



Pilot Testing Project Report:

Options for the Reduction of Arsenic from a Groundwater Source

Walkerton Clean Water Centre

August 30, 2018

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Executive Summary

Background

Arsenic (As) is a naturally occurring metal, which is widely distributed throughout the Earth's crust. It can be introduced to water through industrial effluents or natural erosion and weathering of arsenic-containing rocks and minerals (Health Canada, 2006). Arsenic is classified as a human carcinogen (Health Canada, 2006). Long-term exposure to arsenic through drinking water is related to a series of health issues, including cancer, skin lesions, and cardiovascular disease (IPCS, 2001).

In Ontario, arsenic is a regulated drinking water contaminant (O. Reg. 169/03). As of January 1st, 2018, the regulated maximum acceptable concentration (MAC) of arsenic was lowered from 25 µg/L to 10 µg/L (Ontario Regulatory Agency, 2015). Shelburne, a town located in South Central Ontario discovered that several drinking water supply wells had arsenic levels exceeding the updated MAC.

Objectives

The overall objective of this pilot testing project was to reduce arsenic in the treated well water using a suitable and practical solution based on the existing system.

Specific objectives of this pilot testing project were as follows:

- To reduce arsenic in the treated well water to less than or equal to 5 µg/L using:
 - Chlorine oxidation followed by adsorptive media
 - Chlorine oxidation followed by cartridge microfiltration
- To reduce iron in the treated well water as low as possible for aesthetic purposes.

Approach

This project was conducted in two phases: bench-scale jar tests (Phase 1) and pilot-scale experiments (Phase 2). The objectives of each phase were demonstrated in Figure ES-1.

During Phase 1, Jar Test 1 and 2 were conducted to determine the optimum chlorine dose for arsenic oxidation. This determined optimum chlorine dose was then used in Jar Test 3 with addition of ferric chloride coagulant to determine if this coagulant could increase the arsenic removal efficiency. Iron levels were monitored during the three jar tests.

During Phase 2, raw water was pumped through the pilot system and dosed with chlorine at the optimum dose, which was previously determined from Phase 1. Then, the water was pumped either through a contact tank (Experiment 1-3) or bypassed the tank (Experiments 4-6). Afterwards, the flow was split into two different filter trains simultaneously as follows:

- Train 1: Adsorptive media filtration
- Train 2: Cartridge microfiltration (1 μm filter followed by a 0.35 μm filter)

Arsenic and iron levels were monitored throughout the six pilot-scale experiments.

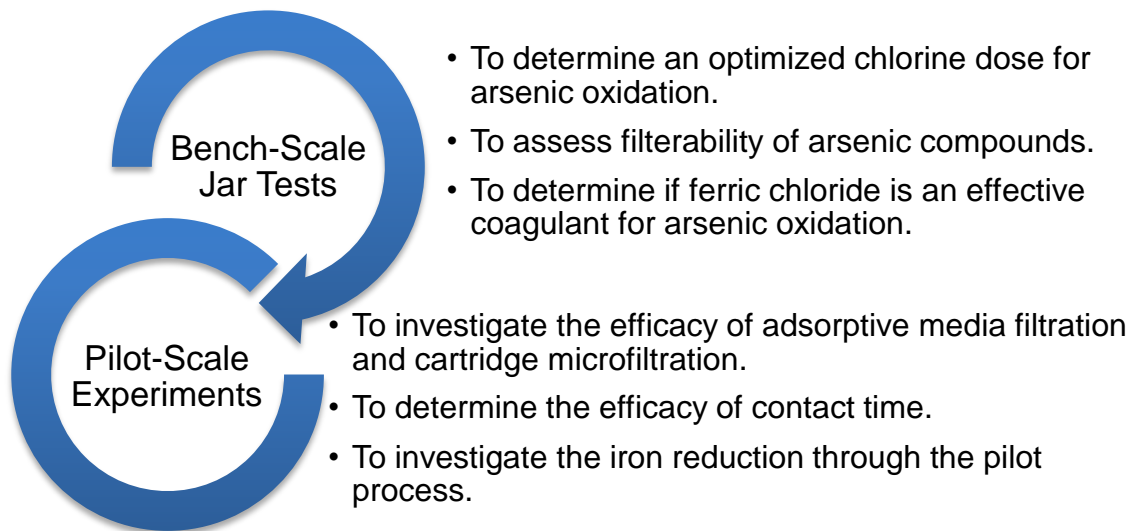


Figure ES-1. Objectives of bench-scale jar tests and pilot-scale experiments

Key Findings

The bench-scale jar testing determined that:

- Chlorine was effective for arsenic reduction. An optimum chlorine dose of 4 mg/L was determined, which reduced arsenic levels by 32% (from 9.6 µg/L to 6.5 µg/L).
- Combining chlorine and ferric chloride reduced arsenic levels by 38% (from 11.9 µg/L to 7.6 µg/L), using the optimized dosages (chlorine of 4 mg/L and ferric chloride of 1.25 mg/L).
- Iron was effectively oxidized into particulate form and removed by filtration (0.45 µm) in all jar testing experiments.

The pilot-scale experiments determined that:

- The chlorine contact tank did not overly affect the reduction capabilities for arsenic or iron.
- The adsorptive media filter reduced arsenic levels by 95% (from 10.2 µg/L to 0.47 µg/L) and > 98% (from 10.6 µg/L to < 0.2 µg/L), when using and bypassing the contact tank, respectively.
- The cartridge filters showed limited removal capacity, and reduced arsenic levels by only 4% (from 10.2 µg/L to 9.8 µg/L) and 2% (from 10.6 µg/L to 10.4 µg/L), when using and bypassing the contact tank, respectively.
- Both trains effectively removed the remaining iron; however, no definite conclusions can be drawn due to the degradation of water quality during transportation and/or storage.

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1. Introduction

Arsenic is a naturally occurring metal, which is widely distributed in rocks and mineral deposits throughout the Earth's crust. It is naturally introduced to water through erosion and weathering of arsenic-containing soils, rocks, minerals, and ores (Health Canada, 2006). Arsenic compounds are also used in the manufacture of a variety of products and may enter water bodies directly from industrial effluents and indirectly from atmospheric deposition (Health Canada, 2006). In water, arsenic most likely presents in the oxidation states, including arsenite [As(III)] and arsenate [As(V)] (WHO, 2011). Arsenic is classified as a human carcinogen (Health Canada, 2006). Long-term exposure to arsenic through drinking water is related to cancer, skin lesions, developmental effects, cardiovascular disease, neurotoxicity and diabetes (IPCS, 2001).

As of January 1st, 2018, the Ontario Ministry of Environment lowered the maximum acceptable concentration (MAC) of arsenic in treated water from 25 µg/L to 10 µg/L, based on the best worldwide arsenic exposure and health information available to Health Canada (Ontario Regulatory Agency, 2015). Many drinking water systems in Ontario have been affected by this and may no longer be compliant.

Shelburne, a town located in South Central Ontario, with a population under 10,000 has naturally occurring arsenic in several of their existing groundwater wells, which are currently used as the drinking water supply. Of these wells, Well 3 has arsenic levels that vary from 11 to 15 µg/L, which is no longer compliant with the updated MAC. Wells 5 and 6 also have high average arsenic levels of 15 - 16 µg/L. In response to this issue, Shelburne has invested in the development of new wells, Wells 7 and 8, located in a deeper aquifer with much lower arsenic levels. The supply from Wells 5/6 and Wells 7/8 are blended to provide water with average arsenic levels of 8 - 9 µg/L which meet the updated MAC. A blending solution was also considered for Well 3, but a detailed investigation has determined that this solution would not be sufficient to lower the arsenic levels below the updated MAC with the existing infrastructure and well capacities. As

such, Shelburne decided to conduct a pilot testing project to explore options for reducing arsenic levels in Well 3.

The existing treatment process of Well 3 is disinfection (using sodium hypochlorite) and sequestering (using CalciQuest®, a liquid phosphate solution). Water from Well 3 has iron levels ranging from 0.18 to 0.57 mg/L, whereas Ontario's aesthetic objective recommends the iron level to be equal to or less than 0.3 mg/L (Ontario MOE, 2006). Therefore, to meet these aesthetic objectives, iron levels are recommended to be lowered in Well 3 treated water. The sequestering system is used to keep iron in its dissolved states and prevent the generation of "red water".

1.1 Process Selection

Typical technologies used to reduce arsenic levels include the following (WRF/USEPA, 2002):

1) Adsorptive processes:

This is a physical-chemical process wherein As(III) and As(V) are adsorbed to either an alumina or iron based adsorbent.

2) Precipitative and membrane processes:

Chlorination followed by filtration may be an effective and economical option to reduce arsenic concentrations to less than 10 µg/L. Ferric chloride is a more effective coagulant for removing arsenic (As[V]) than alum. Microfiltration may be used to filter oxidized arsenic particles. Cartridge microfilters fouled by arsenic and iron may be easier to dispose due to their reduced volume of solid hazardous waste compared to that of liquid backwash waste. The liquid backwash waste would require treatment as well as adherence to health and safety and environmental policies and procedures (Ontario MOE, 2011). Although both nanofiltration and reverse osmosis are effective membrane processes to remove arsenic, high capital and operational costs may limit their use in this municipal water treatment

setting, and hence these technologies were not pursued further in this project.

3) Ion exchange processes:

Anionic resins in chloride form can be used to reduce arsenic. Although this process is effective, ion exchange is non-selective and may remove all negative ions (arsenite, arsenate, sulphate, organics, etc.), which may affect the treated water quality (e.g. pH and alkalinity) (Chen et al., 2006). Again, disposal of resin regeneration wash water must be compliant to health and safety and environmental policies and procedures. Therefore, this technology was not pursued further in this project.

1.2 Objectives

The overall objective of this pilot testing project was to reduce arsenic in the treated water from Well 3, using a suitable and practical solution based on the existing system.

Specific objectives of this pilot testing project were as follows:

- To reduce arsenic in Well 3 treated water to less than or equal to 5 µg/L using:
 - Chlorine oxidation followed by adsorptive media.
 - Chlorine oxidation followed by cartridge microfiltration.
- To reduce iron in Well 3 treated water as low as possible for aesthetic purposes.

2. Materials and Methods

2.1 Phase 1: Jar Testing (Bench Scale)

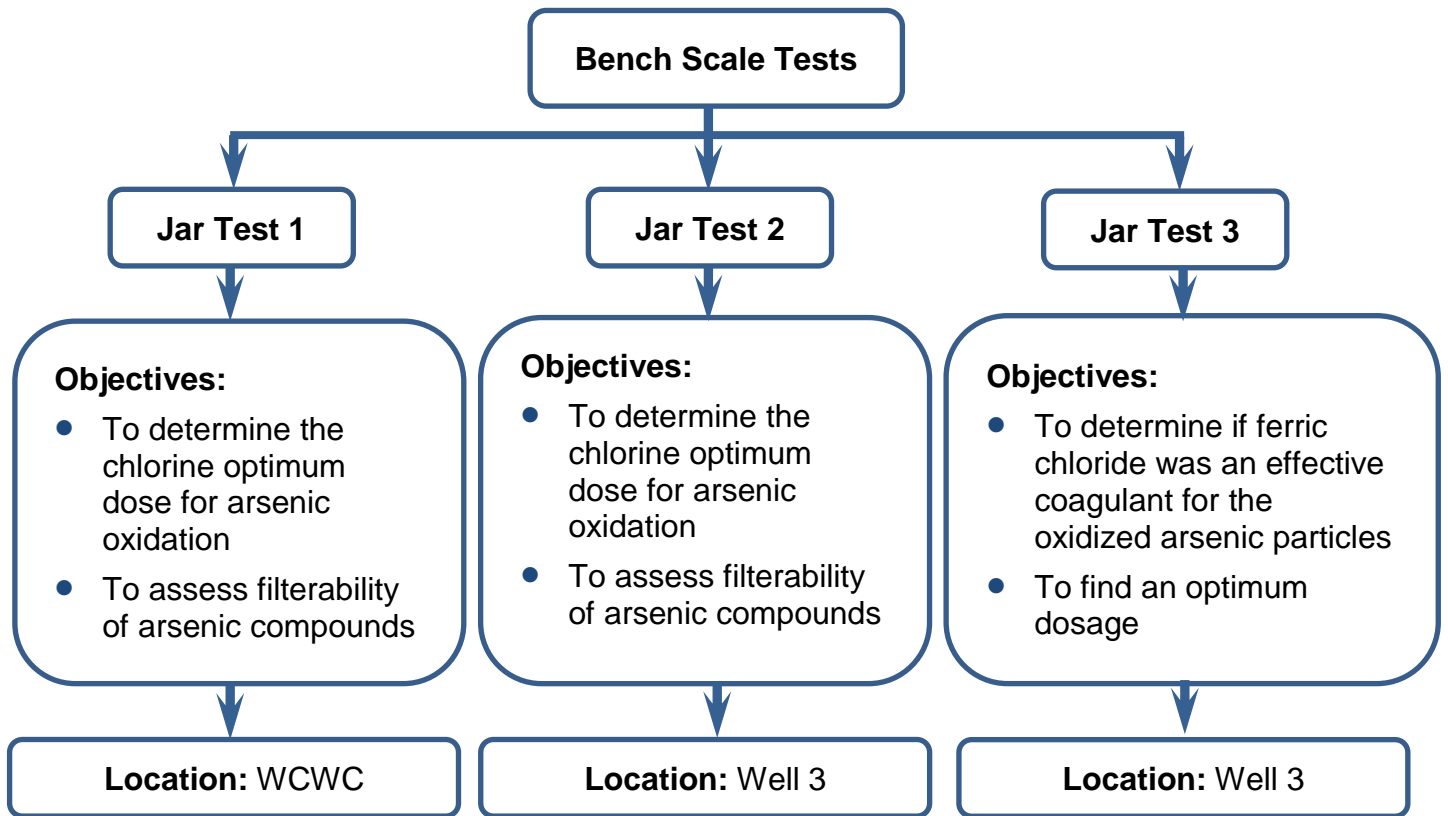
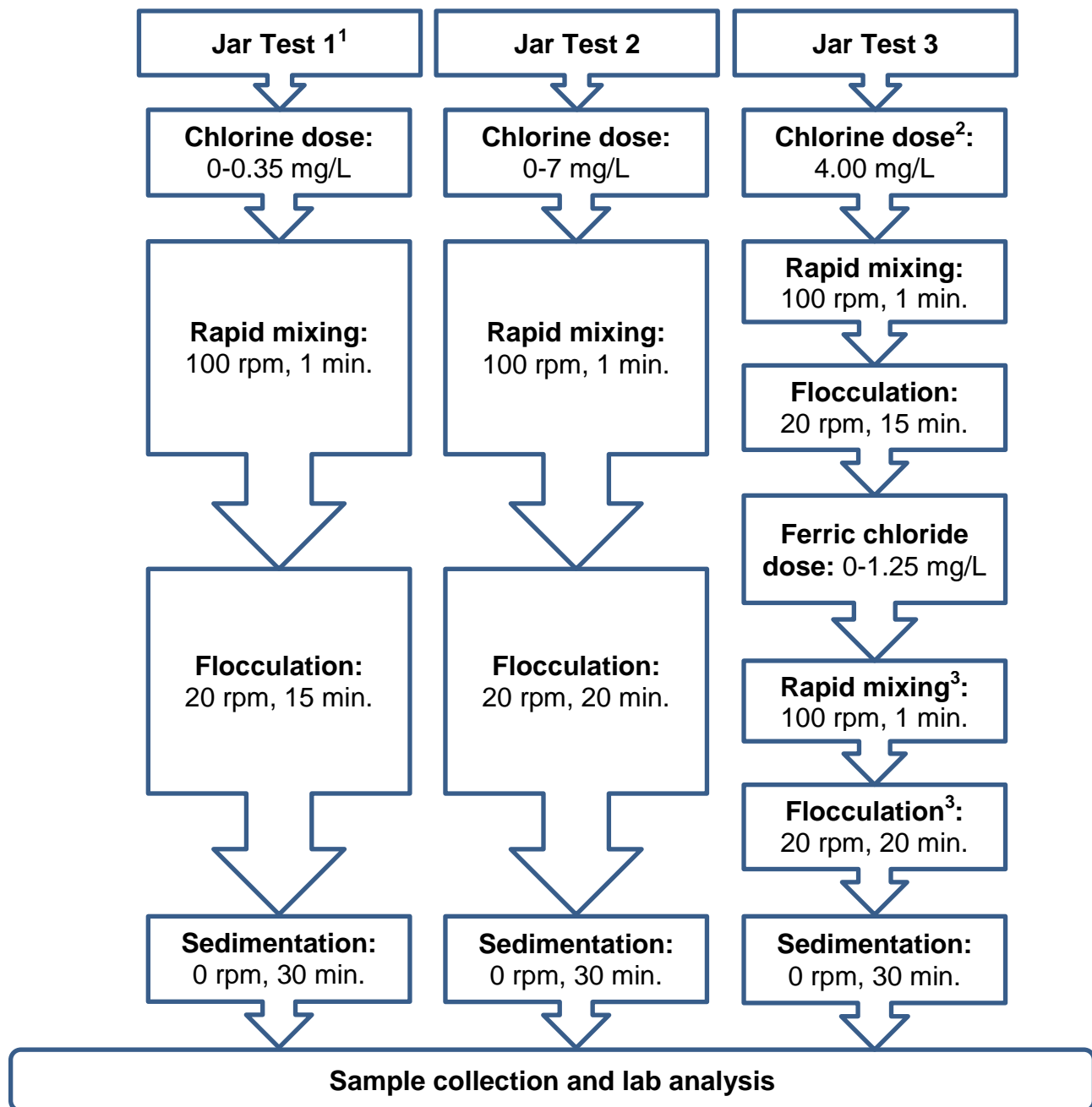


Figure 1. Jar test objectives and set-up locations

2.1.1 Methodology

For Jar Test 1, raw water was collected from Shelburne's Well 3 and then shipped to the Centre. A 6-paddle programmable jar tester was used to mimic the coagulation/flocculation and sedimentation process with chlorine doses of 0 - 0.35 mg/L (Figure 2). This jar tester was programmed to run sequentially for 1-minute rapid mixing at 100 rpm, 15-minute flocculation at 20 rpm, and 30-minute sedimentation with no disturbance. Jar Test 2 had a similar set-up as Jar Test 1 but was conducted on-site for reasons explained in section 3.1.1.

Jar Test 3 was conducted to determine if ferric chloride coagulation could further reduce the arsenic levels and if so, what the optimum dosage would be for this water source. Experimental conditions for all jar tests are summarized in Figure 2.



¹ Jar Test 1 was conducted at the Centre with water collected one day before the test. Subsequent tests were conducted on-site and the jar testing procedure was altered to better represent experimental conditions.

² Optimum dose of chlorine determined in Jar Test 2 was applied to Jar Test 3.

³ As two chemicals were added, a second rapid mixing/flocculation period was added to Jar Test 3 procedure to achieve proper mixing conditions.

Figure 2. Jar test conditions

2.1.2 Sampling and Analysis

Grab samples were collected from each jar after the sedimentation stage was completed. A portion of each sample was filtered through a 0.45 µm membrane filter. Analysis of arsenic and iron were conducted on both filtered and unfiltered samples. Samples were sent to an external laboratory for arsenic analysis. Other water quality parameters were analyzed either on-site at Well 3 or at the Centre (Table 1).

Table 1. Water quality analysis

Water Quality Parameter	Method	Analysis Location					
		Jar Test			Pilot Experiment		
		1	2	3	1-3	4-6	
Turbidity	Nephelometric Method	WCWC	Well 3	WCWC	WCWC	WCWC	
pH	Hach Method 8156						
Alkalinity	Hach Method 8203						
True colour (filtered)	Hach Method 8025						
Apparent colour (unfiltered)	Hach Method 8025						
UV ₂₅₄ absorbance	Hach Method 10054						
Dissolved organic carbon	Persulphate-Ultraviolet Oxidation Method						WCWC
Iron (filtered)	Hach Method 8008						Well 3
Iron (unfiltered)	Hach Method 8008						Well 3
Arsenic (filtered)	Standard methods 3030/EPA 200.8	External lab					
Arsenic (unfiltered)	Standard methods 3030/EPA 200.8						

2.2 Phase 2: Pilot Plant Tests

For pilot testing, raw water from Well 3 was hauled to the Centre to fill an outdoor storage tank (capacity of 40,000 L). The pilot testing project required

approximately 15,000 litres of raw water. The storage tank has a circulation system to mix its contents and prevent freezing during winter conditions. However, this circulation system was not applied to this project in order to avoid the oxidation of arsenic and iron inside the storage tank. Raw water was pumped from the outdoor storage tank to the pilot plant system located in the Centre's Technology Demonstration Facility.

The pilot plant set-up is presented in Figure 3. Raw water was pumped and dosed with chlorine at the optimum dose, which was determined from Jar Test 2, and then either passed through or bypassed the contact tank. The chlorinated water was then split into two different filter trains simultaneously as follows:

- 1) Train 1 - Adsorptive media filtration. This adsorptive media is a granular iron oxide media designed specifically to remove arsenic from groundwater.
- 2) Train 2 - Cartridge microfiltration (1 μm followed by 0.35 μm).

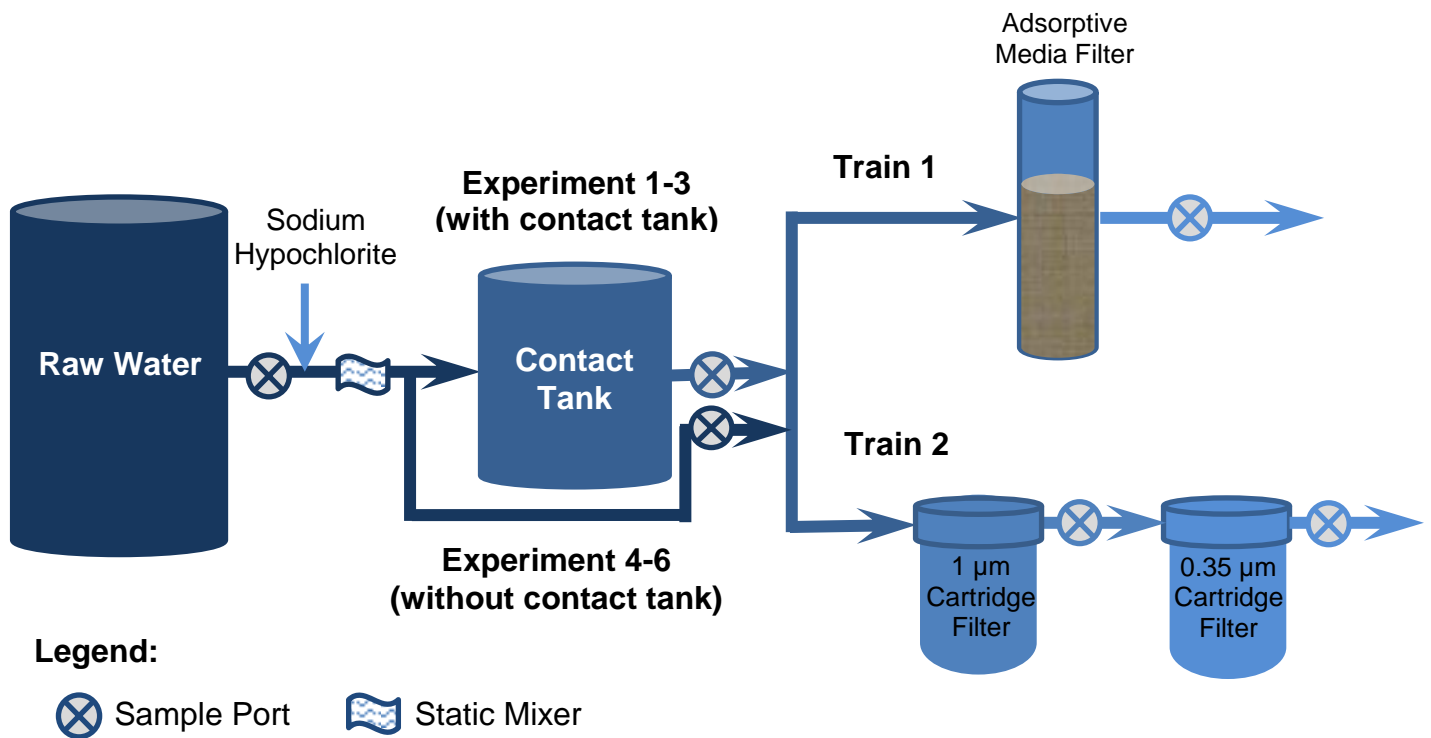


Figure 3. Schematic of pilot plant set-up

2.2.1 Methodology

All experiments were conducted for a duration at least three times the system's detention to allow the process to reach steady state conditions. For Experiments 1-3, the pilot system included the contact tank (Figure 2). Those three experiments were replicates using the same experimental conditions to confirm repeatability of results. Train 2 had two cartridge microfilters in series: a 1 μm filter connected prior to a 0.35 μm filter. Microfilter cartridges were replaced after Experiment 3 was completed. On Train 1, the adsorptive media was backwashed following Experiment 3 and the backwash water was collected for proper disposal.

In Experiments 4-6, the contact tank was bypassed (Figure 3). Experiments 4-6 were replicates using the same experimental conditions. Train 1 and Train 2 filter conditions remained the same as Experiments 1-3.

2.2.2 Monitoring and Sampling

As is indicated by Figure 3, raw water, filter influents and effluents were collected at the end of each experimental run. Samples were sent to an external lab for arsenic analysis.

General water quality parameters, including turbidity, pH, alkalinity, colour, ultraviolet absorbance at 254 nm, dissolved organic carbon and iron were analyzed either on-site or in-house. Further details of the sample analysis are shown in Table 1.

3. Results and Discussion

3.1 Phase 1: Jar Testing

3.1.1 Jar Test 1

Chlorine doses of 0-0.35 mg/L were applied in Jar Test 1, based on a recommended stoichiometric requirement of 0.23 mg/L. In spite of the chlorine dosages applied, the free chlorine levels in all jars were ≤ 0.04 mg/L. This indicated that there could be other compounds in the water causing additional chlorine demand. Ammonia was found in the raw water at 0.13 mg/L as $\text{NH}_3\text{-N}$ which required approximately 1 mg/L of chlorine to quench. The ammonia level was considered in the determination of chlorine dosages for Jar Test 2.

Arsenic analysis was conducted at the external laboratory on the raw water sample collected on-site and the samples collected from the jar test. Figure 4 demonstrates the concentration changes of both total and dissolved arsenic with varying chlorine doses from Jar Test 1. Total arsenic levels did not change during transportation from Well 3 to the Centre, as demonstrated by comparing the results for raw water samples collected on-site (at Well 3, 9.6 $\mu\text{g/L}$) and at the Centre (9.6 $\mu\text{g/L}$) (Figure 4). Therefore, changes in arsenic concentrations could be negligible during water transportation from Well 3 to the Centre.

As is shown in Figure 4, the total arsenic concentration was 9.6 $\mu\text{g/L}$ in raw water, whereas it increased to 10.3-10.7 $\mu\text{g/L}$ after the jar test (rapid mixing, flocculation and sedimentation). This could be explained by sediment particles breaking down during the test, releasing more arsenic compounds into the water. The average concentrations of total and dissolved arsenic in all the jars were 10.5 and 9.1 $\mu\text{g/L}$, respectively. This indicates the membrane filter used in this test could further remove approximately 10% of the arsenic from water.

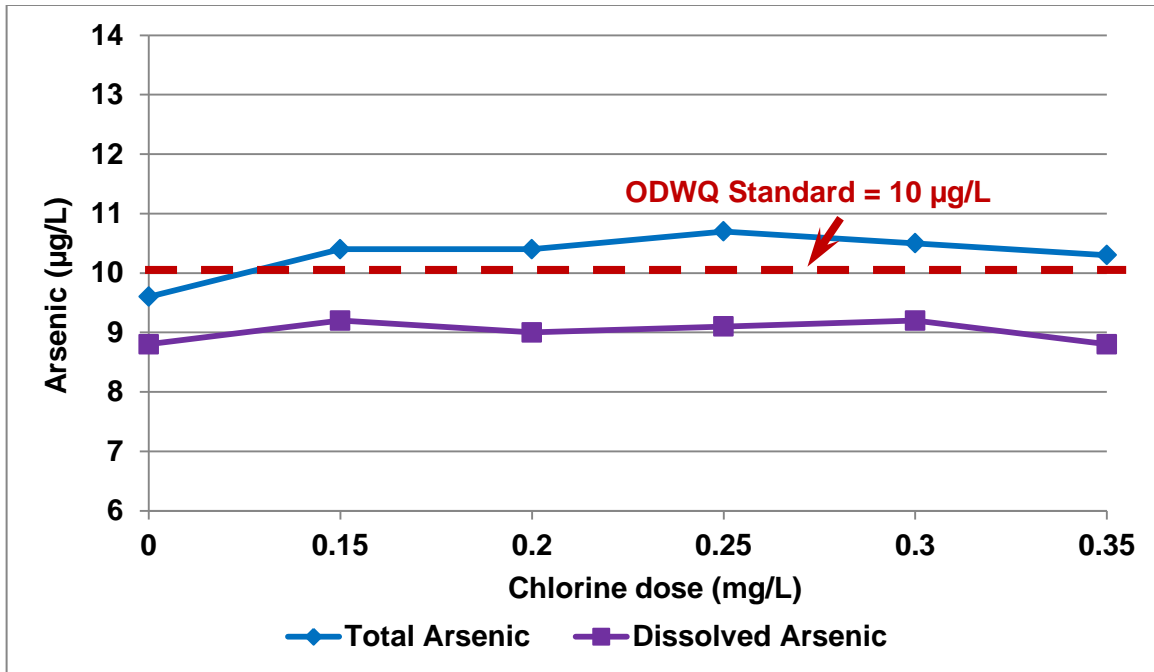


Figure 4. Arsenic levels during Jar Test 1

At the Centre, the concentration of total iron was measured as 0.34 mg/L in raw water. The total iron levels of all jar test samples were quite close (0.30-0.34 mg/L). Therefore, the jar testing conditions had limited impact on total iron levels. However, the dissolved iron concentrations of the raw water and all jar test samples were below the method detection limit (MDL, 0.02 mg/L). This indicated that the dissolved iron compounds could have oxidized during transportation or storage. Based on this observation, the subsequent jar tests were conducted on-site (at Well 3).

3.1.2 Jar Test 2

Jar Test 2 was conducted on-site at the WTP's Well 3 to eliminate water quality deterioration. Higher chlorine dosages (3.5 - 7 mg/L) were applied to this jar test to compensate for the chlorine demand of ammonia and other compounds. Concentrations of both total and dissolved arsenic in Jar Test 2 are plotted in Figure 5. Total arsenic levels increased slightly after the jar test. With higher chlorine doses, this jar test was capable of removing more dissolved arsenic than Jar Test 1. The lowest dissolved arsenic levels (6.5 µg/L) were obtained when 4

and 7 mg/L of chlorine were applied (Figure 5). Therefore, the optimum chlorine dose of 4 mg/L was selected for further testing as it performed the best in Jar Test 2 and it was close to the dose that was already being applied at Well 3 for disinfection. This optimum chlorine dose provided approximately 32% arsenic reduction. The optimum chlorine dose of 4 mg/L was applied to all sequential tests, including Jar Test 3 and all pilot tests.

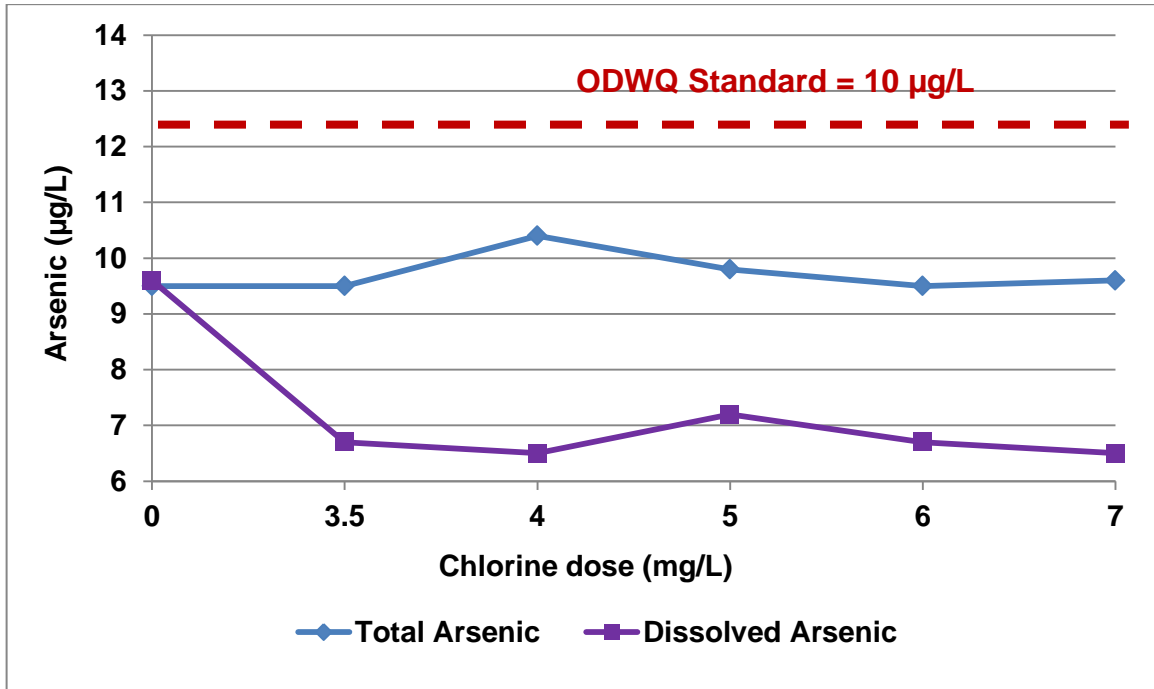


Figure 5. Arsenic levels during Jar Test 2

The total iron concentration in the raw water was 0.37 mg/L, while the filtered level was 0.34 mg/L. Similarly to Jar Test 1, the dissolved iron concentrations were all less than the MDL. This indicated that nearly all the iron in the samples had been adequately oxidized in the jar test and filtered using the 0.45 µm membrane filter.

3.1.3 Jar Test 3

Jar Test 3 was conducted on-site (Well 3), using the optimum chlorine dosage determined from Jar Test 2 (4 mg/L) for all 6 jars. Ferric chloride coagulant was also dosed (0.25 to 1.25 mg/L) to explore if any additional removal of arsenic

could be achieved. As two chemicals were added, a second rapid mixing/flocculation period was added to Jar Test 3 to ensure proper mixing conditions (Figure 2).

Total and dissolved arsenic concentrations of Jar Test 3 were shown in Figure 6. The total arsenic level in raw water was 11.9 $\mu\text{g/L}$. However, this level increased to 12.2 - 12.8 $\mu\text{g/L}$ after the first rapid mixing/flocculation period. At this stage, the dissolved arsenic concentration was 10.6 $\mu\text{g/L}$, thus filtration provided about 15% reduction of arsenic. As no sedimentation was allowed, this reduction was lower than that of the jar with optimum chlorine dose in Jar Test 2 (Section 3.1.2).

After ferric chloride coagulant was dosed followed by flocculation/sedimentation, the dissolved arsenic concentration was reduced to 9.6 $\mu\text{g/L}$ - 7.6 $\mu\text{g/L}$, showing a 15% - 38% reduction. This indicated that chlorination followed by ferric chloride coagulation was slightly more effective for arsenic removal than chlorination alone.

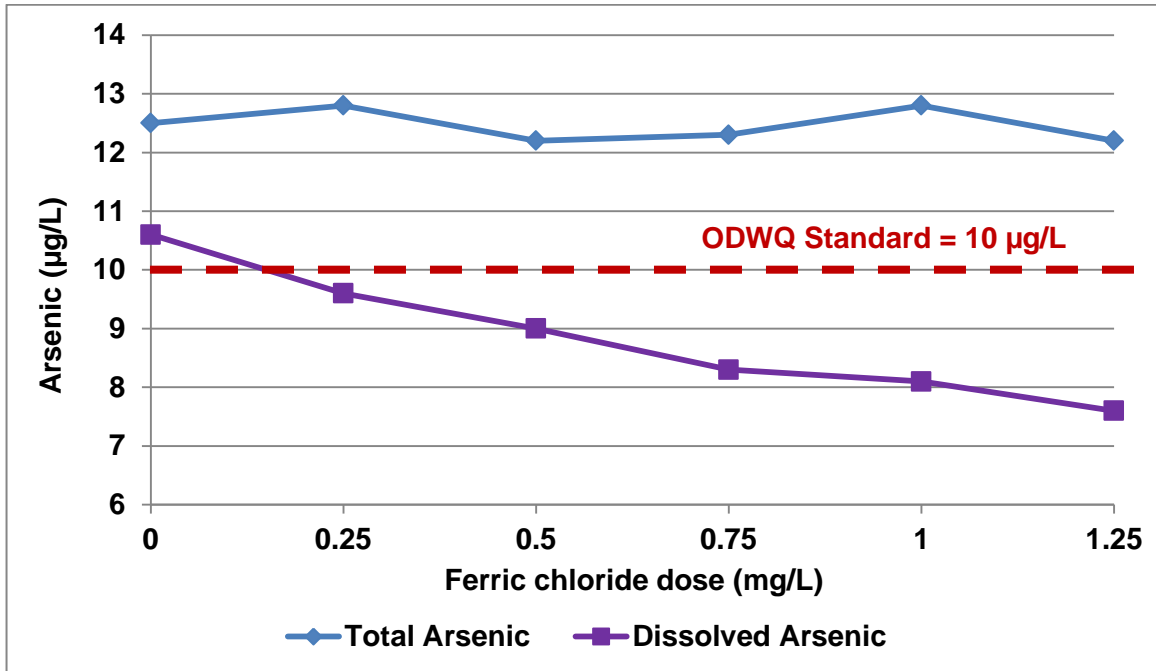


Figure 6. Arsenic levels with chlorine dose of 4 mg/L during Jar Test 3

The dissolved iron level increased to 0.35 to 0.85 mg/L with addition of ferric chlorine coagulant, indicating that this coagulant might be overdosed. However, the iron levels were all less than the MDL after filtration, showing that nearly all the iron was oxidized into the particulate form. Overall, the effect of ferric chloride coagulation on arsenic reduction was limited.

3.2 Phase 2: Pilot Testing

3.2.1 Experiment 1-3 with chlorine contact chamber

3.2.1.1 Arsenic Reduction

Figure 7 presents the arsenic levels observed during pilot testing Experiments 1-3. The average total arsenic level of raw water was 10.2 µg/L which is slightly above the updated MAC of 10.0 µg/L (Ontario Regulatory Agency, 2015). An optimum chlorine dose (4 mg/L) determined from Jar Test 2 was applied to Pilot Experiments 1-3. Similar to the jar tests results, the total arsenic levels increased slightly (by 0.2 µg/L) after chlorine was dosed. The average dissolved arsenic concentrations in all samples were 10.0 µg/L, indicating that 98% of the total arsenic was in the dissolved form.

Two types of removal technologies (arsenic adsorptive media and cartridge filtration) were tested in parallel for these pilot experiments. For Train 1 (arsenic adsorptive media), an average total arsenic level of 0.47 µg/L was detected in the effluent, indicating a significant arsenic reduction of 95%. For Train 2, two cartridge filters of 1 µm and 0.35 µm were connected in series. The average total arsenic concentration in the effluent was 9.80 µg/L, showing a very limited arsenic reduction of 4%. This also indicated that the majority of arsenic compounds had sizes smaller than 0.35 µm.

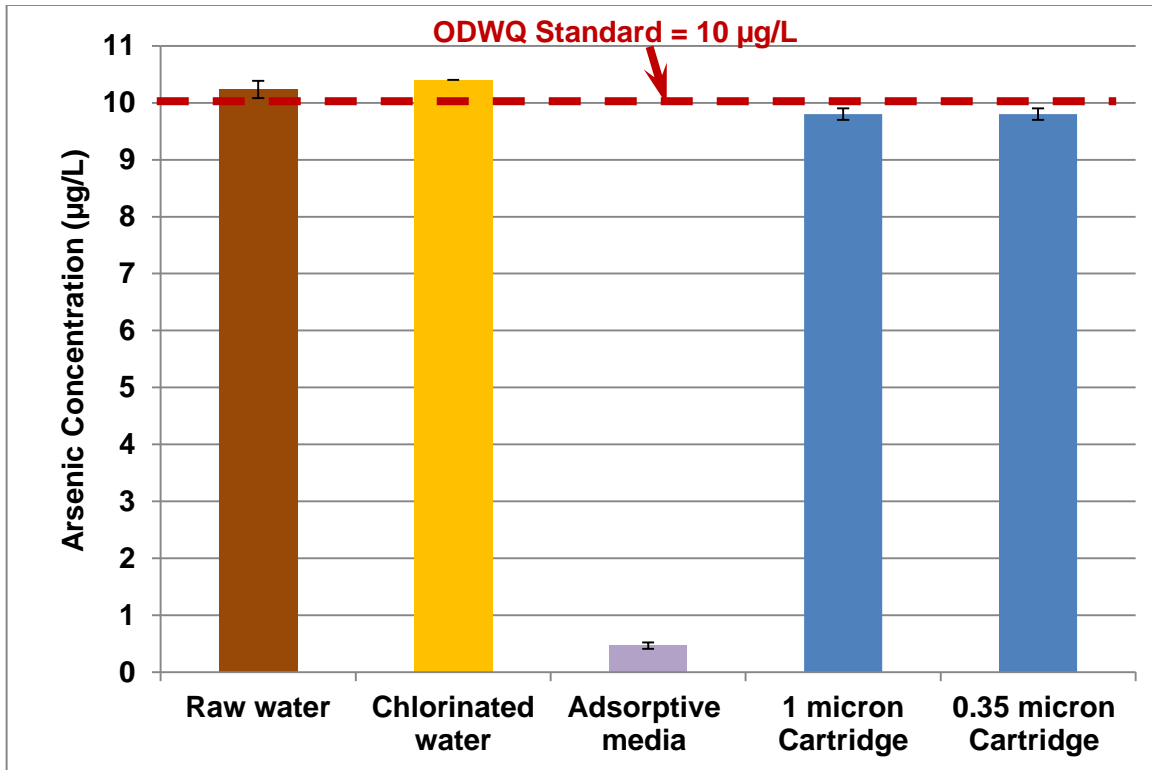


Figure 7. Arsenic levels during Experiments 1-3 with error bars displaying 1 standard deviation (chlorine dose of 4 mg/L, with contact tank)

3.2.1.2 Iron Reduction

To prevent iron deterioration, the water hauler intentionally overflowed the tanker truck to make sure that minimal head space was left in the water tank during transport. However, the average raw water total and dissolved iron levels were 0.07 and 0.02 mg/L, respectively. Comparing the iron measurements obtained on-site in Jar Test 2 (total and dissolved iron of 0.37 and 0.34 mg/L, respectively, Section 3.1.2), the iron levels changed either during transportation or storage, likely due to aeration. Furthermore, the total iron levels were reduced to less than the MDL (≤ 0.02 mg/L) in both trains. Overall, iron removal capabilities of adsorptive media and cartridge filters could not be investigated properly.

3.2.1.3 General Water Quality

The raw water turbidity was measured as 10.8 - 14.2 NTU and the apparent color was 85 - 100 PtCo units, which were not typical for this groundwater source. This

may have been associated with the new connection installed in Well 3 for the water tanker truck to collect raw water from. This new connection could fill the truck in only about 13 minutes. It is speculated that the high filling flowrate increased the mixing of sediments in the well water, and therefore increased the raw water turbidity as well as apparent color. The average of alkalinity and pH of the raw water were recorded as 224 mg/L as CaCO₃ and 7.8, respectively.

Although the raw water turbidity was higher than normal, the adsorptive media filter and the cartridge filters reduced the average treated water turbidity to 0.54 and 0.27 NTU, respectively. The treated water effluent of the adsorptive media had apparent colour ranging from 4 - 7 PtCo units, whereas the cartridge filters had an apparent colour range of 0 - 2 PtCo units.

The average dissolved organic carbon (DOC) of the filtered raw water was 0.87 mg/L and the average UV absorbance was 0.017 cm⁻¹, indicating a fairly low level of organics. DOC levels in the treated water were not measured, because the treatment processes in use were not expected to have much capacity for organics removal.

Total chlorine was measured before and after the adsorptive media as 3.31 and 0.31 mg/L, respectively, indicating that the adsorptive media had a chlorine demand of 3.0 mg/L.

3.2.2 Experiment 4-6 without chlorine contact chamber

3.2.2.1 Arsenic Reduction

Experiments 4-6 were conducted similarly to Experiments 1-3, but the chlorine contact tank was bypassed in these trials. It should be noted that chlorine needs approximately 1 minute of contact time for arsenic oxidation (Ohio EPA, 2010) and approximately 15 minutes of contact time for iron oxidation (Crittenden et al., 2005). Figure 6 shows the arsenic levels in Experiments 4-6. Raw water and the chlorinated water had total arsenic concentrations of 10.6 and 10.4 µg/L, respectively. The effluent of the adsorptive media filter showed that the arsenic

was reduced by > 98% (< 0.2 µg/L). However, the cartridge filters showed only a 2% reduction and the average arsenic concentration was 10.40 µg/L. This level is still higher than the updated MAC for arsenic (10 µg/L, Ontario Regulatory Agency, 2015).

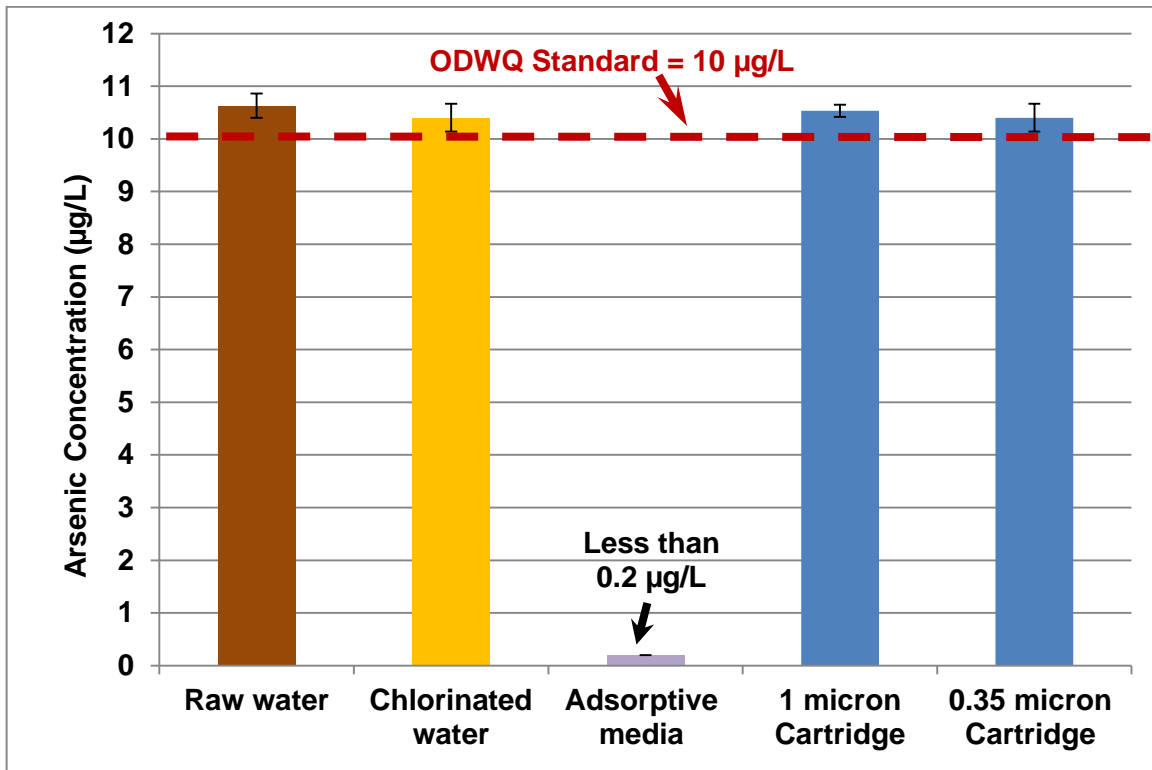


Figure 8. Arsenic levels during Experiments 4-6 with error bars displaying 1 standard deviation (chlorine dose of 4 mg/L, without contact tank)

Although the raw water hauled to the Centre had additional sand/silt/sediment, the arsenic levels were similar for the samples collected at Well 3 and at the Centre, indicating that the additional amount of solids did not affect the arsenic results.

However, it is important to note the following:

- Arsenic removal capacity of the adsorptive media was tested only for a short period of time as discussed in this report. Investigation of the long-term efficacy is beyond the scope of this project.

- The adsorptive media was backwashed after approximately 6 hours of operation. Investigation on the optimum backwash time is beyond the scope of this project.
- Similar to above, confirming lifespan of the adsorptive media is beyond the scope of this project.
- Backwash water needs to be tested for arsenic level and to be disposed of according to applicable regulations.

3.2.2.2 Iron Reduction

Experiments 4-6 were conducted one day after Experiments 1-3 using the same batch of raw water. Therefore, the raw water used for Experiments 4-6 had an extra day of storage in the tank. This extra storage period reduced the total iron levels further to 0.05 mg/L - 0.07 mg/L. Filtered raw water and chlorinated water had iron levels less than 0.03 mg/L. All filtration effluents had iron levels less than the MDL (0.02 mg/L). Overall, the iron reduction capability of the adsorptive media filter and the cartridge filters could not be fully investigated in the pilot plant experiments due to deterioration of iron after storage.

3.2.2.3 General Water Quality

General water quality parameters were similar to what was observed in Experiments 1-3 with the exception of turbidity and apparent colour. Due to the extra day of storage time, the raw water turbidity settled to 6.1 - 7.2 NTU compared to 10.8 - 14.2 NTU (Experiments 1-3). The apparent colour was reduced from 85 - 100 PtCo units (Experiments 1-3) to 46 - 57 PtCo units.

The average chlorine levels prior to and after the adsorptive media filter were 3.0 mg/L and 1.6 mg/L, respectively, indicating a chlorine demand of 1.4 mg/L. The fluctuation of chlorine demand from 3.0 mg/L for Experiments 1-3 (Day 1) to 1.4 mg/L for Experiments 4-6 (Day 2) suggests that the chlorine demand of this media is variable and may have decreased during operation.

4. Conclusions

Through jar testing experiments, it was determined that:

- Chlorine addition was effective for arsenic reduction.
- An optimum chlorine dose of 4 mg/L was determined, which reduced arsenic levels by 32% (from 9.6 µg/L to 6.5 µg/L).
- Combining chlorine and ferric chloride addition reduced arsenic levels by 38% (from 12.2 µg/L to 7.6 µg/L), using the optimized dosages (chlorine at 4 mg/L and ferric chloride at 1.25 mg/L).
- Iron was effectively oxidized into particulate form and removed by filtration (0.45 µm) in all jar testing experiments.
- Ammonia was detected in the source water and chlorine dosages were adjusted accordingly to compensate for the extra demand created by ammonia.

Through pilot testing experiments, it was determined that:

- The chlorine contact tank did not overly affect the reduction capabilities for arsenic or iron.
- The adsorptive media filter reduced arsenic levels by 95% (from 10.2 µg/L to 0.47 µg/L) and > 98% (from 10.6 µg/L to < 0.2 µg/L), when using and bypassing the contact tank, respectively.
- Adsorptive media demonstrated a chlorine demand; however, this demand was becoming satisfied during operation.
- The cartridge filters showed limited removal capacity and reduced arsenic levels by only 4% (from 10.2 µg/L to 9.8 µg/L) and 2% (from 10.6 µg/L to 10.4 µg/L), when using and bypassing the contact tank, respectively.
- Iron was almost completely oxidized during transport and storage of the raw water due to aeration.

- Both trains effectively removed the remaining iron; however, no definite conclusions can be drawn due to the degradation of water quality.

It is important to highlight the following limitations that fell outside the scope of this project. The items listed below should be considered and consulted with an engineering consultant prior to pursuing any of the aforementioned technologies further.

- Arsenic reduction capacity of the adsorptive media was only tested for a short term (6 hours). The performance of this media may change overtime.
- In this project, the adsorptive media filter was backwashed after about 6 hours of operation. Investigation of the optimum filter run time was beyond the scope of this project.
- Investigation of the adsorptive media filter lifespan was beyond the scope of this project.

5. References

- Chen, J.P., Yang, L., Ng, W.-J., Wang, L.K., and Thong, S.-L. (2006). "Ion exchange." Advanced physicochemical treatment processes. Handbook of environmental engineering. L. K. Wang, Y.-T. Hung, and N. K. Shamas, eds., Humana Press, New York, 261–292.
- Crittenden, J.C., Trusell, R.R., Hand, D.W., Howe, K.J. and Tchobanoglous, G. (2005). *Water Treatment Principles and Design*. New York: John Wiley & Sons, Inc.
- Health Canada. (2006). *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document - Arsenic*. Water Quality and Health Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.
- International Programme on Chemical Safety [IPCS]. (2001). *Arsenic and Arsenic Compounds*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 224).
- Ohio Environmental Protection Agency [Ohio EPA]. (2010). *Guidelines for Arsenic Removal Treatment for Small Public Drinking Water Systems*. Strickland, T., Fisher, L., and Korleski, C. Division of Drinking and Ground Waters.
- Ontario Drinking Water Quality Standards (Standard No. O. Reg. 169/03).
- Ontario Ministry of the Environment [Ontario MOE]. (2006). *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines* (Document No. PIBS 4449e01).
- Ontario Ministry of the Environment [Ontario MOE]. (2011). *Soil, Groundwater and sediment standards for use under Part XV.1 of the Environmental Protection Act* (Report No. PIBS 7382e01).
- Ontario Regulatory Agency. (2015). Regulatory Amendments to Update Ontario Drinking Water Quality Standards, and Testing and Reporting Requirements.
- Water Research Foundation [WRF]/United States Environmental Protection Agency [USEPA]. (2002). *Implementation of Arsenic Treatment Systems*.

Part 1. Process Selection (Report No. ISBN 1-58321-236-1). Denver, CO: WRF and American Water Works Association [AWWA].
World Health Organization [WHO]. (2011). *Arsenic in Drinking Water. Background document for development of WHO Guidelines for Drinking-water Quality.* WHO Press, Switzerland.

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Walkerton Clean Water Centre
20 Ontario Road, P.O. Box 160
Walkerton, ON, N0G 2V0
519-881-2003 or toll-free 866-515-0550