidize iron with very little contact time needed prior to filtration, which is dependent on the iron concentration, chlorine dosage, pH, and temperature. Chlorination is appropriate for both small and large oxidation applications and will reduce the overall footprint when comparing it to aeration alone due to the reduced contact time. Chlorine can also be used to prevent the growth of sulfur reducing bacteria (WSC & EPA, 2007). There is flexibility with the dosage and concentration of chlorine residual in the water provided the system meets its CT disinfection requirements.

4.2.2 Filtration

There are two types of preferred filtration techniques that can be used for particulate removal that produce similar results but vary in capital, operational, and maintenance expenses. Generally, media-based filtration will have more capital, but less operational and maintenance costs compared to cartridge filtration.

The most common media options for particulate removal are either a mono-media comprised of sand or anthracite, or a dual media usually comprised of anthracite and sand or granular activated carbon and sand. The media is housed in a pressure vessel with a strainer system. In residential and commercial applications, a control valve is mounted at the head to provide a control interface for the operator. Some interface functions include the ability to initiate backwashes using capacity, runtime, or a manual setting, and some can monitor the stages of the backwash cycle. The Centre has previously used a mono-media sand filter with a nominal rating of 3-5 μm for precipitated iron particulate removal and found it was able to reduce the concentration of iron to near or below the MDL for a water source. Media based filtration is a reusable technology because of the backwash feature and is commonly adopted in residential to municipal scale potable water systems. A capital and maintenance consideration is the

management of backwash waste that must be collected and disposed of in accordance with local and provincial regulations.

Cartridge filtration is applicable for residential, commercial, and small municipal systems and has a variety of options when considering particulate removal. Cartridges are made from cellulose or synthetic based materials and are either surface pleated (filter at the surface) or depth (filter throughout the depth of the filter's radius). Many filters are rated nominal for filtration efficiency for a specified pore size (example: 99.7% removal of 5 µm), but some are absolute for a specified size and will not allow any particles that size or larger to pass (example: 100% removal of ≥ 1 µm). There are many pore sizes available for both surface and depth filters that include but are not limited to 100, 50, 25, 20, 10, 5, 1, 0.35 µm. Some depth filters are dual gradient and include two filtration ratings across the gradient of the depth (example: 25- 1 µm), which may further reduce the system's design footprint.

The cartridge filtration system in phases 1 and 2 housed five surface pleated filters in series with nominal ratings of decreasing micron sizes (Figure 4.1 and Figure 4.2). The largest was 50 µm followed by 20 µm, 10 µm, 5 µm and 1 µm. The nominal surface filters used were 10" in length by 4.5" in diameter, made from thin cellulose and pleated to increase surface area. Water entered the filter housing and passed from the outside to the inside of the filter where particles of the specified size range were collected at the surface based on efficiency.

In phase 3, the filtration system was comprised of three cartridge filters. Two were dual gradient nominal depth with a 50 - 5 µm and 25 - 1 µm rating followed by one 0.35 µm surface pleated nominal filter (Figure 4.3). The dual gradient depth filters used were also 10" in length by 4.5" in diameter and made with a thick cellulose layer. Filtration also occurred from the outside inward and is based on particulate size efficiency similar to surface pleated; however, the size of the particulate rating decreased as the water traveled through the depth of the filter.

5. Results and Discussion

5.1 Bench Scale

5.1.1 Objective 1: Untreated Well Water Quality

The results for the untreated well water sampling and analysis can be found in Table 5.1. Noted parameters were iron, sulfide, sulfate, and ammonia. The composition of iron was mostly dissolved when analyzed immediately, in agreement with the turbidity and UV transmittance immediately after sampling. The offensive odour caused by sulfide was noticeable in the untreated water and was measured at 0.08 mg/L. Sulfate, which is a source of food for sulfur reducing bacteria and the probable cause for the production of sulfide gas, was detected at 1,300 mg/L.

The ammonia concentration was recorded at an average of 0.43 mg/L and was expected to influence chlorination (Table 5.1). Two ammonia tests were completed on-site internally, with a portable instrument (HACH SL1000) and at the WCWC lab with a colourimetric method that produced similar results. The two methods are affected by iron and sulfate interferences; therefore, ammonia samples were sent to an external lab for confirmation which also produced similar results. The range of ammonia was recorded from 0.35 mg/L up to 0.58 mg/L.

Manganese was originally recorded above the AO using Method 8149; however, the sample contained levels of hardness that could interfere with the result. Grab samples were sent to an external lab and confirmed an average concentration of approximately 15.0 µg/L which is below the AO of 50 µg/L. This suggested that manganese should not be targeted for removal during this study.

Table 5.1. Bench: Objective 1

Untreated Well Water Quality			
Parameter	Concentration	AO/OG	MDL
Turbidity	0.23 NTU	5	0.01
(Total) Iron	1.36 mg/L	0.3 mg/L	0.02 mg/L
(Dissolved) Iron	1.36 mg/L		
Alkalinity	181 mg/L	30- 500 mg/L	-
Ammonia	0.43 mg/L	n/a	0.01 mg/L
Dissolved Organic Carbon	0.668 mg/L	5 mg/L	0.03 µg/L
pH	6.69	6.5-8.5	-
UV transmittance	96.1 %	75%	-
Sulfate	1300 mg/L	500 mg/L	0.04 mg/L
Sulfide	<0.006 mg/L	0.05 mg/L	0.006 mg/L
Manganese	~15.1 µg/L	50 µg/L	0.01 µg/L

5.1.2 Objective 2: Iron Precipitation and Filtration

Iron was oxidized and filtered out to below the aesthetic objective with a dose of 2 mg/L of chlorine and reached the method's minimum detection limit with a dose of 3 mg/L (**Table 8.1**). The reaction appeared to be instantaneous and similar results were obtained over the 5 minutes of contact time for each corresponding dose as the slope of each plotted line is horizontal (Figure 5.1). The pH remained within the operational guideline for all chlorine dose treatments.
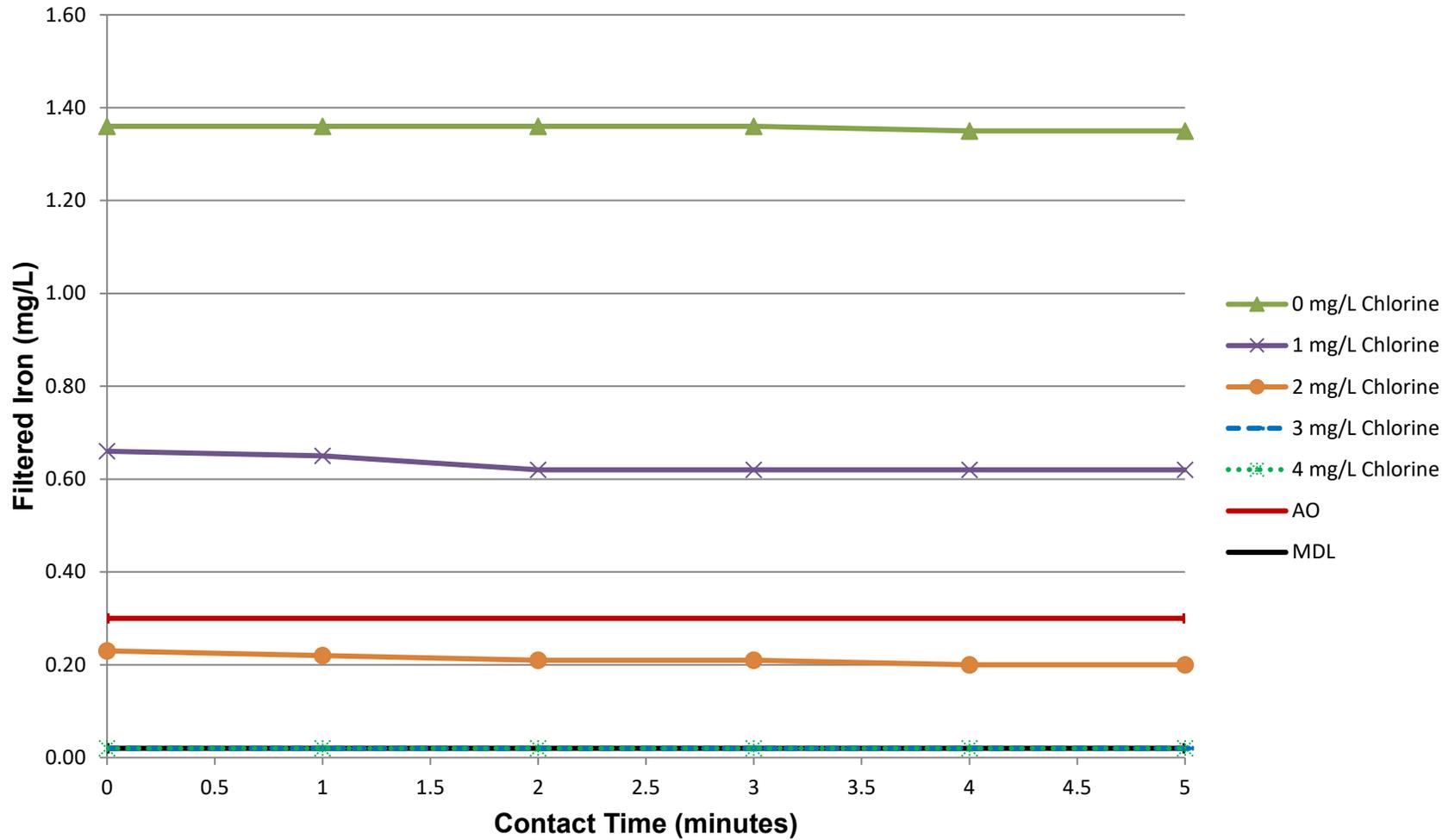
Figure 5.1. Bench: Objective 2a

5.1.3 Objective 3: Chlorine Dose, Residual and Contact Time

The presence of ammonia at an average of 0.43 mg/L appears to affect the dose of chlorine based on the results, illustrated in Figure 5.2 and **Figure 5.3**. A chlorine breakpoint curve was observed as it follows the typical relationship when graphed.

As the graph suggests, ammonia reacts with the chlorine dose to form chloramines between doses of ~1-4 mg/L and ~1-5 mg/L as indicated in Figure 5.2 and **Figure 5.3**, respectively. As the chlorine dose increases beyond the formation stage, the combined residual decreases due to the destruction of chloramines. Breakpoint was achieved at doses of ~6 mg/L and ~6.8 mg/L as indicated in Figure 5.2 and **Figure 5.3** respectively, where the combined residual and free residual intersect and begin to increase in difference. This graph can be used to understand the demands present in the source water and can assist in planning a disinfection strategy for the system.

Chlorination Breakpoint of Well Water

Formation of Chloramines

Destruction of Chloramines

Breakpoint

Free Residual
Combined Residual

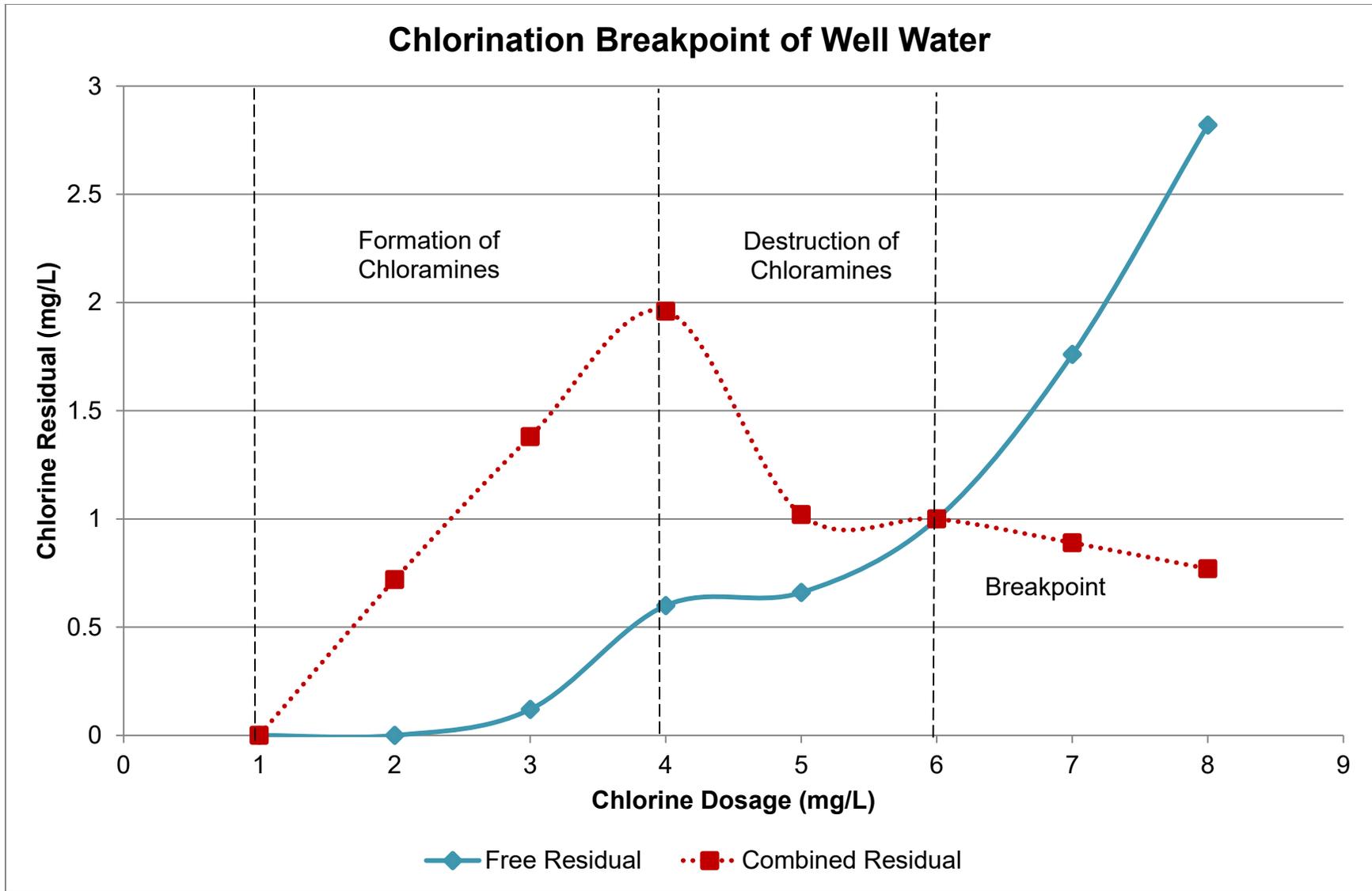Chlorine Residual (mg/L)

Chlorine Dosage (mg/L)
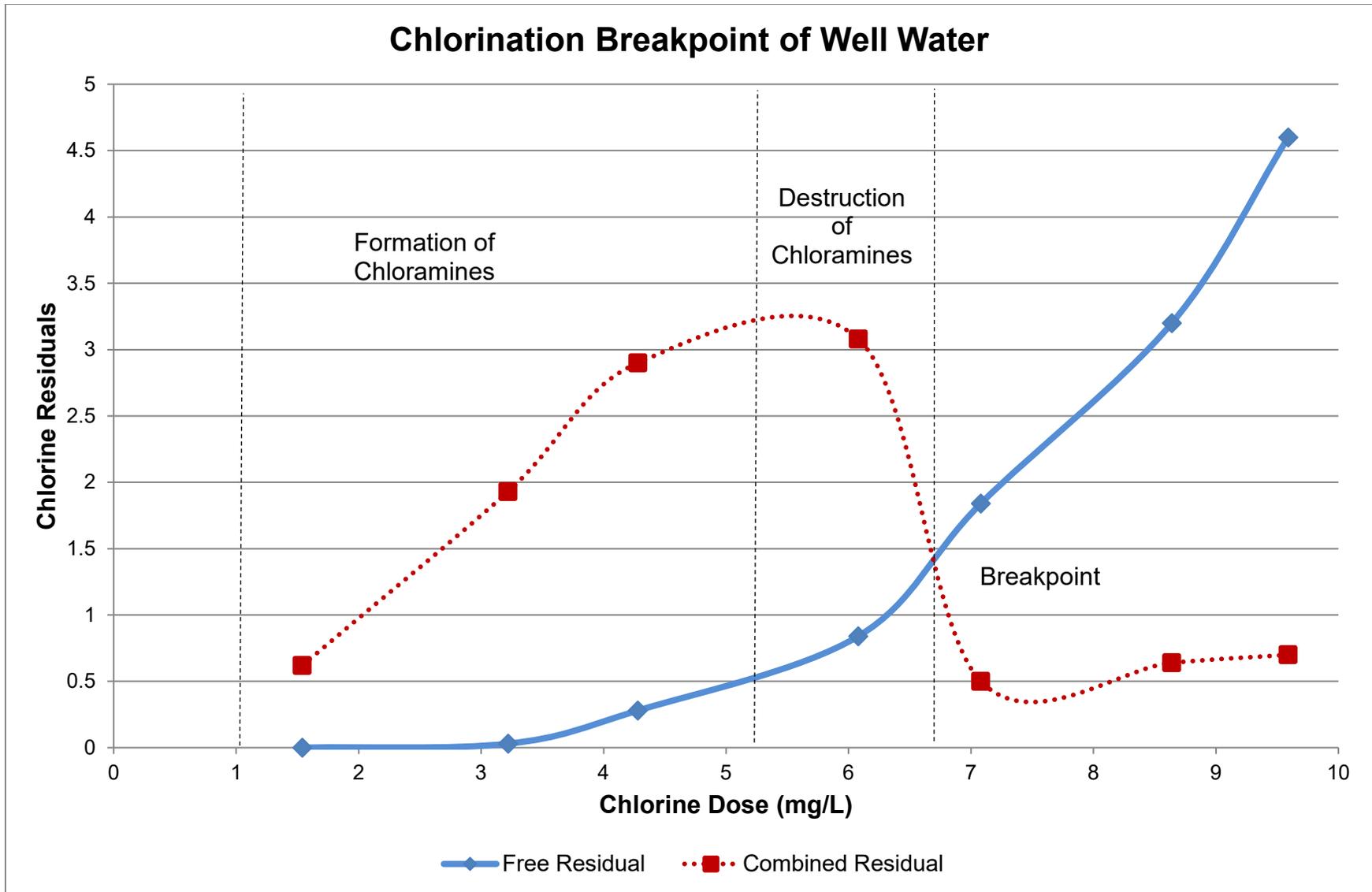
Figure 5.2. Bench: Objective 3 (Rep. 1)

Figure 5.3. Bench: Objective 3 (Rep 2)

5.1.4 Objective 4: Disinfection By-Product Formation

Disinfection by-product formation potential was assessed by subjecting the finished water to a simulated distribution system which estimated distribution system's storage time. Haloacetic acids were not detected in any of the samples for both chlorine doses. Trihalomethanes were detected in all the samples and were approximately three times higher in samples subjected to the higher dose of chlorine; however, the highest values obtained were 18 µg/L and 19 µg/L and are below 20% of the maximum acceptable concentration (MAC) (Table 5.2). N-nitrosodimethylamine was detected in all the samples but was also reported at 20% of the MAC. If the water quality and system conditions were to remain similar year-round, both doses of chlorine should not produce a level of disinfection by-products that would cause concern for the community.

Table 5.2. Bench: Objective 4

Disinfection By-Product Formation												
Chlorine Dose	THM (µg/L)				HAA (µg/L)				NDMA (µg/L)			
	Rep 1	Rep 2	MAC	MDL	Rep 1	Rep 2	MAC	MDL	Rep 1	Rep 2	MAC	MDL
4	6.0	5.8	100[2]	0.37	<5.3	<5.3	80[1,2]	5.3	0.0018	0.0014	0.009	0.0008
8	18	19			<5.3	<5.3			0.0011	0.0014		

[1] On January 1, 2020, O. Reg. 169/03, Schedule 2 is to be amended by adding a MAC for HAA
[2] Expressed as a running annual average of quarterly results

5.2 Pilot Scale

5.2.1 Phase 1

The results of phase 1 showed that iron was still detected after every filter and that the 1µm filter was necessary to reduce the concentration below the AO (Figure 5.4). The filters were monitored for pressure differential and volume treated which can be used to estimate the life expectancy based on the level of desired performance (**Figure 5.5**).

The free chlorine residual target was ~1.2 –1.5 mg/L after filtration and was monitored continuously with free chlorine probes. To achieve this concentration, the target chlorination dose added was approximately ~ 7.0 - 7.5 mg/L. This value was estimated using a combination of the breakpoint curve and the point of entry (POE)/unfiltered chlorine residuals as the sodium hypochlorite stock was diluted and found to vary depending on mixing.

The hydrogen sulfide odour was still noticeable during phase 1 and sulfide was detected at 0.080 mg/L, 0.081 mg/L and 0.081 mg/L for the raw and mono-sand media and cartridge filter trains respectfully, all above the AO of 0.05 mg/L (**Table 8.5**).

It appeared that the filters had a high chlorine demand initially that decreased over time (Figure 8.3). Variation in the UV transmittance data (Figure 8.4) for the media filtration train was likely due to the production of air bubbles during aeration that interfered with the analyzer. The pH remained within the OG and was consistent during phase 1 with minimal variation (Figure 8.5). The turbidity values followed the expected trend as the cartridge filter effluent yielded the lowest turbidity followed by media filtration, raw/untreated, and the highest being post-chlorination oxidation (unfiltered) due to the precipitated iron (Figure 8.6).
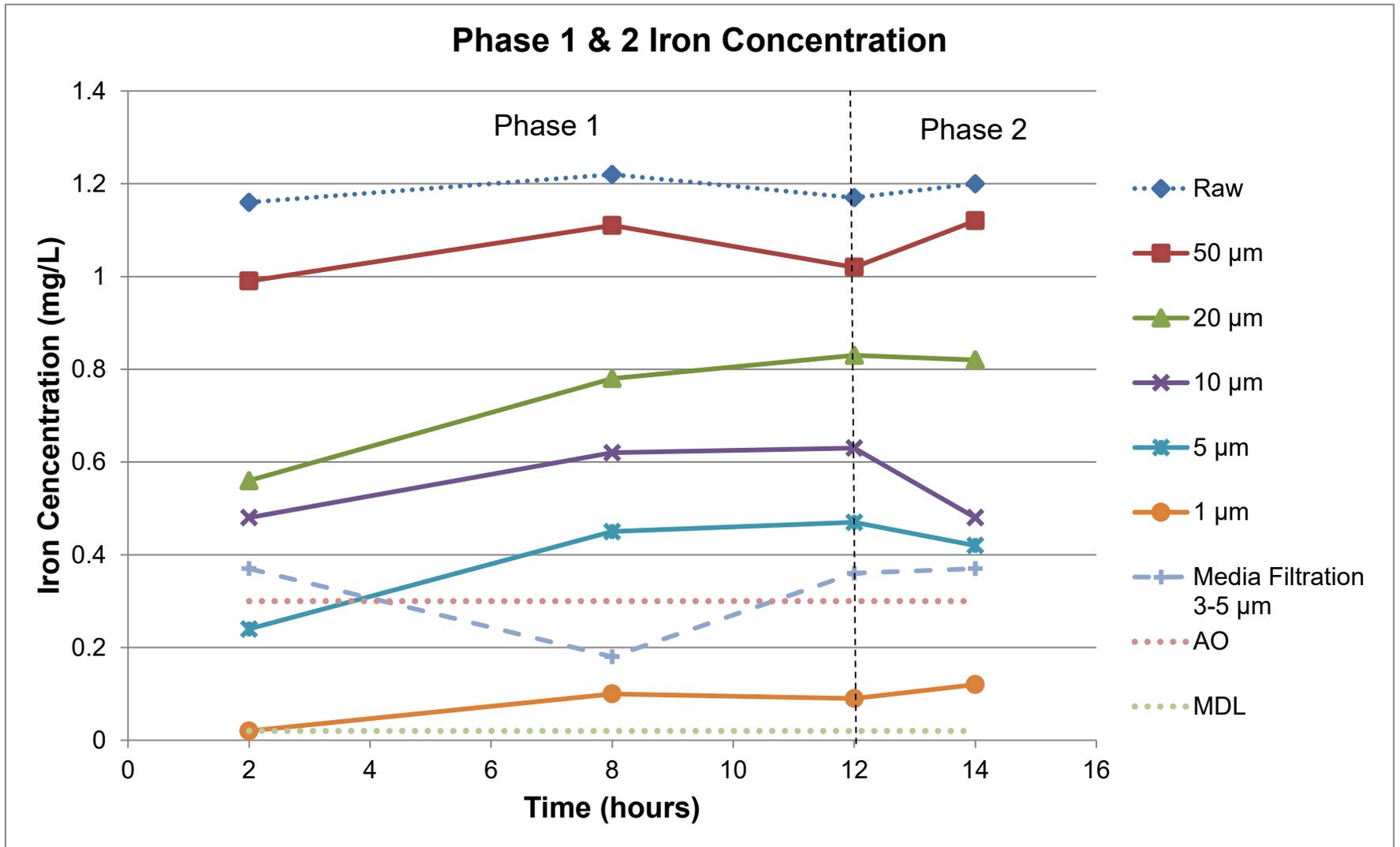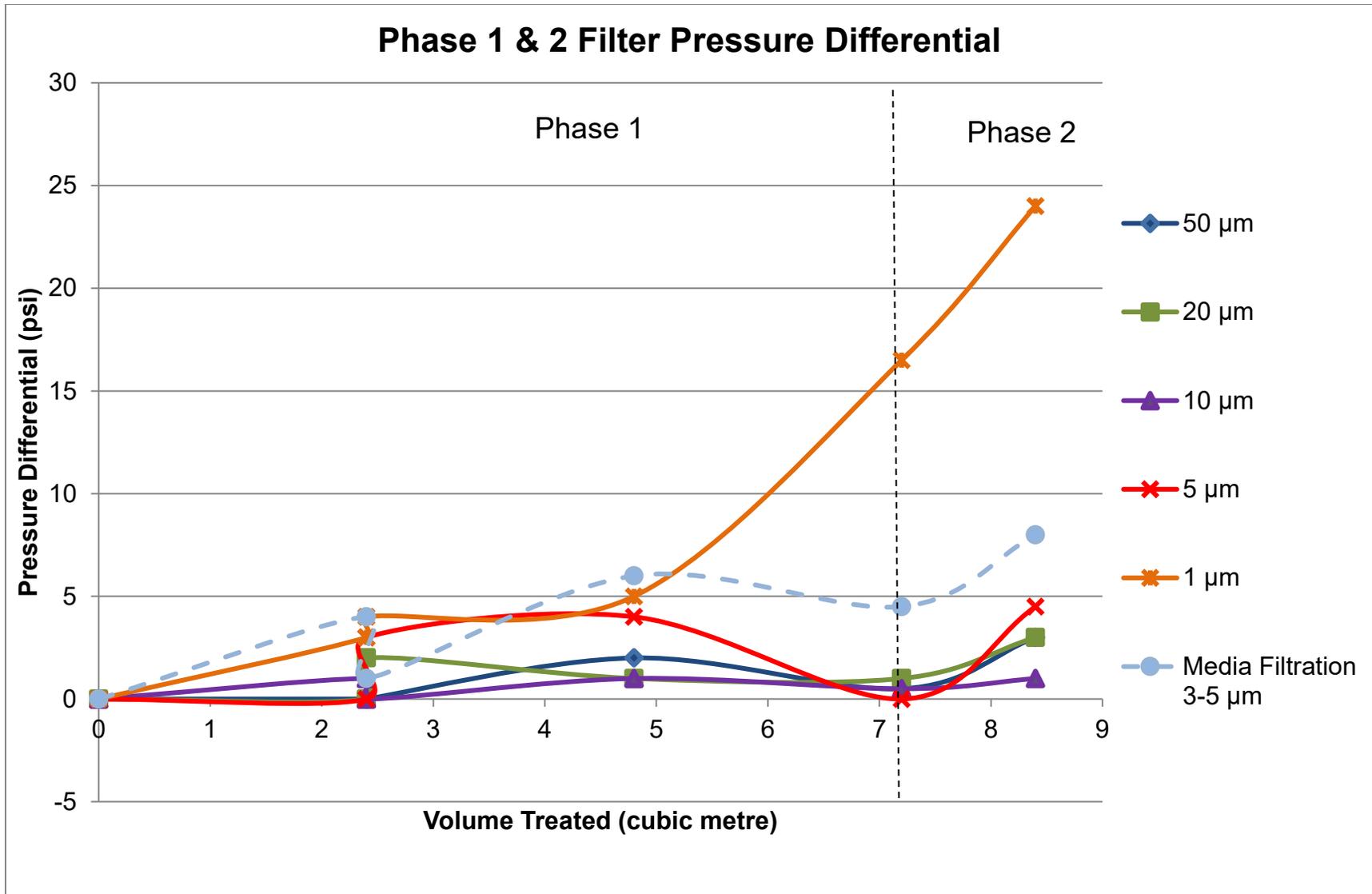
Figure 5.4. Pilot: Phase 1 & 2 Objective 1a

Figure 5.5. Pilot: Phase 1 & 2 Objective 2

5.2.2 Phase 2

The aeration system was removed from the pilot in phase 2 and chlorine injection was moved upstream of the hydro-pneumatic tank (contact and ventilation) to oxidize sulfide and increase the chlorine contact time prior to filtration. There was no noticeable change in the iron removal of the media or cartridge filters after increasing the contact time. The filters were monitored for pressure differential and volume treated which can be used to estimate the life expectancy based on the level of desired performance (Figure 5.5). The sulfide odour seemed to be reduced as it was no longer observed by staff on-site. The dose of chlorine was reduced to maintain a chloramination dose of ~ 3.5 - 4.5 mg/L based on the results from the chlorination breakpoint curve. It appeared that the chlorine demand of the filters was reduced when operating with a combined chlorine residual (Figure 8.3). The turbidity followed the expected trend as the cartridge filter effluent yielded the lowest turbidity followed by media filtration, raw/untreated, and the highest turbidity being chlorinated-unfiltered due to the precipitated iron (Figure 8.6).

5.2.3 Phase 3

The 50 - 5 µm and 25 - 1 µm dual gradient nominal depth cartridge filters followed by the 0.35 µm surface pleated nominal cartridge filter removed iron below the MDL during the life of the filters. Additionally, they were able to treat over twice the volume observed in phases 1 and 2 before experiencing a similar loss in pressure performance (Figure 5.6). The average particle size loading for each filter (Figure 8.7) can be used to estimate the life expectancy if larger filters are used.

The sulfide odour was suspected to be reduced through staff observation and was not detected in the analyzed samples; it is possible the reported values were underestimated since it was also not detected in the untreated water (Table 8.8).

The chlorine dose used to maintain a typical combined chlorine residual did not produce disinfection by-products above the MACs.

UV transmittance (Figure 8.9), pH (Figure 8.10), and turbidity (Figure 8.11) were similar to that recorded during the first two phases, further suggesting that precipitated iron is the primary influence in readings of elevated turbidity and reductions in UV transmittance.
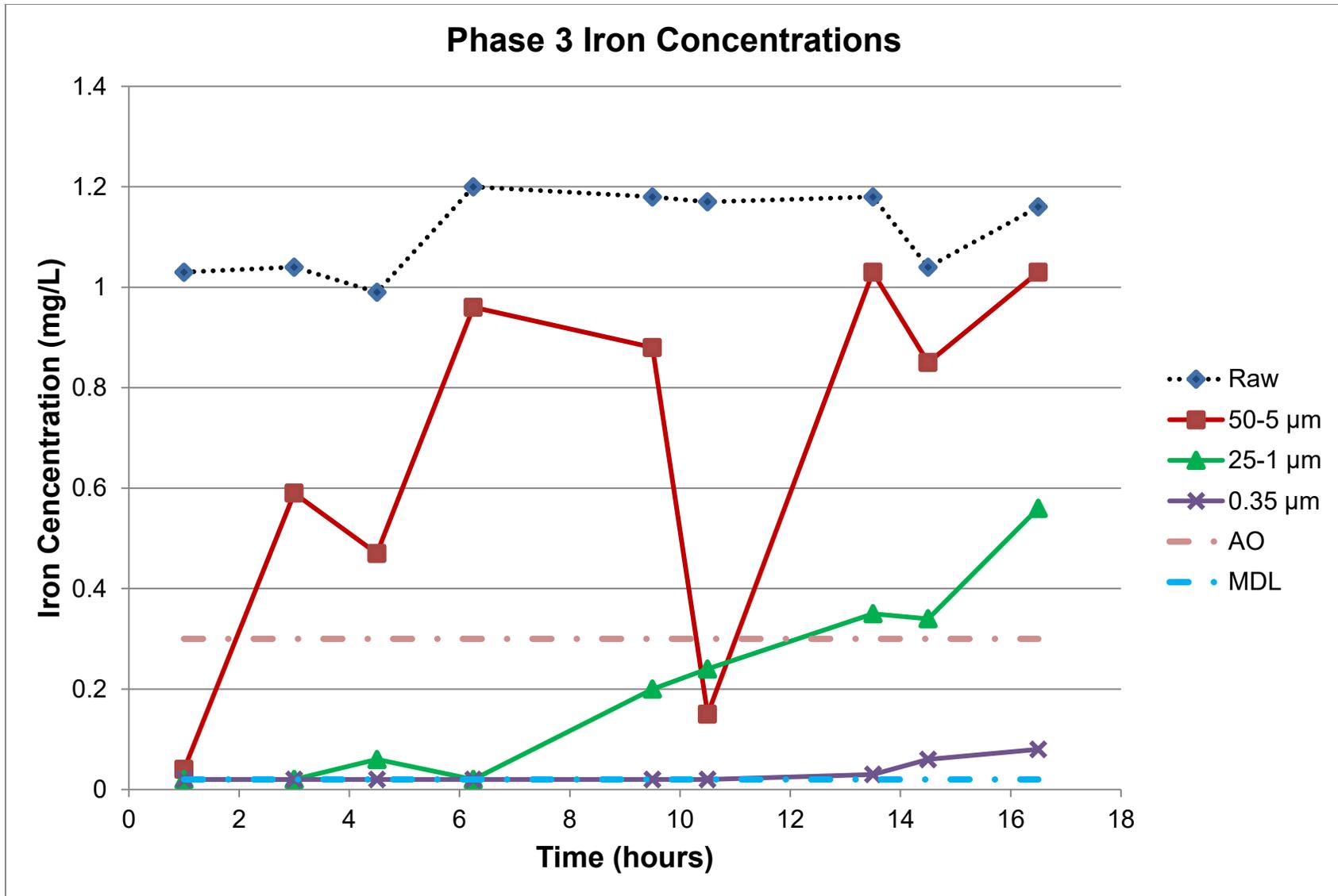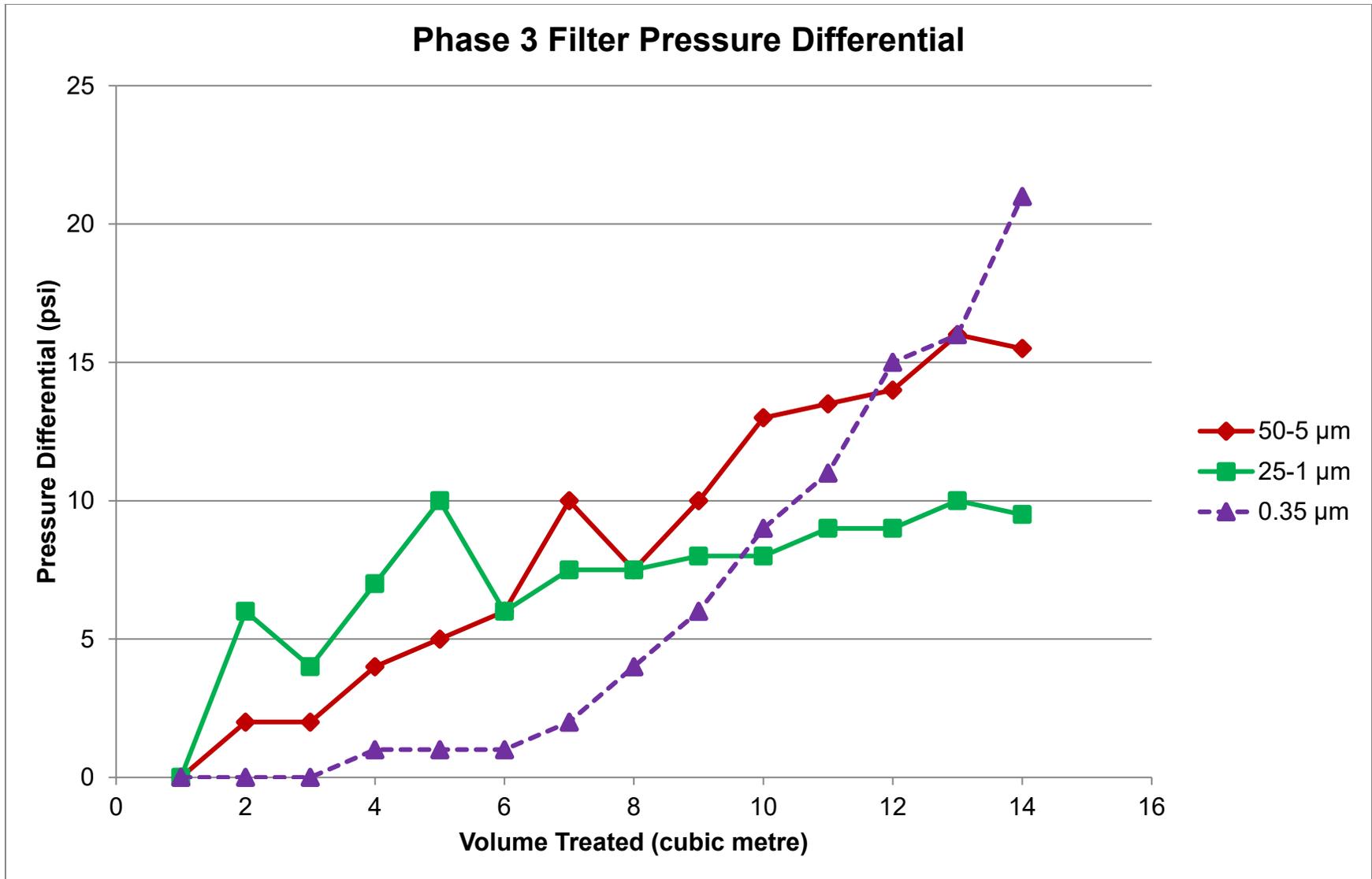
Figure 5.6. Pilot: Phase 3 Objective 1a

Figure 5.7. Pilot: Phase 3 Objective 2

6. Conclusions

It was concluded that the untreated well water was above the respective aesthetic objectives for iron, sulfate, and sulfide. Iron was determined to be dissolved in the well and, as it precipitates, was the probable cause for elevated turbidity in the distribution system. Chlorine was an effective oxidant for the precipitation of iron and a filter ≤ 1 µm was needed to reduce the concentration of iron below the aesthetic objective. The 3-5 µm mono-media sand filter was ineffective for the removal of iron below the aesthetic objective. The filter performance was measured throughout the study, and the data acquired can enable the community to determine the economic feasibility of iron removal using cartridge filtration. Passive aeration with ventilation was ineffective at oxidizing and venting sulfide at the quantitative and qualitative levels. Although not supported with quantitative data, the reduction in the offensive sulfide gas odour was achieved at the qualitative level using chlorine as an oxidant prior to ventilation. The well water was dosed using typical chlorination and chloramination concentrations to achieve a residual that were within Ontario's guidelines, and disinfection by-product formation was below the respective MAC levels for THMs, HAAs, and NDMA in all samples. The turbidity, pH, and UV transmittance values followed the expected trends and met the provincial aesthetic objectives or operational guidelines.

7. References

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8. Appendices

Table 8.1. Bench: Objective 2a

Contact time (minutes)	Filtered (Dissolved) Iron Concentrations (mg/L)											
	Chlorine Dose (mg/L)										AO	MDL
	0 mg/L		1 mg/L		2 mg/L		3 mg/L		4 mg/L			
	DI Blank	Sample	DI Blank	Sample	DI Blank	Sample	DI Blank	Sample	DI Blank	Sample		
0	0.02	1.36	0.02	0.66	0.02	0.23	0.02	0.02	0.02	0.02	0.3	0.02
1		1.36		0.65		0.22		0.02		0.02		
2		1.36		0.62		0.21		0.02		0.02		
3		1.36		0.62		0.21		0.02		0.02		
4		1.35		0.62		0.2		0.02		0.02		
5		1.35		0.62		0.2		0.02		0.02		

Table 8.2. Bench: Objective 2b

	pH of Chlorine Doses				
	Chlorine Dose (mg/L)				
	0	1	2	3	4
pH	6.69	6.89	6.78	6.78	6.94

Table 8.3. Bench: Objective 3 Chlorine Doses, Demand, and Residuals

Contact Time (hrs)	1 mg/L Free	1 mg/L Combined	2 mg/L Free	2 mg/L Combined	3 mg/L Free	3 mg/L Combined	4 mg/L Free	4 mg/L Combined	5 mg/L Free	5 mg/L Combined	6 mg/L Free	6 mg/L Combined	7 mg/L Free	7 mg/L Combined	8 mg/L Free	8 mg/L Combined
Chlorine Doses, Demand, and Residuals (mg/L)																
0	0	0	0.01	0.71	0.12	1.38	0.6	1.955	0.66	1.02	1.00	1.00	1.76	0.89	2.82	0.77
0.5	N/A						0.225	2.27	0.31	0.34	0.75	0.20	1.69	0.6	2.74	0.59
24	N/A						0.265	1.095	0.125	0.04	0.55	0.14	1.69	0.075	2.44	0.3

Table 8.4. Bench: Objective 3 Residual Chlorine Matrix

Chlorination Matrix (mg/L)								
Chlorine Dosage	1	2	3	4	5	6	7	8
DI Free	1.07	1.87	2.88	4.04	4.9	5.45	7.14	8.32
Free Residual	0	0	0.12	0.6	0.66	1	1.76	2.82
Combined Residual	0	0.72	1.38	1.96	1.02	1	0.89	0.77
Demand	0	1.05	1.79	3.52	4.32	4.6	5.42	5.54
Total Residual	0	0.72	1.5	2.56	1.68	2	2.65	3.59

Phase 1 & 2 Filtered Particle Size Exclusion Analysis

■	> 50 µm
■	50-20 µm
■	20- 10 µm
■	10- 5 µm
■	5-1 µm
■	< 1 µm
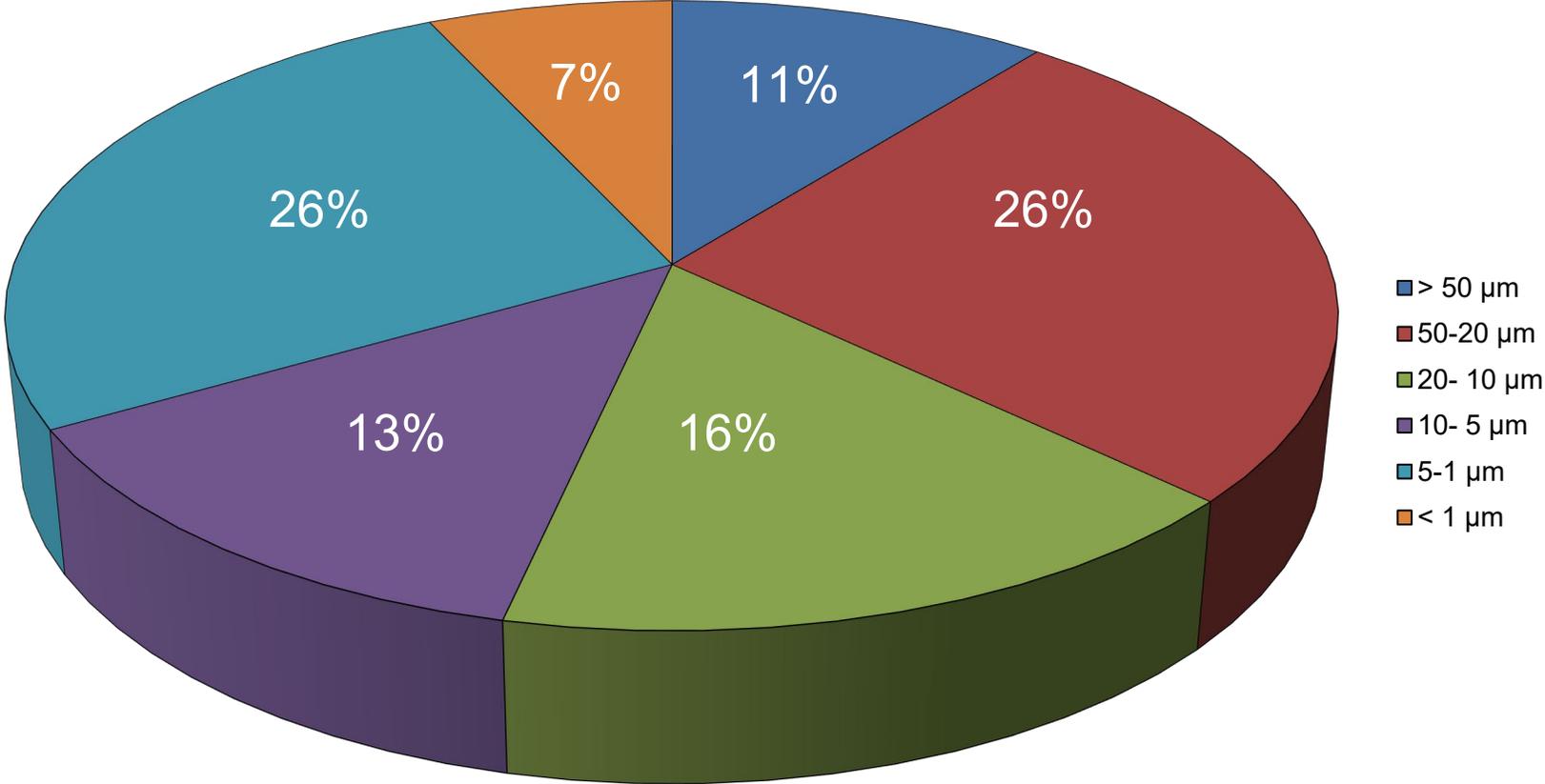
Percents rounded to nearest whole number

Figure 8.1. Pilot: Phase 1 & 2 Objective 1b

Table 8.5. Pilot: Phase 1 & 2 Objective 3

	External Laboratory Analysis								
	Sulfate (mg/L)			Manganese (µg/L)			Sulfide		
Time (hours)	Raw	Cartridge	Media	Raw	Cartridge	Media	Raw	Cartridge	Media
0	1300			0.02			0.006		
6	1300	1200	1200	13.9	3.39	3.3	0.006	0.006	0.006
11	1300	1300	1400	14.3	1.71	9.8	0.08	0.081	0.081
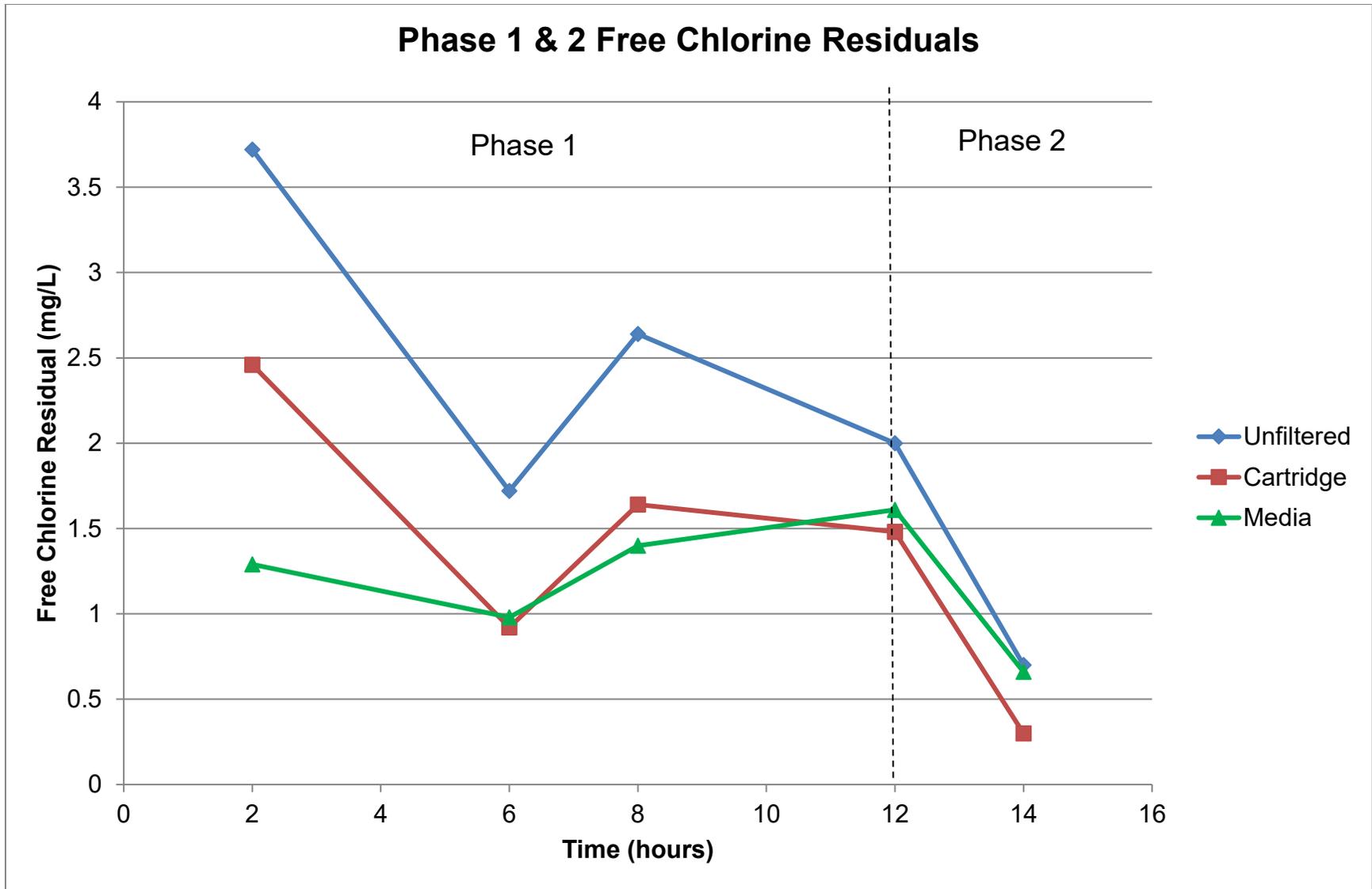
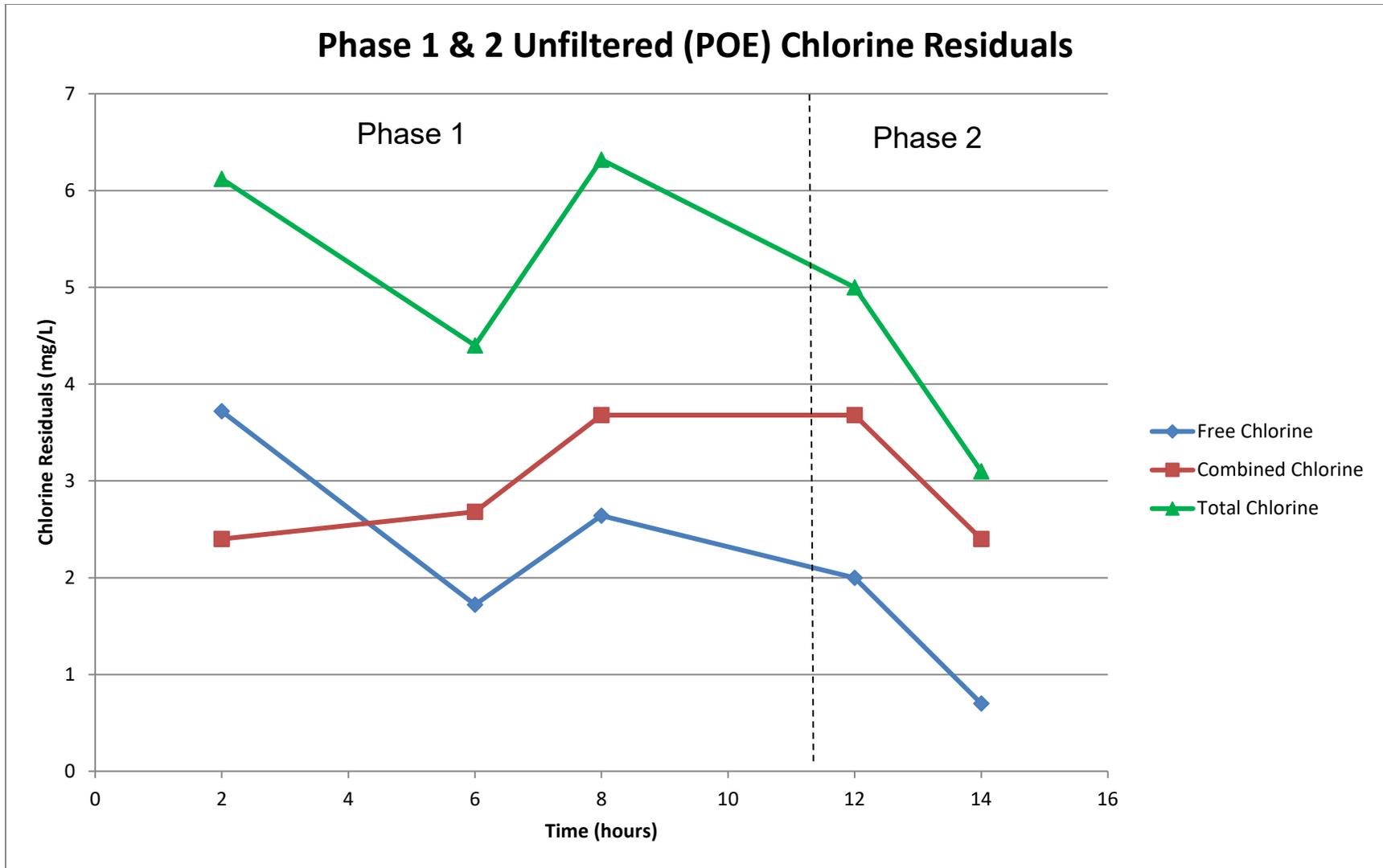**Figure 8.2. Pilot: Phase 1 & 2 Objective 4 Free Chlorine Residuals**

Figure 8.3. Pilot: Phase 1 & 3 Objective 4 Unfiltered Chlorine Residuals
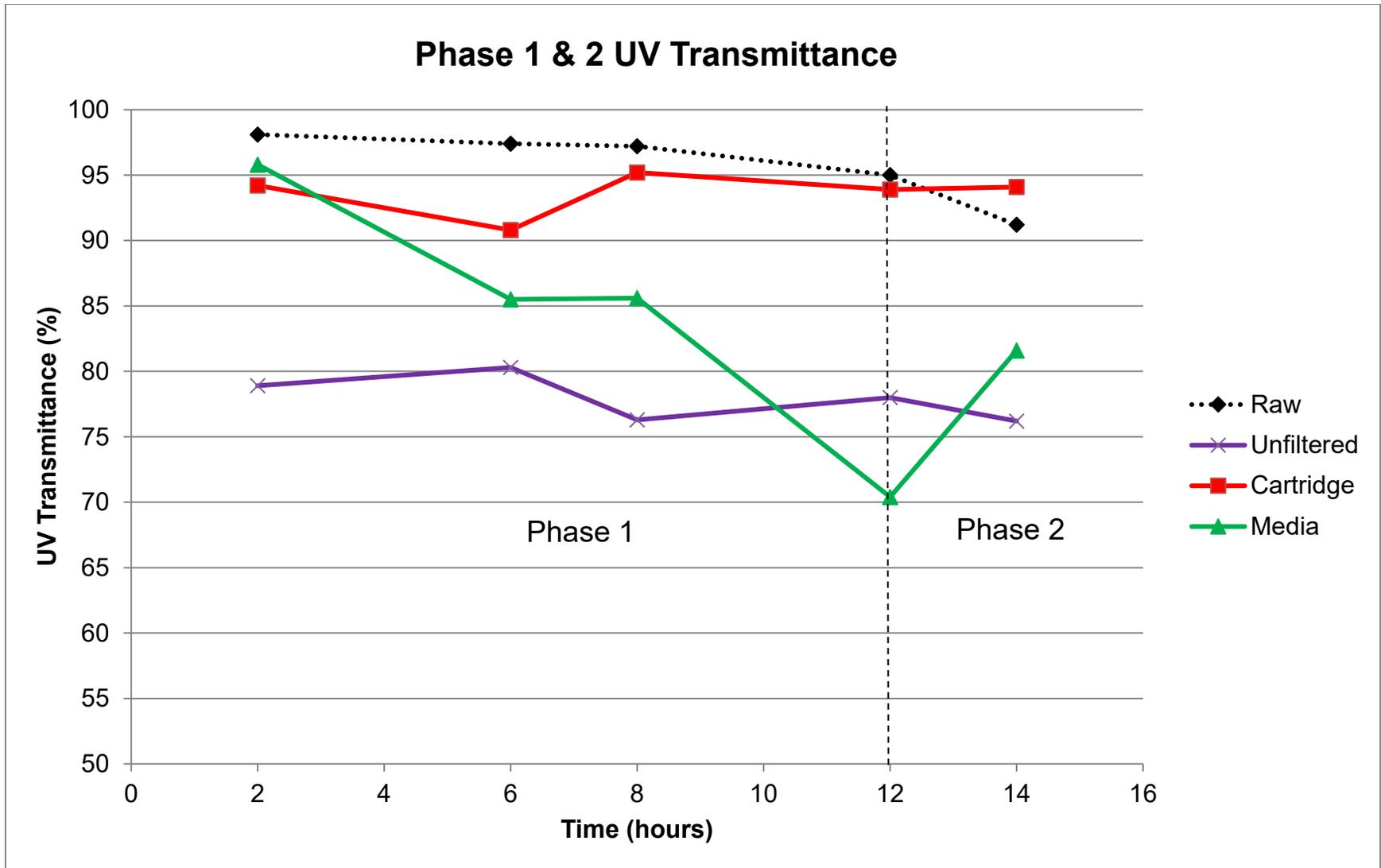
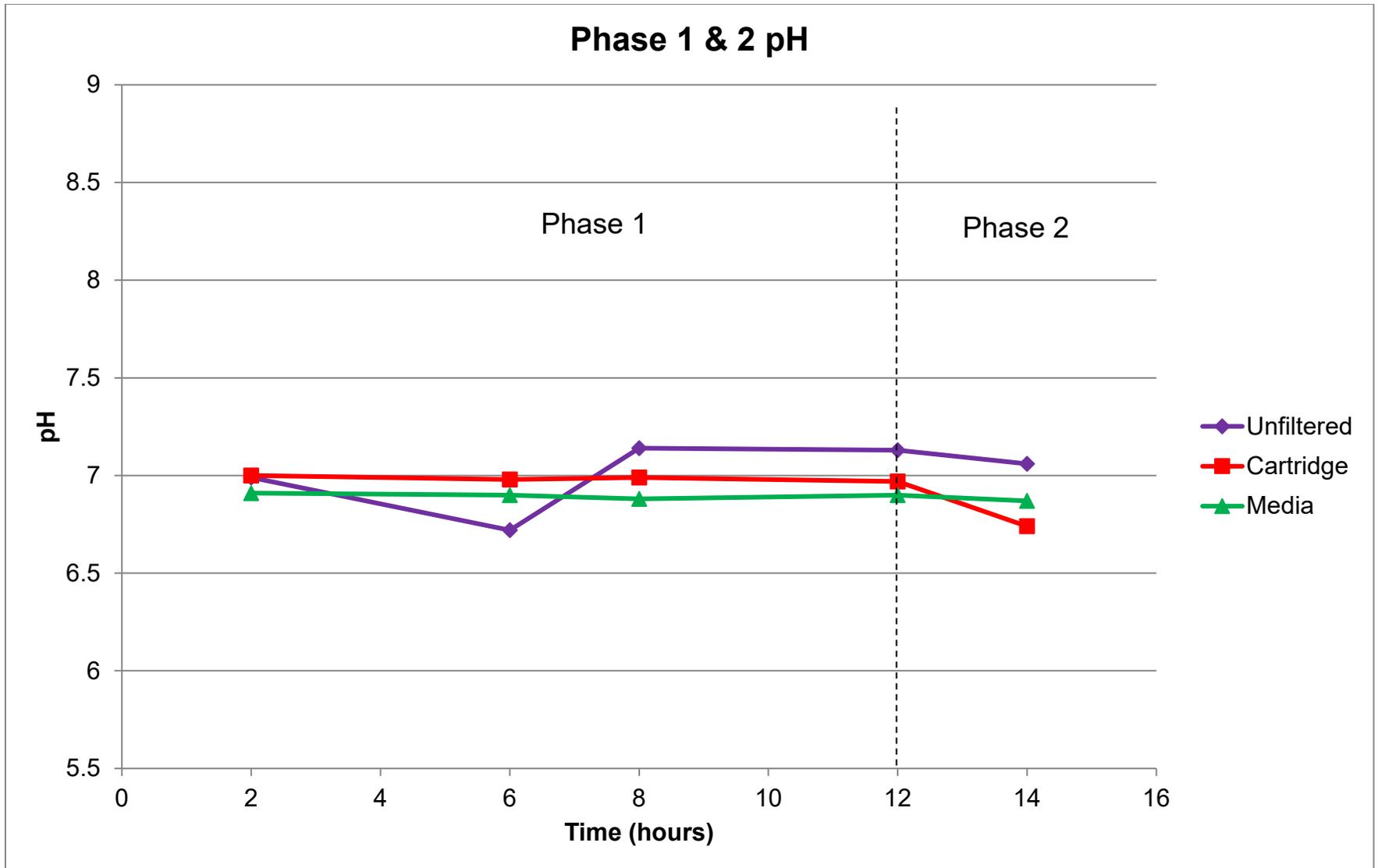**Figure 8.4. Pilot: Phase 1 & 2 Objective 5a**
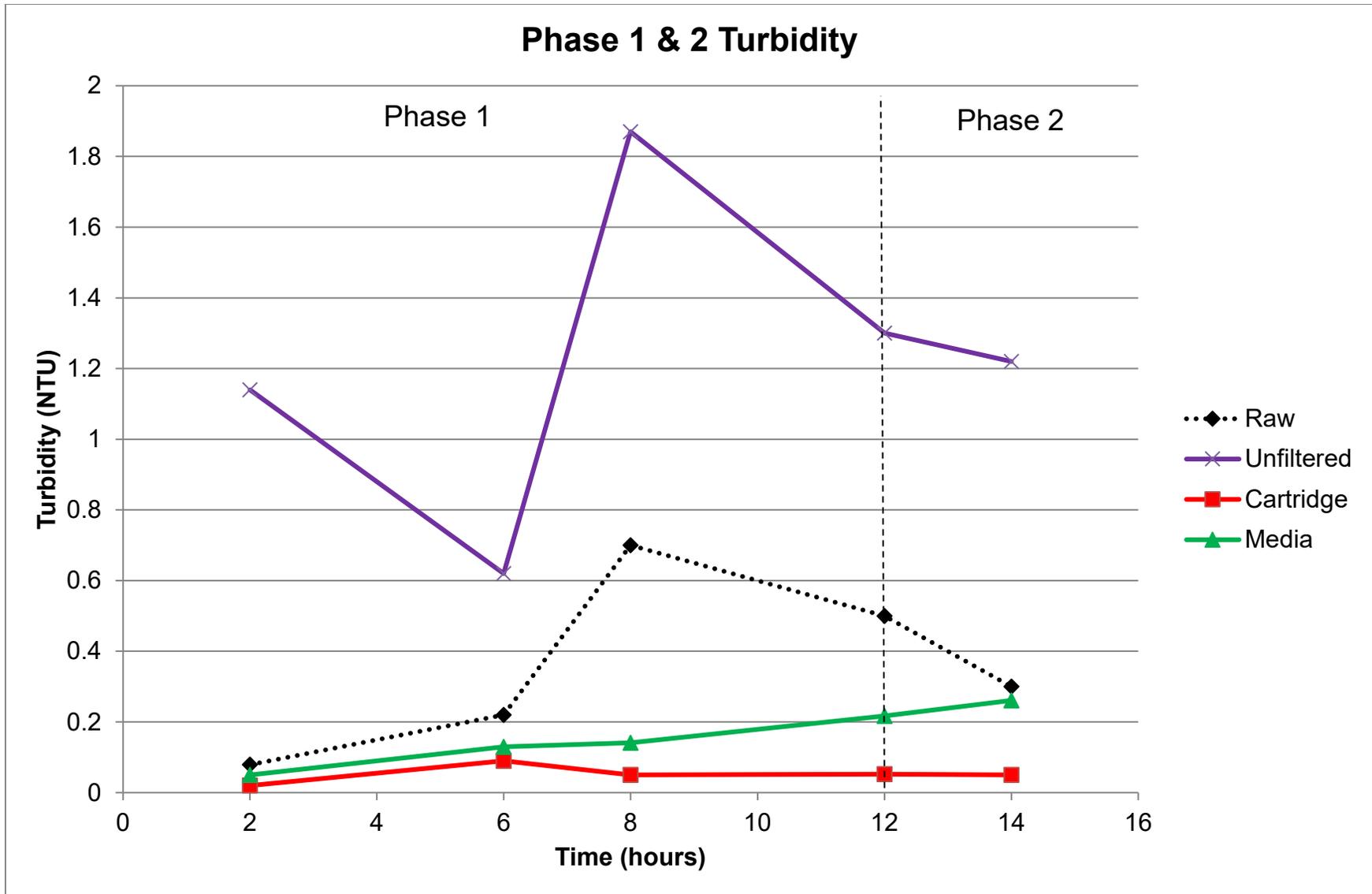
Figure 8.5. Pilot: Phase 1 & 2 Objective 5b
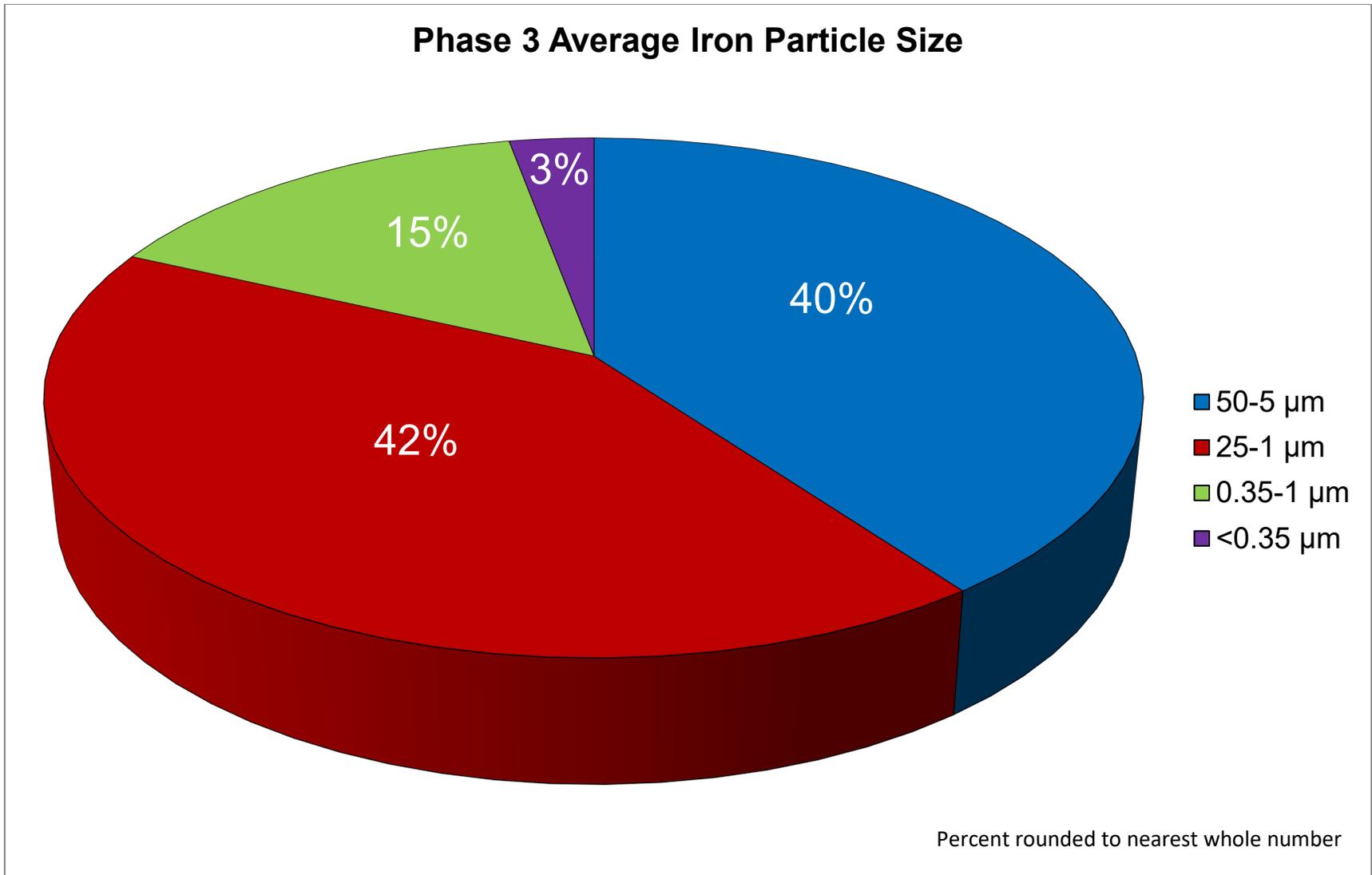
Figure 8.6. Pilot: Phase 1 & 2 Objective 5c

Phase 3 Average Iron Particle Size

- 50-5 µm: 40%
- 25-1 µm: 42%
- 0.35-1 µm: 15%
- <0.35 µm: 3%

Percent rounded to nearest whole number

Figure 8.7. Pilot: Phase 3 Objective 1b

Table 8.6. Pilot: Phase 3 Objective 1a

Visit	Time (hours)	Raw	Cartridge Filtration			AO	MDL
			50-5 µm	25-1 µm	0.35 µm		
3-Jul-18	1	1.03	0.04	0.02	0.02	0.3	0.02
	3	1.04	0.59	0.02	0.02	0.3	0.02
	4.5	0.99	0.47	0.06	0.02	0.3	0.02
4-Jul-18	6.25	1.2	0.96	0.02	0.02	0.3	0.02
	9.5	1.18	0.88	0.2	0.02	0.3	0.02
5-Jul-18	10.5	1.17	0.15	0.24	0.02	0.3	0.02
	13.5	1.18	1.03	0.35	0.03	0.3	0.02
	14.5	1.04	0.85	0.34	0.06	0.3	0.02
9-Jul-18	16.5	1.16	1.03	0.56	0.08	0.3	0.02

The header "Phase 3 Iron Concentrations" spans the table.

Table 8.7. Pilot: Phase 3 Objective 2 Filter Performance

Visit	Time (hours)	Raw	Cartridge Filtration 50-5 µm	25-1 µm	0.35 µm	Flowrate (L/min) Cartridge	Volume Cartridge (L)	Cartridge (m³)	Cartridge Filtration 50-5 µm	25-1 µm	0.35 µm
	0	0	0	0	0	0	0	0	0	0	0
3-Jul-18	1	53	51	45	45	20	1200	1.2	2	6	0
	3	49	47	43	43	20	3600	3.6	2	4	0
	5	57	53	46	45	20	6000	6	4	7	1
4-Jul-18	6	60	55	45	44	20	7200	7.2	5	10	1
	9.5	46	40	34	33	20	11400	11.4	6	6	1
5-Jul-18	10.5	55	45	37.5	35.5	20	12600	12.6	10	7.5	2
	11.5	50	42.5	35	31	20	13800	13.8	7.5	7.5	4
	13	52	42	34	28	20	15600	15.6	10	8	6
	14.25	45	32	24	15	20	17100	17.1	13	8	9
	14.5	49.5	36	27	16	20	17400	17.4	13.5	9	11
	15.5	54	40	31	16	20	18600	18.6	14	9	15
9-Jul-18	16	60	44	34	18	20	19200	19.2	16	10	16
	17	59	43.5	34	13	20	20400	20.4	15.5	9.5	21

Table 8.8. Pilot: Phase 3 Objective 3

Time (Hours)	External Laboratory Analysis								
	Sulfate (mg/L)			Manganese (mg/L)			Sulfide (mg/L)		
	Raw	Cartridge Rep 1	Cartridge Rep 2	Raw	Cartridge Rep 1	Cartridge Rep 2	Raw	Cartridge Rep 1	Cartridge Rep 2
16	1400	1400	1300	14.6	4.5	4.25	<0.006[1]	<0.006[2]	<0.006[2]

[1]Likely underestimated due to the volatility of the compound
[2] Accuracy of testing could be underestimated due to the volatility of the compound
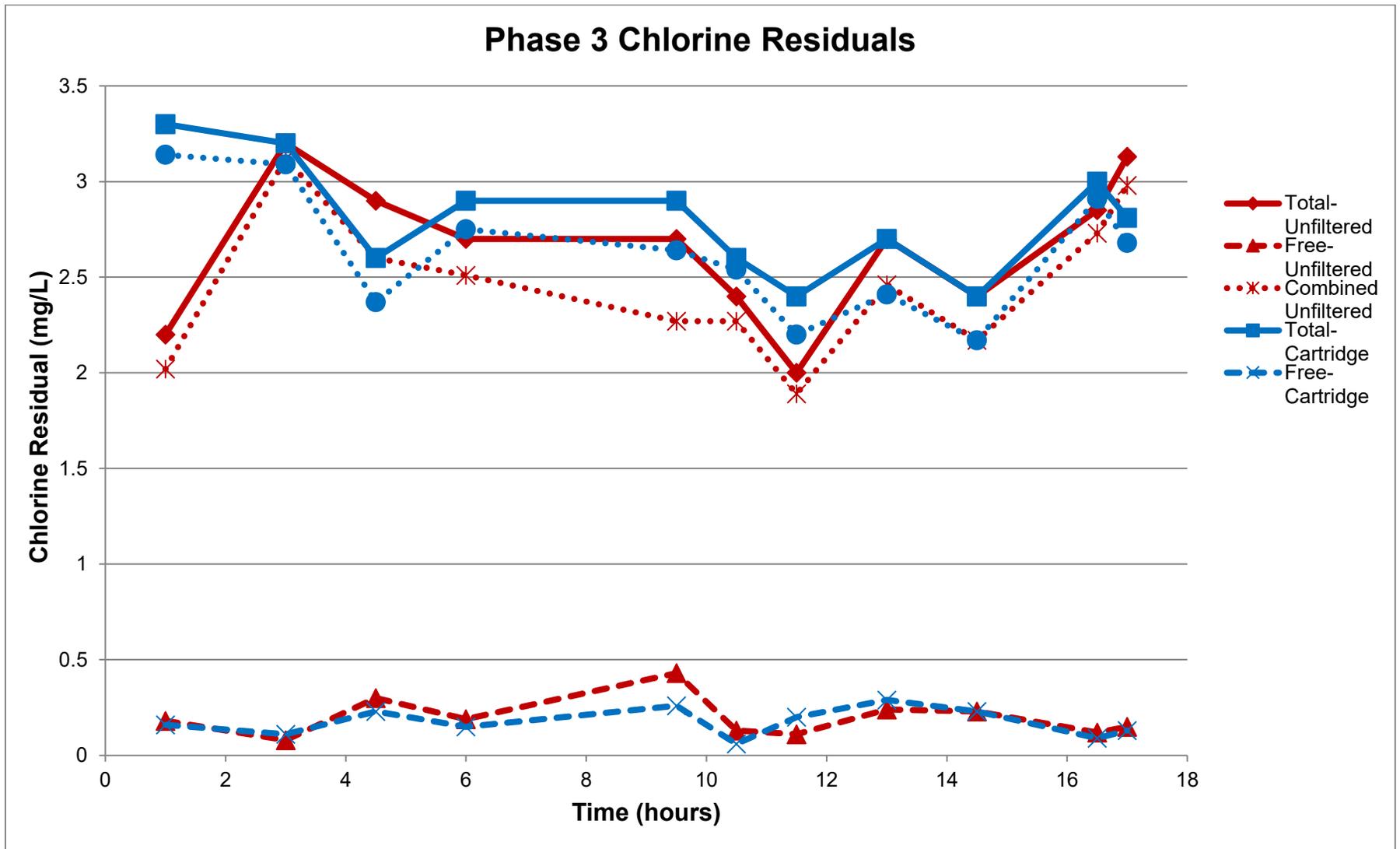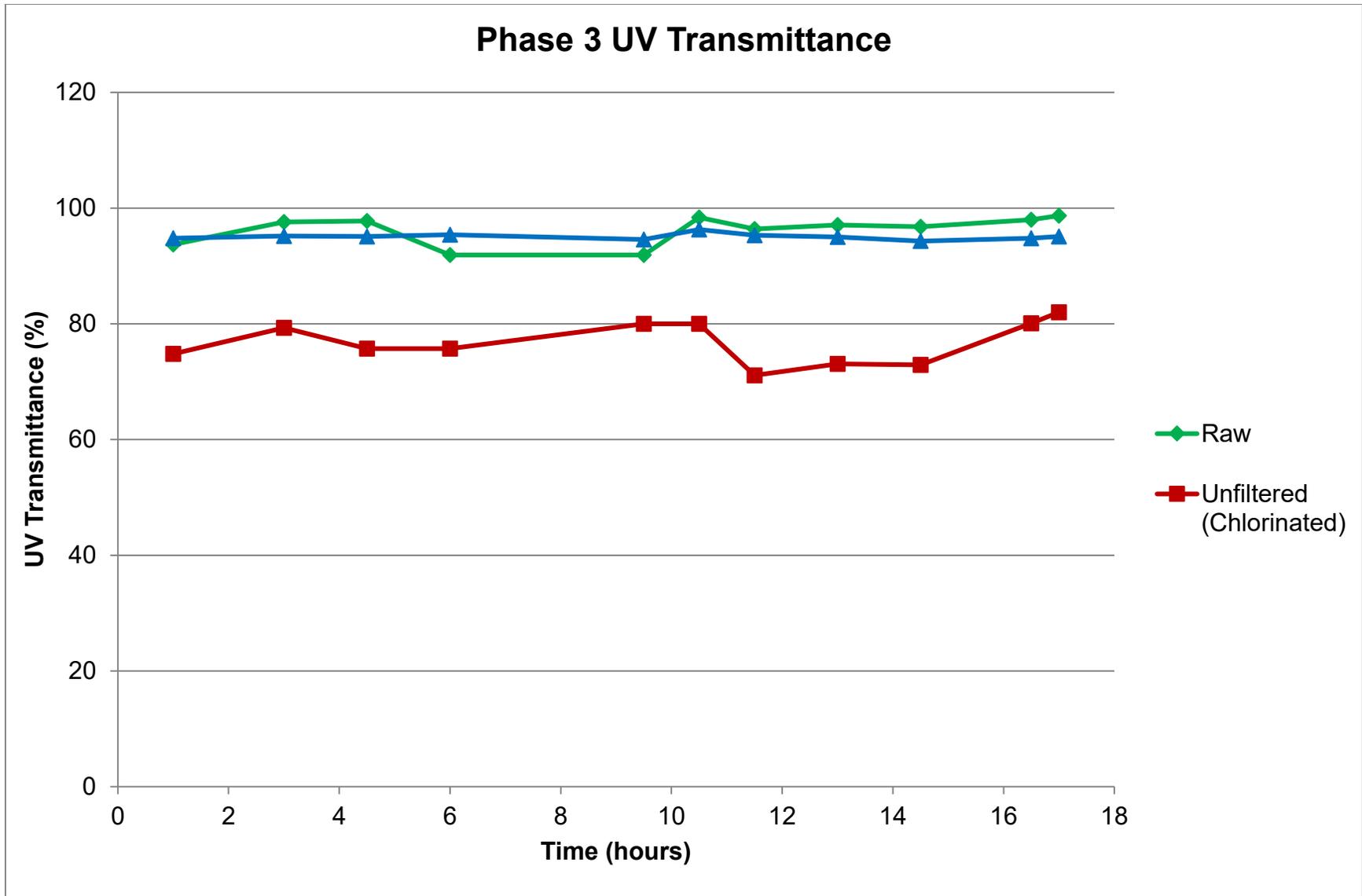
Figure 8.8. Pilot: Phase 3 Objective 4

Figure 8.9. Pilot: Phase 3 Objective 5a

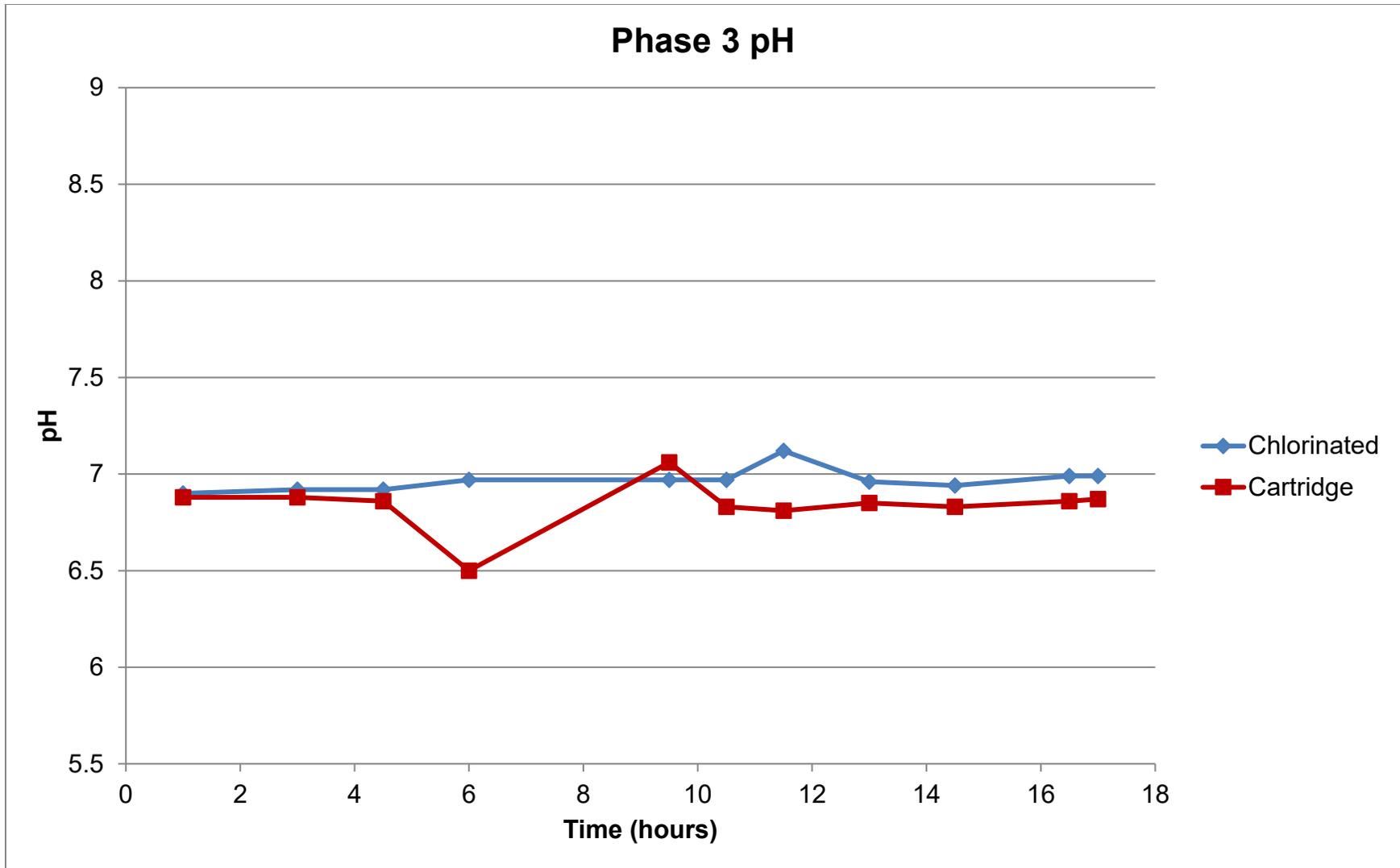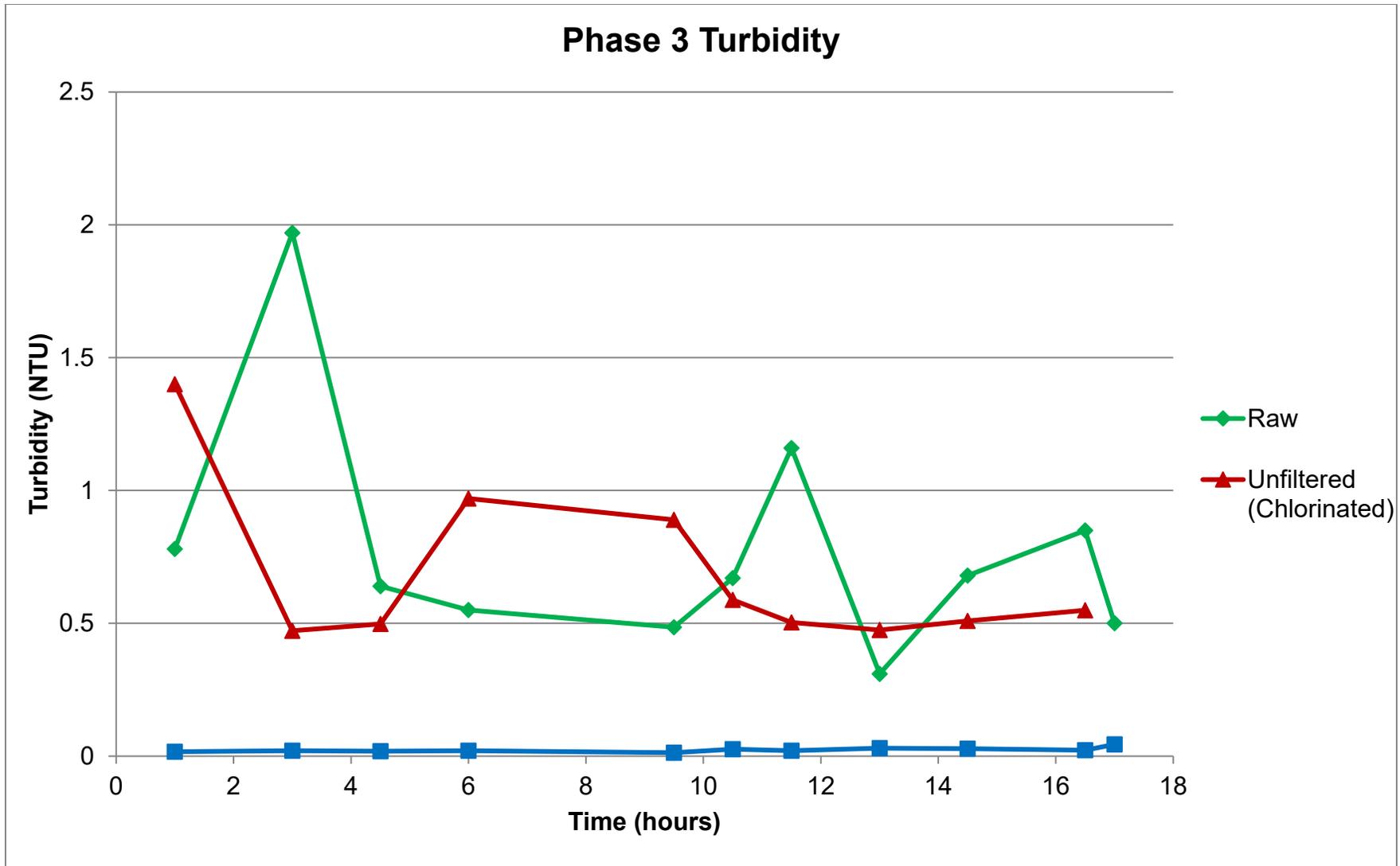**Figure 8.10 Pilot: Phase 3 Objective 5b**

Figure 8.11. Pilot: Phase 3 Objective 5c