Summary Report

Winnipeg Discoloured Water Investigation

Prepared for
City of Winnipeg

December 2013

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December 20, 2013

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Tim Shanks, M.Eng, P.Eng
Water Distribution Engineer
Water Services Division, Water & Waste Dept.
552 Plinguet Ave
Winnipeg, MB
R2J 0G1

Subject: Discoloured Water Investigation

Dear Mr. Shanks,

Attached please find our report that presents the findings-to-date from the investigations into the occurrence and causes of discolouored water in the City of Winnipeg's water system and to make recommendations for the control and mitigation discoloured water.

The findings of this study were determined using a combination of field investigations, water quality sampling, bench-scale studies, and demonstration testing. The cooperation and input provided by City staff were critical to the preparation of this report.

Sincerely,
CH2M HILL Canada Limited

PROVINCE OF MANITOBA
P. WOBMA
Member
30076
REGISTERED PROFESSIONAL ENGINEER

December 20, 2013

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SECTION 1

Introduction and Problem Statement

The City has tracked customer calls regarding "dirty water" for many years. Historically, these have primarily been due to the disturbance of sediment and buildups in water mains. Before the commissioning of the new water treatment plant (WTP) in December 2009, this sediment was attributed to the buildup of dead algae and other compounds present in the unfiltered water supply. With the start of the new WTP, the quality of the water entering the distribution system has improved, however service requests referencing "discoloured water" occurred. The number of service requests per year has varied (see Figure 1, Monthly Discoloured Water Service Requests), and following a decline in the 2011 – and after two years of operation with the new WTP – an increase in the number of service requests for discoloured water occurred in 2012. This study was initiated in 2012 to address the occurrence, control and prevention of discoloured water in the Winnipeg distribution system.

Discoloured water refers to observations of yellow, brown or black water in solution and water samples are generally free of large sediment, although some smaller pieces of suspended matter may be seen. Observations of discoloured water are seasonal in nature, peaking in late summer (see Figure 1). Some, but not all, discoloured water events could be attributed to construction and maintenance activities, such as water main servicing in the distribution system. The occurrence of discoloured water is widespread in the City, although some areas experience more events than others (see Figure 2, Geographical Distribution of Service Requests for Discoloured Water).

The purpose of this report is to

i) comment on observations of discoloured water events in the City's distribution system based on data provided by the City
ii) comment on the safety of this water for consumers
iii) identify potential causes for these events, and
iv) make recommendations for the control and mitigation of future discoloured water occurrences, including cost and schedule

A summary timeline of the discoloured water investigation is provided below:

- Fall 2012, the consultant was retained in response to an increase in the number of service requests recorded in 2012 after declining numbers were recorded for 2011
- November 2012, recommendation made to increase chlorine residuals in the distribution system
- June 2013, results from scale analyses of lead service lines received
- Summer 2013, the link to the role of manganese was established and the changing nature of the discoloured water in 2010/11 versus 2012/13 was identified
- September 2013, in plant testing was carried out to screen alternative control strategies; in plant sampling was conducted to understand the fate and transport of iron and manganese in the plant
- November 2013, samples of water mains were obtained and sent to lab for analysis
- November 2013, start of full-scale demonstration trial with pre-filter pH adjustment
- January 2014, anticipated implementation of coagulant change

Figure 1: Monthly Discoloured Water Service Requests

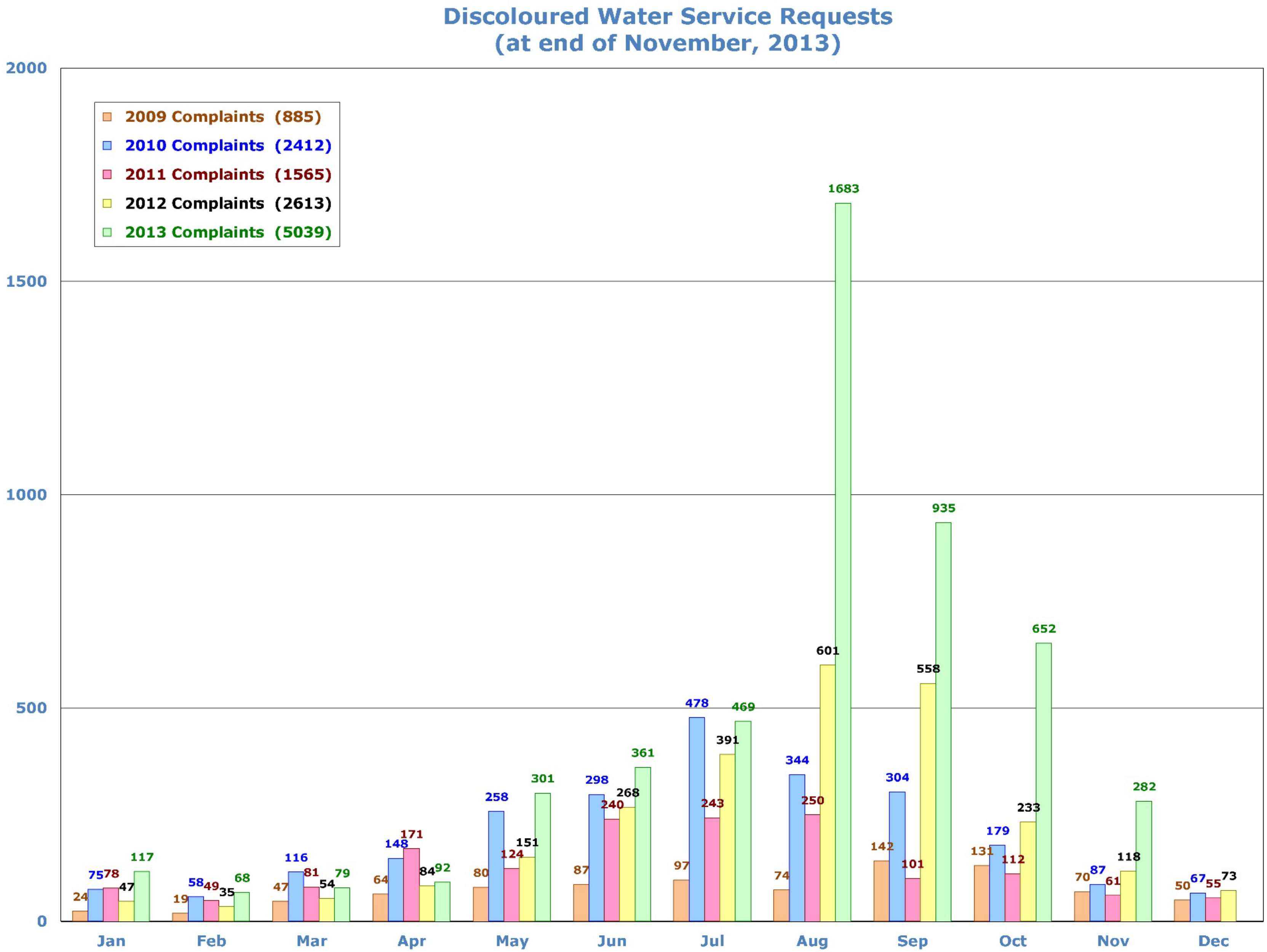
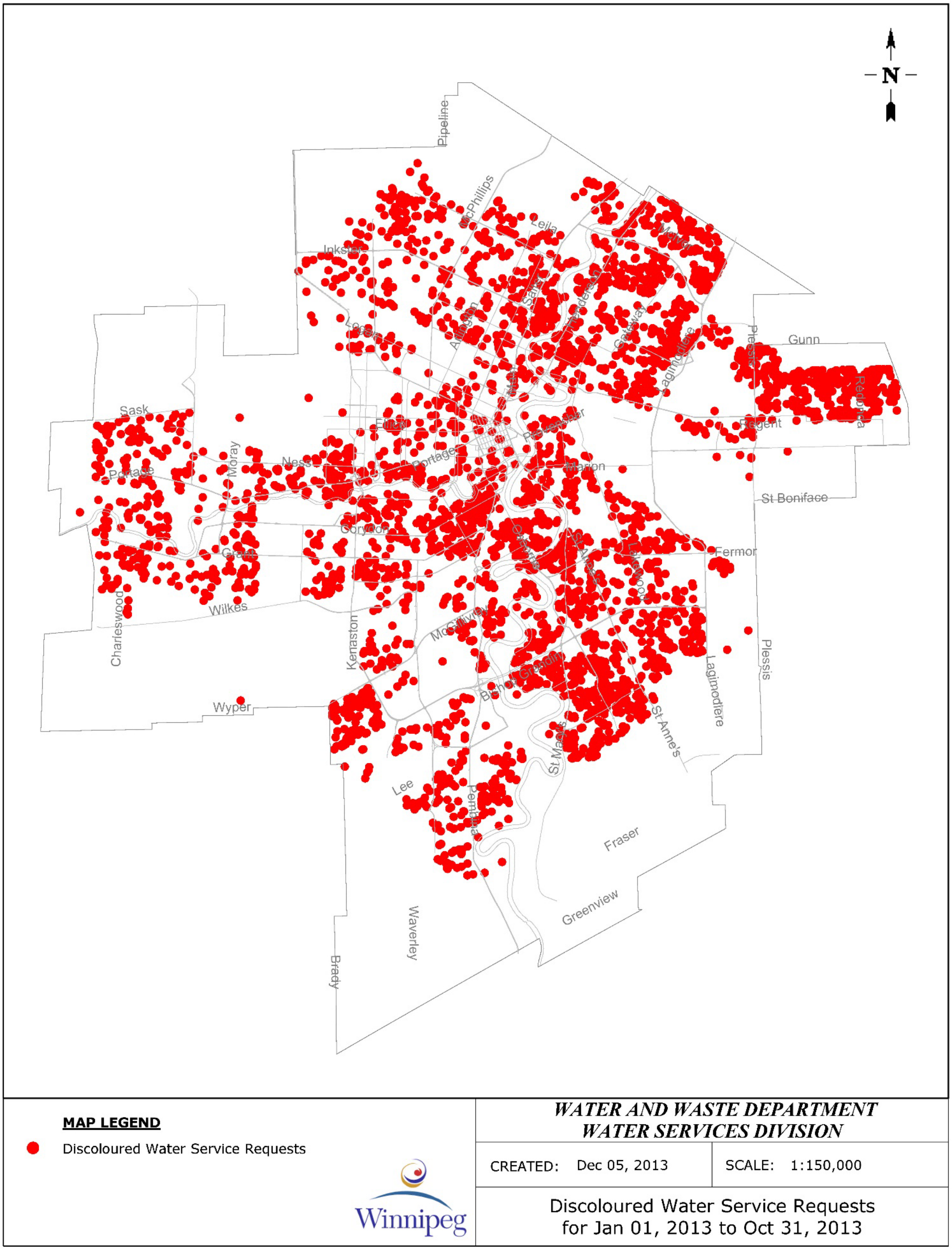


Figure 2: Geographical Distribution of Service Requests for Discoloured Water



SECTION 2
Safety of the Water Supply

Yes, the water is safe. The City's drinking water quality meets all provincial requirements and federal guidelines for microbiological, physical and chemical parameters. The Guidelines for Canadian Drinking Water Quality identify a non-health based Aesthetic Objective for manganese at 0.05 mg/L and this has been exceeded in some treated water and distribution system samples. Elevated levels above the aesthetic objective for colour-causing compounds (both iron and manganese) have been measured in samples from the customer tap.

While many consumers assume that discoloured water is not safe to drink, elevated iron and manganese are not health concerns at the levels observed. This position was affirmed in the following statement by Dr. Lisa Richards, Medical Officer of Health of the Winnipeg Regional Health Authority:

> *"In my role as Medical Officer of Health for the Winnipeg Health Region, I work closely with the Office of Drinking Water and the City of Winnipeg to review the situation with brown water on a regular basis. We have reviewed the results of tests done on the brown water to date. Various components of the water were tested, including bacteria and other parameters. Laboratory results to date for samples submitted by the City of Winnipeg do not indicate the water is unsafe to drink.*
>
> *We agree with the City of Winnipeg's recommendation that residents should not drink the discoloured water or use it for purposes such as preparing food, but there is no indication at this time that drinking the water would pose a health risk.*
>
> *The recommendation is precautionary in the event that new information comes to light that may change our risk assessment. We are monitoring the situation, and assessing any new evidence when it comes available."*

Communications have been maintained with the Province's Office of Drinking Water and the local health authorities to share water quality results and review activities undertaken by the City to investigate, control, and prevent discoloured water in the City's drinking water system.

SECTION 3

Causes of Discoloured Water in the City's Distribution System

In this section, the data reviewed to identify the cause of the discoloured water is discussed, starting with samples collected at the customer's tap, and working backwards in the system: tap samples, water main samples (also referred to as distribution system samples), treated water from the plant (WTP), and the source water for the WTP. This is done to assess where in the water cycle the compounds causing discoloured water are present to help determine how to control and prevent discoloured water occurrences.

Sampling at the Customers' Taps: In response to discoloured water service requests, the City was able to collect water quality information at several customer locations for a wide range of water quality parameters including metals, bacteriological quality, disinfectant residuals, turbidity and colour. Four years of data were collected and results for the bacteriological quality and disinfectant residuals were good in these samples. For samples with higher levels of turbidity and colour, these data reveal that iron and/or manganese were measured at concentrations high enough to be detected by the customer as discoloured water (see Figure 3, Water Quality Coinciding with Service Requests for Discoloured Water, Histogram of Iron Concentrations and see Figure 4, Water Quality Coinciding with Service Requests for Discoloured Water, Histogram of Manganese Concentrations). Also of note is a trend of decreasing iron and increasing manganese levels in the more recent customer samples collected in response to service requests. Although manganese may be dominating the discoloured water occurrences, iron is also an important contributing factor.

Figure 3: Water Quality Coinciding with Service Requests for Discoloured Water, Histogram of Iron Concentrations

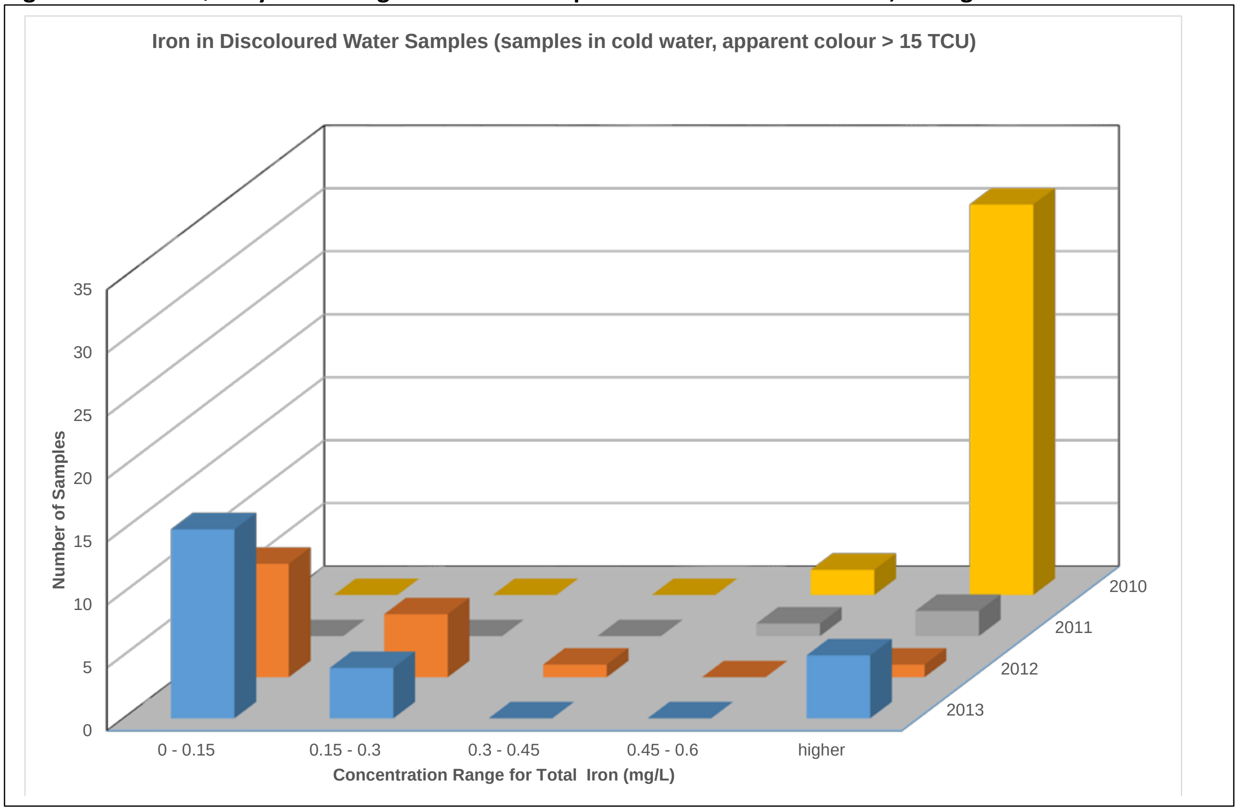
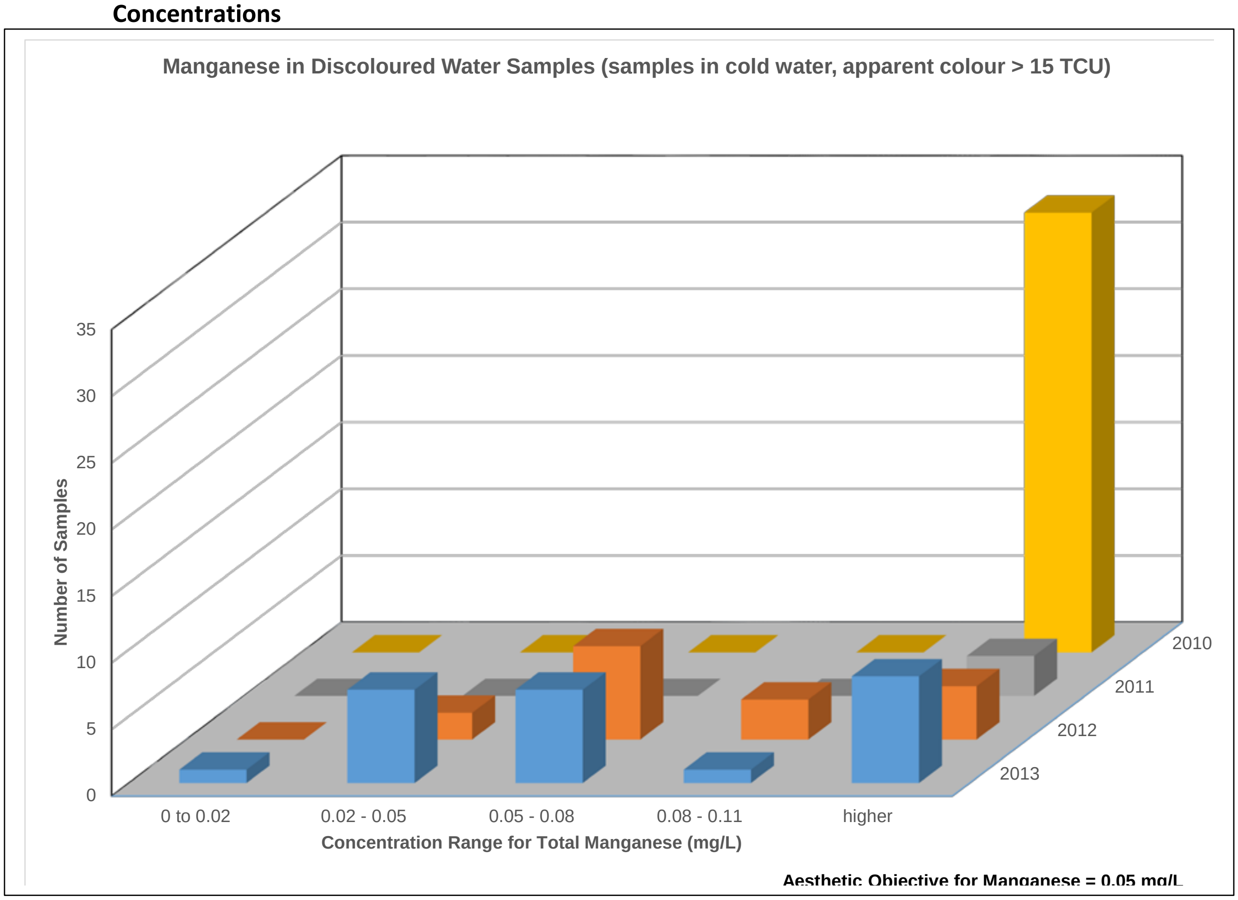


Figure 4: Water Quality Coinciding with Service Requests for Discoloured Water, Histogram of Manganese Concentrations



Based on the experience of others, manganese concentrations of 0.02 mg/L and higher can cause a problem through its accumulation and release as water travels in the distribution system (per the Guidance for the Treatment of Manganese, Water Research Foundation, 2013). The release concentration that causes discoloured water to be noticed or a problem may be higher than 0.02 mg/L, and therefore a treatment objective of 0.015 mg/L provides some margin of safety. The new treatment objective recommended for manganese in treated water leaving the plant is less than the Aesthetic Objective for manganese of 0.05 mg/L identified in the *Guidelines for Canadian Drinking Water Quality*.

Sampling in the Distribution System: Prior to the startup of the WTP in 2009, unfiltered water had been running through the City's distribution system for over 80 years. To understand the longer term impacts of iron and manganese that has collected in the distribution system, historical water quality data collected by the City as part of routine distribution system sampling were analyzed (see Figures 5 and 6).

The levels of iron and manganese reported from distribution system samples in this data set are of importance: because the data show manganese levels increasing and indicate that the discoloured water complaints may be attributable to manganese, yet at the same time, iron levels in distribution system samples are significantly decreasing. The water quality data confirm the trend from the customer samples (collected from service requests). The occurrence of discoloured water was worse in 2013 when compared with previous years, coinciding with the increase in manganese concentrations.

Sampling in the Raw Water, Intake and Treated Water: Some variability occurs in the data for iron and manganese levels in raw water before the start-up of the new WTP with higher concentrations and more frequent spikes in raw water manganese observed year-round since the start of the new WTP. This may be due to more frequent sampling that better captures the variability of the raw water and/or changes in the chemistry of the water in the Deacon Reservoir.

Data for iron and manganese in Shoal Lake, which serves as the intake for the Deacon Reservoir and the WTP, were reviewed for a ten year period starting in 2003. These data also show an increasing trend in seasonal peaks for both iron and manganese since 2009, although at levels that are less than measured in the raw water entering the WTP from Deacon Reservoir. Efforts are underway to look at i) a longer time period to see if the increase of the last 30 or so years is part of historical variations, and ii) the relationship with the level of the water in Shoal Lake.

The concentrations of iron measured in treated water from the WTP are consistently lower than the source water, and are at historical lows since operation of the WTP started. Therefore the WTP is effectively removing any iron present in the source water or contributed by chemical addition during treatment.

As for manganese, the concentrations measured in treated water are consistently higher than the raw water, which leads to the conclusion that the treatment processes of the WTP itself are a source of manganese. An increase in manganese in treated water can be seen in the data since March 2013. Historical records for manganese in treated water before and after the new WTP also show an increase with manganese over time. Some reduction of added manganese can be seen within the WTP filtration process but the WTP is not removing the manganese present in the raw water or added during treatment to below the new treatment objective of 0.015 mg/L. It is noted that the WTP was never designed to intentionally control manganese.

Figure 5: Total Iron in Routine Distribution System Samples

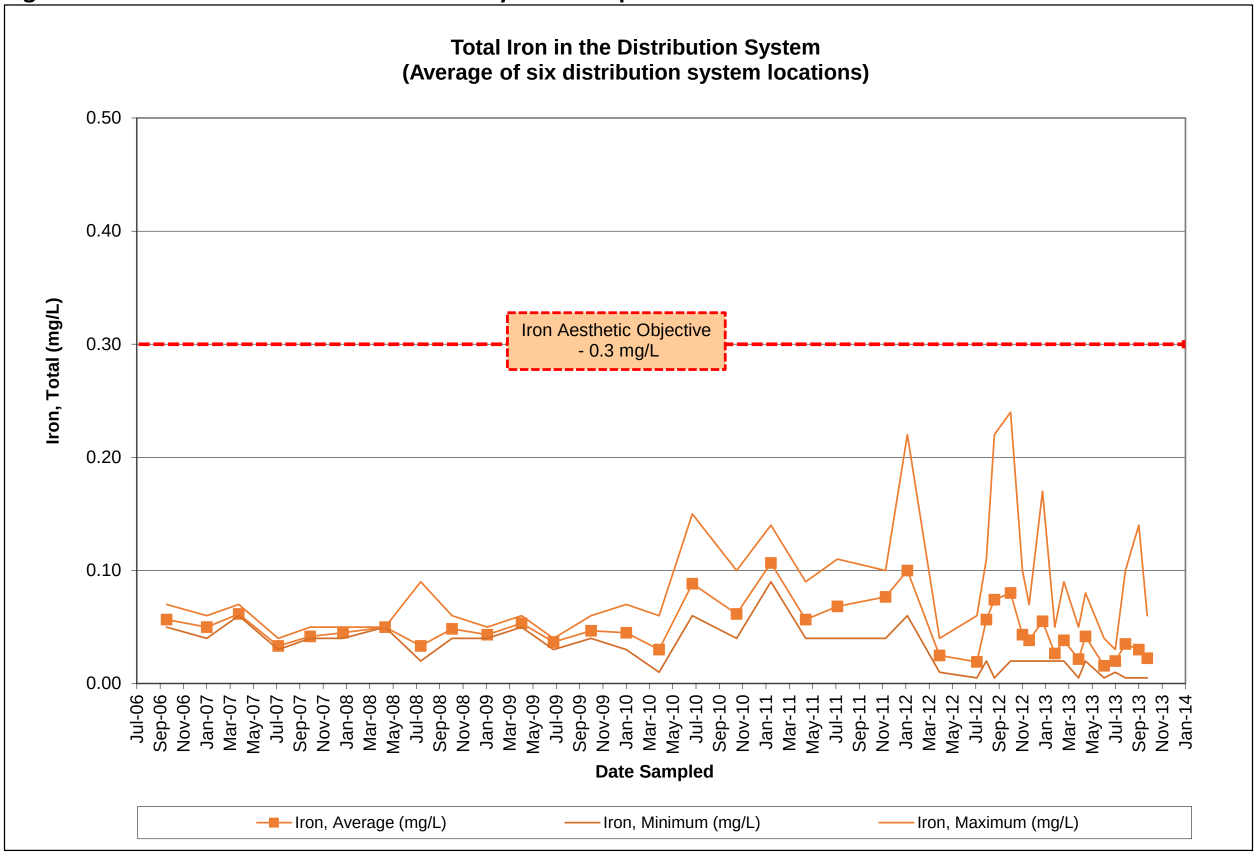
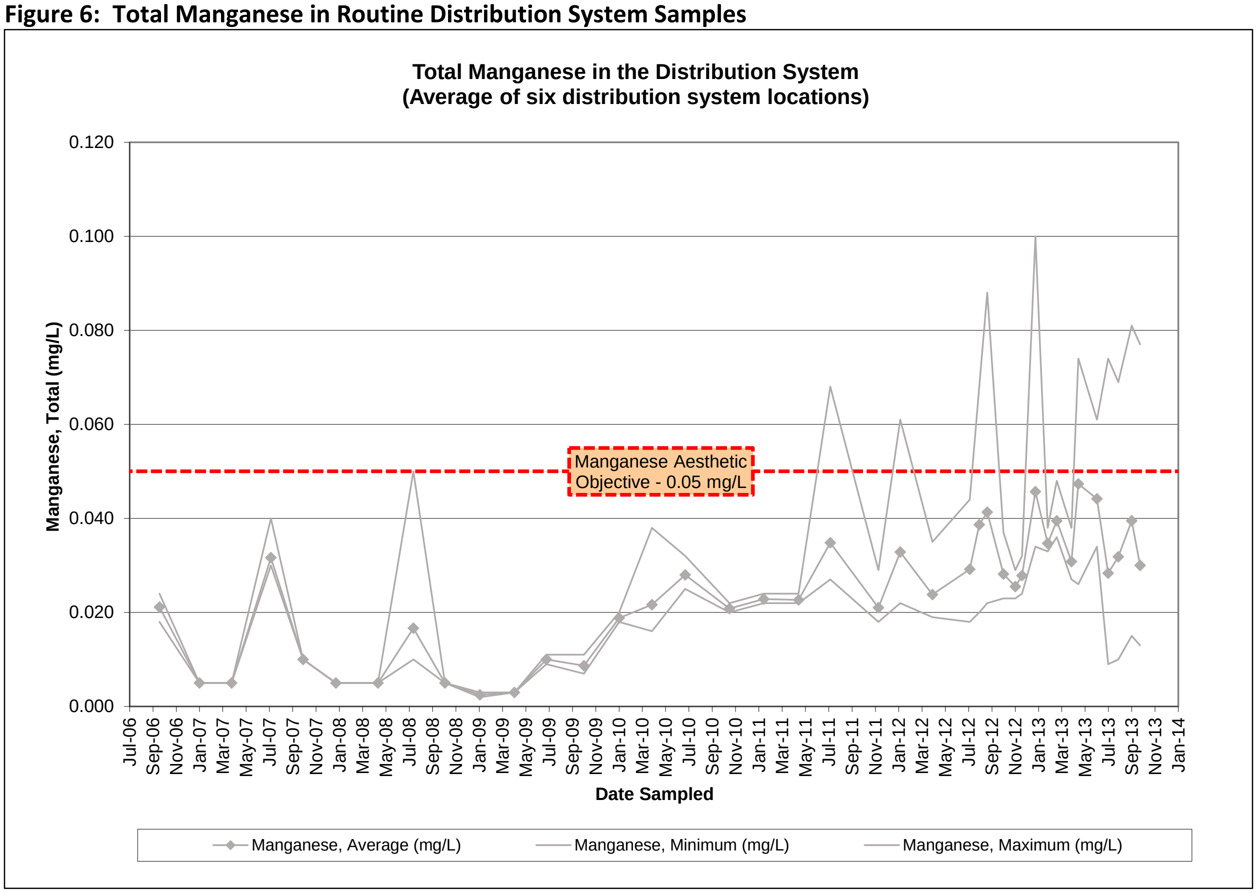


Figure 6: Total Manganese in Routine Distribution System Samples



Summary: The customer tap samples of discoloured water collected in response to service requests show elevated concentrations of iron and/or manganese. From the historical data for Shoal Lake, there is some iron and manganese in the source water. The concentration of iron entering the distribution system from the source water after the WTP went online is very small, and therefore as a cause of the discoloured water problem it has been eliminated. Other sources of iron include distribution system deposits originating from the water source itself, from before the water treatment plant went online, and from unlined iron pipe in the distribution system. The phosphate corrosion inhibitor should be acting to decrease the iron that is released from the iron pipe scales in the distribution system, although this source will probably never be completely eliminated without replacing the iron mains or resurfacing them. The City's flushing program is removing iron particles in distribution system sediment. Iron levels have been decreasing with time as shown by the water quality results for samples from the distribution system and customers' taps. While the iron levels are declining, it is also should be noted that they will never be completely eliminated because of factors such as stagnation of water that result in continued release.

In contrast, manganese is measured at higher concentrations in both the treated water from the WTP and in routine distribution system samples compared with manganese concentrations in the intake (Shoal Lake) and raw water (Deacon Reservoir). Because there are no known sources of manganese in the distribution system (i.e., not from the pipes), the main source of manganese is from chemical addition at the WTP. The continuous accumulation of manganese in the system should be avoided as these accumulations can release under various conditions and cause discoloured water. However, it is unknown how much manganese was in the distribution system before the WTP startup: any amount that was there, even if it was not the cause of customer complaints at that time, could be contributing to the current problem. It appears that manganese in the intake (Shoal Lake) and the raw water (Deacon Reservoir) have been increasing with time, and therefore manganese at both locations should continue to be monitored. If manganese levels in Shoal Lake increase this may influence the selection of control and prevention strategies.

Table 1: Summary of Iron and Manganese in the City's Water System

Location within the Water System	**Iron**	**Manganese**
Sampling at Discoloured Water Sites (Customer's Tap)	Elevated levels	Elevated levels
Distribution System Sampling	Declining levels with time but higher than treated water Below the level of customer detection ***The distribution system water mains are the source of iron in the discoloured water events***	Increasing levels with time Variable, general trend of increasing frequency of occurrence above the level of detection

Table 1: Summary of Iron and Manganese in the City's Water System

Location within the Water System	Iron	Manganese
Treated Water from the Water Plant	Historically low levels Less than raw water levels ***Iron is effectively controlled within the water plant***	Variable, general trend of increasing levels with time Higher than raw water levels ***The source of manganese is the treatment (choice of coagulant) within the plant, and to a lesser degree, the raw water*** ***Not all of the manganese in raw water or that added from coagulant use is removed within the WTP***
Raw Water (Deacon Reservoir)	Low levels of iron	Low levels of manganese, with a gradual increase observed ***Continue monitoring manganese in the Deacon Reservoir***
Intake (Shoal Lake)	Low levels of iron	Low levels of manganese, with seasonal peaks and a gradual increase observed ***Continue monitoring manganese in Shoal Lake***

SECTION 4

Source of Causative Compounds (Where did it come from?)

Although it was concluded that the source of iron is related to the distribution system, the source of manganese appears to be primarily from chemical treatment in the WTP. In this section what is happening with iron in the distribution system is discussed in terms of the water quality conditions that control or aggravate iron release. For manganese, what is happening in both the WTP and the distribution system is described, to provide some explanation for the accumulation and release of manganese in the distribution system.

Role of the WTP: Data for iron and manganese in water entering the distribution system before and after commissioning the new WTP were reviewed in order to establish the role of the WTP. In general, an increase in manganese levels and a decrease in iron levels in treated water were observed when the new WTP went online.

Samples from multiple locations within the WTP were collected and analyzed in September 2013 to evaluate the effectiveness of individual water treatment processes. These data showed that the primary source of manganese is ferric chloride, the chemical used for coagulation. Coagulation is an important part of the water treatment process and ferric chloride is used extensively for coagulation in drinking water plants across North America. The materials used to manufacture ferric-based coagulants contain manganese, and therefore manganese is present in the final product. Although the downstream treatment units provided at the WTP provide some degree of manganese reduction, they do not eliminate all the manganese before treated water is discharged to the distribution system. Further, a change in chemical supplier in 2013 resulted in a product with higher concentrations of manganese, although the chemical product does meet industry standards for water treatment use and it fulfilled the tender requirements of the City.

To reduce the potential for discoloured water, it is recommended that the concentration of manganese in treated water be less than the concentration at which customers can detect the manganese in water (0.02 mg/L) and well below the federal Aesthetic Objective (0.05 mg/L). Therefore, a new treatment objective of less than 0.015 mg/L is recommended for manganese in treated water from the City's WTP.

Role of the Distribution System: Although iron is measured in the distribution system at concentrations higher than in treated water, the concentrations are decreasing. Less iron is entering the distribution system now, compared to before the WTP went on line, so the sources now are most likely iron-based mains, and deposits that were formed before the WTP went online. These sources were the subject of a 2011 report prepared by AECOM for the City of Winnipeg entitled *Discoloured Water Investigation, Report of Findings*. Application of phosphate corrosion inhibitor and maintenance of free chlorine residual throughout the distribution system serve to decrease, but not completely eliminate, iron release to water in the distribution network. Evidence that iron deposits formed on the walls of concrete mains before the WTP went online was obtained when an in-town reservoir (MacLean South) that receives finished water from the WTP through a concrete water main was cleaned in early October 2013. During the cleaning, a substantial amount of particulate iron and manganese was observed to be present; since this reservoir was previously cleaned at the time the WTP went online, the most likely source of the observed iron would be deposits on the walls of the concrete water main. Hydraulic forces, and possibly microbial biofilm activity are likely factors causing the iron release.

As discussed in the AECOM 2011 report, it was suspected that a biofilm associated with iron deposits was present in the distribution network prior to start-up of the WTP, and die off, or a change in biofilm composition, took place as a result of the water quality change when the new WTP came on line in December 2009. A biofilm is a community of microorganisms that grow on the pipe wall, and its composition is very sensitive to water quality. With the distribution system now seeing a higher water quality, the existing biofilm started to die off and release the historical build-up of iron. Biofilms can play a similar role with manganese release. The result was that the City received an increase in discoloured water customer calls. The very high level of iron compared to manganese at that time is consistent with the iron concentrations being higher in the water system before the WTP start-up. There were also iron particles in sediment that likely originated from unlined cast iron pipe, and these too may have contributed to the discolouration. It appears that iron was the driving factor behind the discolouration in the first two years following the start of the new WTP. To manage the condition of the water mains and to maintain water quality as water travels in the system, the City “cleans” the water mains by unidirectional flushing, whereby portions of the distribution system are systematically cleaned in sequence, to ensure that sections of cleaned water mains are not preceded by sections of “dirty” water mains. This flushing activity is important in removing particles of both iron and manganese from the distribution system.

As discussed in Section 3, the primary source of manganese is due to treatment within the WTP, and more specifically, is due to the addition of ferric chloride coagulant. Some manganese may also have deposited in the distribution system before the WTP started up. The fine particles of manganese come from manganese that was oxidized by ozone and free chlorine. If these particles are formed before the filter, and pass through the filter, they may be carried directly to the tap, attach to pipe walls, and settle in reservoirs where they can be stirred up when turbulence occurs. Manganese particles are usually light, fluffy, and difficult to settle. The particles attached to pipe walls can be released within the distribution systems, especially during flow surges caused by construction events and other activities. Because of the manganese "storage" at the pipe walls, there can be delays between manganese levels seen in the source or treated water and what is observed in the distribution system. This also explains the randomness of the occurrence of discoloured water events.

In addition to hydraulic forces, chemical and biological mechanisms very likely play a role in manganese movement through the distribution system. Manganese reducing bacteria, which are usually associated with manganese deposits according to the manual, *Guidance for Treatment of Manganese*, Water Research Foundation, 2013, under certain conditions may chemically reduce the manganese in deposits, and this manganese is released to the water as dissolved manganese. Maintaining chlorine next to the pipe wall will likely prevent this microbial activity. Any dissolved manganese in the distribution system can be oxidized by chlorine to reform manganese particles.

Although distribution system flushing will help to remove silt, loose deposits, and manganese particles, it does not necessarily remove all the deposits and will not necessarily stop the cycle of dissolution and re-precipitation of manganese. Deposits may be in consumer plumbing as well as in the water mains, and distribution main flushing does not remove manganese from the customer’s plumbing.

Summary: The data from the WTP, distribution system and customers' taps suggest that the source and fate of manganese through the WTP is key to the occurrence of manganese in the distribution system and the complaints of discoloured water. Eliminating the source of manganese and flushing the manganese particles from the distribution system is thus a very important step in reducing the occurrence of discoloured water. The (historic) role of iron in causing discoloured water cannot be dismissed; although the occurrence of iron appears to have been reduced by the City, it is likely that corroded iron mains will continue to release some iron. However, the large increase in discoloured water service requests in 2013 compared with 2012 can be attributed to the increased manganese concentrations in treated water entering the distribution system and the subsequent accumulation and release in the system, the significance of which can be seen in the routine distribution system monitoring and the samples collected from the customers' taps in response to service requests.

SECTION 5

Investigative Work to Confirm the Source (How do we know?)

The City has undertaken extensive work to investigate the causes of discoloured water in the system and to make the conclusion that iron and manganese are responsible:

- Review of historical data to understand what water quality parameters could be attributed to the discoloured water and their source
- Consideration of relevant experience and case studies elsewhere
- On-site testing by the City at the WTP to assess performance and the role of treatment optimization
- Off-site bench-scale testing to identify contributing factors and to evaluate the feasibility of alternative manganese control strategies
- Off-site analysis of water main samples and lead service lines

SECTION 6

Controlling and Preventing Discoloured Water

Based on historical data and pilot testing conducted to support the treatment selection and design, treatment for manganese was not provided in the new WTP. Dedicated treatment for manganese control is typically provided for systems with manganese present in the source water, with treatment relying on oxidation. Typical systems include:

- Oxidation with permanganate, which is added at the intake so that there is sufficient time for the necessary reactions to take place before filtration. This process is not applicable for the City because source water is not the primary source of manganese.
- Oxidation with chlorine in a process involving a coating of oxidized manganese on filter media, followed by adsorption of the manganese ion to the oxidized layer, and then application of chlorine to oxidize the manganese ion. This process is also not applicable to the City because the chlorine would destroy the organic removal function of the biologically active carbon filters.
- Biological oxidation of manganese with oxygen in the filter. This process would require that the existing ozone system be eliminated because for this process to be effective, ozone cannot be used just prior to filtration at Winnipeg because this process requires that manganese be in the form of the manganese ion when it enters the filter. Ozone is an essential part of the treatment process, so elimination of ozone in order to remove manganese is not possible, and this process cannot be used.

Options to control the manganese in treated water using the existing treatment process at the WTP to reduce manganese and mitigate discoloured water include:

- Replacing the ferric chloride coagulant with an alternative product that contains less manganese, be it a grade of ferric chloride with less manganese impurity, or another ferric coagulant, or an aluminum-based coagulant that is essentially manganese free.
- Practicing ozonation year round and thereby minimizing the duration of offline maintenance activities on the ozone system; it is important to note that maintenance of the ozone system is critical to safe and effective operations.
- Optimizing the existing process to reduce manganese by raising the pH of water prior to filtration and optimizing the application of filter aid for manganese removal

All of the options would require testing at pilot- or full-scale. The effect of raising the pH and optimizing the application of filter aid for manganese removal should be tested as soon as possible. If these options do not work, the current coagulant should be replaced.

Because the use of coagulant in the WTP is the dominant source of manganese in the water, the feasibility of reducing the dose of the existing coagulant (ferric chloride) was considered. Recognizing that there was a lot of effort invested in dose optimization during testing before the plant was designed, it is unlikely that there will be a lot of room to maneuver with the dose (i.e., at most 5 mg/L). Based on the review undertaken as part of this study, a change to a coagulant that contains minimal levels of manganese is needed as soon as possible. It is acknowledged that the availability of low-manganese ferric chloride in sufficient quantities that are suitable for potable water applications may limit the feasibility of using ferric chloride at the new WTP. Neither reducing the ferric dose nor changing to a ferric chloride product with only half as much manganese will be much help when trying to get the manganese out of the system as fast as possible. To reduce the manganese in treated water, a combination of control strategies may be necessary.

Options available to use the distribution system to control discoloured water were also considered. As detailed in the 2011 report to the City entitled *Discoloured Water Investigation, Report of Findings*, a relatively constant pH, free chlorine throughout the distribution system, continued application of phosphate corrosion inhibitor, and continued flushing, is the best approach that can be used to reduce iron concentrations. The use of sequestering agents that are generally polyphosphate compounds, sometimes called hexametaphosphate, was also considered for use. These compounds are often used to reduce the colour and turbidity that result from oxidized iron and manganese. They are often applied to well waters, and to distribution systems for reducing the colour associated with iron release from corrosion scales. With iron, they function by preventing the particles that result from oxidation from becoming large, thus resulting in less colour and less turbidity. With manganese, the mechanism is not clear. The sequestering agent may function by preventing the oxidized manganese from becoming large particles, thereby reducing the colour and turbidity that result from a given concentration of manganese, or they may associate with soluble manganese and prevent its oxidation to an insoluble form. Polyphosphate molecules slowly revert to orthophosphate, which does not sequester iron and manganese. This reversion may occur in the distribution system, or in washing machines because the reversion occurs faster at higher temperature. When the reversion occurs, the iron and manganese are released.

A concern about polyphosphates is that they may associate with the oxidized manganese particles that are in distribution system sediment and attached to pipe walls, and cause these particles to be suspended in the bulk water. If this were to happen, the manganese-related colour would probably increase. While this is a possibility, it has not been demonstrated to occur, so we can only hypothesize that it might occur.

SECTION 7

Reducing the Compounds Responsible for Discoloured Water from the Distribution System (What do we need to do?)

Operating the distribution system to manage water quality will help to eliminate the iron and manganese already in the distribution system:

- Accelerate the schedule for unidirectional flushing across the system
- Flush the entire system as soon as possible after eliminating the manganese that is now entering the system from treated water
- Continue to regularly clean the storage reservoirs, with all in-town reservoirs cleaned before summer water quality conditions (before June 2014)
- Return to the in-town reservoirs again in fall 2014 to assess the rate and magnitude of iron and manganese accumulation after one year since the previous cleaning effort; adjust the reservoir cleaning frequency accordingly
- Review the hydraulic model of the distribution system to identify opportunities to operate the system in a hydraulically consistent manner to limit non-routine changes in flow direction, flow surges, dead zones, or sheer stresses

SECTION 8

Recommendations and Actions

To control and prevent discoloured water in the City's drinking water system, recommendations are presented for source water control, WTP operations and capital upgrades, and distribution system operations. Based on the mechanisms that influence the fate and transport of both iron and manganese in the distribution system, the following recommendations are offered:

i) Monitor both Shoal Lake and the Deacon Reservoir for manganese to determine if source water contributions have an increasing influence on the plant and whether or not dedicated treatment for manganese is necessary
   - Although dedicated treatment is expected to be unlikely, monitoring of both the intake and the raw water should be continued to confirm manganese levels
   - The frequency with which manganese is sampled in Shoal Lake should be increased to bi-weekly sampling (estimated cost increase for 4 samples per year to 26 samples per year); the frequency of manganese sampling in the Deacon Reservoir should be maintained

ii) Replace the ferric chloride coagulant with an alternative product that contains less manganese
   - Efforts are underway to source an alternative ferric chloride supply; the request for bids closes December 11, 2013 and the expected use of the supply is February 2014
   - Ideally, the new supply should have less than half the manganese content for it to make a significant impact

iii) Select an alternative coagulant and/or:
   - Bench-scale testing with alternative coagulant (less than one month, and repeat for seasonal water conditions), followed by pilot-scale testing (for six to 12 months once pilot equipment is set up)
   - Bench-scale testing conducted before the new plant was design can be reviewed
   - Pilot testing with an alternative coagulant (i.e., ferric sulphate or aluminum based coagulants) would be necessary and the construction of the new pilot plant could be advanced to accommodate this
   - The pilot plant is not constructed at this time; this work is underway but will require at a minimum 6 to 10 months to complete and is expected to be completed by December 2014

iv) Modify the existing WTP treatment process to improve manganese reduction without jeopardizing the ongoing operation of the WTP to produce safe water:
   - Raising the pH of water prior to filtration to improve manganese removal during the filtration process:
      - Full-scale demonstration testing with pre-filter pH adjustment is underway and expected to be completed in early 2014; if results are as expected and manganese removal is increased in the filters, a permanent solution can be implemented
      - This would involve relocating the point of injection of a chemical already available at the plant (sodium hydroxide)
   - Full-scale optimization of the ozone dose and filter aid polymer dose (less than one month, and repeat for seasonal water conditions)

v) Provide consistent water quality to the distribution system

   – Stable pH (7.6 to 7.8 for use with corrosion control), maintenance of chlorine residuals across the system (at the raised levels implemented in late 2012), maintenance of orthophosphate in the system (for iron control and lead control), adequate dissolved oxygen (from year-round ozonation in the plant), and low levels of manganese in treated water are all important water quality factors

   – This has been implemented and monitoring used to confirm the consistency of water quality (i.e., ozone dosing is being continued through the winter, based on this information)

vi) Review distribution system operations from the perspective of operating the distribution system to manage water quality (i.e., maintain flows, avoid dead ends, minimize water age, look at role of changing flow directions)

   – This would involve using the City's hydraulic model to evaluate different operating strategies

vii) Continue to flush the system as a means to reduce the deposits (particulate metals) in the system using unidirectional flushing

   – The frequency of flushing efforts should be increased (i.e., doubled) until the manganese levels in the treated water are mitigated. Information is not available to quantify how much flushing is needed to clear the system. This will be a function of how tuberculated the pipe is and how much manganese has accumulated, and will be system specific. Thus we cannot say how long it will take to eliminate the manganese from the distribution system. Care must be taken to avoid velocities that break tubercles.

   – The entire system and the in-town reservoirs should be flushed as soon as possible after the manganese in treated water is reduced to below the new recommended treatment objective of 0.015 mg/L

   – Flushing a portion of the system, coupled with monitoring, can be used to produce a more quantitative answer to how much flushing is needed to clear the system.

viii) Regularly draw down and inspect the in-town reservoirs

A summary of the recommendations and actions to control and prevent discoloured water in the City’s distribution system is presented in Table 2, with a high level assessment on schedule and budget impacts.

Table 2: Summary of Recommendations and Actions with Schedule and Cost Implications

Recommendation and Action		Schedule	Approximate Cost Impact
i)	Monitor both Shoal Lake and the Deacon Reservoir for manganese	Can begin immediately	Increased sampling costs from quarterly to bi-weekly
ii)	Replace the ferric chloride coagulant	Expected startup of alternative ferric chloride by mid-January 2014	Up to 50 percent cost premium (to be determined by tender results)

Table 2: Summary of Recommendations and Actions with Schedule and Cost Implications

Recommendation and Action		Schedule	Approximate Cost Impact
iii)	Select, test and implement an alternative coagulant	One year to allow for demonstration testing, including 3 months to tender new product supply contract	Cost impact to be determined by product selected and potential secondary impacts (i.e., residuals handling) Leverage new pilot plant and City staff for testing
iv)	Modify existing plant processes to control manganese: • demonstration trial with pre-filter pH adjustment • ozone dose optimization • filter aid polymer dose optimization	• testing underway (allow 2 months for results) • Conduct 1 month of testing after pH trial • Conduct 1 month of testing after ozone trial	• No impact on chemical costs; ≤$40,000 capital • ≤ 50 percent increase in ozone operating costs, due to year-round ozone use • ≤ 20 percent increase in polymer cost
v)	Provide consistent water quality to the distribution system	Implemented	No change to chemical cost for pH adjustment Cost impact limited to operating costs for year-round use of ozone
vi)	Operations optimization of distribution system	6 to 12 months depending on the level of detail (develop recommendations and plan for implementation)	Budget impact will depend on level of detail ($30 - $100,000 to be confirmed)

Table 2: Summary of Recommendations and Actions with Schedule and Cost Implications

Recommendation and Action		Schedule	Approximate Cost Impact
vii)	Cleaning the distribution system: • Double the rate at which the system is unidirectionally flushed • Test a portion of the system to assess the flushing frequency and water quality impact; use results to determine the flushing schedule for the system • Flush the entire system (including the reservoirs) after the manganese in treated water is reduced ≤ 0.015 mg/L • Analyze pipe samples obtained from the system for scale characteristics	• Implement in 2014 • Implement in spring 2014 (allow two to four weeks) • Schedule after the manganese in treated water is reduced • Results expected by mid-December, 2013	• Double staff effort and equipment • Allow for labour effort and analytical needs • Labour effort • Approximately $10,000
viii)	Regularly draw down and inspect the in-town reservoirs	Clean remaining reservoirs before June 2014 Two reservoirs were cleaned in October 2013; schedule next cleaning in October 2014 Use sampling results from October 2014 reservoir cleaning to determine cleaning frequency	Analytical costs plus staff time to drawdown and clean the reservoirs Allow for all reservoirs in 2014

SECTION 9

Estimated Time to See Improvement (How long will it take?)

Levels of iron in the distribution system have declined and are expected to stabilize. Controlling manganese in treated water will be key to controlling discoloured water but due to the behavior of manganese, it is difficult to predict when the discoloured water occurrences will be controlled. Reductions in discoloured water are expected to occur as i) the source of the discoloured water is reduced and ii) the manganese (and to a lesser extent, the iron) is flushed out of the system. Whereas the iron is likely stabilizing, the manganese has been accumulating to varying degrees over the last four years.

The conditions required to realize improvements include a) stabilizing water quality, b) producing water with minimal levels of manganese, and c) practicing unidirectional flushing/reservoir maintenance to keep the system “clean”. Without these conditions, sustainable improvements will not be realized.

Implementing all of the above recommendations will take upwards of two years to complete, however, it will not take two years before improvements are realized. It is expected that improvements will be incremental as progress is made toward implementing the above recommendations, and significant improvements may be realized prior to late summer 2014 when discoloured water traditionally peaks.

SECTION 10

Measuring Success

In this section, proposed monitoring tools are identified to document and confirm performance improvements using i) customer feedback and ii) water quality data. The proposed monitoring tools build upon results from monitoring tools used in 2013 and earlier to monitor discoloured water occurrence and parameters of influence. Distinction is made for incident or event-driven monitoring (items 1 and 2) and routine monitoring (items 3 to 5).

i) Number of service requests received each month with a reference to discoloured water (see Figure 1)

ii) Water quality results for samples collected in cold water from the customer's tap (total iron, total manganese, apparent colour, and turbidity) in response to customer complaints and service records for discoloured water

iii) Water quality results for routine distribution systems samples (total iron, total manganese)

iv) Water quality results for treated water from the water treatment plant (total iron, total manganese) and operations to produce a consistent water quality (chlorine residual, orthophosphate residual, pH)

v) Water quality results for in-plant monitoring, as a tool to optimize performance for manganese control (ozone dose, pH, and filter aid)