4. City Facility Assessments

4.1 Introduction

Facility review sheets (as requested by ODW) were completed for facilities near the sample sites that tested positive for TC/EC. These assessments included investigations of sampling sites (investigation of plumbing, cross connections, filters), pumping stations, water reservoirs, distribution system infrastructure (air relief valves, valve chambers, pipe materials), groundwater wells, operations and maintenance activities, pressure monitoring, and environmental factors. City staff provided computer simulations of typical distribution system hydraulic patterns, along with records on distribution system (DS) operation and maintenance activities, customer water quality complaints, and facilities in the DS. City staff provided graphical illustrations of these data to allow analysis of associations between any suspect activities/facilities and the positive water quality samples of January 26, 2015.

The assessments of the City's water systems were conducted in accordance with the United States Protection Agency's (USEPA) Revised Total Coliform Rule (RTCR). The RTCR Guidance Manual (GM) provides a format for evaluating facilities and operational activities during an incident assessment. This format was used to compile data for the 28 inspection categories, such as an evaluation of potential cross connections and an evaluation of environmental effects. Detailed results of this assessment are provided in **Appendix A**.

Under the RTCR rule, two types of assessments may be conducted:

- A Level 1 Assessment, which includes a general overview of operational practices and basic inspections of the water system (supply, treatment and distribution); or
- A Level 2 Assessment, which investigates the same parameters as a Level 1 assessment, but on a more detailed scale.

The City's water system was investigated under the Level 2 Assessment under this Rule. Assessments focused on the areas that were found to have water samples testing positive for TC and EC. Data for a majority of these assessments were collected by the City for evaluation, by AECOM. The assessment included a review of recent condition assessments where available.

Further analyses included:

- An evaluation of potential backflow and cross connections around sampling sites testing positive for TC/EC;
- An evaluation of air relief valve pits around sampling sites testing positive for TC/EC which were previously identified as having water in them;
- Hydraulic modelling of the distribution system to evaluate water flows patterns and travel times; and
- An evaluation of discoloured water events in relation to sampling sites testing positive for TC/EC.

4.2 Background

4.2.1 Water Treatment and Disinfection

The City's Water Treatment Plant (WTP) includes a variety of pathogen removal and inactivation processes including filtration and chlorination. Sodium hypochlorite is added on a flow paced basis for primary disinfection. The WTP also includes additional treatment systems such as ozone and ultraviolet

(UV) disinfection, which ultimately provide a multi-barrier approach to removing pathogens from the City's water supply. Treated water is delivered to the City's distribution system via three reservoirs and pumping stations located within the City.

It is noted that the primary focus of this assessment is on the facilities and operation of the City's distribution system. A review of data from the three positive TC/EC events indicates that the WTP was not the likely source of any of the positive samples considered in this report. The treatment facility and plant records were reviewed, however, to verify that the plant was performing adequately. The plant was found to be in excellent condition and well operated.

4.2.2 Reservoirs

The City of Winnipeg is serviced by three reservoirs in the distribution system, as follows:

- The McPhillips Reservoir was constructed in the 1970s and is divided into east and west cells, each with 120 ML of storage.
- The Wilkes Reservoir, which supplies the Hurst Pumping Station, is divided into three cells. The south cell is the largest and has a total storage volume of 112 ML. The remaining two smaller cells, located to the north, are designated east and west. Each has storage volumes of 78 and 62 ML, respectively.
- The MacLean Reservoir is the most recent distribution reservoir constructed in the system. The reservoir is divided into identical north and south cells each with approximately 111 ML of storage.

The City regularly drains, cleans and inspects the reservoirs at the McPhillips, MacLean and Hurst pumping stations. This typically occurs on an annual basis, and is a manual operation which is mainly intended to remove sediment that has accumulated at the bottom of the reservoirs and to facilitate regular inspection.

4.2.3 Pumping Stations

The three pumping stations, McPhillips, Hurst, and MacLean, supply all of the water to the City's distribution system.

Each pumping station has chlorination facilities to boost and maintain chlorine residuals within the distribution network. [redacted]

4.2.4 Piping Infrastructure

The City's distribution system consists of a regional feedermain network and local watermain network.

- The regional system consists of a network of feedermains which are supplied by the Hurst, McPhillips and MacLean pumping stations. The pumping stations operate in a single pressure zone with the primary feedermains linking the stations together, thereby providing redundancy to the system. The regional feedermain network is connected to the local watermain network at a limited number of locations, and is predominately constructed of pre-stressed concrete pressure pipe;
- The local watermain network consists of approximately 2,500 km of piping constructed primarily of PVC, asbestos cement, and cast iron piping; and
- All customer service connections, hydrants, and distribution valves are on the local watermain network.

4.3 General Water System Review

In general, the City facilities were found to be in good working order and records were available to assess operations and maintenance activities that presented potential contamination risks to the water supply system. As might be expected in a thorough vulnerability assessment of any complex water utility system, several potential sources of contamination were identified. Each of these was considered in a structured risk evaluation analysis as either a single source of potential contamination, or in a scenario where a common hydraulic event triggered the simultaneous intrusion of contamination from several potential contamination sources.

Based on the inspections conducted, the following observations were noted.

4.3.1 WTP Operation

The WTP was visited on February 26, 2015 and plant records for filter performance and disinfection were reviewed for the month of January 2015. The plant appeared to be well maintained, with all processes operating within established operational goals. Review of plant data for the month of January 2015 indicated no unusual events during the month. No unusual operating conditions were experienced prior to the May 2014 and October 2013 events.

4.3.2 Distribution System Maintenance

The City's operational procedures, including tool disinfection, are documented and generally follow good industry practice.

Operations and maintenance records were reviewed for any activities that might have been associated with a potential contamination of the water supply. Much like the locations of the positive samples, repair activities and main hydrant operation were randomly distributed over the distribution system for the two weeks prior to the contamination event, as shown in **Figure 5** and **Figure 6**. For the two weeks prior to the January 26, 2015 event, no clear pattern between maintenance activities and the positive TC sites was evident. Maintenance activities upstream of water samples testing positive for TC/EC (as shown by the shaded gray area in **Figure 5** and **Figure 6**) do not appear to be responsible for most of the positive samples. While there was some activity in the upstream areas of two of the sample locations that tested positive (SW-07 and NE-01), these sample locations are hydraulically disconnected from the other sample locations. System records were reviewed and found to be normal for the 2 weeks prior to January 26, 2015 event. Similar analysis was performed for valve work and miscellaneous daily work in **Appendix A**. No issues were identified; these observations were consistent across all three events.

4.3.3 Water Sampling Locations

Sampling locations testing positive for TC/EC in the City (**Figure 7**) were evaluated by AECOM and City staff. Of note was the correlation between the positive samples attributed to a single sample collector (**Figure 8**). Some of the existing water sampling locations appear to be at risk of contamination due to the following circumstances:

- The placement of aerators on faucets, many of which are non-removable. Aerators have the potential for collecting debris over a long period of time, which may occasionally influence water samples and be non-reflective of the water quality currently in the distribution system.

  A recent analysis indicated that of the 65 faucets used for collecting microbial samples, 45 had aerators attached, and of these 45 only 21 were reported as removable in 2015. Assuming this same ratio of removable aerators over the past 5 years, the frequency of positive TC detections at the sample locations with aerators was lower than those with aerators that were removed during sampling. Thus, while the practice of taking samples from faucets with aerators attached is not recommended, it does not appear to have affected samples collected prior to January 26, 2015. It is noted that an increase in non-removable aerators has been observed in recent years.

- The use of in-line filters which may not have been maintained. Similar to the aerators, in-line filters require regular maintenance in order to remove debris. If water samples are to be collected from plumbing that contain such filters, maintenance logs for those filters should be kept and evaluated on a regular basis.
- The presence of dormant piping within the premises near the sampling location. Generally, the City is responsible for addressing dormant or 'dead-end' piping that is present in the distribution system, which contains stagnant water which may have deteriorating water quality. Such piping should be identified in private establishments that may be selected for water sampling in order to prevent stagnant water from interfering with the results.
- The use of backflow preventers, including air-gap preventers that are not regularly monitored/ tested.
- Sampling points that are located in areas such as bathrooms, where potential for bacterial cross contamination with fecal coliform bacteria is greater than it needs to be.
- Sampling locations with unusually long service lines. Sampling locations should generally be located close to the water meter as possible to reflect distribution water as opposed to plumbing issues within the building.

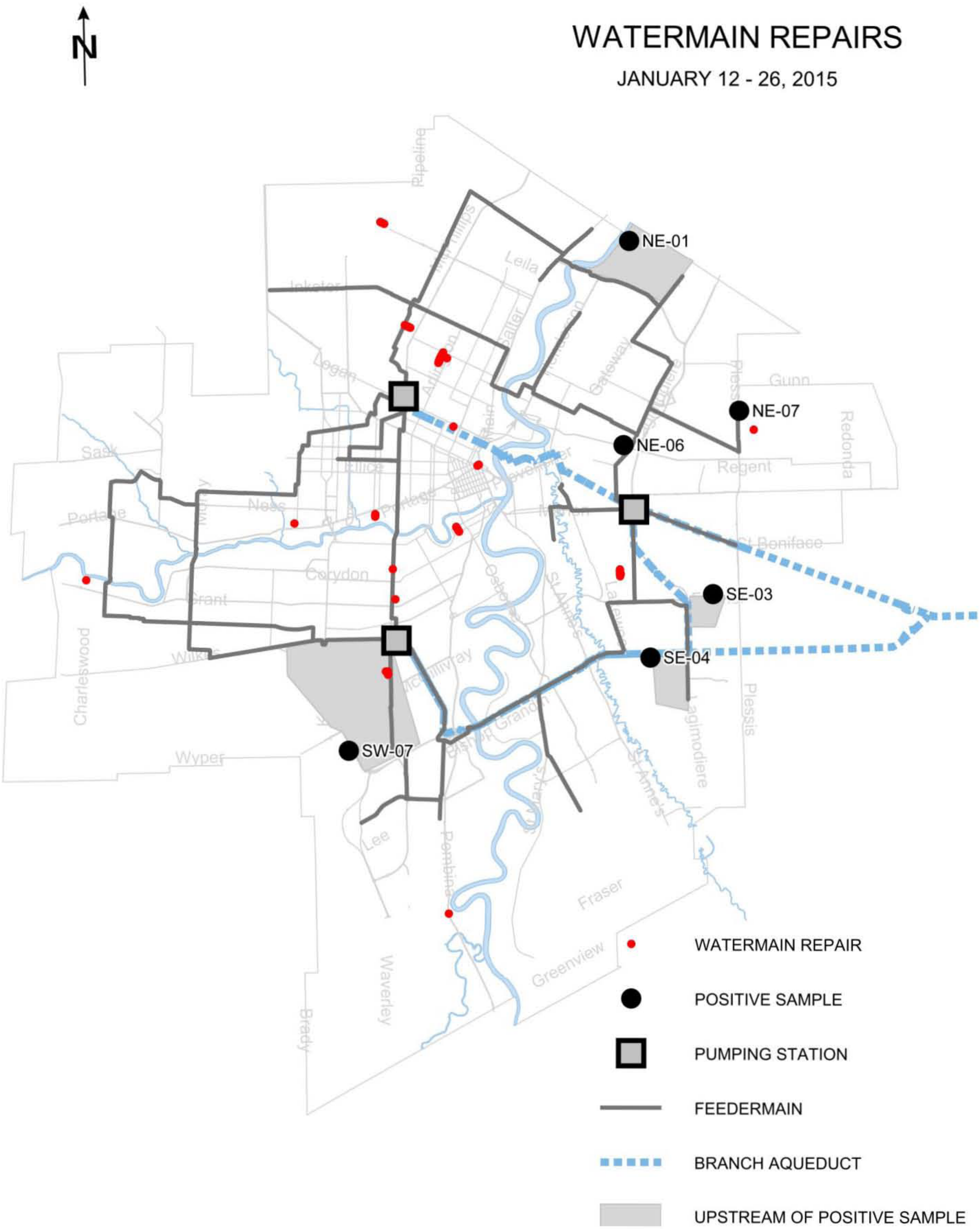

Figure 5: Significant Watermain Repair Activities 14 Days Prior To and Including January 26, 2015.

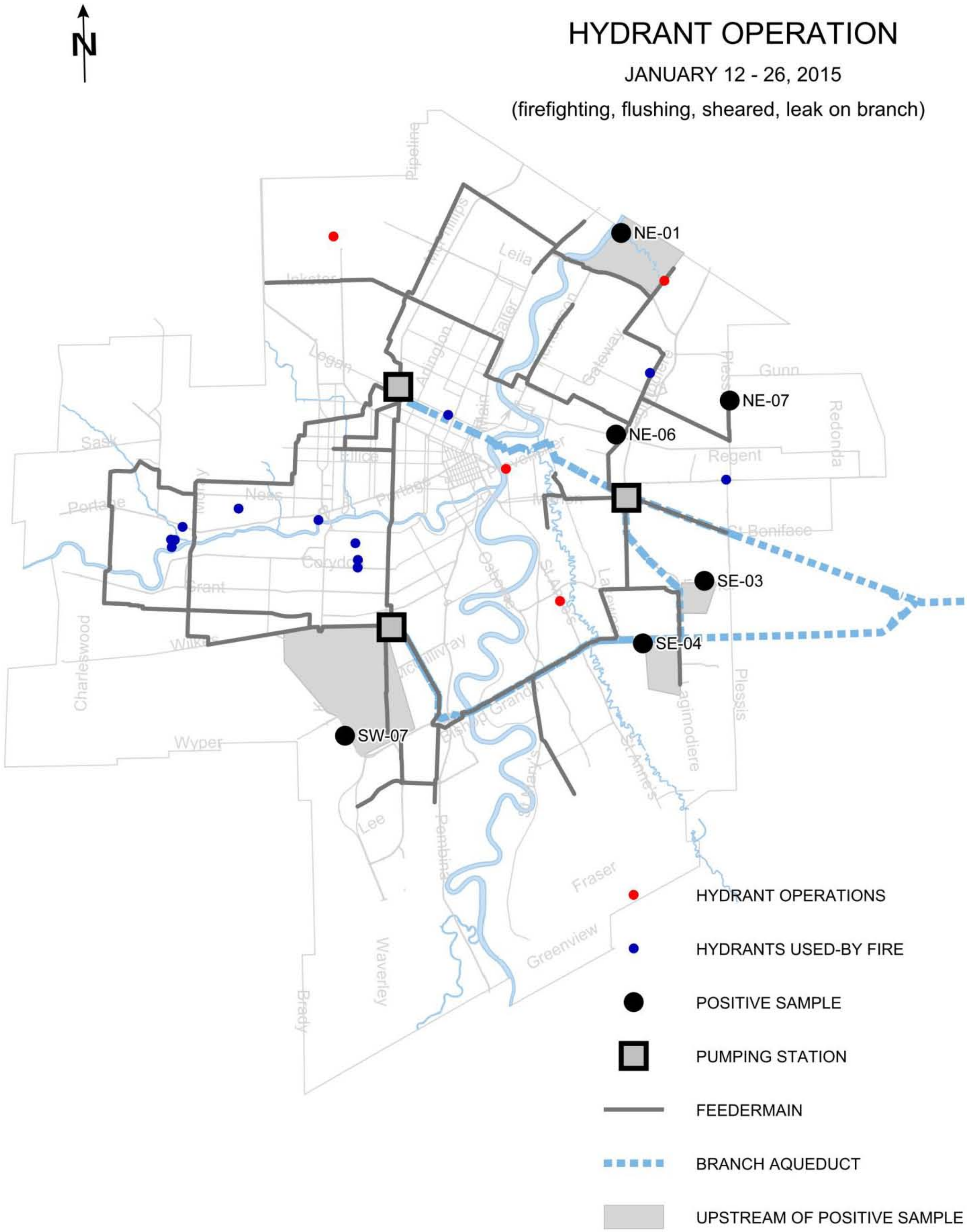

Figure 6: Hydrant Operation, Jan 12-26, 2015

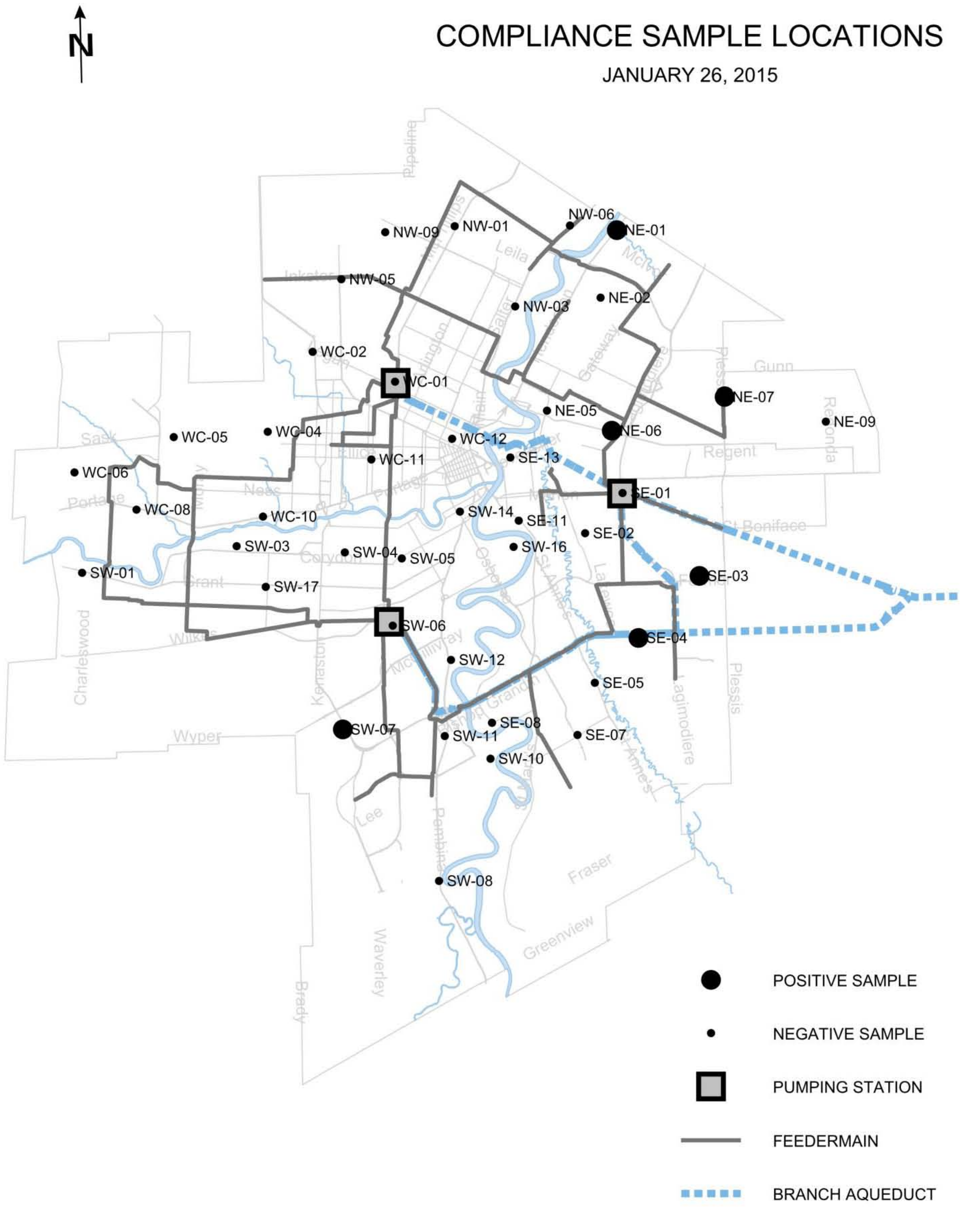

Figure 7: Compliance Sample Locations, Jan 26, 2015

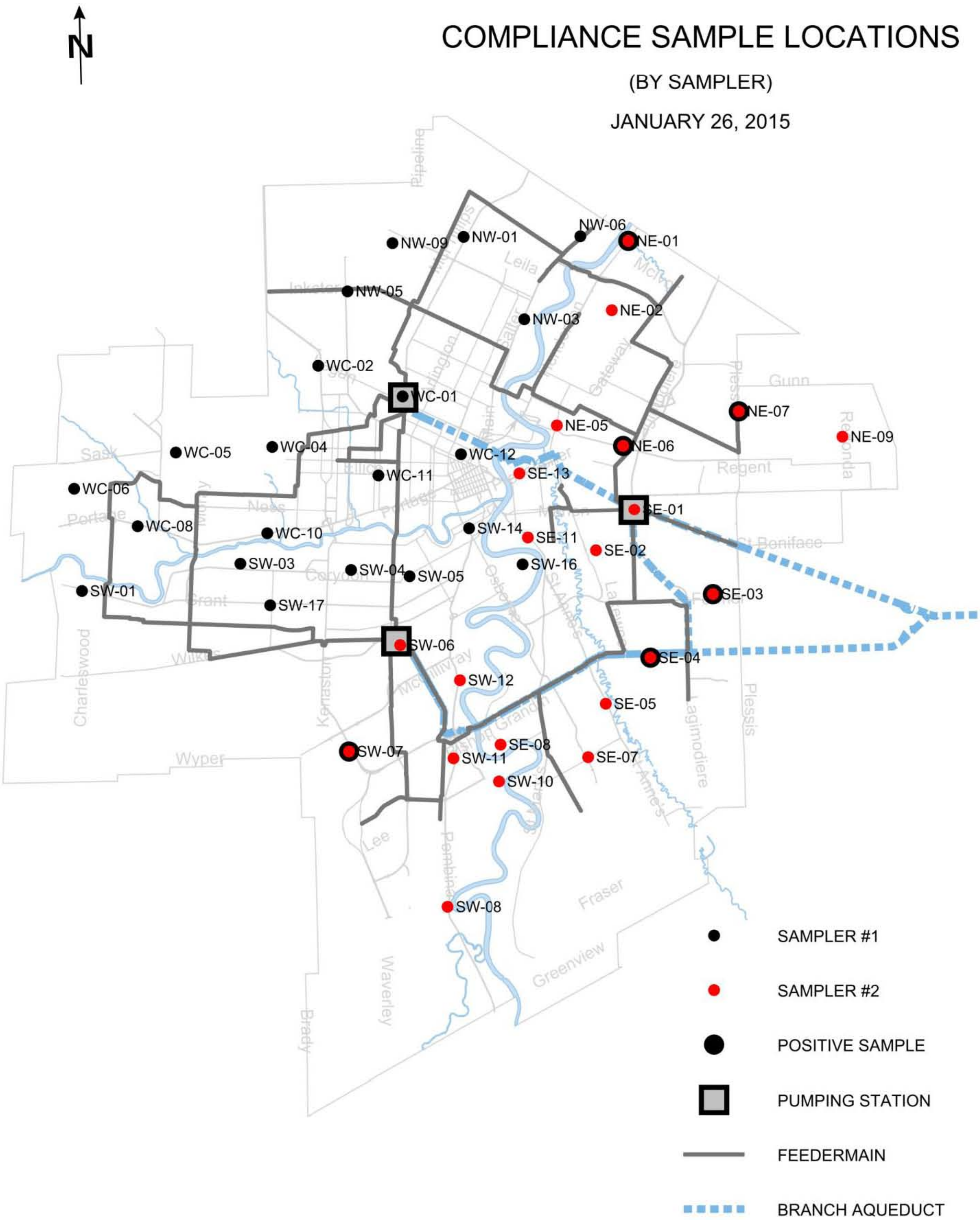

Figure 8: Compliance Sample Locations (by Sample Collector), Jan 26, 2015

4.3.4 General Security

The City protects its facilities from unauthorized entry. Primary facilities were inspected and found to be adequately secured against unauthorized entry.

4.3.5 External Water Sources

Ninety-nine non-domestic licenced groundwater wells exist within the City limits, as shown in **Figure 9**. In order for a cross connection to occur, an illegal connection from the well to the City of Winnipeg watermain system would be required. Although there are some wells in the upstream vicinity of the some of the sample points, they are not hydraulically connected to the other sample locations that tested positive. In addition, there are several wells that are in the upstream location of other sampling points that did not test positive.

River data and rainfall level data is collected at various points within the City. These data were analyzed for the three positive sample events specifically looking at spring runoff as a contributing factor. An example of this data is shown in **Figure 10**. Anomalous changes in river levels within the City were not noted during the 2013 and 2014 events. Ice cover during winter months limits the available readings into 2015. As such, sudden changes in river levels are not expected to be a significant factor during the three positive sample events.

4.3.6 Reservoirs

The MacLean and Wilkes reservoirs and their associated pumping stations were inspected in conjunction with this assessment. Several minor contamination risks were identified for improvement. These facilities were all considered as potential point-source risks in the analysis of water quality data from the January 26, 2015 event. In general, the items identified related to recommendations for additional external signage, a minor addition to non-process plumbing, and replacement of a specific ventilation fixture. Reservoir levels were investigated as potential sources of contamination. Extremely low reservoir levels or large aggregate changes in flow may affect water quality due to disturbance of existing sediments, equipment failure, etc. No extreme changes in reservoir levels were noted, as shown in **Figure 11**, **Figure 12** and **Figure 13**. The apparent sudden drops in reservoir levels at McPhillips on Jan. 16 and 21, 2015 (**Figure 13**) are due to an instrumentation fault. Chlorine residual is continuously monitored at the reservoir discharge and there has been no indication of problems maintaining chlorine levels leaving the reservoirs, indicating this as a source of a contamination is unlikely.

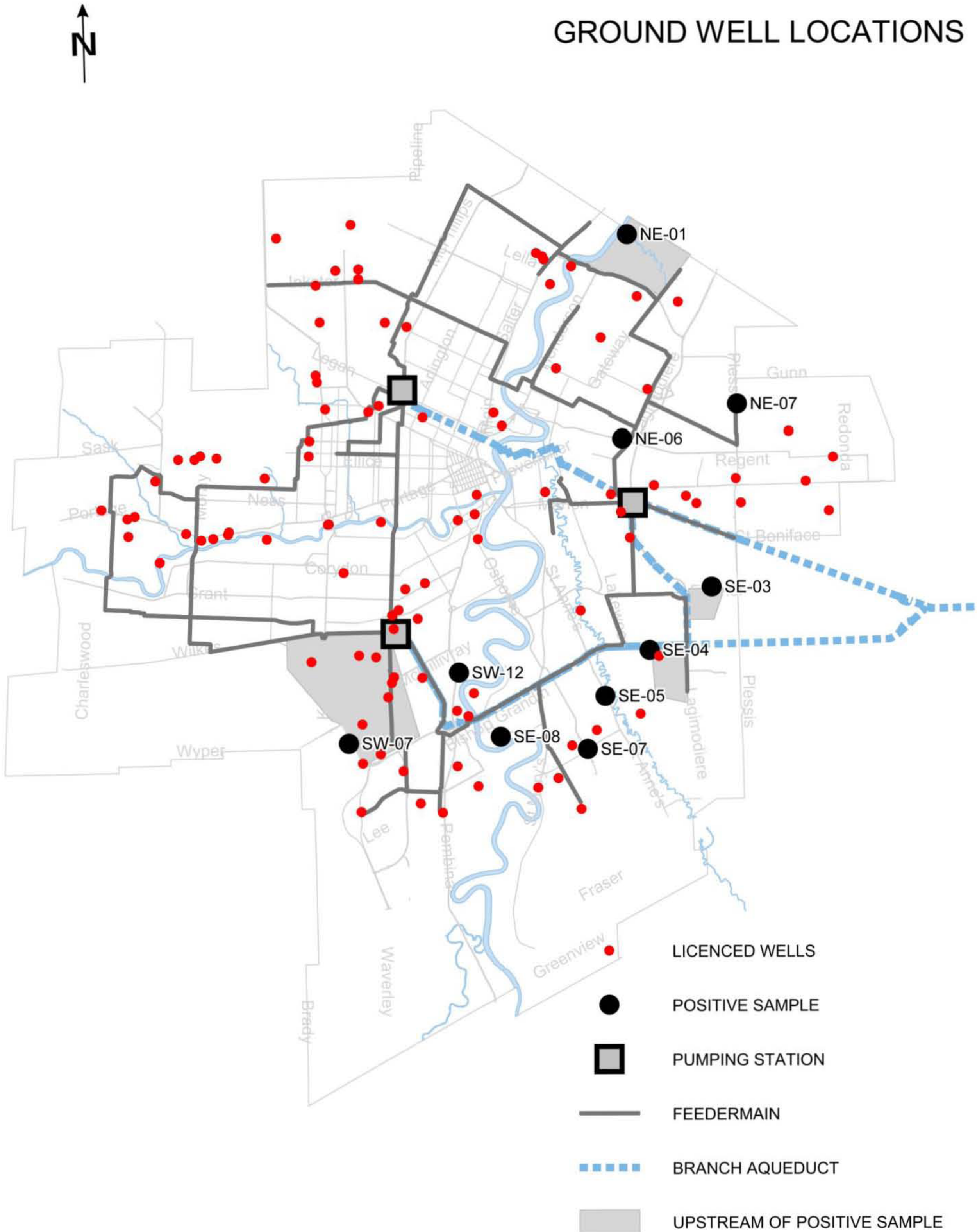

Figure 9: Ground Well Locations

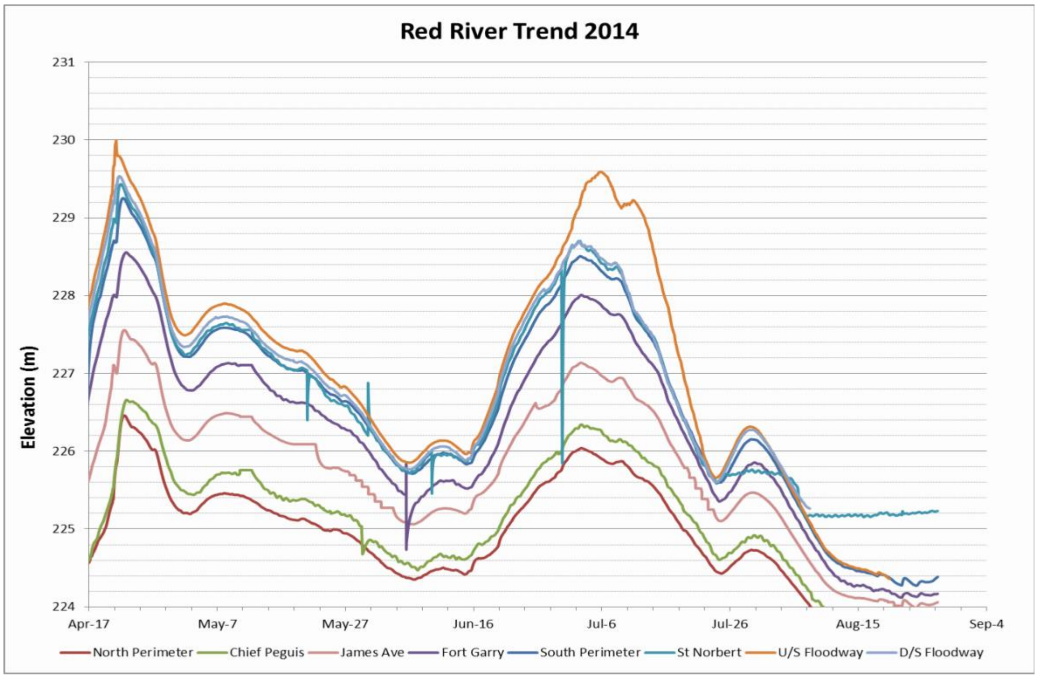

Figure 10: River Elevation Readings, Apr 17-Sep 4, 2014

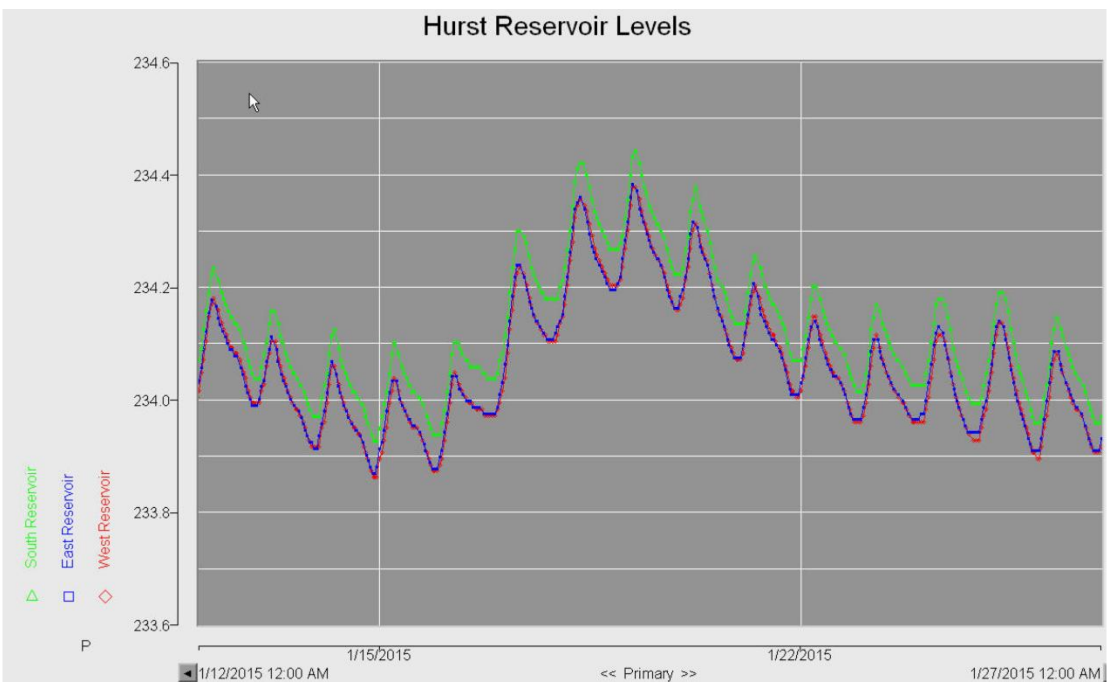

Figure 11: Hurst Reservoir Water Levels, Jan 12-Jan 27, 2015

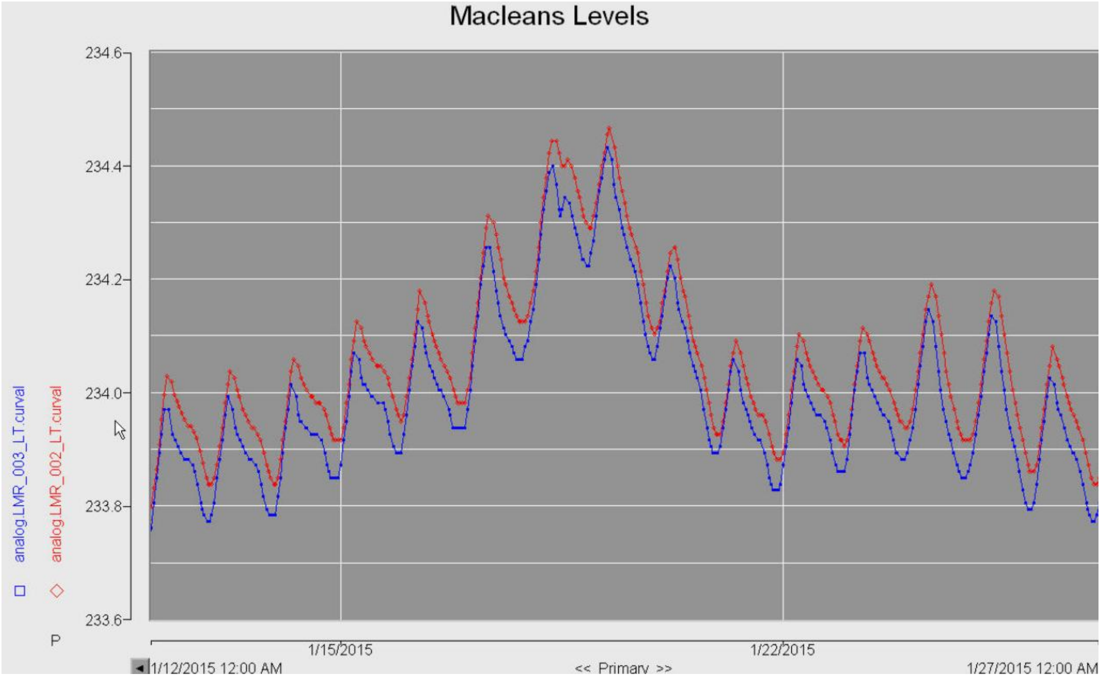

Figure 12: MacLean Reservoir Water Levels, Jan 12-Jan 27, 2015

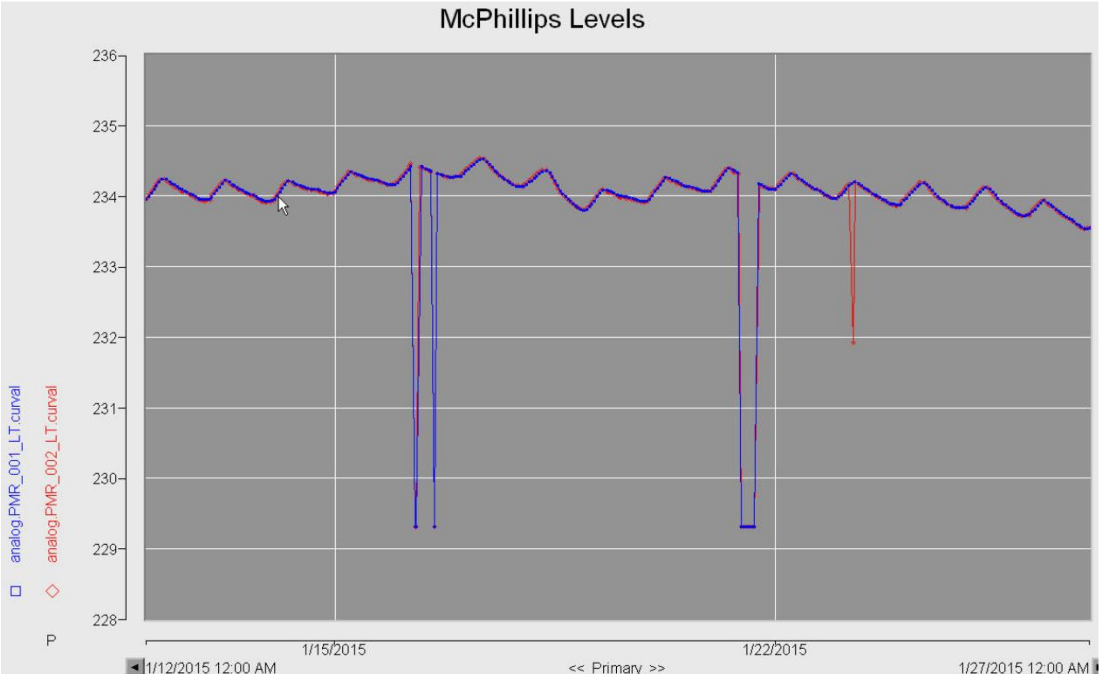

Figure 13: McPhillips Reservoir Water Levels, Jan 12-Jan 27, 2015

4.4 Standard Operating Procedure Evaluation

The City currently has Standard Operating Procedures (SOP) and Safe Work Procedures (SWP) for a majority of its water systems operations. A review of 14 of the City's procedures was conducted, including procedures for disinfection before watermain repair, water quality testing after watermain repair, and site-specific reservoir maintenance. All were found to be adequately descriptive for field application.

While these SOPs are regularly updated, it is suggested that regular reviews of these procedures be conducted to ensure they are up-to-date, address all potential system vulnerabilities, and align with industry best practices. For instance, the disinfection procedures accepted by industry for disinfection of watermains (AWWA C651-14) was updated on February 1, 2015, with new disinfection requirements depending on whether the watermain is new or repaired; these requirements should be considered for incorporation into the City's existing SOP for returning watermains to service. The City is planning to review the new standard and existing SOP.

4.5 Pressure Monitoring Review

The City continuously monitors pressure readings throughout the distribution system and at each pumping station, as noted in **Figure 14**, **Figure 15** and **Figure 16**. Pressure-monitoring points are calibrated annually at a minimum. If issues arise between calibrations (e.g. loss of signal, erroneous readings, plugged impulse lines), the City will perform maintenance as required.

On January 18, 2015 the distribution monitoring stations recorded minimum pressures of 41.59 psi and 47.13 psi, respectively. The pressure drop is attributed to valve operations on the Birds Hill Feedermain. Five pressure monitoring stations reported minimum pressure readings of under 60 psi during the period of December 1, 2014 to February 17, 2015 (data provided in **Table 3**). The remaining 6 stations reported no minimum values less than 60 psi for the period. These data indicate that pressures were maintained above 60 psi most of the time, and always above 42 psi.

On January 16, 2015 a power failure occurred at the McPhillips Pumping Station. Gas engines were able to maintain pressure in the system, which never fell below 65 psi at the station.

Valve operations for 2 weeks prior to January 26, 2015 were reviewed for activity that might have caused hydraulic disruption in the system. The only operation involving a reduction in pressure took place on January 18, 2015 at Panet Road and Fournier Street. This work involved valve operation on the Birds Hill Feeder Main to facilitate nearby maintenance activities. The remaining 6 valve operations between January 19, 2015 and January 26, 2015 were reported as resulting in no reduction in system pressure.

Table 3: Minimum Pressure Readings for Pressure Stations Reporting Below 60 psi

Station	Date	Pressure (psi)
	December 26, 2014	47
	January 18, 2015	42
	January 3, 2015	59
	January 3, 2015	58
	January 18, 2015	47

Overall, available pressure readings were found to be within acceptable ranges. No unusual pressure readings/losses were noted immediately before or after the January 26, 2015 contamination event.

Similar analyses were performed for the October 2013 and May 2014 events and no issues were identified.

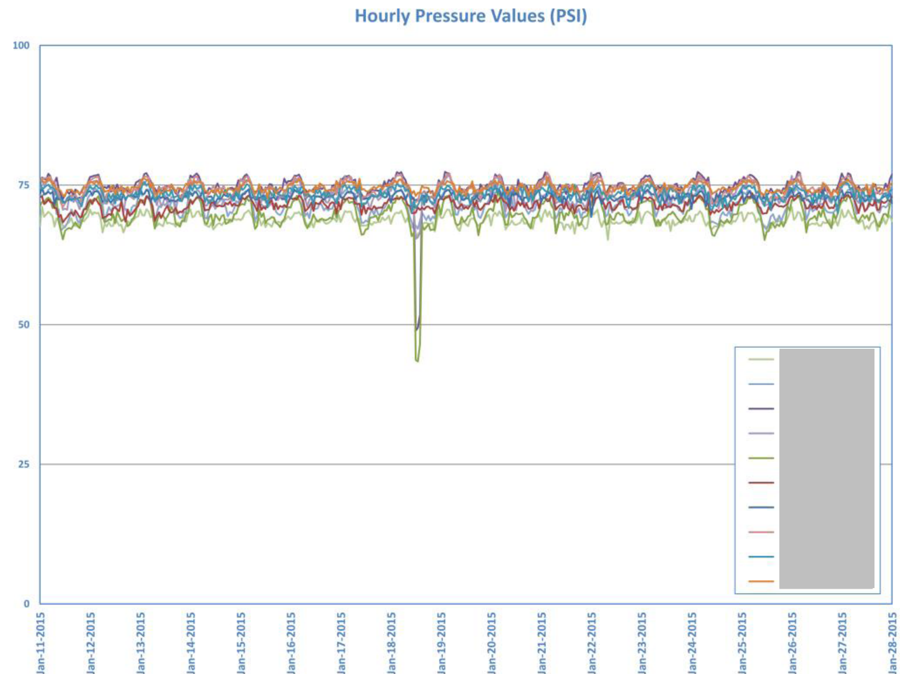

Figure 14: SCADA Hourly Pressure Values

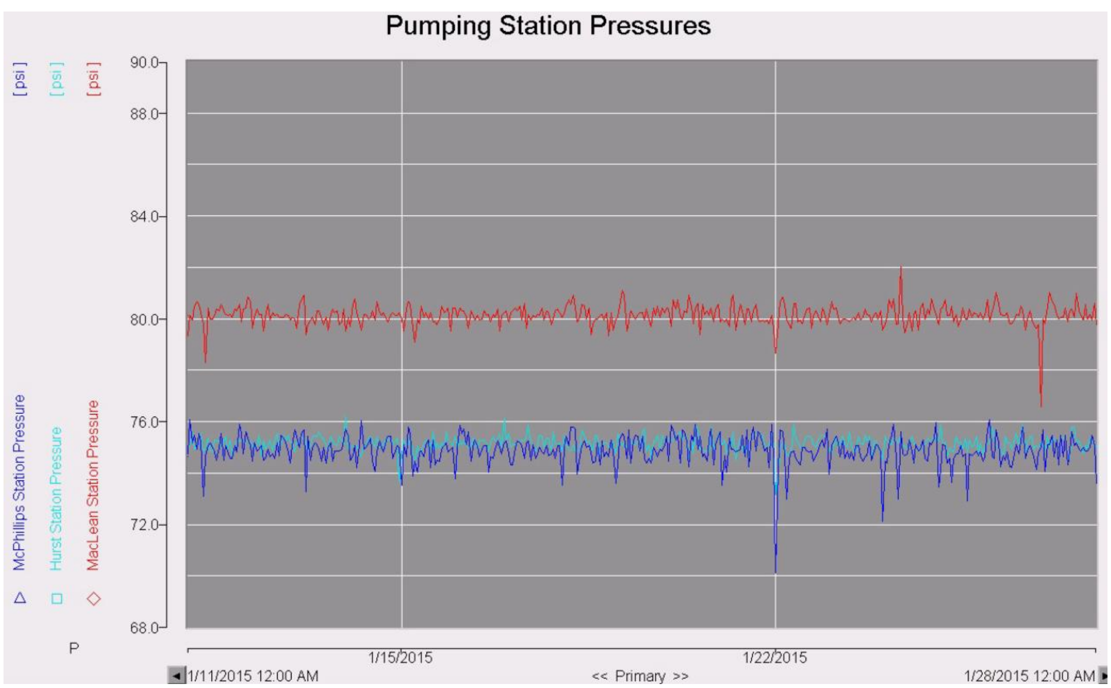

Figure 15: Pumping Station Pressure Readings, Jan 11-Jan 28, 2015

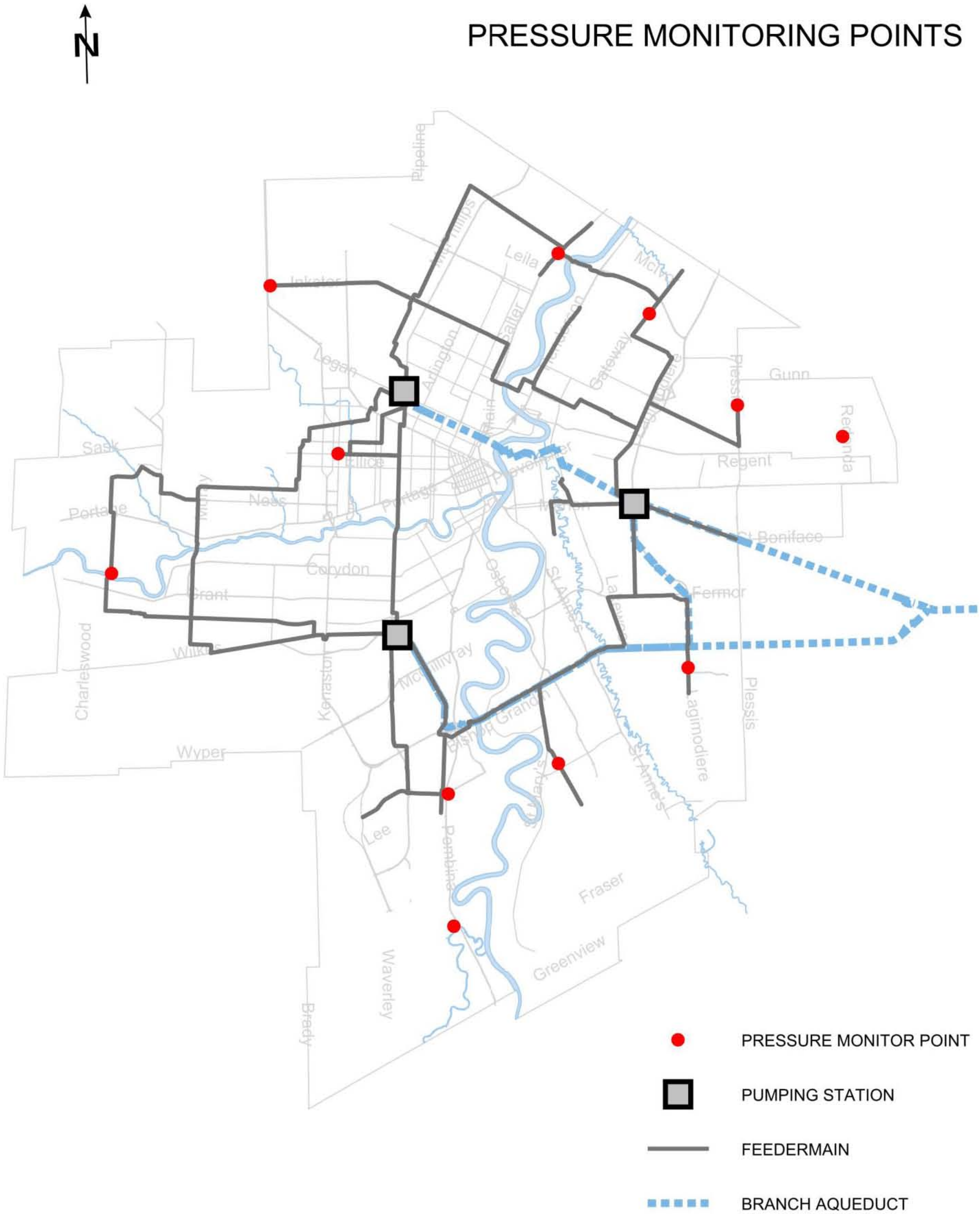

Figure 16: Pressure Monitoring Points in the Distribution System

4.6 Backflow and Cross Connection Evaluation

The City has maintained an active backflow prevention program since 1985. The current staff of 5 committed to the program is commendable for a city the size of Winnipeg. The program manages approximately 11,000 active back flow preventers (BFP) and tracks approximately 9000 per year (82% compliance rating), which indicates a thorough and tenacious program. The program has excellent metrics on inspections, work orders, and compliance records. The program leadership is active in Canadian and US cross connection control programs, and has published in trade journals regarding cross connection control.

Cross connection inspections were conducted at each of the sampling locations where positive TC/EC samples were collected. These inspections provided no indication of a problem associated with the three events.

Cross connection inspection records for facilities located near the positive TC/EC samples were reviewed as possible sources of contamination (**Appendix D**). These were included in the scenario analysis for potential point-source contaminations, as noted in Section 6.

In order to determine if backflow or cross connection contributed to the January 26, 2015 , May 26, 2014, and October 7, 2013 positive sample events, the backflow records were inspected for establishments that were located within a 500 m radius of the water sampling points which tested positive.

4.6.1 Methodology

4.6.1.1 Backflow

Twelve sample points were investigated as follows:

- Six locations that tested positive for TC and/or EC on January 26, 2015 (NE-01, NE-06, NE-07, SE-03, SE-04, and SW-07);
- One location that tested positive for TC/EC on May 26, 2014 (SW-12);
- Three locations that tested positive for TC and/or EC on October 7, 2013 (SE-05, SE-07, and SE-08); and
- Two additional locations that did not test positive on any of the three dates listed above (SE-02 and SW-04).

4.6.1.2 Cross Connection

Fourteen establishments were examined for premise isolation, including ten sample locations and four high risk establishments. These included the following:

- Six locations that tested positive for TC and/or EC on January 26, 2015 (NE-01, NE-06, NE-07, SE-03, SE-04, and SW-07);
- One location that tested positive TC and EC on May 26, 2014 (SW-12);
- Three locations that tested positive for TC and/or EC on October 7, 2013 (SE-05, SE-07, and SE-08); and
- Four establishments that were in the vicinity of the January 26, 2015 positive sample locations that were deemed to be high risk and have the most potential to actually create a cross contamination that would result in positive bacteriological samples.

4.6.2 Results

4.6.2.1 Backflow

The list of backflow records reviewed can be found in **Appendix D**. This list indicates when the backflow preventers were last inspected and what actions were taken if an inspection was overdue.

4.6.2.2 Cross Connection

Sample Locations: Not all of the ten sample locations investigated (NE-01, NE-06, NE-07, SE-03, SE-04, SW-07, SW-12, SE-05, SE-07 and SE-08) had or required backflow preventers. One issue was found at the establishment that houses sample point NE-07. A work order was sent out to resolve the issue and was completed on February 27th, 2015.

It is not suspected that a cross connection occurred at NE-07, just the potential for a cross connection had a depressurization of the distribution system occurred.

High Risk Establishments: The results of these inspections can be found in **Appendix D**. Issues were found for three of the four locations inspected. One of the locations already has plans in place to correct the problems. The other two locations were issued work orders.

4.6.3 Conclusions

Generally, cross connections must be regularly managed to prevent the occurrence of a backflow event. The City has a robust cross connection prevention program in place for public protection.

4.7 Valve Pit Evaluation

The City maintains automatic and manual air relief valves in the distribution system that allows the release of entrained air in the distribution system, protecting both piping and its associated equipment. Such valves are usually installed in valve pits and are installed only on the regional feedermain system. If automatic relief valves are malfunctioning and submerged, they can present a potential contamination source under low pressure conditions.

All air relief valves were inspected in a 2013 assessment of the City’s inventory of feedermain valve chambers. Air relief valve pits previously identified as having water in them and located near the TC-positive sample locations of the January 26, 2015, May 26, 2014, and October 7, 2013 positive sample events were inspected after the January 26, 2015 event as part of the assessment. None of the automatic air relief valves had water above the air relief valve vent. (**Appendix D**)

4.7.1 Methodology

In August of 2013, AECOM completed a “Feedermain Valve Chamber Condition Assessment” report. In this report, all of the air chambers and valve pits in the City were inspected. The ones that were identified as having water in them were plotted on a City map to see where they were in relation to the positive bacteriological sample sites from the January 26, 2015, May 26, 2014, and October 7, 2013 events. None of the air chambers and valve pits previously identified as having water in them were in the vicinity of sample point SW-12, the sole positive sample in the May 26, 2014 event. Fifteen air chambers and valve pits were identified as previously having had water in them and as being in the vicinity of the positive bacteriological sample sites for the January 26, 2015 and October 7, 2013 events. The location of these sites can be seen in **Figure 17**. The original inspection reports for all 15 valves can be found in **Appendix D**.

4.7.2 Results

City staff set out on the first week of March, 2015 to investigate the 15 air chambers and valve pits that were identified as previously having had water in them. The results of these investigations are summarized in **Table 4**.

Table 4: Results of the Air Chamber/Valve Pit Investigation

Valve Pit Inspection #	Asset ID #	Results of Inspection	Corrective Actions
VP-01	W-AV70000003	Water level at the top of pipe -not above air release valve	Chamber pumped out March 8, 2015
VP-02	W-AV70000043	3 inches of water in chamber	
VP-03	W-AV70000044	3 inches of water in chamber	
VP-04	W-AV70000110	Dry	
VP-05	W-AV70000116	Water level over air release valve	Chamber pumped out March 7, 2015
VP-06	W-AV70000293	Dry	
VP-07	W-AV70000312	Dry	
VP-08	W-VP00000103	Chamber full of water -not above air relief valves	Chamber pumped out March 6, 2015
VP-09	W-VP00000115	3 inches of water in chamber	
VP-10	W-VP00000125	2 chambers - both dry	
VP-11	W-VP00000131	Water level over air release valve	Chamber pumped out March 8, 2015
VP-12	W-VP00000177	5 feet of water in chamber -not above air release valve	Chamber pumped out March 6, 2015
VP-13	W-VP00000179	Chamber is alarmed when water level is 2 feet	When alerted, chamber is pumped out
VP-14	W-VP00000195	Dry	
VP-15	W-VP00000568	Some water in the chamber - not above air release valve	Chamber pumped out March 11, 2015

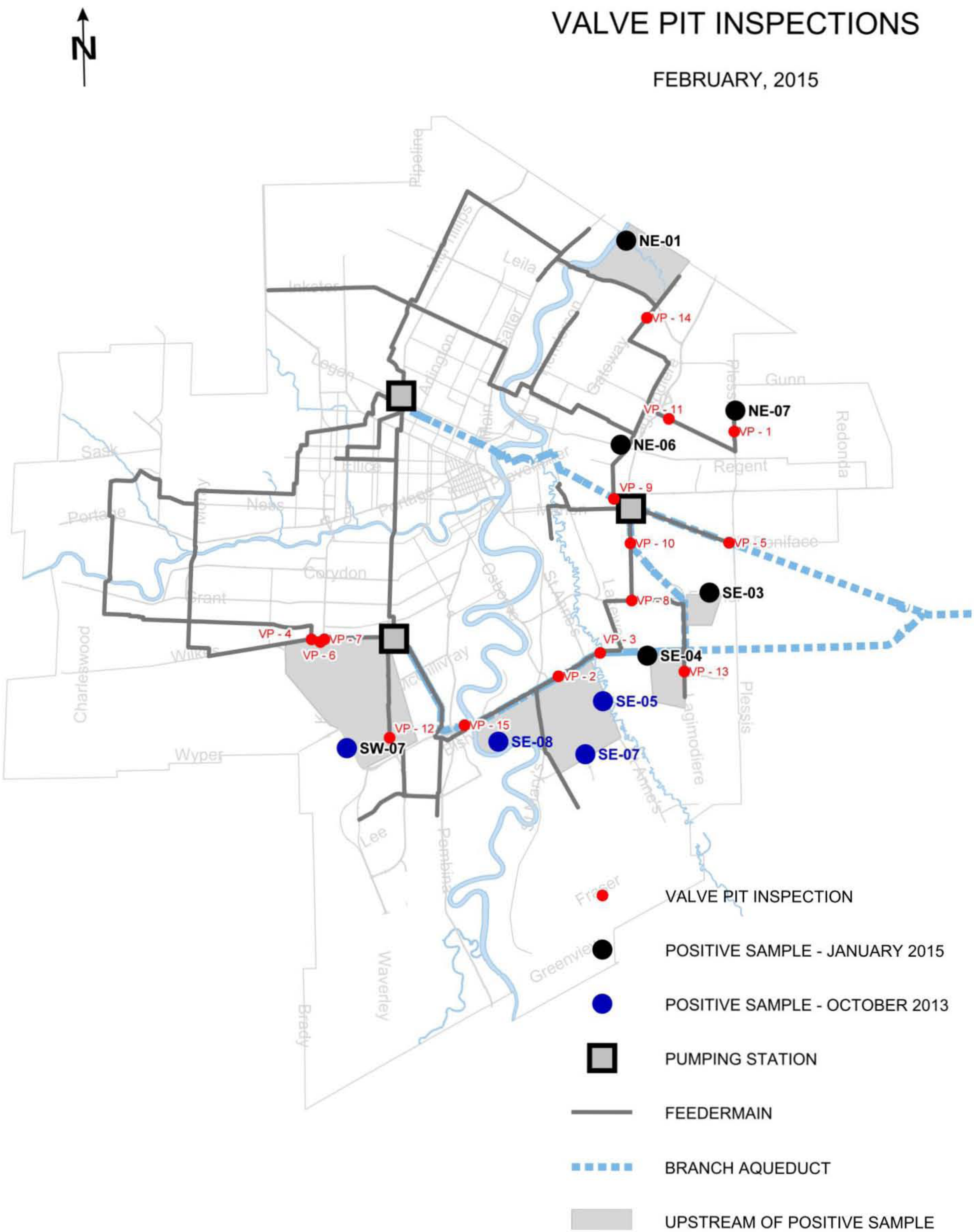

Figure 17: Valve Pit Inspections

4.7.3 Discussion

If a complete loss of pressure occurred in the distribution system, there is potential that water in the valve chamber could be drawn into the feedermain if the automatic air relief valve was submerged. Of the 15 air chambers and valve pits inspected, 10 of them had water. Two of the 10 had water above the air relief valve. The first location where the air relief valve was submerged, VP-05, was on a feedermain flowing east of the MacLean Pumping Station and is not hydraulically connected to any of the sample sites that tested positive for TC on either January 26, 2015 or October 7, 2013. The second location, VP-11, is on a feedermain that feeds sample point NE-07, which tested positive on January 26, 2015. This location, however, is not hydraulically connected to any of the remaining five sample sites which tested positive on January 26, 2015. In addition, both air relief valves that were submerged were manual air relief valves, not automatic. The risk of backsiphoning is associated with automatic air relief valves. Considering this, and the fact that no pressure loss in the system was observed on either event, it is very unlikely that submerged air release valves contributed to the January 26, 2015, May 26, 2014 or the October 7, 2013 positive sample results.

4.7.4 Conclusions

The air chambers/valve pits were likely not the cause of the positive coliform events. Despite this, many of the valve pits were filled with water from the environment – efforts should be made to reduce the chance of having automatic air relief valves from being submerged. Regular inspection and maintenance of such pits are part of the City's current SOPs.

4.8 Hydraulic Model Analysis of January 26, 2015 Distribution Sampling

4.8.1 Hydraulic Modelling

A hydraulic model analysis of the distribution system compliance sampling locations as it pertains to the water quality results from January 26, 2015 was conducted by the City's Winnipeg Water & Waste Department (WWD). This work was undertaken to support the Level 2 Assessment ordered by the Office of Drinking Water and completed by AECOM. **Appendix D** contains a summary of hydraulic analyses for the positive distribution sample results from 2013 and 2014.

The WWD Water Planning & Project Delivery Branch currently uses and maintains an EPANET hydraulic model of the water distribution system. The model file represents an 'all-pipes' network representation and the model performance is verified annually against field measurements. Hydraulic modeling simulations can be used to estimate distribution flow patterns, calculate water age (i.e. travel time), and source tracing analysis.

4.8.2 Source Tracing and Water Age Analysis

EPANET software allows source tracing and water age analyses to simulate the movement of water over time. This makes possible an evaluation of hydraulic flow patterns in the distribution system to estimate water travel time (water age), as well as the zone of influence both upstream and downstream of a user-specified model node. Further, the zone of influence of a water source (i.e. pumping station) can be estimated. In this manner, the movement of a contaminant within the water distribution system can be simulated.

4.8.3 Hydraulic Model Parameters

The following summarizes the assumptions, parameters and limitations of the hydraulic model analysis:

1. An Average Daily Demand of 190 MLD was selected for the analysis which is representative of normal City of Winnipeg water demand in January.
2. Typical diurnal demand pattern for the City.
3. The McPhillips Pumping Station is turned off for night time demand (12:00 am – 6:00 am).
4. 1-hour computational time step.
5. Constant discharge pressure at the pumping stations as per normal operations.
6. Normal distribution operations (i.e. no watermain breaks, hydrant flow etc.).
7. All valves are assumed to be in the open position, except for where the North Kildonan 600 mm feedermain crosses the Red River as this section was known to be offline on January 26, 2015 due pipe failure experienced the previous summer.

4.8.4 Scenario Analysis and Findings

4.8.4.1 Single Point Contamination in the Local Distribution System

A trace analysis was completed for each location sampled on January 26, 2015 which tested positive for EC and TC. The simulations were performed with a model node representative of the positive sample location as the source to estimate the downstream zone of influence of water passing through the sample location. Also, simulations were performed with the source node representative of the feedermain offtake(s) which supply each of the positive sample locations to estimate the upstream flow path of water to the sample location. Refer to **Appendix D** for screen captures from EPANET model trace simulations, which are representative of one time step during the simulation.

From a review of the flow patterns upstream of the sample locations which tested positive, it is noted that NE-06, NE-07 and SE-03 have little to no upstream influence. That is, they are located very close to feedermain offtakes, and as such, there is very little opportunity for any backflow from customer connections to be the cause of the sample results at these locations.

The January 26, 2015 sample at NE-07 had relatively higher values of EC and TC. A single point source contamination in the local water distribution system in vicinity of NE-07 is considered very unlikely as none of the other positive sample locations are within the hydraulic zone of influence downstream of NE-07. This is also supported by the model predicted feedermain flow directions and water age. The water age analysis is discussed later in this document. The feedermain flow paths are summarized in **Figure 19** (refer to Section 6) and indicate the normal feedermain flow directions for daytime and nighttime.

None of the January 26, 2015 sample locations which tested positive are connected in terms of the hydraulic zone of influence, downstream and upstream, within the local water distribution network. As such, a single point source contamination in the local water distribution system, in the vicinity of any of the sample locations which tested positive on January 26, 2015, is very unlikely. Additional sample locations which were tested on January 26, 2015 (and were found negative) were reviewed to determine if they are located within the hydraulic zone of influence of the samples locations which tested positive, as described below:

- NE-05 is located within the downstream zone of influence NE-06. From the model simulation, the estimated water travel time from NE-06 to NE-05 is 14 hours. The January 26, 2015 sample from NE-05 tested negative for TC and EC. NE-06 and NE-05 were sampled at 9:20 am and 9:10 am, respectively on January 26, 2015.

- NE-09 is located within the downstream zone of influence NE-07. From the model simulation, the estimated water travel time from NE-07 to NE-09 is 38 hours. The January 26, 2015 sample from NE-09 tested negative for TC and EC. NE-07 and NE-09 were sampled at 9:38 am and 9:55 am, respectively on January 26, 2015.
- SE-05 is located within the downstream zone of influence SE-04. From the model simulation, the estimated water travel time from SE-04 to SE-05 is 38 hours. The January 26, 2015 sample from SE-05 tested negative for TC and EC on January 26, 2015. SE-04 and SE-05 were sampled at 2:45 pm and 2:28 pm, respectively on January 26, 2015.

4.8.4.2 Single Point Contamination at the MacLean Reservoir

Five of the six positive samples from January 26, 2015 are supplied by the MacLean Reservoir and Pumping Station. These sample locations are in relatively close proximity to feedermain offtakes, and somewhat follow the north or south feedermain flow path from the pumping station, albeit with some negative samples in between. As such, the possibility of a single point contamination at the MacLean Reservoir was reviewed as part of the hydraulic model analysis.

Water age simulations were completed to estimate the travel time of water from the MacLean Pumping Station to each of the locations sampled on January 26, 2015 that are supplied by the MacLean Reservoir.

Table 6 shows the results of the analysis sorted by travel time from the MacLean Pumping Station to each sample location, as well as the time that the samples were taken. **Figure 19** (refer to Section 6) summarizes this information on a map of the feedermain network shown along with the sample locations. Refer to **Appendix D** for a screen capture from the EPANET model which shows colour coded simulated water age in the distribution system for one time step representative of typical or average water age.

Based on the hydraulic model predicted travel time of water from the MacLean Pumping Station to the sample locations which tested positive on January 26, 2015, the time that a potential contamination would have left the MacLean Pumping Station was back-calculated; this is summarized in **Table 5** below.

Table 5: Back-Calculated Date That Potential Contamination Would Have Left the MacLean Pumping Station

NE-01	
NE-07	
SE-04	
SE-03	
NE-06	

Table 6: Average Water Age for Sample Locations Supplied by the MacLean Reservoir

Sampling Location	*E.coli*-QT (MPNU/ 100 mL)	Total Coliform-QT (MPNU/ 100mL)	Time Sampled (hrs)	Water Age from MacLean (hrs)	Water Age from MacLean (days)
MacLean Station Discharge					
SE-01 [redacted]	<1	<1	10:18	-	-
From MacLean to NE Sorted by Travel Time					
NE-06 [redacted]	<1	1	9:20	[redacted]	[redacted]
NE-05 [redacted]	<1	<1	9:10	[redacted]	[redacted]
NE-07 [redacted]	9	53	9:38	[redacted]	[redacted]
NE-02 [redacted]	<1	<1	8:54	[redacted]	[redacted]
NE-09 [redacted]	<1	<1	9:55	[redacted]	[redacted]
NE-01 [redacted]	1	5	8:42	[redacted]	[redacted]
From MacLean to SE Sorted by Travel Time					
SE-02 [redacted]	<1	<1	10:37	[redacted]	[redacted]
SE-03 [redacted] Ave.	1	4	15:04	[redacted]	[redacted]
SE-04 [redacted]	1	3	14:45	[redacted]	[redacted]
SE-05 [redacted].	<1	<1	14:28	[redacted]	[redacted]
SE-13 [redacted]	<1	<1	11:12	[redacted]	[redacted]
SE-11 [redacted]	<1	<1	10:52	[redacted]	[redacted]

The water travel time to the sample locations which tested positive in the northeast zone varies by as much as two days. Three samples from the northeast with travel times between the highest and the lowest values for travel time (both of which were tested as positive) came back as negative. It is noted that the follow up testing completed on January 28 and 29, 2015 came back negative at all of the re-sample locations. The water travel time to all sample locations in the southeast varies by as much as only 10 hours. Four of the six locations in the southeast sampled on January 26, 2015 came back negative. The sample locations in the southeast which tested negative were also in relatively close proximity to feedermain offtakes.

From the results shown in **Table 5**, a potential contamination from the MacLean Reservoir would have had to have been present over a two day period to align with the positive sample results.

Finally, for a contamination of the MacLean Reservoir to be a plausible scenario it would be expected to notice higher values for EC and TC for the samples sites with the shortest water age. The measured high chlorine residual for all samples which tested positive also does not support this scenario.

4.8.4.3 Contamination from January 18, 2015 Feedermain Operations

It was suggested that the Level 2 Assessment include a review of the operation of the Birds Hill Feedermain on January 18, 2015 which caused numerous discoloured water complaints from customers. Refer to **Appendix D** for a map indicating the locations of the discoloured water complaints received by the Department on January 18, 2015.

Comparing the water age map and the locations of the January 18, 2015 discoloured water calls (**Appendix D**), it is evident that the water in the affected area turns over in 1 to 4 days. As such, this water had left the distribution system prior to the sampling conducted on January 26, 2015. The presence of any contamination may have been detected as part of the routine sampling conducted on January 19, 2015.

4.8.5 Conclusions

Based on the results of the hydraulic analysis, it is highly unlikely that the following scenarios contributed to the January 26, 2015 positive samples:

- a single point contamination of the distribution system;
- a single point contamination of the MacLean Reservoir; or
- contamination from the January 18, 2015 Birds Hills Feedermain operation

The appearance and disappearance of contamination (within a day) in sample locations with hydraulic travel times that are days apart do not appear to be indicative of a single contamination event.

4.9 Effect of Discoloured Water on the January 26, 2015 Positive Bacteriological Samples

4.9.1 Methodology

Prior to this assessment, the City had undertaken extensive investigations on causes and possible effects of discolored water. No links to bacteriological parameters were found. However, as part of this assessment, the most recent positive TC/EC event was investigated as it related to discolored water to see if the previous conclusion is still valid. Discoloured water complaint data for 2 weeks prior to the January 26, 2015 positive bacteriological samples were examined to see if there was any correlation between discoloured water and the event. To determine this, the discoloured water calls (information requests and Service Requests (SR)) were examined to see if any of the complaints were in the vicinity (upstream and downstream influence) of the six positive EC and TC samples. For the occasions where a substantial number of complaints in the vicinity of the sample point was observed (greater than 10), the estimated number of times that the water would have turned over between when the calls were received and when the positive samples were taken was calculated. This number was calculated by taking the number of days between when the calls were received and when the positive samples were taken and dividing this number by the estimated average water age at the sampling point. The average water age and upstream / downstream zone of influence were estimated from hydraulic model simulation as outlined in Section 4.8.

4.9.2 Observations

Table 7 summarizes two weeks of complaint data in relation to the six positive samples taken on January 26, 2015. For occurrences where the number of complaints is greater than 10, the estimated number of times that the water would have turned over between when the calls were received and when the positive samples were taken is listed. **Appendix D** illustrates complaint data for each day for the two weeks leading up to and including January 26, 2015.

Table 7: Number of Discoloured Water Complaints in the Vicinity of the Six Positive Sample Points

Sampling Location	Parameter	Jan 12, 2015	Jan 13, 2015	Jan 14, 2015	Jan 15, 2015	Jan 16, 2015	Jan 17, 2015	Jan 18, 2015	Jan 19, 2015	Jan 20, 2015	Jan 21, 2015	Jan 22, 2015	Jan 23, 2015	Jan 24, 2015	Jan 25, 2015	Jan 26, 2015
NE-01	# of Discoloured Water Calls							**1**	**2**		**1**	**>10**	**1**	**1**	**3**	**>10**
	# of Turnovers											1.4				0
NE-06	# of Discoloured Water Calls	**2**	**2**					**>10**		**5**	**1**			**4**		**7**
	# of Turnovers							11.4								
NE-07	# of Discoloured Water Calls							**>10**	**11**	**2**					**3**	
	# of Turnovers							4.4	3.9							
SE-03	# of Discoloured Water Calls															
	# of Turnovers															
SE-04	# of Discoloured Water Calls															
	# of Turnovers															
SW-07	# of Discoloured Water Calls		**1**				**1**			**1**		**>10**	**5**		**6**	**1**
	# of Turnovers											3.2				

An analysis of each of the sampling points identified in the above table follows:

- **Sample Point NE-01:** For eight of the 15 days examined, there were calls in the vicinity of the NE-01 sampling point. On six occasions, there were only three calls or less. On two occasions (January 22, 2015 and January 26, 2015), there were over 10 calls. Considering the occasions where there were over 10 calls for the January 22, 2015 occasion, it is estimated that the water would have been turned over 1.4 times before being sampled and for the January 26, 2015 occasion, the water would have been representative.
- **Sample Point NE-06:** For seven of the 15 days examined, there were calls in the vicinity of the NE-06 sampling point. On six occasions, there were only seven calls or less. On one occasion (January 18, 2015), there were over 10 calls. Considering the occasion where there were over 10 calls, January 18, 2015, it is estimated that the water would have been turned over 11.4 times before being sampled.
- **Sample Point NE-07:** For four of the 15 days examined, there were calls in the vicinity of the NE-07 sampling point. On two occasions, there were only three calls or less. On two occasions (January 18 and 19, 2015), there were over 10 calls. Considering the occasions where there were over 10 calls, for the January 18, 2015 occasion, it is estimated that the water would have been turned over 4.4 times before being sampled and for the January 19, 2015 occasion, it is estimated that the water would have been turned over 3.9 times before being sampled.
- **Sample Point SE-03:** For the 15 days examined, there were no calls in the vicinity of the SE-03 sampling point.

- **Sample Point SE-04:** For the 15 days examined, there were no calls in the vicinity of the SE-04 sampling point.
- **Sample Point SW-07:** For seven of the 15 days examined, there were calls in the vicinity of the SW-07 sampling point. On six occasions, there were only six calls or less. On one occasion (January 22, 2015), there were over 10 calls. Considering the occasion where there were over 10 calls, January 22, 2015, it is estimated that the water would have been turned over 3.2 times before being sampled.

4.9.3 Discussion

4.9.3.1 Analysis of Discoloured Water Complaints with Regards to the January 26, 2015 Positive Bacteriological Samples

For the six sites examined, there were a total of six occurrences in the two weeks prior to the January 26, 2015 positive samples where the discoloured water calls in the vicinity of the positive samples were greater than 10. Three of the six occurrences took place before January 19, 2015. On January 19, 2015, all six locations were sampled and none of them came back positive for TC or EC. It is therefore likely that these occurrences can be ruled out as having contributed to the positive samples.

Of the three occurrences that happened after the January 19, 2015 sampling, two of them occurred at sampling point NE-01 and one occurred at SW-07. For SW-07, the occurrence took place on January 22, 2015 and it is estimated that the water at this point would have turned over 3.2 times. It is therefore unlikely that the discolored water would have contributed to the positive sample. For NE-01, the occurrences took place on January 22, 2015 and January 26, 2015. For the January 22, 2015 occurrence, it is estimated that the water would have turned over only 1.4 times and for the January 26, 2015 occurrence, the water would have been representative as to what was in the system.

4.9.3.2 Analysis of the January 26, 2015 Discoloured Water Event

On January 26, 2015 there were greater than 10 discoloured water calls in the vicinity of sample site NE-01. On the same day, NE-01, along with five other sample locations tested positive for EC and/or TC. NE-01 is fed from the MacLean Pumping Station. Water from the MacLean Pumping Station flows north to NE-01 and NE-01 does not hydraulically feed any of the other five positive sample locations. The scenario of a single point contamination originating at NE-01 is therefore hydraulically impossible. NE-01, however, was the first sample taken on the sample collector’s route so a possible scenario could be that NE-01 was truly a contaminated site and the sample collector inadvertently contaminated the five other samples with water obtained at the NE-01 site. The analytical data, however, does not support this hypothesis. NE-01 tested positive for 1 MPNU/ 100 mL of EC and 5 MPNU/ 100 mL of TC. NE-07 tested positive for 9 MPNU/ 100 mL of EC and 53 MPNU/ 100 mL of TC. In the case where one sample contaminates another, the original contamination would be diluted and therefore the readings should be lower, not higher. In addition to this, none of the 7 EC isolates from the 4 sample sites tested for genetic fingerprinting were similar to each other. In the situation where one sample was contaminating another, it is likely that identical genetic fingerprinting would be observed. For these reasons, the scenario where NE-01 was truly a contamination event and the five other samples were inadvertently contaminated by it is highly unlikely.

4.9.3.3 Analysis of the January 18, 2015 Discoloured Water Event

During the two weeks prior to the positive January 26, 2015 samples, there was one day, January 18, 2015, where a significant number of discoloured water complaints were received (615 Information Requests and 47 SRs). The incident was linked to the closure of a section of the Birds Hill feedermain by

City staff to undertake some nearby repair work. Model analysis of this incident revealed that it was likely that a large number of flow reversals and changes in velocity would have occurred, leading to the calls. Pressure data indicated pressures in the area as low as 42 psi (normally around 70 psi). This incident caused a significant number of discoloured water calls in the vicinity of two of the sample points (NE-06 and NE-07) which later tested positive for TC and EC. It was noted above, however, that both of these samples tested negative the day after the incident. In addition to this, the water would have turned over 11.4 times and 4.4 times for NE-06 and NE-07 respectively. This incident also produced a high number of complaints in the vicinity of other sample points (NW-05, WC-12) and these locations did not have positive results for EC or TC.

4.9.3.4 Historical Correlation between Discoloured Water Complaints and Positive Bacteriological Samples

Over the past few years, there have been many occurrences of discoloured water in the distribution system. The City has separately completed a thorough investigation of discolored water occurrences and causes which found no evidence of health concerns with observed discolored water events. Monthly SRs for the past three years were plotted against monthly occurrences of positive bacteriological samples to see if there was a correlation. As seen in **Figure 18**, no relation between SRs and positive samples could be drawn.

4.9.4 Conclusions

From the analysis described in this report, it is likely that only one sample point, NE-01, was under the influence of discoloured water at the time it was sampled (January 26, 2015). It is very unlikely that NE-01 was a single point source of contamination as it is not hydraulically connected to the other sample points that tested positive. In addition, it is unlikely that NE-01 was truly a contamination event and the five other samples were inadvertently contaminated by it. In this scenario, lower positive results along with similar genetic fingerprinting would have been anticipated. This was not the case.

It is unlikely that the January 18, 2015 incident which caused high levels of customer complaints can be tied to the six positive bacteriological samples on January 26, 2015. No positive results were observed when the samples site were sampled on January 19, 2015 and it is estimated that the water would have turned over 2.9 to 11.4 times (depending on the location of the site) between the incident and January 26, 2015.

No link could be found between historical discoloured water complaints and historical positive bacteriological samples.

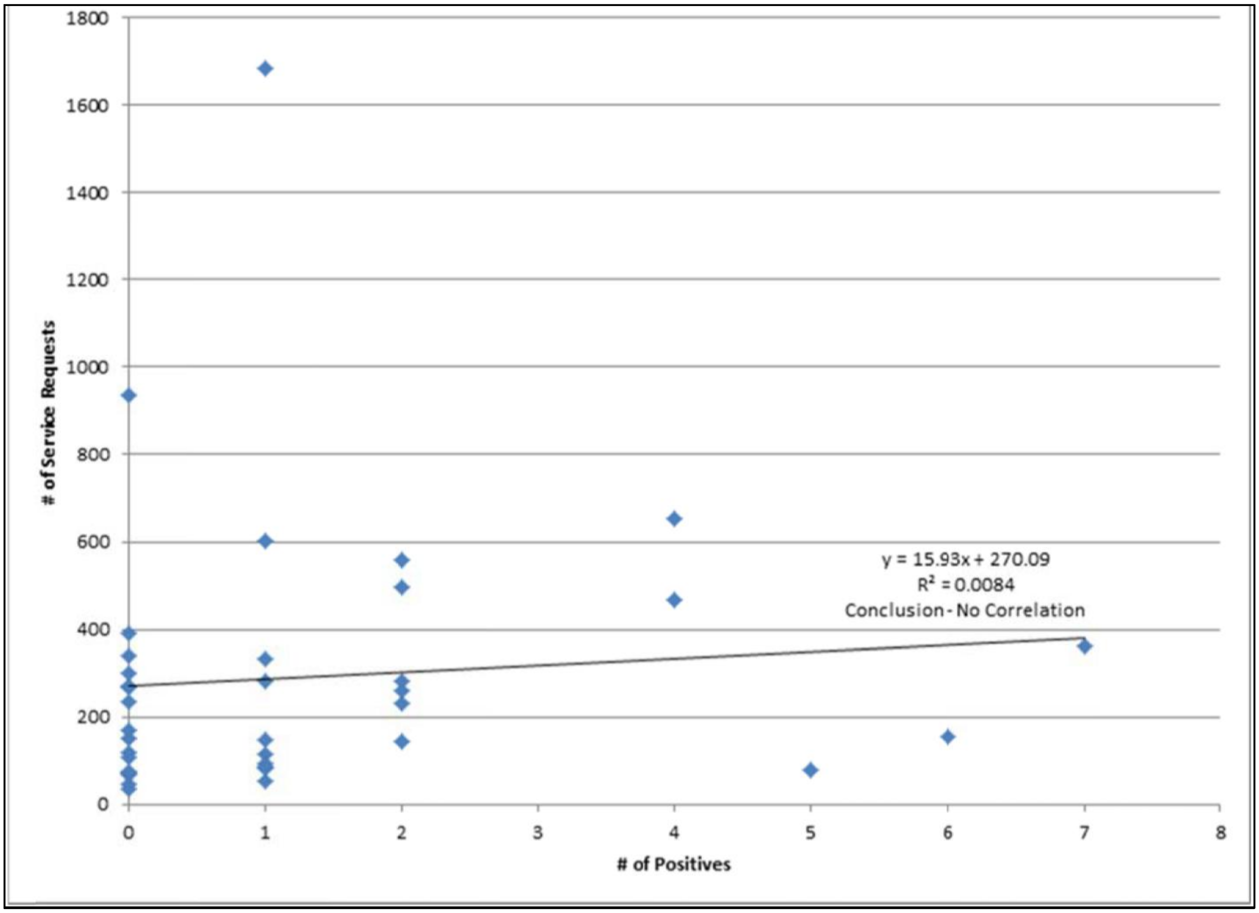

Figure 18: Monthly Service Requests vs Monthly Occurrence of Positive Bacteriological Samples