Pilot Testing Project Report:

Exploring Iron Reduction Options for a Groundwater Source

Walkerton Clean Water Centre

September 14, 2018

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Executive Summary

Background

Iron is an essential element in human nutrition with no evidence of dietary iron toxicity in the general population (Health Canada, 1978). Thus, no regulatory health limit has been set. However, water may taste and appear unpalatable when the iron concentration exceeds 0.3 mg/L (WHO, 2003). Water in which this occurs can promote the growth of iron bacteria, stain laundry and plumbing fixtures, and gradually clog distribution pipelines (Health Canada, 1978). As a consequence, the aesthetic objective for iron in drinking water is set as ≤ 0.3 mg/L (Ontario MOE, 2003).

A township located in South-Central Ontario has found increasing iron levels in one of their groundwater wells, which is currently used as their drinking water supply source. Therefore, the township was interested in exploring different options for iron removal.

Objectives

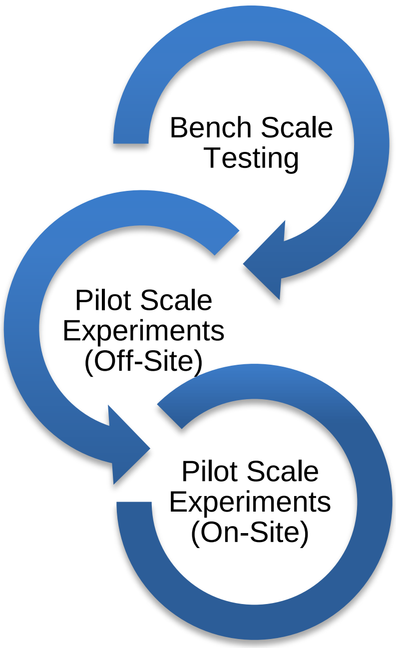
The overall goal of this pilot testing project is to reduce iron in the treated well water.

Specific objectives of pilot testing are:

- To reduce the iron concentration to a level below 0.3 mg/L;
- To investigate the use of air, chlorine and potassium permanganate ($KMnO_4$) to oxidize iron;
- To assess cartridge and pressurized monomedia sand filters to remove the oxidized iron.

Approach

This project was conducted in three phases: bench scale testing (Phase 1), off-site pilot scale experiments (Phase 2), and on-site pilot scale experiments (Phase 3). The objectives of each phase are presented in Figure ES-1.



- To determine the optimum chlorine dose for iron oxidation
- To find the optimum $KMnO_4$ dose for iron oxidation
- To find an optimum chlorine contact time

- To investigate the efficacy of iron reduce for monomedia sand filtration and cartridge filtration
- To compare the efficacy of chlorination and aeration to oxidize iron
- To investigate the size distribution of the oxidized iron particles

- To investigate the efficacy of adsorptive media filtration and cartridge microfiltration on the reduction of iron
- To determine the efficacy of contact time using a storage tank on the reduction of iron
- To determine the effect of flow rate on filtration performance

Figure ES - 1. Objectives of bench scale testing and pilot scale experiments

Phase 1: During Phase 1, Jar Test 1 and 2 were conducted to determine the optimum chlorine and $KMnO_4$ doses for iron oxidation, respectively. This determined optimum chlorine dose was then used in Jar Test 3 to determine optimum flocculation time. Iron levels were monitored during the three jar tests.

Phase 2: Phase 2 experiments were conducted at the Centre. Raw water was collected from the township's well and hauled to the Centre. During Phase 2, two experiments were designed to investigate the iron oxidation processes and properties of the oxidized iron compounds, respectively.

During Experiment 1 Phase 2, raw water was pumped through the pilot system and split into two trains:

- Train 1: Water was aerated and pumped through a hydro-pneumatic contact tank.
- Train 2: Water was dosed with chlorine at the optimum dose, which was previously determined from Phase 1, and then pumped through a chlorine contact tank.

Afterwards, the flow from either Train 1 or 2 was further split into two filtration trains simultaneously:

- Filtration Train 1: Mono sand media filtration
- Filtration Train 2: Cartridge microfiltration (1 µm filter followed by 0.35 µm filter)

During Experiment 2 Phase 2, raw water was pumped through the pilot system and dosed with chlorine at its predetermined optimum dose. Then, the flow was split into two filtration trains as follows:

- Train 1: Mono sand media filtration
- Train 2: Cartridge microfiltration with filters in the order of 10 µm, 5 µm, 1 µm and 0.35 µm

Iron levels were monitored throughout the pilot-scale experiments.

Phase 3: During Phase 3, pilot scale experiments were conducted on-site to eliminate iron oxidation which occurred during water transport and storage. Untreated well water was pumped and directed through the pilot system. The water was chlorinated, and then either pumped into or bypassed a contact chamber, followed by two filtration trains. A mono sand filter and cartridge filters (10 µm and 5 µm in series) were used in Trains 1 and 2, respectively. Two flow rates of 8 and 14 L/min were also used for each setup to investigate the impact of flow rate on the iron oxidation processes.

Key Findings

Through the bench scale tests, it was determined that:

- All filtered iron concentrations were less than the method detection limit (0.02 mg/L) when chlorine was applied.
- The manganese concentration of the raw water was 12 µg/L, which is 75% less than the aesthetic objective of 50 µg/L (Ontario MOE, 2006). Therefore, manganese reduction was not investigated during pilot testing.
- Less than 5 minutes of contact time was sufficient for iron oxidation in bench scale tests.

The pilot plant experiments conducted at the Centre determined that:

- Mono media filtration and cartridge filtration were effective to reduce iron from the raw water (≤ 0.04 mg/L).
- Mono sand media filtration showed slightly less iron reduction than cartridge filtration.

Iron particle size distribution testing conducted at the Centre demonstrated that:

- 26% of the iron particles were bigger than 10 µm, while 31% of iron particles were between 5 to 10 µm in size and 43% of iron particles were 1 to 5 µm in size based on the experimental conditions.

The pilot testing conducted on-site at the township showed that:

- At the low flow rate (8 L/min):
    - Both filtration trains showed similar iron reduction, when the contact chamber was used.
    - Cartridge filtration was slightly more effective than mono sand media filtration, when the contact chamber was bypassed.
- The increased flow rate reduced the efficacy of the mono sand media filter. The cartridge filters were barely affected by the change in flow rate.
- Overall, the mono sand media filter and the cartridge filters were more effective with the chlorine contact chamber at the design capacity.

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1. Introduction

Iron is the fourth most abundant element and the most abundant heavy metal in the earth's crust (Health Canada, 1978). It is introduced to natural waters through weathering or erosion of iron-containing rocks and minerals, acidic mine water drainage, landfill leachates, sewage effluents, and iron-related industries (Health Canada, 1978). In water, iron is most likely present as Fe(II) or Fe(III). Fe(III)-containing salts are generally found in surface water when pH is above 7 (Health Canada, 1978). Most of those salts are unstable and are precipitated as insoluble Fe(III) hydroxide, which can settle out as a rust-coloured silt (WHO, 2003). Therefore, the iron concentration in well-aerated waters is usually low. Anaerobic groundwater may contain high levels of iron presenting in its reducing state, Fe(II) (WHO, 2003).

Iron is an essential element in human nutrition and there is no evidence of dietary iron toxicity in the general population (Health Canada, 1978). Therefore, no regulation limit has been set. However, water may taste and appear unpalatable, when the iron concentration exceeds 0.3 mg/L (WHO, 2003). Water in which this occurs can promote the growth of iron bacteria, stain laundry and plumbing fixtures, and gradually clog distribution pipelines (Health Canada, 1978). As a consequence, the aesthetic objective for iron in drinking water is set as ≤ 0.3 mg/L (Ontario MOE, 2003).

A township located in South-Central Ontario has found increasing iron levels in one of their groundwater wells, which is currently used as the source for their drinking water supply. Therefore, the township is interested in exploring different options for iron reduction. One of the many methods to reduce iron in groundwater is oxidation by aeration, chlorination or potassium permanganate ($KMnO_4$), followed by filtration. The township is also interested in comparing different filtration techniques for the reduction of iron.

The overall goal of this pilot testing project is to reduce iron in the treated well water.

Specific objectives of pilot testing are:

- To reduce iron to a level below 0.3 mg/L,
- To investigate the use of air, chlorine and $KMnO_4$ to oxidize iron,
- To assess cartridge and pressure mono media filters to remove the oxidized iron.

The purpose of this pilot testing project is not to run all processes until exhaustion nor is it to determine operating costs and maintenance requirements for each process.

2. Materials and Methods

2.1 Bench Scale Testing

The objective of the bench scale testing was to find an optimal dose of chlorine and $KMnO_4$. Samples were collected from the untreated well influent. Detailed conditions of each bench test are provided in Table 1. Immediately following the rapid mixing/flocculation process, water was collected and filtered using a 0.45 µm membrane filter. Turbidity, dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UV_{254}), iron, manganese, apparent colour and true colour were analyzed for each jar. The rapid mixing/flocculation process was staggered to ensure the same reaction time for all jars. Bench Scale Test 1 aimed at finding the optimum dose of chlorine to oxidize iron. Similarly, Bench Scale Test 2 was conducted to find an optimized dose of $KMnO_4$ to oxidize iron. Bench Scale Test 3 was conducted to find an optimum flocculation time (or contact time) for chlorination. Results of the bench scale testing were used for the following pilot testing experiments.

Table 1. Bench test conditions

	Bench Test 1	Bench Test 2	Bench Test 3
Objectives	To find optimum chlorine dose	To find optimum $KMnO_4$ dose	To find optimum flocculation time
Chlorine dose	0.20 – 0.45 mg/L	0 mg/L	0.33 mg/L
$KMnO_4$ dose	0 mg/L	0.0125 – 0.25 mg/L	0 mg/L
Rapid Mixing at 100 rpm	1 min	1 min	1 min
Flocculation at 20 rpm	15 min	5 min	5 – 30 min

2.2 Pilot Scale Experiments Conducted at the Centre

Raw water from the well was hauled to the Centre to fill an outdoor storage tank. The pilot testing project required approximately 30,000 litres of raw water. To avoid oxidation of iron and manganese, the raw water was not mixed in the storage tank. Raw water was pumped into the pilot plant located in the Centre's Technology Demonstration Facility for pilot testing.

2.2.1 Pilot Plant Setup at the Centre

The pilot plant setup for Experiment 1A and 1B is presented in Figure 1. These two experiments were replicates using the same experimental conditions to confirm repeatability of results. Raw water was pumped from the outdoor tank. In Train 1, diffused air was added before water was pumped into the hydro-pneumatic contact tank providing approximately 15 minutes of contact time. In Train 2, sodium hypochlorite was dosed followed by a static mixer and then pumped into the contact chamber to achieve a contact time of approximately 15 minutes. It should be noted that chlorine requires approximately 15 minutes of contact time for iron oxidation (Crittenden et al., 2005). The water from both contactors was passed through the mono sand media filter and cartridge filters (1 μm followed by 0.35 μm size), simultaneously. In short, these experiments investigated the chlorine and diffused air oxidation along with two types of pressure filtrations to reduce iron in groundwater.

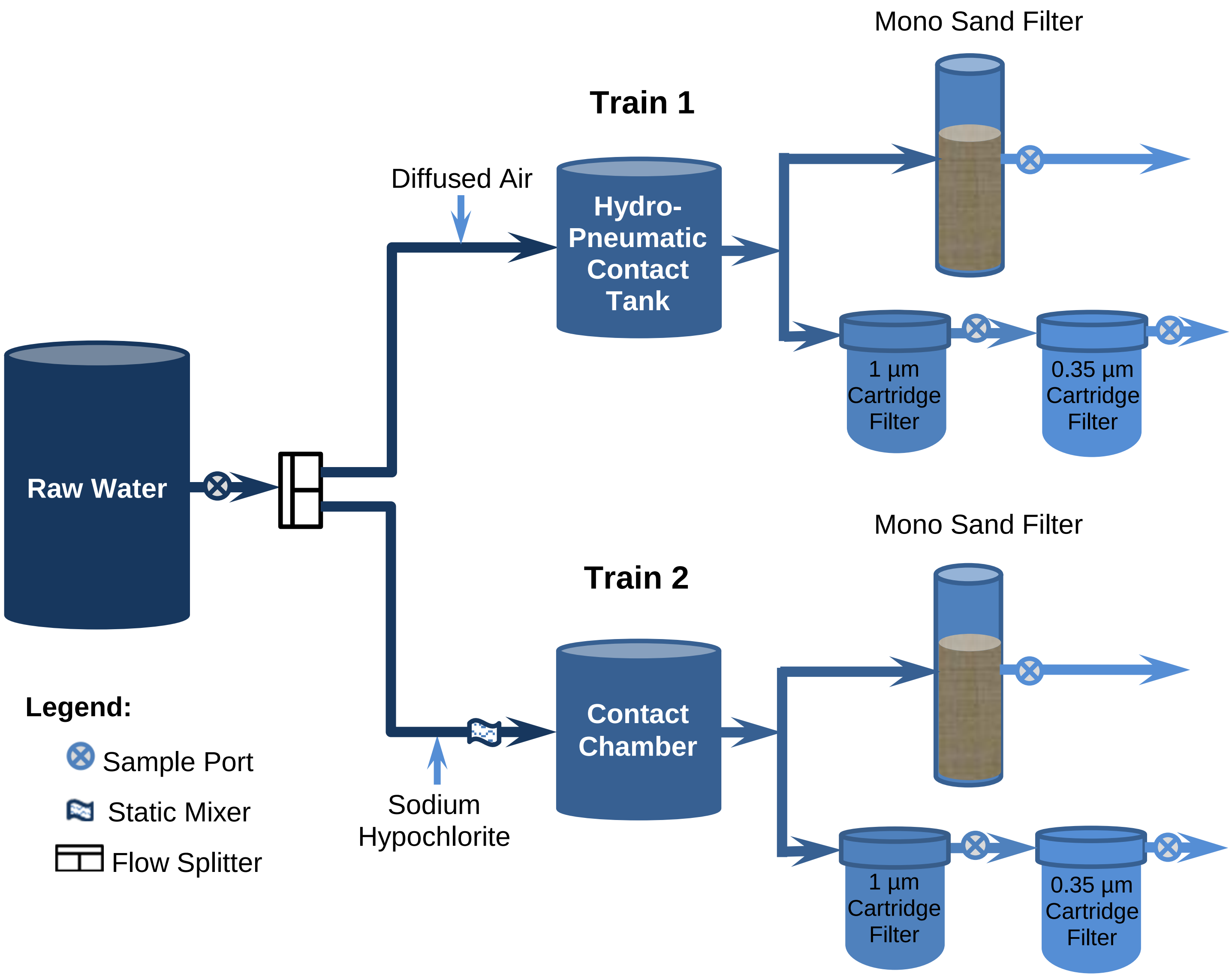

Figure 1. Schematic of pilot plant setup at the Centre – Experiments 1A and 1B

Figure 2 shows the setup of Experiments 2A and 2B, in which no oxidant was used. Water passed through mono sand media and cartridge filters. Cartridge filters of 10 µm, 5 µm, 1 µm and 0.35 µm were placed in series to assess filterability of iron particles.

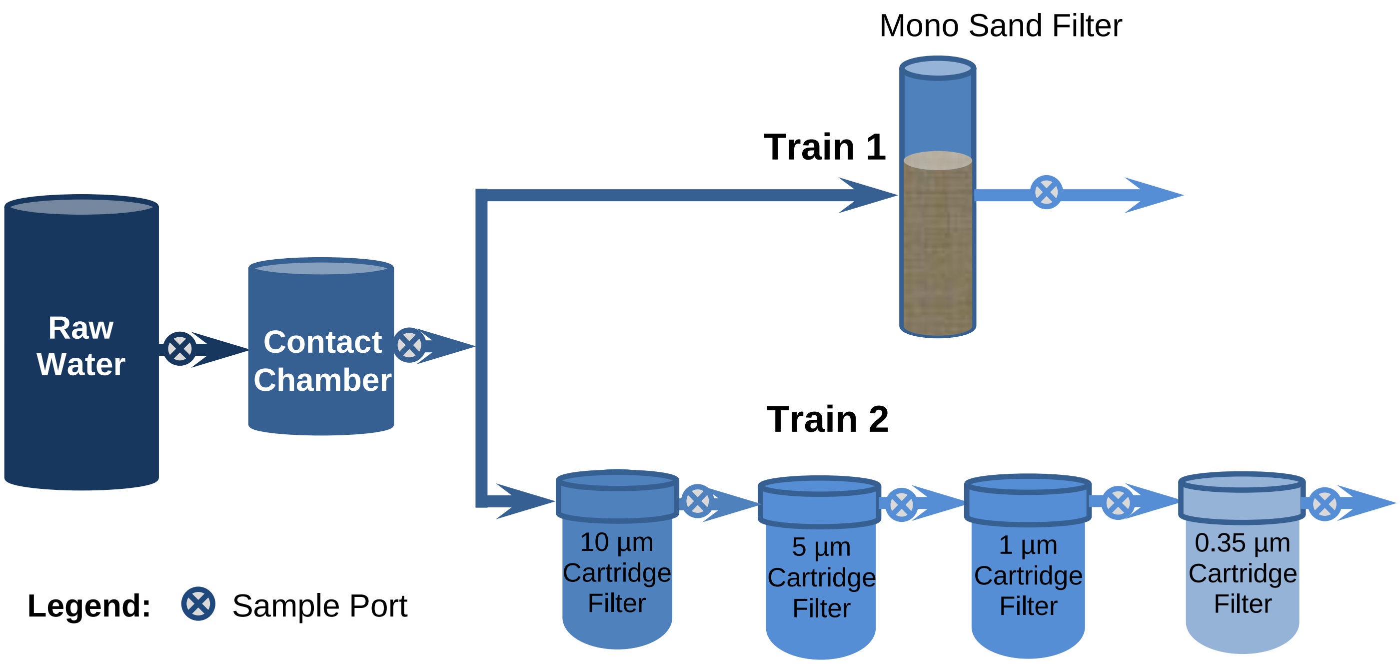

Figure 2. Schematic of pilot plant setup at the Centre – Experiments 2A and 2B

2.2.2 Methodology

Raw water was hauled from the township's well to the Centre. The detention time of the pilot plant for the replicated Experiments 1A and 1B was approximately 23 minutes. One day later, raw water was passed through the pilot plant (Figure 1) for approximately 3 detention times to replace the existing water in the pilot system that was used for leak testing. The chlorine dose of Experiments 1A and 1B were 0.92 and 1.11 mg/L, respectively. Raw water passed through the pilot system for another 3 detention times and samples were then collected for Experiment 1A. Experiment 1B was conducted on the next day as a replicate of Experiment 1A, to confirm replicability of results.

Results of Experiments 1A and 1B showed that iron had been transferred into the oxidized state and filtration may be sufficient enough for iron oxidation. Therefore, chlorine was eliminated for Experiments 2A and 2B. Additionally, 10 µm and 5 µm filters were added in the series to determine the size distribution of the oxidized iron particles.

2.3 Pilot Scale Experiments Conducted On-site

The pilot plant experiments were then conducted on-site at the township's well to eliminate the impact of the natural iron oxidation. The pilot setup and experimental conditions are provided in Figure 3 and Table 4, respectively. The untreated water from the well was pumped directly through the pilot system. Sodium hypochlorite was dosed initially in raw water for iron oxidation followed by a static mixer. The flow was then pumped into (Experiments 3A and 3B) or bypassed a contact chamber (Experiments 4A and 4B), followed by two filtration trains. A mono sand media filter and cartridge filters (10 µm and 5 µm in series) were used in Trains 1 and 2, respectively. In addition, two flow rates of approximately 8 and 14 L/min were tested for each pair of experiments.

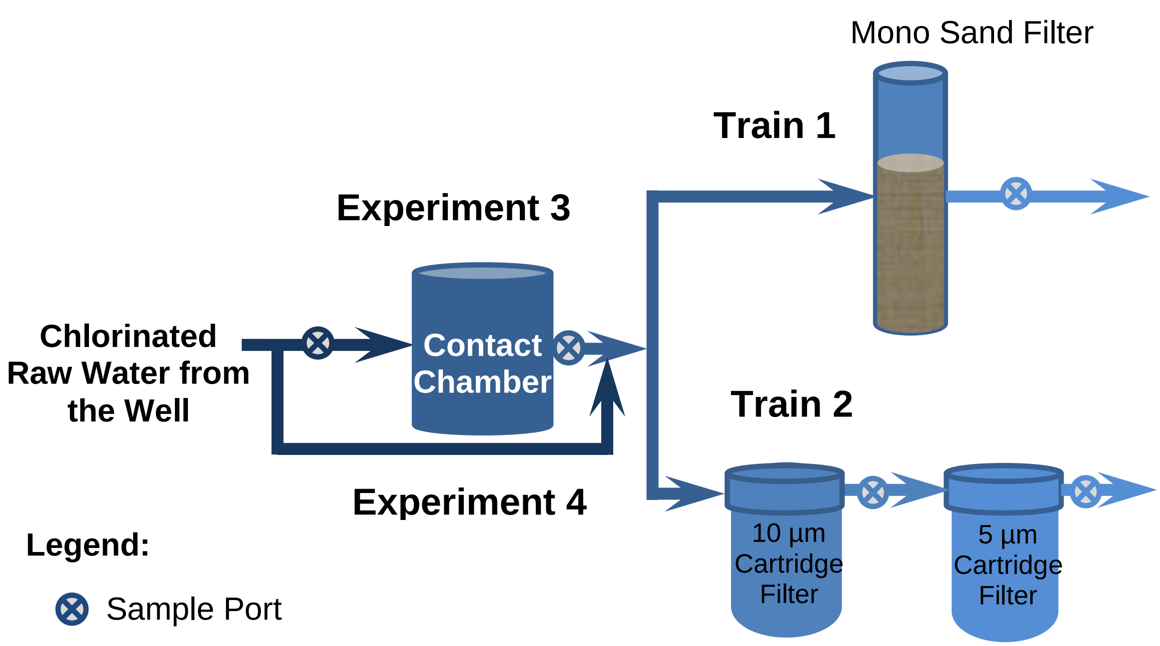

Figure 3. Schematic of pilot plant setup on-site – Experiments 3A, 3B, 4A and 4B

Table 2. Pilot testing conditions – Experiments 3A, 3B, 4A and 4B

Experiment	Approximate Flow Rate (L/min)	Contact Chamber
3 A	8	Yes
3 B	14	Yes
4 A	8	No
4 B	14	No

3. Results and Discussion

3.1 Bench Scale Results

3.1.1 Bench Scale Test 1

Bench Scale Test 1 was conducted to find an optimum dosage of chlorine to reduce iron by oxidation followed by filtration. Chlorine dosages of 0.20 - 0.45 mg/L were selected based on the iron and manganese concentrations in the raw water. In a typical jar test, coagulant or oxidant is added to each jar at the same time. However, in this test, each jar was treated individually, meaning it was dosed, rapid mixed, flocculated, filtered and analysed before the next jar was treated. This was done to ensure that the reaction time for chlorine and iron in each jar was approximately the same. To simulate the ideal filtration process in the jar test, the samples were filtered using a 0.45 µm pore size membrane filter. All filtered samples showed iron concentrations of less than the method detection limit (MDL), 0.02 mg/L. It should be noted that the water temperature was 15 - 16˚C during the jar test, whereas the water temperature was 8.5 - 9.0˚C, when the raw water sample was collected a day prior to the jar tests.

3.1.2 Bench Scale Test 2

Bench Scale Test 2 was conducted to find an optimum dosage of $KMnO_4$ for iron reduction using oxidation followed by filtration. $KMnO_4$ dosages of 0.0125 - 0.25 mg/L were used based on the iron and manganese concentration in the raw water. Similar to Bench Scale Test 1, each jar was treated individually, meaning that after $KMnO_4$ was dosed, water was rapid mixed, flocculated, filtered and analysed before the next jar was treated. Samples were sent to a licensed laboratory for manganese analysis. The laboratory found that the raw water manganese concentration was 0.0117 mg/L. As the $KMnO_4$ dosage increased, the concentration of manganese in the treated water also increased. Health Canada has proposed a guideline for the concentration of manganese in treated water to be less than 0.05 mg/L (Health Canada, 2016). The township's raw water has a concentration of manganese that is approximately a quarter of the proposed guideline, thus it was decided to focus on iron removal only. The filtered iron concentration was less than 0.02 mg/L for all samples.

3.1.3 Bench Scale Test 3

Bench Scale Test 3 was conducted to determine an optimum contact time for chlorine oxidation. The results of this jar test were used to adjust the pilot testing set-up. The optimum chlorine dose was selected from Bench Scale Test 1 as 0.33 mg/L. Flocculation (or contact) time was adjusted from 5 - 30 minutes.

This jar test showed that a 5 minute contact time was sufficient to reduce iron by chlorine oxidation. The 5 minutes of contact time would be applied in pilot testing. The measured free chlorine residual was 0.03 mg/L or less in all jars. The pH ranged from 7.1 to 7.8, and temperature ranged from 16˚C to 18˚C.

3.2 Results of Pilot Testing Conducted at the Centre

3.2.1 Experiments 1A and 1B: Comparing aeration and chlorination followed by filtration

3.2.1.1 Iron Reduction

Figure 4 shows the iron levels in the raw and treated water during Experiments 1A and 1B. The raw water iron level was 0.43 and 0.40 mg/L for Experiments 1A and 1B, respectively. The circulation pump of the tank was not operated during pilot testing to prevent oxidation of iron in the tank. Cartridge filtration by 1 µm and

0.35 µm effectively reduced iron concentration to 0.02 mg/L or less. Moreover, the mono sand media filtration was also effective to reduce iron to 0.04 mg/L or less. It should be noted that the mono sand media filter can be backwashed, whereas the cartridge filters are not designed with a backwash function and are therefore consumable. The operation and maintenance differ for the two filter types and either could be better suited to a treatment train based on that specific location's needs. Overall, both cartridge and the mono sand media filtration were found to be effective to filter the oxidized iron.

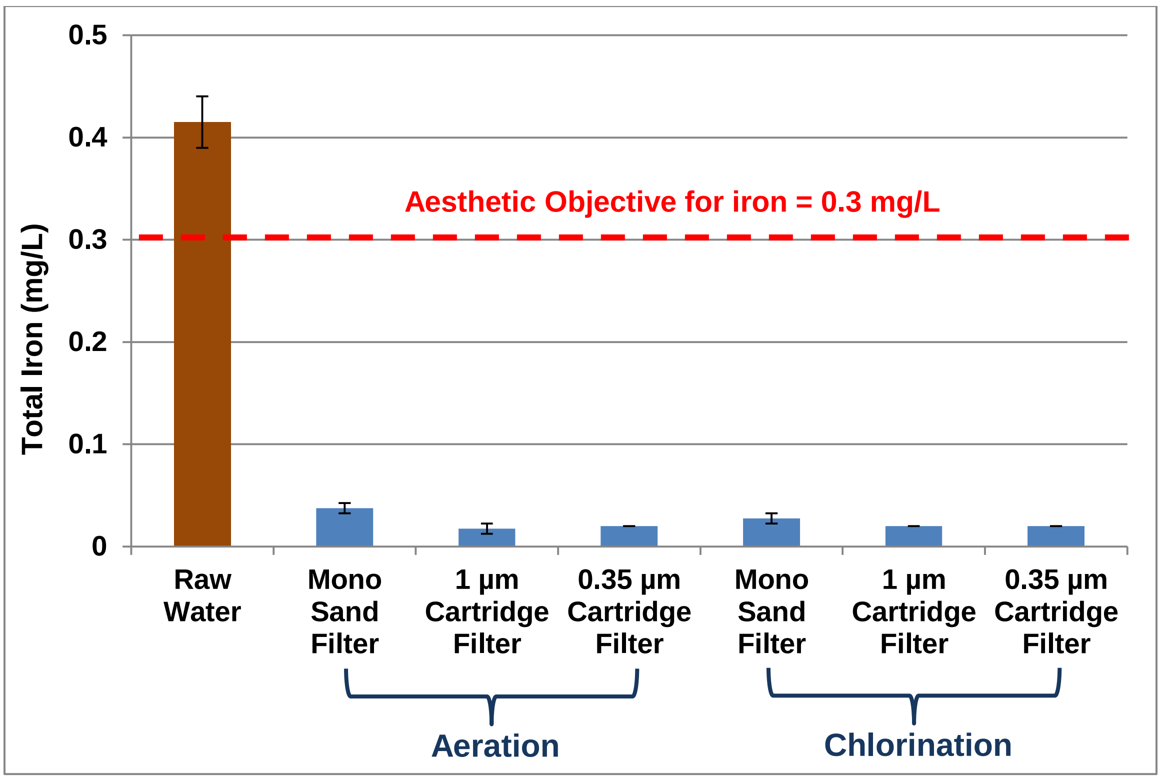

Figure 4. Total iron levels in raw and treated waters during Experiments 1A and 1B

3.2.1.2 General Water Quality

The average pH of the raw water was 7.69 (sample number, n = 4). Aeration was expected to have no impact on water pH, and the average effluent pH from the aeration train was measured as 7.76. Chlorination would increase the water's pH through the dosing of sodium hypochlorite; however, no significant changes in the effluent pH were noted (pH = 7.72), which is likely due to the low chlorine dose used in the test (0.33 mg/L).

The average DOC of the raw water was 0.74 mg/L (n = 4), whereas the average DOC of the aeration and chlorination trains were 0.86 mg/L and 0.82 mg/L, respectively (n = 2). Therefore, neither train was able to reduce DOC levels.

The raw water alkalinity was measured as 149 mg/L and 184 mg/L as $CaCO_3$ for Experiments 1A and 1B, respectively. No significant alkalinity changes were noted throughout the treatment process from both experiments.

The chlorine dose was obtained as 0.92 mg/L and 1.11 mg/L from Experiments 1A and 1B, respectively. To determine the chlorine demand in Train 2 (chlorination), total chlorine was measured in the effluent samples collected from the mono sand filter and each of the cartridge filters. The mono sand filter consumed 0.06 – 0.29 mg/L of total chlorine during the test, while both cartridge filters showed limited total chlorine demand.

3.2.2 Experiments 2A and 2B: Evaluating oxidized iron particle sizes

According to results of Experiments 1A and 1B, the total iron concentrations measured from the pilot system effluents ranged from 0.38 mg/L to 0.44 mg/L, whereas the dissolved iron concentrations were all below the aforementioned MDL (0.02 mg/L). Therefore, Experiments 2A and 2B were conducted without oxidation. Four cartridge filters were connected in series with decreasing pore sizes (10 µm, 5 µm, 1 µm and 0.35 µm) were tested in parallel with the mono sand media filter. The series of cartridge filters was utilized to investigate the size distribution of the oxidized iron compounds present in the raw water.

3.2.2.1 Iron Reduction

The average raw water iron concentration in Experiments 2A and 2B was 0.37 mg/L (n = 4), which was lower than that noted in Experiments 1A and 1B. A different truckload of water was used for this experiment, which is likely the cause of the variability in iron concentrations. Figure 5 presents the iron levels in the raw water and effluent from the filtration processes. The mono sand media filter effectively filtered out the majority of the oxidized iron particles and had a total iron concentration of 0.04 mg/L on average (n = 3) in the effluent, indicating an 89% iron reduction. The cartridge filters in series, 10 µm, 5 µm, 1 µm and 0.35 µm, were able to reduce total iron concentrations to 0.28, 0.17, 0.02 and 0.02 mg/L, respectively.

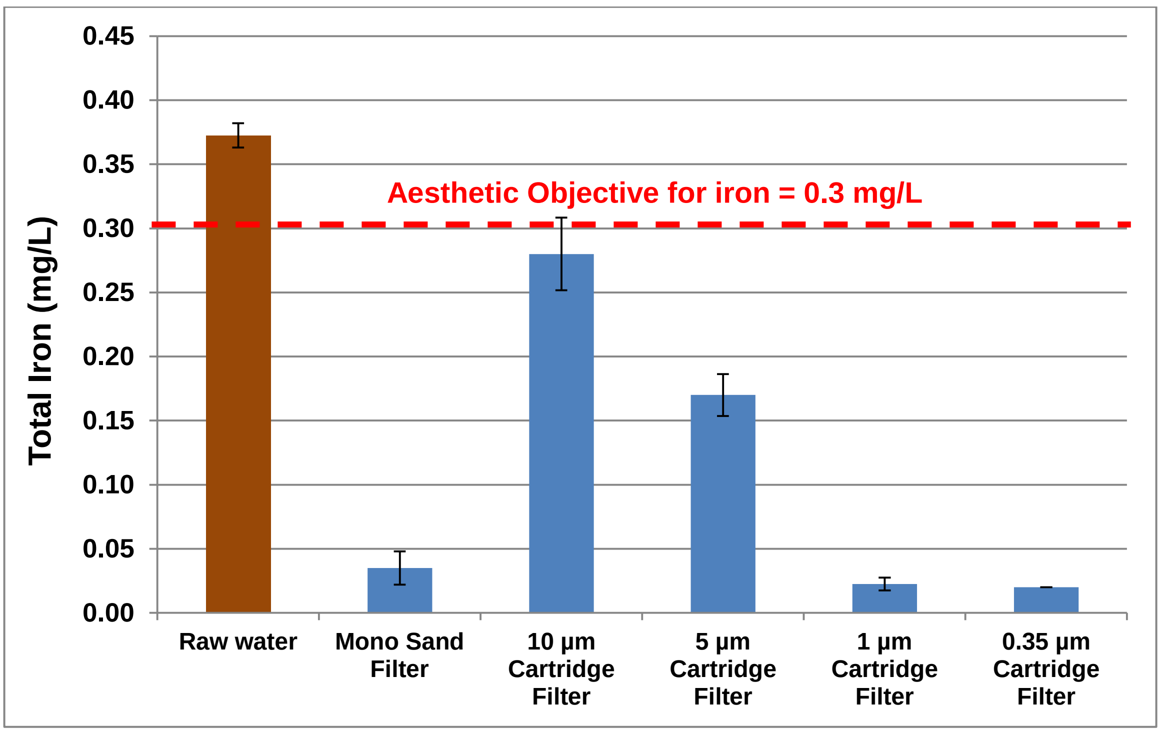

Figure 5. Total iron levels in raw and treated waters in Experiments 2A and 2B

Figure 6 shows the size distribution of the oxidized iron compounds in the raw water, based on the total iron reduction achieved by the series of cartridge filters in Experiments 2A and 2B. It demonstrates that about 26% of oxidized iron compounds were larger than 10 µm, while 31% of those particles were between 5 to 10 µm in size, and the remaining 43% of particles were between 1 to 5 µm.

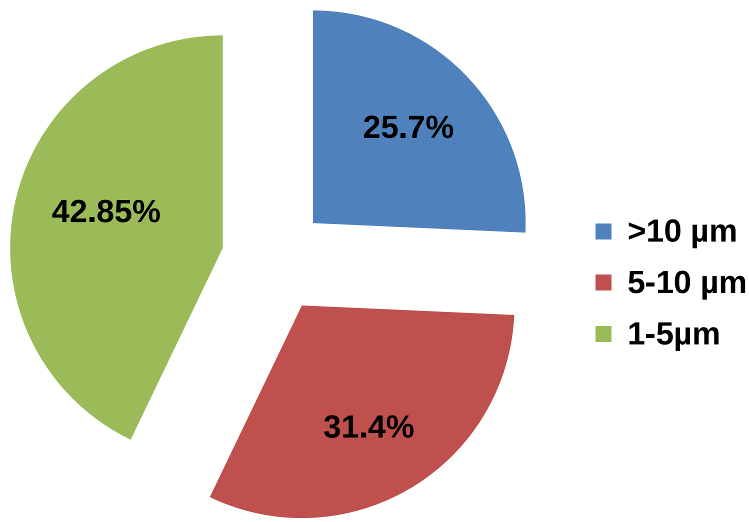

Figure 6. Size distribution of the oxidized iron particles in raw water

3.2.2.2 General Water Quality

With no chemical additives, Experiments 2A and 2B were expected to have limited variability in water quality throughout the processes. Therefore, analysis of pH, alkalinity, DOC and UV absorbance was conducted only for raw water. The pH was measured as 7.5 - 7.6, while the alkalinity was 167 - 187 mg/L as $CaCO_3$. The DOC was 0.67 - 0.70 mg/L and the UV absorbance was 0.010 - 0.011 cm^{-1}. The effluents of the mono sand media filter and 0.35 µm cartridge filter had similar apparent colour results, which were 19.5 and 17 Pt-Co units on average (n = 4), respectively. The turbidity measured from the 0.35 µm cartridge filter effluent (0.23 NTU on average, n = 2) was lower than that of the mono sand filter (0.93 NTU, n = 2).

3.3 Results of Pilot Testing Conducted On-site

According to the size distribution of the raw water iron compounds obtained from Experiments 2A and 2B, the majority of the particles in the raw water may have already oxidized during water shipment and storage prior to the experiments at the Centre. To better understand the oxidation processes of iron, grab samples were collected from the raw well water and analyzed for both total and dissolved iron concentrations. Based on the grab sample results, the dissolved iron concentration measured on-site was much higher than that measured off-site, indicating that a great amount of iron might have been transferred to the oxidized state during water shipment and storage. To eliminate the impact of iron oxidation, the subsequent pilot experiments were conducted on-site at the township's well.

As the township applies chlorination as its primary and secondary disinfection, the pilot system used the chlorinated raw water directly from the well as influent. The setup of this pilot system is provided in Section 2.3. To investigate the impact of flow rate on iron reduction, two flow rates (8 and 14 L/min) were designed for Experiments 3A/4A and 3B/4B, respectively.

3.3.1 Experiments 3A and 3B: Comparing chlorination using different contact times followed by filtration

3.3.1.1 Iron Reduction

To better understand the effect of chlorination, the dissolved iron levels were measured for both the raw water and the chlorinated raw water samples. It was found that the dissolved iron level in chlorinated raw water (<0.02 mg/L) was much less than that in raw water (0.39 mg/L), indicating that the chlorine contact time to oxidize iron was minimal in those experiments.

Figure 7 demonstrates total iron concentrations measured from the raw water and the treated water from all filters in Experiments 3A and 3B. The total iron concentrations in the raw water and the chlorinated raw water were measured as 0.41 and 0.40 mg/L, respectively. A contact chamber was included in the experiments, which allowed approximately 19 and 7 minutes of chlorine contact time for Experiments 3A and 3B, respectively.

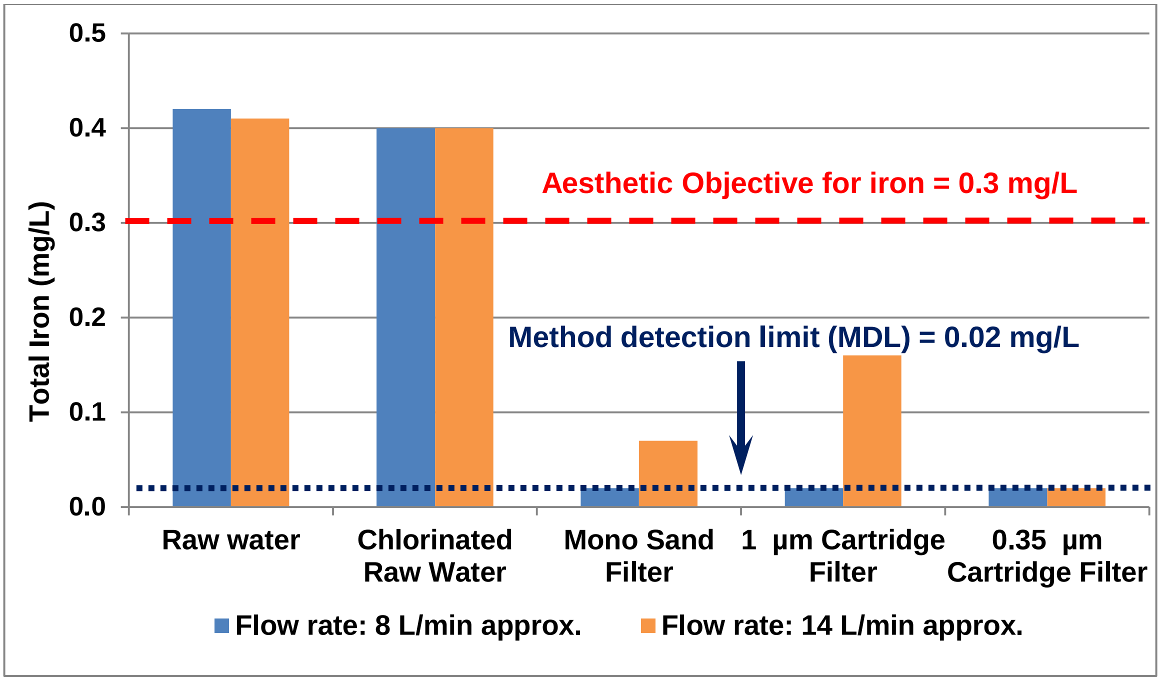

Figure 7. Total iron levels in raw and treated waters in Experiments 3A and 3B using different chlorine contact times

The mono sand media filter reduced the total iron concentration to 0.03 mg/L in Experiment 3A (93% reduction) and 0.07 mg/L in Experiment 3B (83% reduction). This filter achieved a higher total iron reduction at the lower flow rate. The lower flow rate increased the chlorine contact time and empty bed contact time (EBCT) of each filter, and thus increased removal efficacy of the pilot system. Therefore, it is likely that the increased EBCT resulted in higher iron removal efficacy of the filters.

The findings obtained from the 1 µm cartridge filter were similar. This cartridge filter had total iron concentrations of 0.09 and 0.16 mg/L from its effluent in Experiments 3A and 3B, respectively. The 0.35 µm cartridge filter was capable of reducing total iron levels to below the MDL (0.02 mg/L) in both experiments. Therefore, both the mono sand media filtration and the cartridge filtration series effectively reduced iron from the well water.

3.3.1.1 General Water Quality

The pH of the raw water and the chlorinated water were 7.43 and 7.35, respectively. The mono sand media filter and the cartridge filters had limited effects on pH in both experiments, with an effluent pH of 7.38 and 7.33 on average (n = 2), respectively. The same apparent colour levels were obtained for both the raw water and the chlorinated raw water samples, as 5 Pt-Co units, which is also the MDL. Therefore, apparent colour was not further investigated in these experiments. Turbidity was measured as 0.25 and 0.27 NTU in the raw water and the chlorinated raw water samples. The effluent turbidity of the mono sand media filter (0.25 NTU for Experiment 3A and 0.56 NTU for Experiment 3B) was higher than that of the series of cartridge filters (0.15 NTU for Experiment 3A and 0.13 NTU for Experiment 3B) in both experiments.

3.3.2 Experiments 4A and 4B: Comparing chlorination followed by different types of filtration without a chlorine contact chamber

Based on the findings of Experiments 3A and 3B, chorine contact time for iron oxidation could be minimal. Therefore, the chlorine contact chamber was bypassed in Experiments 4A and 4B.

3.3.2.1 Iron Reduction

As shown in Figure 8, the total iron levels were measured for the raw and the treated water samples in Experiments 4A and 4B. Similar to Experiments 3A and 3B, the dissolved iron concentration of the chlorinated raw water was below the MDL (0.02 mg/L). The same total iron levels were measured from the raw water and the chlorinated raw water as 0.40 mg/L.

During Experiment 4A, the flow rate through the pilot system was adjusted to approximately 8 L/min. The mono sand media filter, 1 µm and 0.35 µm cartridge filters were able to reduce total iron levels to 0.07, 0.09, and 0.03 mg/L, respectively. The mono sand media filter was less effective for iron reduction than the series of cartridge filters. However, it should be noted that the mono sand media filter can be backwashed, providing a longer service life and reduced costs in the long run.

When the flow rate was increased to 14 L/min in Experiment 4B, the iron concentration of the effluent from the mono sand media filter increased to 0.09 mg/L, while the 1 µm and 0.35 µm cartridge filters were 0.18 mg/L and 0.03 mg/L, respectively.

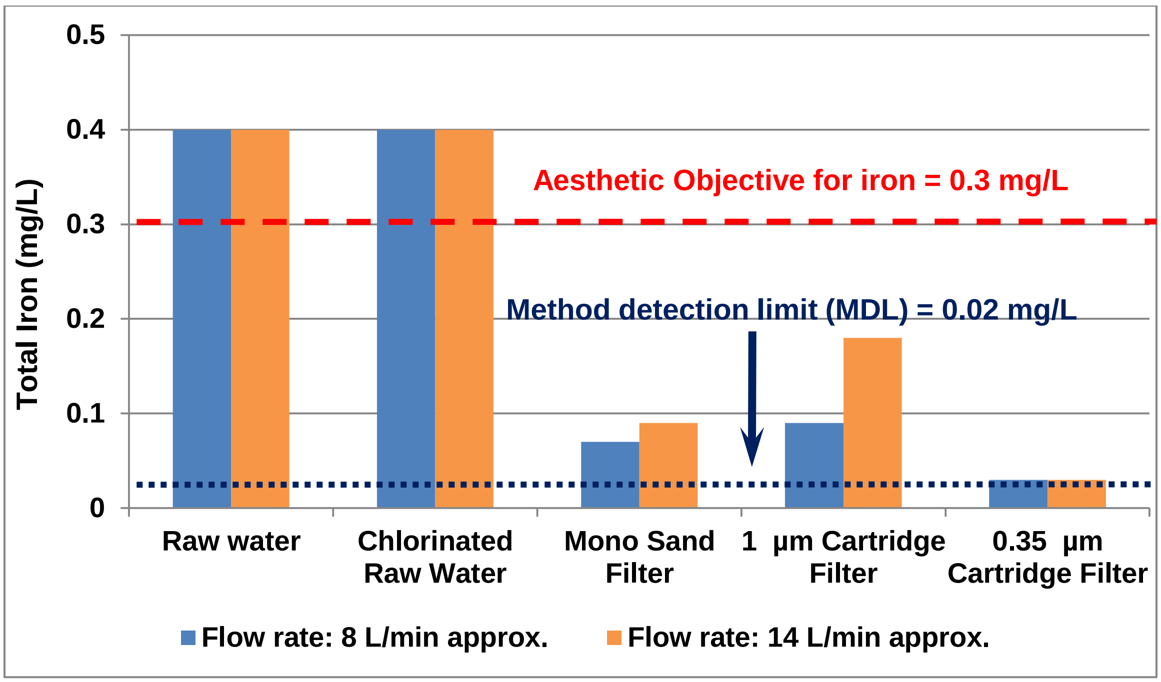

Figure 8. Total iron levels in raw and treated waters in Experiments 4A and 4B without a chlorine contact chamber

3.3.2.1 General Water Quality

The pH of the raw water and the chlorinated water were obtained as 7.4 and 7.3, respectively. Similar to Experiments 3A and 3B, the mono sand media filter and the cartridge filters had limited effects on the water's pH (7.26 - 7.47). The mono sand media filter had higher effluent turbidity (0.28 NTU for Experiment 4A and 0.47 NTU for Experiment 4B) than that of the series of cartridge filters (0.11 and 0.13 NTU for Experiments 4A and 4B, respectively).

4. Conclusions

Through the bench scale tests, it was determined that:

- Bench Scale Test 1:
  - All filtered iron concentrations were less than the MDL (0.02 mg/L), due to chlorination treatment.
  - The stoichiometric requirement of chlorine to reduce iron and manganese was 0.32 mg/L.
- Bench Scale Test 2:
  - The manganese concentration of the raw water was 12 µg/L, which is about 75% less than the aesthetic objective of 50 µg/L as per Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines (Ontario MOE, 2006). Therefore, manganese reduction was not investigated further during the pilot tests.
- Bench Scale Test 3:
  - Less than 5 minutes of contact time was found sufficient to oxidize iron compounds.

The pilot plant experiments conducted at the Centre determined that:

- Mono sand media filtration and cartridge filtration series were effective to reduce iron from the raw water (≤ 0.04 mg/L).
- Mono sand media filtration showed slightly less iron reduction than the cartridge filtration series.

Iron size distribution testing conducted at the Centre demonstrated that:

- 26% of the iron particles were bigger than 10 µm, while 31% of iron particles were between 5 to 10 µm in size and 43% of iron particles were 1 to 5 µm in size based on the experimental conditions.

The pilot testing conducted on-site showed that:

- When a chlorine contact chamber was used at a flow rate of 8 L/min:
    - Both filtration trains showed similar iron reduction.
        - Mono sand media filtration reduced iron from 0.42 mg/L to 0.03 mg/L (93%).
        - Cartridge filtration reduced iron from 0.42 mg/L to 0.02 mg/L (95%).
- When a chlorine contact chamber was used at a flow rate of 14 L/min:
    - The cartridge filtration series was more effective than the mono sand media filtration.
        - Mono sand media filtration reduced iron from 0.41 mg/L to 0.07 mg/L (83%).
        - Cartridge filtration reduced iron from 0.41 mg/L to 0.02 mg/L (95%).
- When chlorine contact chamber was bypassed at a flow rate of 8 L/min:
    - The cartridge filtration series was slightly more effective than the mono sand media filtration.
        - Mono sand media filtration reduced iron from 0.40 mg/L to 0.07 mg/L (83%).
        - Cartridge filtration reduced iron from 0.40 mg/L to 0.03 mg/L (93%).
- When chlorine contact chamber was bypassed at a flow rate of 14 L/min:
    - The cartridge filtration series was slightly more effective than the mono sand media filtration.
        - Mono sand media filtration reduced iron from 0.41 mg/L to 0.09 mg/L (78%).
        - Cartridge filtration reduced iron from 0.40 mg/L to 0.03 mg/L (93%).

- Overall, the mono sand media filter and the cartridge filters performed better in conjunction with the chlorine contact chamber at the design capacity.

5. References

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Pilot Testing Services

For pilot testing inquiries, please visit:

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Drinking Water Resource Library

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