Water AECOM

City of Winnipeg

Discoloured Water Investigation Report of Findings

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3. Study Findings

While a specific cause for the increase in consumer complaints cannot be ascertained with 100% certainty, there are a number of clear conclusions that can be drawn from the investigation.

1. Most importantly, it has been confirmed that the water continues to be safe to drink. Analysis conducted by the City shows no microbiological contamination. While elevated levels of colour, iron and manganese have been confirmed, these are aesthetic parameters. Maintenance of a chlorine residual remains a critical requirement and a review of recent data suggests that the City has been able to maintain residual disinfectant levels at or above historic levels with equal or less applied chlorine. The effect of the new WTP is as expected with a reduction in organics in the treatment process resulting in reduced chlorine demands downstream.
2. A review of the City compiled complaint information shows that for the years 2003 to 2008, the annual number of complaints averaged between 14 and 27 per month. Seasonal variation produced monthly totals ranging from about 5 to 60 with the highest number occurring during the late summer to early fall months. The rollout of the City's 311 system has increased the average annual number of complaints by approximately 350% (seasonal variations are about the same as discussed in point 4 below). It is uncertain to what degree the 311 effect has further impacted the 2010 data set and for the purposes of this assessment we have assumed it was equal to the impact observed in 2009. For the period of January through October, 2010, the total number of complaints has further increased another threefold over the 2009 values (based on the cumulative number of calls through October 2010 versus the same time period in 2009).
3. As noted in the Background section of this Report, the data was normalized to as great a degree as possible to remove the *"311 effect"*. Based on this normalized view of data (see **Figure 2**), 2009 appears to be a relatively average year for complaints while the adjusted 2010 data set still reflects considerably higher numbers of complaints than in the overall dataset. The adjusted seasonal peaks were still three times higher than the

maximum monthly complaints reported in 2006 and 2007 (the worst previous monthly totals observed prior to 2009).

4. Although the magnitude of complaints has increased markedly, the monthly variation pattern is reasonably consistent with past variations that have been observed seasonally. To examine and illustrate this, monthly peaking factors were generated to examine seasonal trends. The peaking factors compared each monthly total to the average monthly total for each individual year. The results are depicted in **Figure 3**. While the magnitude of complaints has increased markedly, the seasonal variation pattern for 2010 observed in **Figure 3** appears very similar to typical annual seasonal variations prior to the commissioning of the WTP.

5. Treated water quality leaving the new WTP is excellent. While parameters such as colour and iron remain low, parameters such as turbidity, colour, organics, and algae, are much lower than they were prior to the WTP. In addition, other parameters such as pH and chlorine residual are more consistent than in pre-water treatment years due to the addition of new treatment processes. This is generally beneficial to water distribution system stability and corrosion/lead control. Inspection of a recently cleaned reservoir showed no discolouration or sediment build-up. Finished water turbidity and particle levels are very low so this finding is not unexpected but does help confirm that the particulate matter is not originating from the WTP but rather from within the distribution system.

6. Analysis of the water quality from the affected consumers' taps shows elevated levels of turbidity, colour, iron and manganese. The largest fraction of the iron and manganese was found to be particulate. The presence of manganese along with iron and diatom remains (algae) suggests that the iron is coming from previous deposits from the unfiltered supply rather than iron release from tuburculated cast iron and galvanized pipe. Flushing at the tap appears to resolve the problem although the time to clear was reported to vary from minutes to hours. It is unclear if taps were open continuously for the longer reported times. The duration of the events suggests that the issue may reside in both the in-home plumbing and the City distribution system, with shorter flushing times to clear water being associated with in-home plumbing and longer flushing times to clear water being associated with the City distribution system.

7. Analysis of recovered solids from pipe sections, filters and water samples shows the presence of large amounts of damaged or older diatoms and other debris. Most interestingly, the algae found (mostly described as older fragillaria) are not typical of those found in the raw water supply at the present time. This indicates the materials are old and have been present since before the WTP was put into service.

   Visually, the pipe samples show a thin layer of residue. This was more visually evident on the polyvinyl chloride (PVC) section examined although quite possibly due to the nature of the residue on a PVC surface than on an unlined cast iron surface (e.g. it has more contrast and is easier to see). Based on the one PVC sample observed, it is reasonable to assume that the residue can be removed relatively quickly by flushing at high velocity as opposed to more aggressive forms of watermain cleaning such as swabbing techniques.

   Corrosion in the cast iron sections examined appeared typical to that seen historically suggesting no significant negative impact that could be attributable to WTP operation. The cast iron sample was not heavily tuberculated and the tubercles that were present appeared hard and not likely to release large concentrations of iron under normal operating conditions. Microscopic examination of recovered material from filters was described as "slimy" with large amounts of bacteria and empty diatom frustrules. As stated above, it is believed that these materials have been present since before the WTP and are now sloughing off.

8. The observations that the materials are old and were present pre-WTP are consistent with observations from the City's 2009 Watermain Flushing Research Project which indicated significant presence of high turbidity water at numerous locations in the system after six years of uni-directional flushing (see **Figure 4**). While the uni-directional flushing program was very successful in improving overall aesthetic water quality in the distribution system, the 2009 research did indicate that significant materials were present in the water distribution system, especially in areas of the system where normal operation produces low average flow velocities.

9. The spatial groupings of complaints reported in 2010 display a distinct clustering effect with increased densities of complaints being reported in a number of distinct areas of the system (see **Figure 5**). While not confirmed by detailed hydraulic modelling, there is a distinct increase in frequency of complaints in areas of the system that would be considered "null" points between the distribution pumping stations or system extremities that would be anticipated to have lower velocity profiles on a regular basis. This suggests that some areas of the system may be more prone to suffering event related complaints due to their unique boundary conditions or flow characteristics under normal operation.

10. The spatial and temporal analysis showed that the complaints are widespread across the City, but also that there is a close relationship between complaints of coloured water and system "events" (e.g. valve operation, flushing, construction, major changes in pumping station operation, etc.). This is evident both visually, in a review of complaints versus time graphically in an avi format; and statistically; as robust statistical analysis shows significantly more clusters of complaints that are closely related both spatially and temporally than one would see if the complaints were truly random occurrences (see **Appendix A**). While not all the complaints are event related, a substantial portion of the data set is.

11. There does not appear to be any strong correlation between complaints and pipe material or pipe age. **Figure 6**, **Figure 7**, and **Figure 8** depict the spatial density of ferrous metal, cementitous, and thermoplastic lined pipes. A robust statistical assessment (see **Appendix A**) does not show any correlation of any distinct material type that independently accounts for the majority of the complaints.

12. Even accounting for the *"311 effect"*, it does appear that an "event" generates more complaints now than prior to the WTP being put into service. It is postulated that the biofilm on the pipe wall may be sloughing off as heterotrophs die due to the reduced amount of nutrients and organics in the finished water.

    While we have no definitive proof as to the cause of the apparent discoloured water, we do have a few confirmed facts: the amount of "food" for biofilm growth, debris and algae entering the distribution system has been significantly reduced since the WTP was brought on-line. We also have evidence that the water and sediment samples collected include varying amounts of dead algal material. The discoloured complaints are also noted in areas with primarily PVC piping. In our opinion, the two most likely causes are sloughing of biofilm and iron release from iron tubercles. In the former case, flushing and maintenance of a high chlorine residual should accelerate the system cleanup. In the latter case, flushing, keeping pH constant, high chlorine residual, high oxygen concentrations, and the presence of orthophosphate are important in stabilizing the tubercles so that iron release is minimized. It is also to be noted that historic flushing practises had to use raw water while flushing programs carried out going forward will be driven with a treated water source.

13. A review of the completed homeowner questionnaires suggests the discoloured water is evident in hot and cold water taps and varies in description from yellow to red to brown. The colour appears to be mostly associated with the iron. The larger the particle size, the more the colour will tend to appear dark. As stated earlier, a constant pH and a measurable chlorine residual is critical to minimizing iron impacts. Maintenance of the corrosion control dose at present levels is also recommended because phosphate has been shown to decrease the amount of iron that is released from iron tubercles. It should also be noted that although an iron based coagulant is used at the water treatment plant, the finished water iron levels are no higher than the raw water levels and are well below drinking water quality guidelines.

14. The trial watermain flushing program on Victoria Crescent appeared to be successful in that no unusual complaints were received during the work and significant "dirty" water was removed through the process. Conversely, subsequent flushing in Transcona resulted in complaints beyond the normal impact radius experienced in the uni-directional flushing program. It has since been established that there were issues with valve positions which contributed to the observed problems in Transcona.

    However, the Victoria Crescent area had very few documented complaints prior to the flushing (it is located in an area that had a very low complaint density prior to the flushing) while the Transcona area is in an area with a moderate complaint density and one would anticipate it to be a more sensitive to event related complaints due to its normal system operational mode.

15. The City's ongoing lead monitoring program does not show any appreciable change in lead release since the WTP was put into service. The data provided to us for the period June 2006 to December 2010 shows high variability in the first-draw samples, with lead concentrations generally falling in the 50 – 200 µg/L range. The performance of the phosphate-based inhibitor should not be negatively impacted post-WTP as the finished water residual is now maintained in a pH range of 7.6 to 7.8, which is the ideal range for the inhibitor. Prior to the water treatment plant, the raw water pH could fluctuate between 7.0 and 9.0. Making any adjustments to the inhibitor dose at this point in time could carry some risk as it will introduce another change to the distribution system.

16. While we have been unable to find another utility with identical issues, there are two that are worth discussion; a large city in Oklahoma and Dauphin, MB.

    In the latter case, Dauphin went from an unfiltered supply to a filtered supply similar to Winnipeg. Raw water conditions were more severe with very high organics and colour. Coincident with the new WTP being put into service, the entire distribution system was swabbed and flushed. No complaints of coloured water were noted once the plant was put on-line. There are three major differences between Dauphin and Winnipeg: size of utility, visual appearance of pre-water treatment water and the degree of distribution system cleaning. The smaller size of the utility made it more practical to clean the entire system in one season using treated water. If coloured water events did periodically happen, it is uncertain if residents would have complained as it may still have been considered relative to pre-treatment conditions.

    The large city in Oklahoma had red water complaints that were attributed to a reddish film; probably biofilm with iron bacteria. Unfortunately, because of a change in plant staff, recommended work to better identify the cause of the problem and to develop control procedures was not done. Although there may be other examples, it should be recognized that few large utilities exist without filtration. One of the factors that differentiate Winnipeg's system from many other large cities is that water treatment and filtration of source water has only been recently added in 2010. The existing distribution system, however, has been subject to high organic, high algal raw water for many years.

    Our research was primarily limited to in-house review of case studies within AECOM, CH2M HILL and those carried out by Dr. Snoeyink. We also utilized a number of industry search engines such as the ASCE research library. It should be noted that distribution system water quality is very complex, somewhat unique to each utility and still not very well researched and thus understood. Winnipeg's old system receiving unfiltered water high in organics and algae with recent conversion to a high quality treated supply is somewhat unique. While there are many papers published on coloured water issues caused by iron (note that Dr. Snoeyink's research group has published extensively in this area), none appear to directly align with what Winnipeg is experiencing. Boston, for example, has a non-filtered supply but did not have extensive algal problems. They had a coloured water problem during low-flow time periods which was resolved by maintenance of a constant pH.

17. While it is not certain that the increase in complaints is solely attributable to the sloughing of biofilm and corrosion deposits, it appears to be the most likely cause. It is also believed that the system will clean itself up over time if chlorine residuals are maintained, and that strategic flushing will accelerate the process.

    To put a concrete time frame on when the complaints would be anticipated to substantially decline would require the carrying out of a trial flushing program to ascertain how effective a targeted flushing program would be and what level of flushing is required (e.g. will conventional flushing or uni-directional flushing work or will swabbing or more aggressive techniques be required). It does appear that sufficient data has been gathered in the 2010 season to assess the effectiveness of such a program and it appears that some form of flushing would be the most prudent course of action to minimize public exposure to this aesthetic issue over the short to longer term (i.e. it will make it go away more expeditiously).

Flushing should be part of a regular distribution system maintenance program and is considered to be best practise. We have recommended a pilot flushing program to help confirm this recommendation. By strategically flushing a known problem area and then reassessing, we can better predict the full impact that flushing will have. If the iron in the biofilm originated from the raw water before the WTP was put in service, this source of iron no longer exists, and any iron-containing biofilm removed by flushing will not be available to be released to customer's tap water. Also flushing with WTP water versus raw non-filtered water should be more effective.

The Data gleaned from the trial flushing should help predict how effective flushing is with respect to complaints and system cleaning.

Flushing with treated water is also an improvement over what was possible historically. While we believe the biofilm sloughing might eventually cease even without flushing, we do not recommend that the City consider this option. Equally important is the continued control of pH, chlorine, phosphate and system hydraulics/water age.

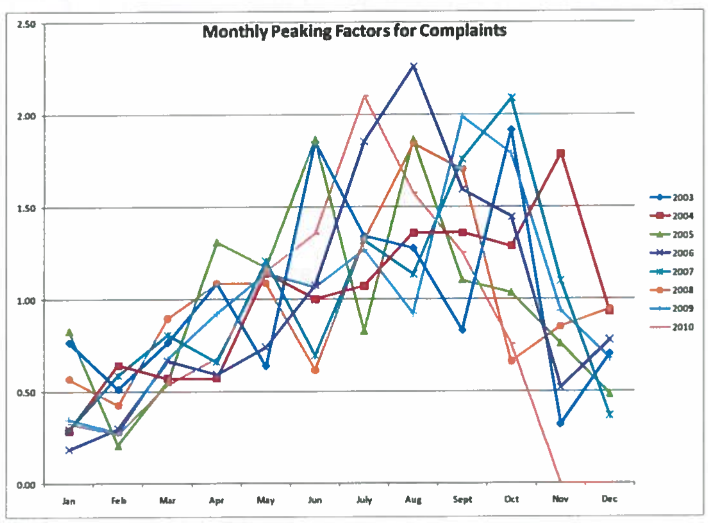

Figure 3: Monthly Peaking Factors for Complaints 2003-2010

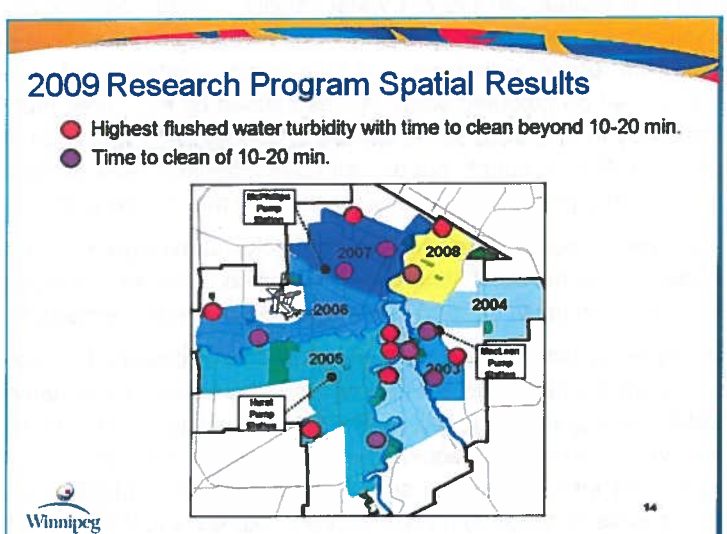

Figure 4: Results of 2009 Flushing Research Project

To summarize, it is our opinion that the phenomenon described is related to historic accumulation of corrosion, debris and biofilm within the distribution system that is now being dislodged. It is also apparent that the phenomenon has seasonal effects, whether due to temperature effects or increased operational intensity, and can be expected to increase in frequency next summer. Lastly, while the effect will likely dissipate over time, the most prudent way to lower the frequency of occurrence would be continuing an aggressive watermain cleaning program focussed on areas of the system that are more prone to the debris being dislodged under normal operation. This would likely include "null" areas of the system (points between major distribution pumping stations where considerable flow reversals occur) and the system extremities where normal average velocities are lower.

4. Recommendations and Future Work

We would recommend:

1. To select an appropriate trial area for a targeted UDF trial in early 2011 (i.e. as early as weather permits conducting such a program). Select a candidate area that had a high incidence of complaints in 2010 and where system operational characteristics are conducive to excessive debris accumulation (e.g. normal system operation either has numerous flow reversal and/or low average flow velocities). Collect as much background information on specific event data in the target areas to maximize the understanding of cause and effect of normal system operations at dislodging material from the pipe wall. The primary purpose is to facilitate proper data interpretation from the trial (by either reasonably replicating 2010 exposure conditions in the 2011 trials or by understanding what role operational actions may have on data output). A secondary benefit would be to better understand cause and effect of specific operations in sensitive areas of the system.

   Carefully plan a UDF flushing sequence approach and monitor progress and cleaning activities in a controlled manner (e.g. a balance of the 2009 Flushing Research techniques combined with some of the additional testing employed in 2010).

   Monitor complaint frequency over the course of 2011 and conduct spot trials in the fall of 2011 assessing the effectiveness of the cleaning activities. The desired output from the program would be a clear understanding of the effectiveness of UDF techniques at resolving this specific aesthetic issue.

   Information gathering during the UDF trial would be twofold and include both specific event data collection and overall program complaint data. Specific event flushing data would include data such as total iron, turbidity versus time and time to clean up. Overall program data would statistically look at the number of complaints generated in the affected area and compare this to the 2010 complaint record, for both frequency and spatial relevance.

   Depending on the findings of the test UDF work. Recommendations might range from continuation of existing practises, to more targeted UDF, to more intensive approaches such as swabbing.

2. In preparation for the program noted in point 1 above, study the boundary effects associated with the 2010 flushing program in Transcona and other known operational events from 2010 to ascertain the limit of public notification required and correct approach for communicating the nature of the activities to the public.

3. Based on the results of the trial UDF program, expand and/or continue planned flushing programs. It is suggested that the targeted areas be revisited to align with the high complaint density/null areas.

4. Collect additional biofilm samples from harvested pipe sections as the opportunity arises. Specialized laboratory analysis can be conducted through Dr. Snoeyink. The results should help confirm the nature of the materials. The key objective is to determine the presence of iron bacteria. If found, it would help confirm the root cause of the coloured water issues.

5. Some consideration could be given to raising the distribution system chlorine residuals while maintaining a pH on the higher end of the ideal range (7.8) but without creating overly high chlorine levels which may drive other consumer complaints. Tight pH control should lead to a decrease in iron from residential plumbing. Regulated minimum levels must be maintained throughout the distribution system. While we do not have a specific value to recommend at this point, chlorine is one of the key tools in addressing biofilm issues. In general terms, the higher the residual, the better. It should be noted that a chlorine residual of 0.1 mg/L is not enough to kill biofilm. Also, if water with 0.1 mg/L residual becomes stagnant, pipe wall chlorine demand will result in the chlorine concentration near the pipe wall going to zero. A suggested minimum value, is 0.3 mg/L with >1.0 mg/L required when doing a "burn".

6. Ongoing data collection is recommended however it can be scaled back considerably. Complaints should continue to be logged but individual home sampling would only be recommended if unusual observations were noted.

   We suggest that pH, turbidity, DO, chlorine, total iron, total manganese, true colour and the time required to run clear be recorded as a minimum at each location including raw water, WTP outlet and distribution. It has been noted that there are complaints that are not associated with the potable water supply in which case no sampling is necessary. Microscopic analysis of sediment/biofilm need not continue as the findings to date have been very consistent. Lead and copper testing is recommended to continue as is the routine sampling at the WTP and reservoirs.

   While DO does likely increase as the water goes through DAF and ozonation, we do not expect delivered water at the tap to be appreciably different from historic levels. Analysis for DO is suggested, however, we do not have historic values to compare against. A comparison against raw water DO should, however, be a good approximation of historic values. Practically, the two key parameters that we can control are pH and chlorine.

   As higher DO can accelerate corrosion, the existing lead and corrosion control practises should continue. There may be merit in undertaking parallel loop tests to investigate impacts of changing the lead and corrosion control parameters.

   It should be noted that the role of oxygen in corrosion is complex. It is well established, for example, that the corrosion rate of a clean iron surface increases as oxygen concentration increases. Unless iron pipe is new, however, most distribution systems do not have clean iron surfaces. It is also well established that oxygen prevents iron release from iron scales and tubercles. The reason for this latter effect is that oxygen converts the very soluble Fe (II) to the very insoluble Fe (III) solids. Maintenance of oxygen and chlorine next to the surface of iron scales results in the formation of a dense shell-like layer on the outer surface of iron scales that tends to prevent the Fe (II) corrosion product from diffusing out of the scales to the bulk water where it causes coloured water. This is the reason why WTPs in general, do not notice and increase in red water occurrence when beginning to use ozone, which results in higher oxygen levels in distributed water.

Figure 5: Spatial Variation of Complaints: Jan-Oct 2010

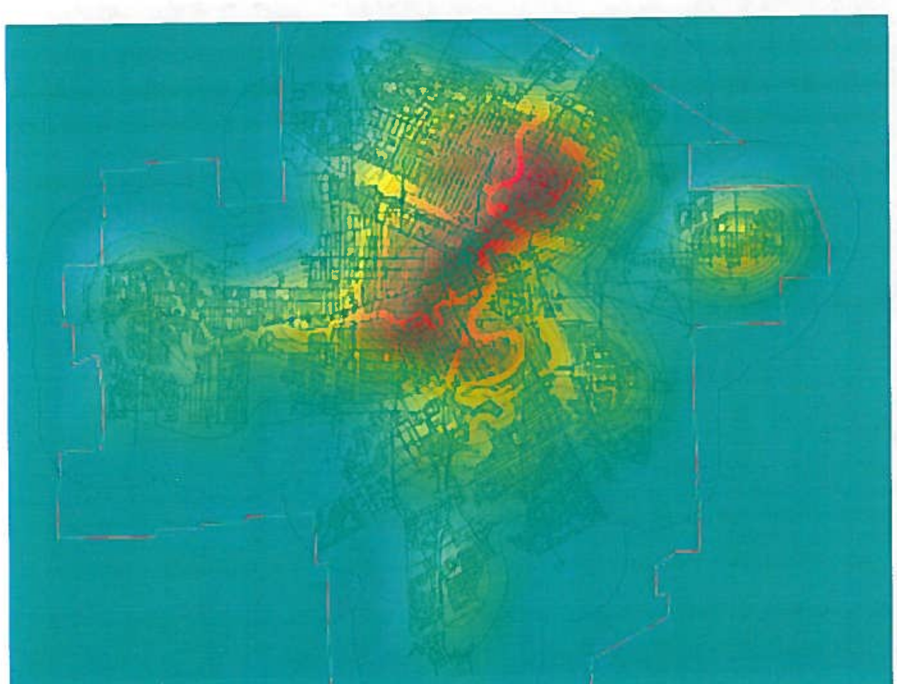

Figure 6: Density of Ferrous Metal Pipes

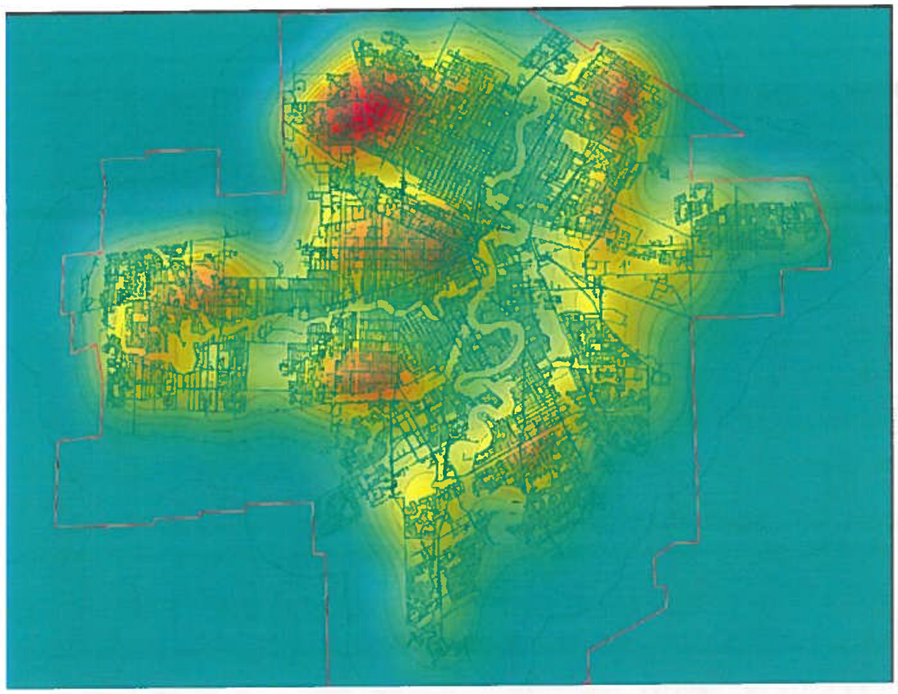

Figure 7: Density of Cementitous Pipes

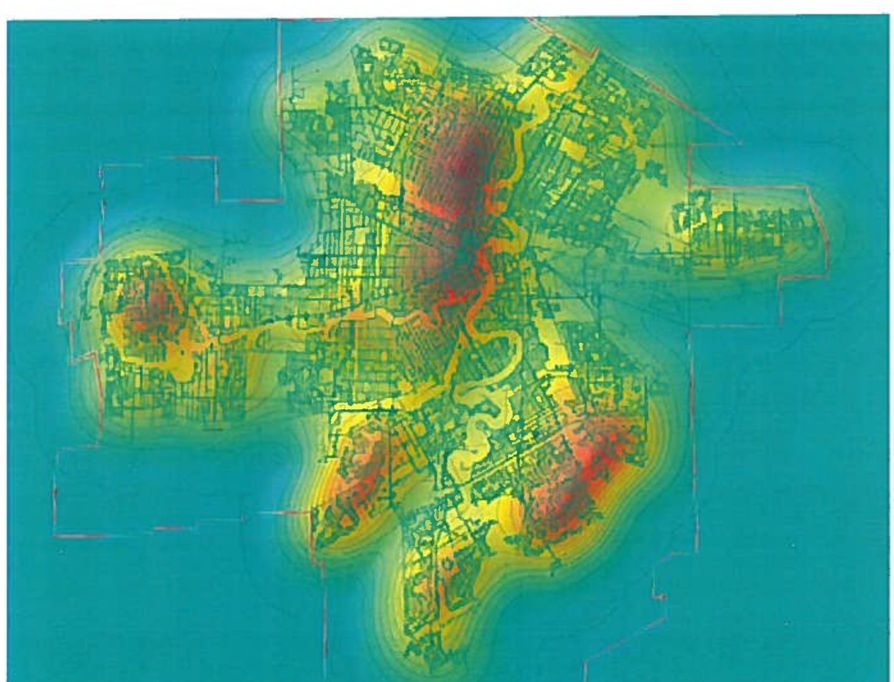

Figure 8: Density of Thermoplastic Pipes