FAST Start Program
Memorandum

February 28, 2017

To: Hon. Dr. Karen Weaver
Mayor, City of Flint

From: Michael McDaniel, FAST Start Coordinator
Dr. Mackenzie L. Davis, Emeritus Professor of Environmental Engineering, Michigan State University

Subject: An Analysis of Selected Service Line Pipe Materials

1. The City of Flint was offered plastic piping from JM Eagle in February, 2016. It was the informal consensus of city staff and others, by June 2016, that while plastic piping has been used in other municipalities, including in some instances for residential service line (SLR) replacement, that not enough was known of the longevity of polyethylene (PE) and cross-linked polyethylene (PEX) pipes, or their long-term ability to withstand contamination, and that plastic pipes therefore lacked the benefits of Copper (Cu) for service lines.

In short, the City of Flint Water Services Department, the City of Flint's Building Code and the contracts for residential service line replacement specify that copper be used for residential service lines. Upon review of published literature, water utility experiences, and scientific research papers and upon independent analysis, we do NOT recommend that the City accept any form of plastic piping for residential service lines. This memorandum is intended to detail and memorialize the reasons for the decision to forego the offer of plastic piping.

2. The concerns of the City are supported by even a cursory review of the literature: "[L]ittle is known about contaminant interaction with aged PE pipes despite the fact that long-term disinfected water exposure is known to change surface, bulk, and mechanical properties of these materials. As a result, potable water distribution system designers, operators, regulators, and managers do not know if oxidation of new pipe caused by chlorination affects contaminant diffusion and desorption[1]."

[1] (Executive Summary) Andrea M. Dietrich, Andrew J. Whelton, and Daniel L. Gallagher, Chemical Permeation/Desorption in New and Chlorine-Aged Polyethylene Pipes Water Research Foundation, 2010.

3. To that end, the service of Dr. Mackenzie Davis, emeritus professor of environmental engineering at Michigan State University, was sought by the FAST Start program. This memorandum is jointly authored, but the Attachments, and thus the analytical findings outlined in paragraphs 4-8, are the work of Dr. Davis.

4. Of the numerous materials available for service line replacement the following were selected for analysis and/or supplementary data: copper (Cu); polyethylene (PE); cross-linked polyethylene (PEX or XPE); and polyvinyl chloride (PVC)[2].

5. The following organizations provide standards for the various pipe materials in commercial use: American Water Works Association (AWWA); American Society for Testing Materials (ASTM); National Sanitation Foundation International (NSF International); and the Plastic Pipe Institute (PPI). AWWA and ASTM are organizations of professionals that produce standards on the acceptability of behavior of materials for a specific use, e.g. water distribution, wastewater collection, etc. NSF is not the National Science Foundation funded by the federal government. NSF International, located in Ann Arbor, has a long history of the use of the 'NSF' abbreviation. It is funded by for-pay services provided by companies that wish an "independent" assessment of compliance with the standards developed by AWWA and ASTM. PPI is an industry "institute" organized to promote the use of plastic pipe in a variety of applications. It does not provide "standards" nor does it provide in-house testing data to verify claims for the properties or behavior of plastic pipe. These abbreviations are used in the remaining paragraphs of this memorandum and in the attachments.

6. An environmental impact analysis (EIA) is presented in Attachment 1. It is focused on the very limited aspect of potential chemical releases of the pipe material to the drinking water inside of the pipe. The results in Attachment 2 may be summarized as follows:

- Cu – releases copper. Drinking water standards limit Cu concentrations to a maximum contaminant level goal (MCLG) of 1.3 mg/L and an action level of 1.3 mg/L. Modern copper pipe metallurgy, when combined with appropriate water treatment to minimize corrosion, typically maintains the Cu concentration below the MCLG. Potential biofilm formation is inhibited by copper.
- PE – volatile organic compounds (VOCs) such as ketones are released to water in the pipe. These result in taste and odor from the water.
- PEX – VOCs released to water result in intense odor from the water. VOCs found include ETBE, cyclohexane, toluene, and xylene. Assimilable Organic Carbon

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[2] Copper was selected because it is widely used, including currently by the City and by the Lansing Board of Water and Light. Polyethylene (PE) was considered because it is the pipe material offered to the City by JM Eagle. Cross-linked polyethylene (PEX) was selected because of its popularity as an alternative to PE, based on an online literature search. In addition, the AWWA C904 Subcommittee of the Standards Committee on polyolefin pressure pipe published a report on PEX that introduced it as "typically used for underground water service lines." Polyvinyl chloride (PVC) was included because the AWWA Research Foundation (AWWARF) funded a comprehensive study to evaluate the water industry's experience with the material. The findings are extensively discussed in *Buried Pipe Design* by Dr. A.P. Moser, Utah State University, McGraw-Hill, 2001.

(AOC), which provides a carbon source for microbial growth, also has been observed. Biofilm potential is higher than that of copper.

7. Because the service lines in Flint have been in existence, in most cases, since construction of the residence, longevity was the paramount consideration. The eras of construction that suggest the greatest likelihood of lead service lines are from the 1920s and 1940s. As the existing service lines have been uncovered for replacement, they have been found under sidewalks, driveways, neighboring driveways, and in many different configurations. Further, because of these rather inaccessible locations, repair and/or replacement of these lines has been found to be costly, since it requires damage to, and subsequent repair of, adjacent sidewalks, curbs and street surfaces. The City requires confidence that the replaced service line will be a long-term solution, eradicating the lead service line while also promising to last for at least an equivalent length of time. Service life is a critical parameter in a life cycle engineering economic analysis of alternatives.

The determination of a service life for copper pipe is relatively simple because of its long use in home plumbing and use as a service line. Determining a service life for PE is more difficult because of the comparatively short time it has been used in home plumbing and used as a service pipe.

7.a. Actual service life and service life claims are presented in Attachment 2. Copper pipe has the longest record of actual service life. The range of reported actual use is 60 to 80 years. The projected useful life is 100 years. Two cases were selected for life cycle cost analysis: 75-year service life and 100-year service life.

The hypothesized projected life for PE and PEX ranges from 50 to 100 years. No PE pipe has been in use for more than 30 years. Failure of PE pipe in the Las Vegas Valley Water District, installed in late 1970s and early 1980s, fell in the range of 23 to 29 years. PEX pipe has been gaining market share for about 10-15 years in the U.S. The longest warranty for PE/PEX pipe is 25 years. Thus, 25 years was selected as service life for life cycle cost analysis.

7.b. The discussion of PE projected life involves a critical review of two frequently quoted sources for a projected service of 100 years: (1) Jana Laboratories Technical Report titled "*Impact of Potable Disinfectants on PE Pipe*," and (2) S. Cooper and D. Gecker, "*Evaluating the Impact of Disinfectants on PE Pipe*," Journal of American Water Works Association. Because PEX is fundamentally derived from the same materials, in this memorandum it is assumed to apply to it as well.

The Jana technical report, used by PPI to justify a 100-year service life, is reviewed in Appendix A to Attachment 2. The Jana report is an exhaustive discussion of the state of the art of failure analysis for plastic pipe. It presents a summary of the explanations for long-term aging mechanisms of PE in potable water applications. It follows our current laboratory understanding of the end-use factors that lead to failure.

It does NOT present a coherent explanation of the data purported to support the claims of life expectancy greater than 100 years. It includes a graph displaying only eight or nine data points. It does not show both of the Rate Process Method equations or the values for the variables used for the calculation to determine the length of service extrapolation. The "Case Studies" which are presented are without any experimental data to verify the conclusions. In a footnote to Table 1, on page 24, it is noted that the ORP values, which are a primary criterion for assessing the aggressiveness of the water, were estimated, not measured.

7.c. The AWWA article titled "*Evaluating the Impact of Disinfectant on PE Pipe*" uses the Jana technical report as justification for a 100-year service life. It is reviewed in Appendix B to Attachment 2. It is not a peer reviewed article. The authors referred to the use of Weibull analysis in predicting service life but did not present any data showing how the statistical process was used to forecast the service life of polyethylene pipe. Although the role of disinfectant on pipe service life was mentioned, the authors did not present a scientific explanation of the mechanism or any data relating disinfectant concentration to pipe service life.

8. A life cycle engineering economic analysis is presented in Attachment 3. The present worth cost of a single house installation of copper, polyethylene, and cross-linked polyethylene are compared in an Excel spreadsheet. Type K copper pipe was used to select a unit price. PE and PEX unit costs were taken from online advertisements. For a copper life expectancy of 100 years, and PE and PEX life expectancies of 25 years, the life cycle costs are: PE = $4,793 per house, and PEX = $4,852 per house. Rather than having a life cycle cost, Cu has a life cycle benefit of $9,283 per house because of the high salvage value of copper at the end of life of the copper pipe.

9. Review of the scientific literature and of articles detailing water utilities concerns also was conducted. These issues, such as the concern with degradation due to chlorine, also had been raised by city staff from their experience and training. That review raises three concerns: (a) the risk of premature failure due to oxidative degradation from chlorine or other oxidizing disinfectant (Paragraph 10 below); (b) a risk of outside contaminants permeating through the pipe wall and into the water being delivered into the home (Paragraph 11); and (c) a risk for organic and other compounds leaching from the pipe wall itself into the water (Paragraph 12). The literature also suggests that odor in potable water carried by plastic piping could be a concern, but was not included in this review (Kelley, Stenson, et al., 2014).

10. Another concern is the potential susceptibility of plastic pipe to degradation when treated with an oxidizing disinfectant, like chlorine, which may cause premature failure. PE and PEX pipe have a demonstrated risk for oxidative attack and failure due to oxidative disinfectants in potable water such as chlorine. Oxidative disinfectants in the potable water attack the pipe wall by consuming anti-oxidant compounds intentionally added to the plastic, eventually depleting the pipe wall of this necessary protection. This results in premature failure, which develops first as small micro-cracks that continue to grow and propagate throughout the pipe wall ending in brittle failure and leaks. It appears that degradation of the full pipe wall thickness is not necessary for failure, as a

degradation of a layer 50 – 60 microns deep is all that would be required for failure (Duvall, Edwards, 2012). Utility experience in the United States indicates that many utilities that began using plastic for water services in the 1970s and 1980s have experienced such failures in as short as 10 years, and normally in 20 – 30 years, much shorter than the lifespans predicted by accelerated testing used to confirm the recommendation to use plastic pipe in this application (Duvall, Edwards, 2012). Although there is less data thus far, PVC and chlorinated polyvinyl chloride (CPVC) are not impervious to attack by chlorine-based disinfectants (Eng, Sassi, Steele, Vitarelli, 2011). The possibility of premature failure due to oxidative degradation that would compel costly infrastructure repairs is, of course, contrary to the City's first objective of ensuring longevity in its water distribution system.

11. As noted briefly in Paragraph 2 above, there are concerns regarding the lack of data on the ability of external contaminants to permeate plastic piping. Plastic pipe has exhibited a risk for the permeation of outside contaminants, like hydrocarbons and other organics, through the pipe wall and into the residential water. Plastic pipes have demonstrate a risk for permeation of hydrocarbons, insecticides and other organics from the soil or outside environment through the pipe wall and into the potable water (Holsen, Park, Jenkins, Selleck, 1991). Reported cases appear to focus on the permeation of petroleum-based aromatics such as benzene, toluene, and ethylbenzene that come in contact with underground piping either through contaminated soils, gasoline spills or other events. In specific testing with polyethylene piping, it was rapidly permeated when exposed to either free gasoline or aqueous gasoline solutions (Mao, Gaunt, Ong 2006). Internal pressure of the service lines does not seem to affect the permeation process. Flushing the contaminated service line with clean water for a protracted period does not correct a permeation event (Selleck, Marinas, 1991). More recent studies also investigated the permeation in at least one type of cross-linked polyethylene (PEX) pipe, finding that permeation of certain contaminants through PEX-a pipe occurred much more quickly than any high density polyethylene (HDPE) pipe examined (Dietrich, Whelton, Gallagher, 2010).

12. As Professor Davis pointed out to the FAST Start Program early in our discussions, there is also a risk for leaching of organic and unknown compounds from the wall of plastic pipe into the potable water conveyed by it. Unlike copper, obviously, plastic pipe is not constructed solely of a single element or compound, but rather consists of a plastic polymer and other agents like antioxidants, heat stabilizers, and plasticizers, which give the piping its necessary properties and protection. In addition to the risk of permeation of chemical compounds through the pipe wall, plastic piping has been found to allow leaching of chemicals directly from the pipe wall. Besides the analysis of the scientific literature contained in Attachment 2, other sources support the conclusion that chemical compounds may permeate through the piping. One study indicates that HDPE and PEX pipes in contact with potable water released various volatile organic compounds (VOCs) that affected the taste and odor of the potable water conveyed. (Skjevrak, Due, Gjerstad, Herikstad, 2002). Similar results were reported for HDPE pipe in chlorinated water (Heim, Deitrich, 2007).

More recent studies indicate that PEX and polypropylene pipes leached organic chemicals that affected taste and odor of the water (Kelley, Stenson, et al., 2014), but were not evaluated for health effects as the contaminant compounds could not be identified (Connell, Stenson, Weinrich, LeChevallier, Boyd, Chosal, Dey, Whelton, 2016).

13. There are practical concerns as well which favor copper lines over PE/PEX. The electrical code requires all homes to be grounded. Traditionally, homes in Flint have been grounded to the metallic piping (galvanized and copper service lines) whenever available. If the City decides to replace the metallic piping with a nonconductive type of piping, then the City will have to accept the additional expense to have every residence where a line is replaced also be re-grounded. The cost of this work and associated permits has been estimated at $300-350 per residence. There will be the additional direct expense to the City as it must deal with more electrical inspections. These costs alone are believed to equal or exceed the materials cost savings of not using copper piping.

14. The City also must consider carefully the partnership with JM Eagle. In 2013, a federal jury found the company, then known as J-M Manufacturing, had defrauded three states and 42 cities in the U.S. by knowingly selling them defective PVC pipe for use in public water systems for over 10 years. Please see http://dealbook.nytimes.com/2013/11/15/jury-finds-pipe-maker-defrauded-governments/?_r=1 for an article on the seven-week jury trial.

While there is absolutely no indication that the offer from JM Eagle to the City involves defective pipe, or even PVC pipe, it would not seem to be in the City's best interests to align itself with the company when the City is seeking to assure state and federal legislative bodies and executive agencies of its stewardship and remediation capabilities and to restore the trust of its citizenry in the City's water treatment and distribution systems.

15. There appears to be movement from plastics back to copper piping, based on a survey of utility experiences. Plastic piping for utility-side water piping began to gain market share in the late 1960s and early 1970s. Plastic piping offered benefits including being corrosion resistant, lightweight, easily installed and low cost, with the additional promise of a long (100-year) service life. Through the 1980s and 1990s, plastic established a nearly 50 percent market share of the underground water service market, first replacing cast iron and galvanized steel and then copper. But since then, it seems copper piping has had a resurgence.

It seems likely that the actual service lifetimes of 10 – 30 years that many utilities that had installed plastic pipe for water service use in the late 1990s and early 2000s experienced was a cause for the shift back to copper. For example, the appearance of widespread failures due to oxidative damage in disinfected waters and other failures led utilities such as the Las Vegas Valley Water District[3] to reconsider and replace thousands of failing plastic water services with copper piping. This potential trend back to copper for water service lines emphasizes the uncertainties with the longevity and long-term efficacy of various forms of plastic piping and with the unknown extent of its susceptibility to contamination from internal and external leaching or contaminants.

When these factors are combined with the (a) known service life of copper piping, (b) the salvage value of copper positively offsetting its greater cost, and (c) the additional cost of installation of plastic piping due to the need to re-ground the residential electrical wiring, then the City must continue to use copper piping as the best alternative.

Other References:

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[3] http://hdpefailures.com/pipe%20failures-nv.html
Case studies of failures of HDPE in water service applications can be found at http://hdpeoxidation.com/

Kelley, K.; Stenson, A.; Dey, R.; Whelton, A.; *Release of Drinking Water Contaminants and Odor Impacts Caused by Green Building Cross-linked Polyethylene (PEX) Plumbing Systems*; Elsevier; Water Research Volume 67, December 2014, pp 19 – 32.

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