6. Analysis of Data Relevant to the January 26, 2015 Event

Having identified a list of possible scenarios that could explain the TC and EC results of January 26, 2015 the team next considered the available data and how those data tended to either support or refute each scenario. This exercise was conducted to identify what data were available, what additional data was needed, and which scenarios were deserving of more intensive investigation.

The data available for analysis were listed and to the extent possible presented for consideration, including:

- **Time and ratio-based patterns** of TC/EC/HPC/Chlorine data: How are the data sequenced in time?
- **Geographic patterns** of TC/EC/HPC/Chlorine data: How are the data distributed geographically?
- **Hydraulic p atterns** (flow paths, day and night): How do the flow patterns affect contaminant transport?
- **Chlorine die-off patterns**: How would the disinfecting characteristics of chlorine over a period of contact time impact the levels of TC/EC/HPC in the positive samples?
- **HPC patterns**: How do the HPC levels compare to the levels of TC/EC?
- **Operational patterns**: Do any operational activities correspond with the observed geographical and time-based patterns of the positive samples?
- **Public Heal th d ata**: Are there any public health records indicating a significant increase in Acute Gastrointestinal Illness (AGI) during the week following the January 26, 2015 event?

Each of the above datasets was considered with regards to how the characteristics of each dataset supported a given scenario, refuted the scenario, or was neutral to scenario (neither supporting nor refuting). The characteristics of each dataset related to this analysis are presented below.

6.1 Time and Ratio-based Patterns of TC/EC/HPC/Chlorine data

Distribution samples for TCR compliance prior to the January 26, 2015 event were typically collected every Monday of the week. Previous to January 26, 2015 these locations were last sampled on Monday January 19, 2015. Because of illness, one of the two sample collector's samples were delivered to and analyzed by the contract laboratory the following day (January 27, 2015). Only samples that were delivered to and analyzed by the lab on January 26, 2015, were reported as positive for TC/EC. The positive sample sites were re-sampled on January 27, 2015 and January 28, 2015 along with upstream and downstream samples. All of the samples collected on January 27 and 28, 2015 and the samples collected on January 26, 2015 but delivered to the laboratory on January 27, 2015 were negative for TC/EC.

This indicates that all sample sites were TC/EC negative 7 days prior to January 26, 2015 and TC/EC negative on January 27 and 28, 2015. In addition, non-compliance samples collected on January 20, 2015 were also negative for TC. Thus, any activity that resulted in the January 26, 2015 event likely happened between January 20 and January 27, 2015. In addition, those samples collected on January 26, 2015 but analyzed on January 27, 2015 were negative for TC/EC. This leads to the conclusion that the event of January 26, 2015:

- Did not impact the samples collected the previous week (January 19, 2015);

- Did not impact the samples collected on January 26, 2015 but which were analyzed on January 27, 2015; and
- Did not impact samples collected on January 27 and 28, 2015 for these sample sites.

This indicates that the positive TC/EC samples were all collected by a single sample collector, and that the positive samples were all received and analyzed at the laboratory on the same day (January 26, 2015). The number of positive TC samples collected and analyzed on that day was highly irregular (6 of 21 samples collected, or ~29%), compared to the January 2010-February 2015 database of 0.4% positive.

The ratio of TC samples that were EC positive was analyzed for the City 2010-2015 compliance database. Of the 44 samples that were TC positive prior to January 26, 2015, 3 were positive for EC (or ~7%). Of the 6 samples positive for TC on January 26, 2015, 5 were EC positive (~83%). This indicates that the ratio of positive TC/EC samples was highly irregular during the January 26, 2015 event.

The HPC data collected on compliance samples from January 1, 2010 through February 11, 2015 were analyzed for frequency of detection above detection limits for comparison to the January 26, 2015 event. Over the 5 year period, 10% of all compliance samples collected had HPC values reported above the detection limit of 10 CFU per mL. On January 26, 2015, 1 sample reported a HPC value of 10 CFU per mL, with the remaining 41 samples reported as <10 CFU per mL, or below the detection limit. Thus about 2% of the samples were below detection limit, compared to 10% for the entire dataset from January 2010-February 2015. This indicates that HPC values were typical of good bacterial water quality during the event of January 26, 2015.

Chlorine residual data from the 2010-2015 databases were analyzed and compared to data from the January 26, 2015 event. The average free chlorine residual in the entire database was 0.68 mg/L, compared to 0.78 mg/L for the 6 samples reported as TC positive on January 26, 2015, with the lowest reported value of 0.49 mg/L. Thus the free chlorine residuals for the TC positive samples of January 26, 2015 were indicative of good water quality.

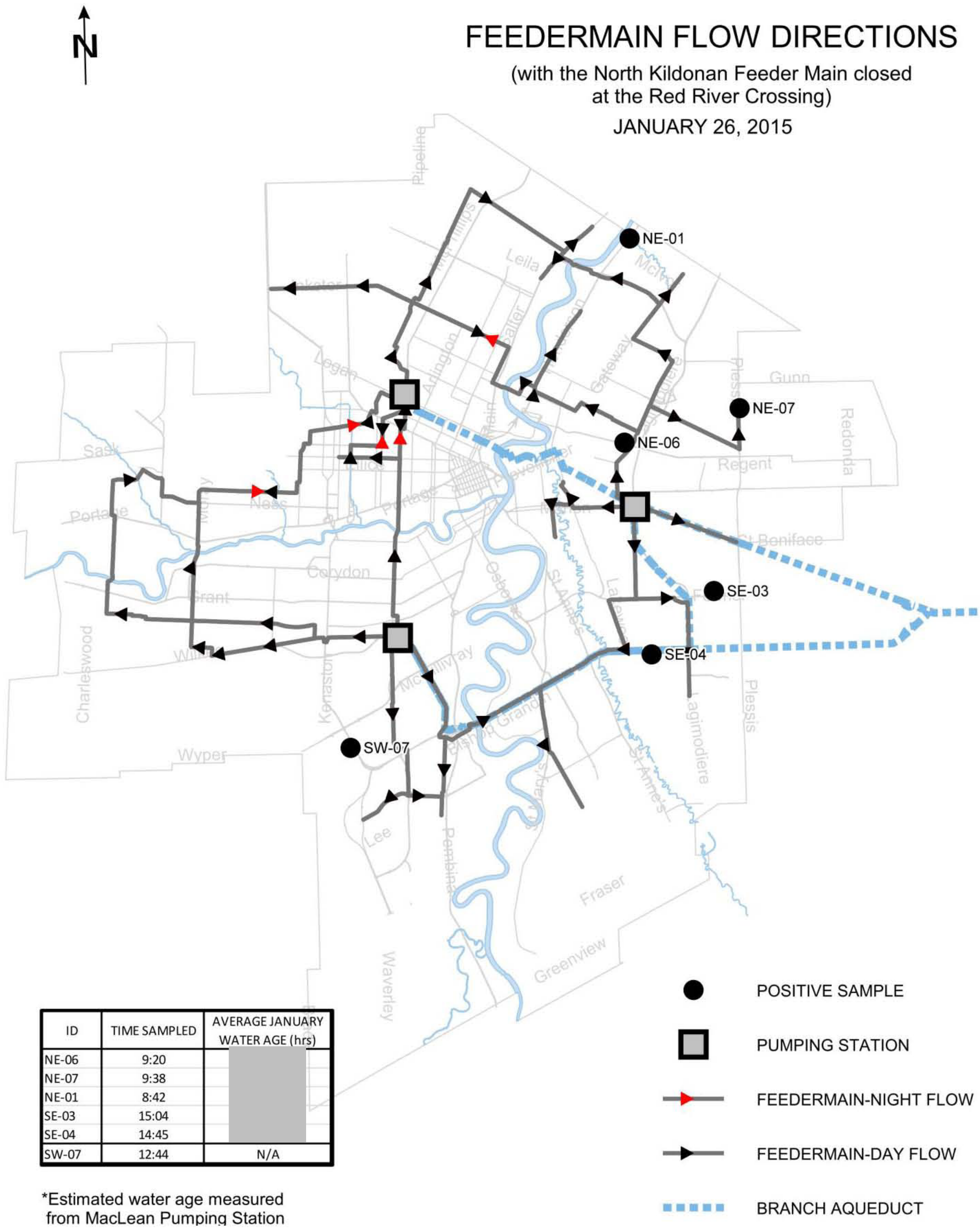
6.2 Geographic Patterns of TC/EC/HPC/Chlorine Data

The geographic spread of the positive TC samples collected on January 26, 2015 was analyzed as a function of potential contaminant location, which was used in conjunction with the time data to evaluate the single point-source and multiple point-source scenarios. In general, the positive sample locations were randomly dispersed through the distribution system, with positive samples and negative samples showing similar distributions. It was noted to the contiguous positive samples, such as sample locations SE-03 and SE-04, could possibly share a common flow path which has no negative samples in-between. These and other similarly aligned sample locations were closely scrutinized during the single and multiple point-source scenario evaluations and computer simulations.

Similarly, HPC and free chlorine residual data showed neither a geographic pattern consistent with elevated TC densities, nor any aberrations from normal.

6.3 Hydraulic Flow-Paths

Computer models (generated through EPANET) of the distribution system were used to generate flow paths and water age maps of the feedermain system. These models provided the base-maps against which the time characteristics of sample collection and TC detection were evaluated. The base map, showing samples from January 26, 2015, and primary flow paths on the feedermains, is provided in **Figure 19**.



ID	TIME SAMPLED	AVERAGE JANUARY WATER AGE (hrs)
NE-06	9:20	
NE-07	9:38	
NE-01	8:42	
SE-03	15:04	
SE-04	14:45	
SW-07	12:44	N/A

*Estimated water age measured from MacLean Pumping Station

Figure 19: Computer Model Results Showing Flow Paths, Sample Locations, and Water Age

Water quality data were analyzed against the time of day sampled and the “water-age/time-of-travel” between locations where the positive TC samples were reported. This information was used to evaluate the pattern of contaminant spread from a single point-source and multiple point-source scenarios. In general, the time of travel analysis did not indicate that the single point-source would have been characterized by the appearance and disappearance of contamination within a day in sample locations with hydraulic travel times that are days apart.

6.4 Chlorine Die-Off Characteristics

In the event of contamination of a distribution system, it is typical to see free chlorine residuals decrease as the contamination consumes the chlorine residual. The typical pattern associated with sanitary contamination of a drinking water supply is to see free chlorine residuals decrease as levels of HPC, TC, and EC increase. Thus, the increased detections of TC and EC observed on January 26, 2015 should have been be associated with decreased free chlorine levels if a significant contamination in the DS occurred. As is indicated in the **Table 8** (condensed version of **Table 2**), the highest level of TC density was also associated with the highest free chlorine residual. These data were tested for correlation (**Figure 20**), and the relationship between free chlorine residual and TC density was found to be random, although the data tendency was towards higher chlorine residuals associated with higher TC levels. This finding is counter-indicative of a either a single point-source or a multiple point-source contamination event in the distribution system.

Table 8: Positive Samples Collected January 26, 2015

Sample Name	Free Chlorine (mg/L)	Turbidity (NTU)	EC (MPNU/ 100 mL)	TC (MPNU/ 100 mL)	HPC (CFU/mL)
SW-07	0.74	0.17	1	1	<10
SE-04	0.78	0.31	1	3	<10
SE-03	0.76	0.25	1	4	<10
NE-01	0.49	0.26	1	5	<10
NE-07	0.96	0.19	9	53	<10
NE-06	0.95	0.31	<1	1	<10

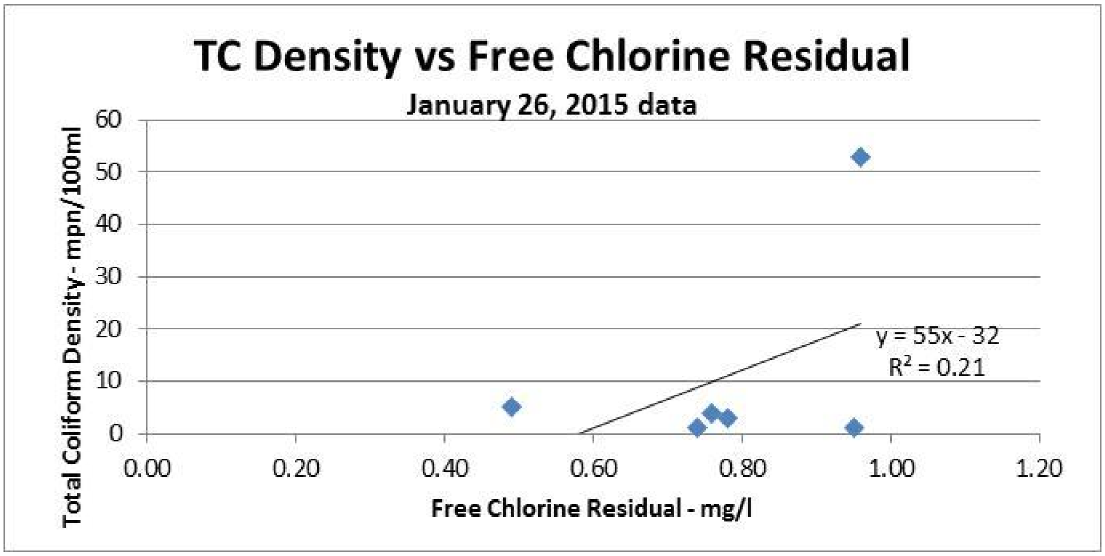


Figure 20: Correlation between TC Density and Free Chlorine Residual for Positive TC Samples of January 26, 2015.

Similar to the discussion on free chlorine above, elevated HPC counts are typically encountered prior to and in conjunction with TC positives samples (particularly in the case of biofilm development in water distribution systems), and are likewise found in sanitary contamination of water distribution systems. HPC levels on January 26, 2015 were low, and did not indicate any association with the samples reported as positive for TC.

6.5 Maintenance Operations

Distribution system maintenance operations (such as main leak/break repair, valve closures, hydrant operations, etc.) were reviewed to see if there was any activity that might be associated with the positive TC samples reported on January 26, 2015. Logs of all maintenance activities are provided in **Appendix E**, and the activities that had a potential for contamination are plotted on maps of the City in **Appendix E**. An example of one of these maps showing the watermain repairs for January 12-26, 2015 is shown in **Figure 5** in Section 4. There were no unusual maintenance activities reported for the 2 weeks prior to January 26, 2015. Of those routine maintenance items in the two days prior to January 26, 2015, none provided a pattern consistent with the location of the positive samples reported on January 26, 2015.

6.6 Public Health Data

In an acute, widespread sanitary contamination of a large public drinking water supply, it is reasonable to expect an increase in AGI case admissions at health clinics and hospitals. Another common metric is an increase in anti-diarrheal over-the-counter medications. The Winnipeg Regional Health Authority was contacted regarding any unusual increase in AGI cases following the January 26, 2015 event, and Lisa Richards (Medical Health Officer, WRHA) reported: "*I did indeed work with our epidemiology unit during both BWAs, and there was no unusual enteric activity for the reportable diseases*." This indicates that the event of January 26, 2015 was not associated with any observed increase in AGI in an epidemiologically targeted evaluation of available data.

6.7 Laboratory Protocol Review

AECOM reviewed the lab analysis process from sample receipt through incubation. Observations from this visit indicated an operating procedure following the HPC analysis that could affect the TC/EC analysis. Steps have been taken to reduce the risk of contamination from this process for all Winnipeg drinking water samples submitted to the lab. It is noted that the contract lab holds formal accreditation by the Canadian Association for Laboratory Accreditation (CALA) for 24 different microbiology test methods, and conducts bi-annual third party site audits and required twice-yearly participation in a formal proficiency test program. Routine cleaning practices, work area contamination monitoring, and method blanks are standard practice. The lab participates in performance testing samples each year for the tests used on the City of Winnipeg samples, and since the late 1990s, has consistently met accrediting agency criteria for demonstrating proficiency and maintenance of accreditation.

6.8 Scenario Analysis

Each of the potential sources of contamination implicated in the January 26, 2015 event was considered as a single point-source, a multiple point-source triggered by a single hydraulic event, or a sampling/lab analysis source. Each of these three scenarios was evaluated with a simple metric for fit to available data and patterns:

- The data pattern fits the scenario: +1
- The data pattern is neutral to scenario (neither supports nor contradicts): 0
- The data pattern contradicts scenario: -1

This analysis is not intended to be rigorous, but rather provides a systematic framework against which the 3 scenarios were discussed and summarized. The team also performed a sensitivity analysis on each of the valuations, adjusting the score based on a more critical interpretation of the data pattern based on uncertainties and less-likely explanations of data patterns. As an example, the random geographic pattern of positive samples could either fit the sample collection/lab scenario (+1), or noting that both were random, be neutral (0). This step was included to counter any bias the group might have, noting that only City staff and AECOM were involved in the analysis. A summary of the discussions used in each of the ratings is discussed below and summarized in **Table 9**, with the result of the sensitivity analysis shown in parentheses.

Time-based patterns: The TC/EC positives all appeared on one day, with all samples on the following day being negative. All other water quality parameters were normal.

- Single point-source: Considering that the 26 sample locations were as much as 17 to 68 hours from the most likely single point-source (MacLean Pumping Station), and that SW-07 is not fed from the MacLean Pumping Station, the temporal pattern does not match what would be expected from a single point-source. (-1);
- Multiple point-sources: Noting that a single hydraulic pulse or surge could disrupt flow patterns in the particular area served by the primary source, it is conceivable that several point sources could be triggered by a short pulse or pressure drop in the system. Residual chorine could then kill any TC/EC disturbed or introduced as a result of the surge, resulting in clean samples the next day. However, this does not explain the positive result at sample location SW-07, which is somewhat hydraulically isolated from the other positive samples. (+1)/(0); and
- Sampling/lab source: These would tend to be independent of any distribution system-based temporal variations and would appear random over the course of the sampling period, or could be sequential based on the time of sampling or time of analysis. (+1)/(0)

Geographical Patterns: The geographical pattern is one of random distribution over the entire area sampled, with negative samples dispersed in an equally random pattern.

- Single point-source: single point-source would be expected to follow a pattern from the point of contamination radially outward. This does not fit the spatial data pattern observed (-1);
- Multiple point-sources: A single pressure pulse could trigger multiple point-sources at points of integrity failure in the distribution system (flooded air relief vaults, faulty backflow preventers, leaking watermains, etc.) (+1); and
- Sample/lab source: These would tend to be independent of any distribution system based spatial variations and would appear random over the course of the sampling period. (+1)/(0)

Hydraulic Flow Patterns: Hydraulic flow paths are presented in **Figure 19**. The occurrence pattern of positive samples appears to be independent of flow paths.

- Single point-source: single point-source contamination would be expected to follow hydraulic flow paths, and be present in a consistent path between source and sample. This type of distribution was not observed. (-1);
- Multiple point-sources: multiple point sources would be expected to be independent of hydraulic flow patterns. With positive samples being independent, and multiple point-sources being independent, this pattern is neutral. (0); and
- Sample/lab source: Similar to the discussion for multiple point-sources, sample/lab sources would tend to be independent of any distribution system hydraulic patterns, and thus neutral. (0)

Chlorine residual patterns: Chlorine residuals were consistently high during the event, and variations in concentration were random across the monitoring area.

- Single point-source: Chlorine residuals would be expected to decrease at the point of contamination, with higher TC associated with lower chlorine residuals. Chlorine residuals observed were counter-indicative for this scenario. (-1);
- Multiple point-sources: Like a single point- source, chlorine residuals would be expected to decrease with proximity to contamination sources. Data are counter-indicative. (-1); and
- Sample/lab source: Sample/lab contamination would be independent of field-measured chlorine residuals, as samples are dechlorinated upon sampling. (+1)

HPC Patterns: The HPC patterns were consistent across all samples and were indicative of low bacterial levels in the distribution system.

- Single point-source: HPC levels are typically very high in the presence of environmental sources of TC and EC. The results are counter-indicative. (-1);
- Multiple point-sources: As with a single point- source, observed data are counter-indicative. (-1); and
- Sample/lab source: Contamination that occurs during sampling resulting in positive TC and EC levels would also likely result in elevated HPCs, and results are counter-indicative of this. However, lab contamination that occurred between the HPC analysis and the TC/EC analysis could explain high TC/EC levels with low HPC levels. This pattern would rate as a (-1) for sample contamination, and (+1) for lab contamination. (0)/(-1)/(+1)

Distribution System Operations/Maintenance Patterns: The maintenance activities data indicate no pattern between distribution system maintenance activities and the TC positive sample locations.

- Single point-source: Maintenance activity would be expected to coincide with positive sample locations. No association was observed. (-1)/(0);
- Multiple point-sources: Same as with single point-source. Although maintenance activities and positive samples were randomly distributed across the sampled area, there would be expected pairs between maintenance and positive sites. No association was observed (-1)/(0); and
- Sample/lab source: Contamination resulting from a sample or lab source would likely be independent of operation activities, thus matching the pattern of no relationship. (0)

Epidemiological Data for AGI: A waterborne disease outbreak would be expected if the source originated in the public water supply. There were no indications of waterborne disease outbreak as a result of the January 26, 2015 event, which is counter-indicative of the source originating in the public water supply.

- Single Point- Source: Any sanitary contamination from a single point-source that resulted in widespread detection of EC would be expected to be accompanied by increased AGI. These data are counter-indicative of that scenario. (-1);
- Multiple point-sources: Same observation as with single point-source. (-1); and
- Sample/lab source: Any contamination that occurs in the process of sampling or analysis would result in no public health impact, which is consistent with the epidemiological data. (+1)

Table 9: Scenario Analysis

Data Scenario	Time Pattern	Geo Pattern	Flow Path	Chlorine Residual	HPC Data	DS Ops Issues	AGI Data	TOTAL (Range)
Single Point Source	-1	-1	-1	-1	-1	-1(0)	-1	**-7** (-7/-6)
Multiple Point Sources	1/(0)	1	0	-1	-1	-1/(0)	-1	**-2** (-3/-1)
Sample/Lab Source	1/(0)	1/(0)	0	1	0 (-1/+1)	1(0)	1	**5** (6/1)

**Value in parenthesis indicates sensitivity analysis range.*

6.9 Scenario Analysis Discussion

The scenario analysis exercise was an attempt to consider and rank events that would support or refute the likely causes of the January 26, 2015 event, but cannot be used to prove or disprove any particular hypothesis. Instead, the data patterns are used to indicate which scenarios are least likely and which are most likely. The sensitivity ranges are intended to display the impact that bias might impart on the analysis. The scenario analysis team met (by conference call on March 20, 2015) and discussed the findings of this assessment. The following paragraphs summarize the analysis, and provide the background for the conclusion of this assessment.

Single Point Source: All data patterns are counter-indicative of a single point- source causing the pattern of TC/EC positives observed on January 26, 2015, and this is thus the least likely of the three scenarios. Any events that are solely point source and would not be dependent on a system hydraulic surge (such as cross connections and isolated maintenance activities) are thus highly unlikely to have caused the positive TC/EC detections.

Multiple Point Sources: For multiple points of system vulnerability to trigger at the same time and result in widespread contamination, the hydraulic event would have to extend over a period of time sufficient to transport the contaminant from the point of contamination into the pipeline. No significant pressure deviations were observed from any of the 11 pressure monitoring points in the distribution system. These pressure monitoring points "poll" every 2 minutes, and thus any surge would have to last less than 2 minutes to not be observed. Noting, however, that this polling interval is not synchronized, a system-wide hydraulic pulse would have had to occur for a duration of less than 2 minutes to elude detection by any monitor. Water-hammer related pressure surges travel at the speed of sound, and are typically measured in fractions of a second. Thus, any water-hammer surge would have likely had inadequate time to allow contamination into the pipe system for more than a second, which would exclude any contamination from service-line related sources (as there is too little time for the surge to allow backflow through any appreciable distance in the service line).

A water-hammer related surge would most likely be created by a power failure resulting in rapid pump shutdown and valve closure. These conditions were not experienced in the period prior to January 26, 2015, and no anomalies were observed in pressure readings in the week prior to the event. Further, it is unlikely that a surge possible of triggering contamination from several susceptible sources throughout a widespread area could occur without some type of observable system impact, such as several broken watermains. The wide range of EC genotypes observed in the positive samples, however, is consistent with varied contaminant sources. This scenario is considered highly unlikely; however, because the HPC, chlorine, and epidemiological data patterns do not fit this scenario, and no other operational data can be found that supports the hypothesis of a short-term hydraulic pulse triggering the contamination.

Sample/Lab Sources: All of the observed data patterns can be explained by contamination that occurred in either the sample collection/lab analysis processes. The wide variation in genotypes observed is consistent with one complex multiple strain contaminant source or several less-complex sources. It is also noted that sample location NE-07 (which had 9 positive EC cells on the QuaniTray) likewise displayed a complex mixture of genotypes (none of the 4 positive cells tested displayed similar genotypic strains of EC). Thus, the complexity of the contaminant source is not necessarily indicative of multiple point-sources, and can be explained by a single complex point-source.

It is difficult to differentiate between a possible contamination event that might have occurred in the sampling process versus the lab analysis process, with the following observations noted:

- **HPC data**: any contamination in the sampling process would be expected to result in elevated levels of HPC and TC/EC. This was not observed, with all 6 positive TC samples having normal levels of HPC. Noting that the lab process involves sequentially analyzing all samples for HPC as a batch, then pre-processing for TC/EC (adjusting volume in the water sample to 100 mL), and then analyzing for TC/EC, it is possible that any contamination occurring after the HPC analysis would match the observation of normal HPC levels with abnormal TC/EC levels.

- **Sample collector/lab analyst**: Samples positive for TC/EC were collected by the same sample collector and analyzed by the same lab analysts. Even though other samples collected by another sample collector on January 26, 2015 were negative, they were also analyzed on another day. Thus it is impossible to determine if the positive samples were a result of a different sample collector or a different day of analysis.

- **Genotypic Strains of EC**: None of the 7 EC isolates from the 4 sample sites tested for genetic fingerprinting were similar to each other. For this trend to result from sample collection, each of the 4 samples would have either been contaminated by a common complex source containing multiple EC genetic strains over the course of the day, or by 4 distinctly different sources over the course of the day (statistically unlikely). Noting that sample location NE-07 (with 9 positive EC cells in the QuantiTray, 4 of which were analyzed for genotype) none of those 4 genotypic strains similar indicates that the contamination in NE-07 contained a wide variety of EC strains. It is impossible to distinguish between multiple contamination events of a single complex source by a sample collector versus multiple contamination events in the lab from a single complex source (occurring between the HPC and TC/EC analyses).

- **Possible sources of contamination**: possible contamination sources of a complex mixture of EC strains include a common point of contact for the sample collector and a complex mixture from the lab.

Contamination during either the sample collection process or laboratory analytical process is the most likely of all scenarios considered. Independent reviewers are split on the likelihood of either, and data and records can be interpreted to support either. It is impossible, however, to prove or disprove either scenario based on the information available.

6.10 Scenario Analysis for Events of October 7, 2013 and May 26, 2014

The event of October 7, 2013 was very similar to the January 26, 2015 event with regards to water quality data and trends. Other than the data for TC/EC on this date, all other measured water quality parameters were normal, and repeat samples on the following two days were negative. Public health data for community-wide AGI were normal throughout the event. A hydraulic model of water flows representative of flow conditions on that day indicated that a single source of contamination was highly unlikely, noting non-contiguous positive samples and positive samples hydraulically isolated from each other. No aberrations in operations activities were noted that might have triggered a system-wide hydraulic pulse, thus minimizing the likelihood of a simultaneous multiple source scenario. In all regards, the event of October 7, 2013 very much resembled the event of January 26, 2015.

The event of May 26, 2014 involved only one sample, and thus the isolated single point source contamination scenario cannot be ruled out. The HPC/TC/EC density ratios (1390/210/11) resemble those that might be expected from an environmental source of contamination, which could have originated in the DS, the sample collection process, or the laboratory process. The chlorine residual and turbidity data were normal and not supportive of a scenario involving a DS contamination event, and repeat samples were negative. Community-wide AGI data were normal. At the time of the event, a review of system activity and monitoring data found no evidence or clear opportunity for distribution system contamination. The compilation of data suggests that this was a sampling or lab contamination event, but a short-term contamination event in the DS which was mitigated by the chlorine residual cannot definitively be ruled out.