The Road to Hell is Paved with Good Intentions
Or the Law of Unintended Consequences

Susan Masten, Ph.D., P.E.
AWMA Regional Conference
December 1, 2016
Background

- 1883: Flint Water Co. incorporated and begins distributing water
- 1887: City of Flint passes ordinance that lead pipe requiring lead pipes: “all connections with any water mains shall be made with lead pipe”
- 1912: Flint Water Co. purchased by the City of Flint
- 1930: Flint River water is treated with alum coagulation/sand filtration (28 MGD)
- 1954: Second Flint water treatment plant is completed (59 MGD)
- 1967: Flint begins purchasing water from Detroit Water and Sewage Department (DWSD).
  - The source of the DWSD water is Lake Huron and treated at the Fort Gratiot plant.
  - Flint plant was “maintained” as a back-up supply.
- 2012ff: The community felt that they were being overcharged. They were concerned because of effects of 2003 blackout
Options....

- Continue purchasing water from DWSD
  - Pipeline 120” line to Imlay City
  - Pipeline 72” line from Imlay City to Flint (capacity > 90 MGD)
  - Pipeline was constructed before 1967 - concerns about integrity, leaks, etc.
- Switch to Karegnondi Water Authority
  - Interim?
    - Treat water at Flint Plant and distribute this water
      - What water?
        - Quantity?
        - Quality?
    - Plant had been essentially idle since 1967 (back up supply)
    - When would the pipeline be completed?
The Flint River source water intake is categorized as having a very high susceptibility to potential contaminant sources.
Raw water quality - Flint River

- Long-term 2 Enhanced Surface Water Treatment Rule
  - FILTERED SYSTEMS SERVING AT LEAST 10,000 PEOPLE: Must collect *Cryptosporidium*, *E. coli*, and turbidity samples at least monthly for 24 months.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria (Standard Plate Count)</td>
<td>960 to &gt;14,760 CFU/100 mL</td>
</tr>
<tr>
<td>Total coliforms</td>
<td>20 to &gt;48,392 CFU/100 mL</td>
</tr>
<tr>
<td>Temperature</td>
<td>1.4 to 25.8 °C</td>
</tr>
<tr>
<td>Chloride</td>
<td>36 to 50 mg/L</td>
</tr>
<tr>
<td>Fluoride</td>
<td>0.14 to 0.24 mg/L</td>
</tr>
<tr>
<td>Turbidity</td>
<td>1.9 to 21.9 NTU</td>
</tr>
<tr>
<td>Average total organic carbon*</td>
<td>5.95 to 10.3 mg C/L</td>
</tr>
</tbody>
</table>

Data from June and December 2014 MORs
* Data for 2014 from MDEQ emails
Design criteria: Water quality and quantity standards

1) Minimum Day Demand – 10-mgd
   Average Day Demand – 15-mgd (14-mgd in 2010 Increasing to 15-mgd in 2050)
   Maximum Day Demand – 28-mgd

2) Turbidity – 0.20 NTU

3) Hardness – 80 to 100 mg/l as CaCO₃

4) Cryptosporidium – 3-Log Inactivation

5) Giardia – >3-Log Inactivation

6) Viruses – >4-Log Inactivation

7) Taste and Odor – Eliminated with pre-ozonation

8) Trihalomethanes – Less than 80 µg/l

9) HAA5 – Less than 60 µg/l

Technical memorandum, Cost of Service Study, Flint Water Treatment Plant, July 2011
Water age

Population: Flint, MI

CITY OF FLINT MAJOR WATER INFRASTRUCTURE
WATER AGE & WATER SAMPLE LOCATION MAP
January 21, 2015
Water treatment: ozonation

Water treatment: Ozonation

TOC + Ozone $\rightarrow$ Low Molecular weight compounds (AOC)

No official link has yet been detected between the city's water supply switching to the Flint River and the uptick in cases, but dozens have been sickened since April 2014.

Legionnaires' cases in Genesee County by month reported

Flint switched its water supply to the Flint River in April 2014.

City's water supply was switched back to Lake Huron.

Note: Monthly case values are approximated for May/June 2015 and August/September 2015.
Background: water treatment
Water treatment: Coagulation/sedimentation

https://spellchek.wordpress.com/2016/01/17/the-flint-water-treatment-process-in-pictures/
Chloride in Flint water

<table>
<thead>
<tr>
<th>Date</th>
<th>Cl$^-$</th>
<th>SO$_4^{2-}$</th>
</tr>
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<tbody>
<tr>
<td>5/22/2014</td>
<td>85</td>
<td>25</td>
</tr>
<tr>
<td>8/6/2014</td>
<td>65</td>
<td>23</td>
</tr>
<tr>
<td>10/28/2014</td>
<td>62</td>
<td>22</td>
</tr>
<tr>
<td>2/16/2015</td>
<td>95</td>
<td>25</td>
</tr>
<tr>
<td>5/12/2015</td>
<td>90</td>
<td>31</td>
</tr>
<tr>
<td>8/11/2015</td>
<td>81</td>
<td>21</td>
</tr>
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The chart shows the concentration of chloride (Cl$^-$) and sulfate (SO$_4^{2-}$) in Flint water from May 2014 to September 2015. The chart is color-coded to indicate raw chloride concentration, ferric chloride dose, and chloride not specifically accounted for.
Larson-Skold Index

- **< 0.8** chlorides and sulfate probably will not interfere with natural film formation.
- **0.8 < index < 1.2** chlorides and sulfates may interfere with natural film formation.
- **> 1.2** the tendency towards high corrosion rates of a local type should be expected as the index increases.
Flint water treatment plant

https://spellchek.wordpress.com/2016/01/17/the-flint-water-treatment-process-in-pictures/
Sludge disposal

Trihalomethane exceedances

### TABLE 2 – TTHM TEST RESULTS (ug/L)

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<td>~25</td>
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<td>162.4</td>
<td>145.3</td>
<td>58.6</td>
<td>16.2</td>
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<td>75.5</td>
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TTHM MCL = 80 ug/L
Variability in the monthly average polymer dosages used at the Flint Water Treatment Plant over the course of 1.5 years. Note that the maximum dosage of the anionic polymer (P-142PWG) is 1.0 mg/L as recommended by NSF International.
Flint water treatment plant

\[
\text{CO}_3^{2-} + \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow 2\text{HCO}_3^{-}
\]


pH and Alkalinity

- pH = - log [H⁺]
- Alkalinity = buffering capacity
  - = [HCO₃⁻] + 2[CO₃²⁻] + [OH⁻] - [H⁺]
Estimated LSI of Flint water

- Feb 1-5, 2015
- Aug 1-5, 2015
- Mar 1-5, 2015
- Dec 1-5, 2014
- June 1-5, 2015

LSI: -2, -1.5, -1, -0.5, 0, 0.5, 1

- Scale forming
- Slightly scale forming
- Slightly undersaturated
- Undersaturated

Raw river water
Treated river water
1887: City of Flint passes ordinance that lead pipe requiring lead pipes: “all connections with any water mains shall be made with lead pipe”
Lead pipe corrosion

More Children With Elevated Lead Levels After Water Change

The city of Flint, Mich., started drawing its water from a local river in April 2014. Recently, doctors at Hurley Medical Center compared lead levels in Flint children with those from elsewhere in Genesee County.

Share of children under age 5 with elevated levels of lead in their blood

- Before the Flint water switch
- After the Flint water switch

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<th>Description</th>
<th>Before</th>
<th>After</th>
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<tr>
<td>Children from Flint</td>
<td>2.1%</td>
<td>4.0%</td>
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<tr>
<td>Flint children in areas with high water lead levels</td>
<td>2.6%</td>
<td>6.3%</td>
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<tr>
<td>Flint children in other areas</td>
<td>1.8%</td>
<td>2.9%</td>
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<tr>
<td>Children from Genesee County (excluding Flint)</td>
<td>0.5%</td>
<td>1.3%</td>
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Notes:
This chart compares blood lead test results at Hurley Medical Center from before the switchover (Jan. 1 through Sept. 15, 2013) and after (Jan. 1 through Sept. 15, 2015). Blood lead levels of 5 ppb or higher are considered elevated.

Source: Dr. Musa Hamas-Talah, Hurley Medical Center
Credit: Alyson Hard/NPR
Flint water treatment plant

Flint water treatment plant

Chlorine reactions in distribution system

- High organic matter concentrations
- High water age
- Lack of passivation layer - reaction with corrosion products or metal pipe
- Reactions with biofilm

- Low chlorine residuals
  - Resulted in boil water alerts during Summer 2014 (3 in 22 days)
Trihalomethane exceedances

- Increase chlorine dose

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TTHM MCL = 80 ug/l
Lead corrosion

Analysis of MDEQ Data

Samples exceeding AL

90th percentile conc. (ppb)

0.0% 2.0% 4.0% 6.0% 8.0% 10.0% 12.0% 14.0% 16.0% 18.0% 20.0% 22.0% 24.0% 26.0% 28.0% 30.0%

1 6 11 16 21 26 31 36 41 46

Group  Date n
1  Sep-15  40
2  Oct 1-15 2015  225
3  Oct 16-31  105
4  November  127
5  Dec 1-10  73
6  December 11-31  102
7  Jan 3-9 2016  68
8  Jan 10-16  103
9  Jan 17-23  2063
10  Jan 24-30  2531
11  Jan 31-Feb 6  2743
12  Feb 7-13  1800
13  Feb 14-20  2057
14  Feb 21-27  1373
15  Feb28-Mar 5  1102
16  Mar 6-12  854
17  Mar 13-19  1306
18  March 20-26  900
19  March 27-Apr2  1100
20  Apr3-9  381
21  Apr10-16  1052
22  April 17-22  382
23  April 24-30  450
24  May1-May7  398
25  May8-May14  221
26  May15-May21  189
27  May22-May28  392
28  May 29-June 4  377
29  June5-June11  104
30  June12-18  137
31  June19-25  229
32  June 26-July 2  148
33  Jul 3-9  110
34  Jul 10-16  128
35  Jul 17-23  343
36  Jul 24-30  105
37  Jul31-Aug6  96
38  Aug7-Aug13  75
39  Aug14-20  243
40  Aug 21-27  121
41  Aug29-Sep3  87
42  Sep4-10  104
43  Sep11-17  101
44  Sep18-24  234
45  Sept25-Oct1  137
Moral of the story

- The road to hell is paved with good intentions
- Numerous actions taken were taken but each time the problem was considered in isolation
- Water treatment is a complex system and must be considered holistically
Questions
CITY OF FLINT MAJOR WATER INFRASTRUCTURE
WATER AGE & WATER SAMPLE LOCATION MAP
January 21, 2016

Predicted BLL Based on Ordinary Kriging (µg/dL)

- 0.7-1.25 (more optimal)
- 1.25-1.75
- 1.75-2
- 2-2.5
- 2.5-3
- 3-5 (more hazardous)

Note: BLL = blood lead level; WLL = water lead level


Source: Hanna-Attisha (2016)