Flint Water System

How could things go so wrong?

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Presented to Lyman Briggs College 1/26/2016
The problem in a nutshell

- The City of Flint switched from purchasing DWSD water (from Lake Huron) to treating water from the Flint River.
  - Complaints from the public regarding color, taste, and odor
  - Complaints from GM that the water was corroding parts at their engine plant
  - Boil water alerts during Summer 2014
  - Exceedances of total trihalomethanes (disinfection byproducts) in 2014 and 2015
  - Low chlorine residuals in distribution system
  - Lead in the water at the tap
Background

- The Flint plant was completed in 1954.
- Flint has purchased water from Detroit Water and Sewage Department (DWSD) since 1967.
- The source of the DWSD water is Lake Huron and treated at the Fort Gratiot plant.
Timeline

- **September 2009** Preliminary Engineering Report, Lake Huron Water Supply Karegnondi Water Authority issued
- **July 2011** Report on the evaluation of the Flint River as a long-term source of drinking water issued
- **December 2012** Michigan Treasury officials meet with Flint city officials to discuss drinking water options, including using the Flint River
- **April 16, 2013** City of Flint EM Ed Kurtz signs agreement with Karegnondi Water Authority (KWA) to supply water to Flint starting in 2016
- **June 26, 2013** Ed Kurtz hires an engineering firm to determine how to equip the Flint Water Plant for the treatment of Flint River water.
Timeline

- **March 31, 2014** Flint plant supervisor, Brent Wright, signs permit application for sludge lagoon upgrades. Application is submitted to DEQ for review and approval
- **April 9, 2014** MDEQ approves permit
- **April 25, 2014** Flint River changeover ceremony
- **April 30, 2014** DWSD Water line closed
Background: water treatment

WATER TREATMENT PLANT
SURFACE WATER SUPPLY

From: http://cof-cof.ca/surface-water-treatment-plant-flow-diagram/
Background: water distribution

http://www.pacificwater.org/userfiles/image/Water%20Demand%20Management/watersupplysystem.gif
Timeline

- June 2014 Complaints regarding water quality begin (smell, taste, discoloration)
- August 14, 2014 Flint water tests positive for E. coli. Boil water advisories issued two days later. Problems continue with three boil water advisory notices issued in a 22-day span in summer
- Summer 2014 29 cases of Legionellosis
- October 13, 2014 GM engine plant announces that it will stop using Flint water
Timeline

- **November 2, 2014** City increases hydrant flushing to address red water concerns
- **December 16, 2014** City receives official violation notice from DEQ for violations of the Safe Drinking Water Act for total trihalomethanes

Photo courtesy of: Erin Brochovitch
Timeline

- **February 2015**: City of Flint tests water of Lee Ann Walters and finds 104 ppb and 397 ppb. Iron level > 3.3 mg/L (> LOQ)
  - Water was filtered at the home
  - Sampling done after flushing
  - Internal plumbing found to be plastic, a portion external service line found to be galvanized iron pipe; the rest was lead

- **February 25, 2015**: Lee Ann Walters contacts Region 5 EPA regarding her concerns over lead levels in her water. Miguel del Toral calls the results alarming
Timeline

- **June 2015** Second violation of D/DBP Rule
- **Late July 2015** Flint installs a granular activated carbon filter to control THMs by removing organic matter
Timeline

- **August 31, 2015** Prof. Marc Edwards, VA Tech says Flint drinking water is "very corrosive" and "causing lead contamination in homes"
  - 20% of the 120 samples exceeded the U.S. EPA lead action level of 15 ppb
  - 42% of the 120 samples had lead levels that were >5 parts per billion, "which suggests a serious lead-in-water problem" according to Prof. Edwards
Timeline

- **September 24, 2015** Dr. Mona Hanna-Attisha releases study showing that the number of Flint infants and children with elevated blood lead levels have increased since the switch to Flint River Water.
Timeline

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

Children from Flint
- 2.1% before
- 4.0% after

Flint children in areas with high water lead levels
- 2.6% before
- 6.3% after

Flint children in other areas
- 1.6% before
- 2.4% after

Children from Genesee County (excluding Flint)
- 0.0% before
- 1.0% after

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 µg/dL are considered elevated.

Source: Dr. Mona Hanna-Attisha, Hurley Medical Center
Credit: Alisson Hunt/NPR
Timeline

- October 16, 2015 Flint switches back to “Detroit” water which comes from Lake Huron
- December 9, 2015 Flint starts adding additional phosphate to increase the concentration from 1 to 2.5 mg/L

http://flintwaterstudy.org/page/2/
So what went wrong?

Flint River

- Poor water quality
  - relatively high DOC, hardness, turbidity ranges from ~1.5 to 40 NTU
  - high chloride levels
  - intake is upstream of most development in Flint, but there is still some concern about industrial contaminants and sewage in water
What is it about Flint...?

- Population in Flint peaked in 1960 at ~200,000
- Population now <100,000. Water usage is down by 2/3, so water spends much more time in system than is conventional
- Many older houses have lead services lines and/or plumbing (estimated at 15,000)
- Some distribution mains are thought to be lead
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What happened to the water?

- Corrosion: oxidation of a metal
- In drinking water systems
  - oxidant is usually oxygen and/or chlorine or hypochlorite
  - reductant is lead, copper, or iron in pipes
    - Fe\(^0\) → Fe\(^{2+}\), iron oxides
    - Pb\(^0\) → Pb\(^{2+}\)
    - Cu\(^0\) → Cu\(^{2+}\)
- for metals such as Fe, Pb and Cu, corrosion is thermodynamically favorable in the pipe environment

https://water.me.vccs.edu/courses/ENV110/clipart/pipewall2.gif
Passivation occurs when a layer forms on the metal surface, so that oxygen or chlorine or hypochlorite cannot reach the metal surface. The film acts as a barrier to further oxidation.
Why was the Flint River water red?

- Iron corrosion
  - Iron oxide can protect the metal from corrosion to some extent but in iron piping carbonate compounds, such as calcite ($\text{CaCO}_3$) and siderite ($\text{FeCO}_3$) are generally more protective than Fe oxides ($\text{Fe}_x\text{O}_y$).
  - To protect the iron pipes, the water should be saturated with respect to $\text{CaCO}_3$. 

Photo: Ryan Garza Detroit Free Press

http://flintwaterstudy.org/page/2/
Could they have known this would happen?

- **Langelier Saturation Index (LSI)**
  - indicator of the approximate degree of saturation of calcium carbonate in water
  - \( \text{LSI} = \text{pH} - \text{pH}_s \)
  - \( \text{pH}_s = A + B - C - D \)
  - \( A \) - accounts for temperature
  - \( B \) - accounts for salinity
  - \( C \) - accounts for hardness
  - \( D \) - accounts for alkalinity
Estimated LSI of Flint water

decreasing LSI values:
- serious scale forming, non-corrosive
- slightly scale forming, some corrosion
- slightly corrosive, non-scale forming
- seriously corrosive

LSI values:
-1.5 – 1

Raw river water: blue
Treated river water: green

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

Graph shows the LSI values for raw and treated river water over time, indicating the corrosive properties of the water.
Estimated LSI of Flint water

- 1.5
- 1
- 0.5
- 0
- 0.5
- 1

-2 -1.5 -1 -0.5 0 0.5 1

-2 -1.5 -1 -0.5 0 0.5 1

LSI

- Raw river water
- Treated river water

scale forming, non-corrosive
slightly scale forming, some corrosion
slightly corrosive, non-scale forming
seriously corrosive

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

- In lead piping systems, carbonate (cerussite, PbCO$_3$) and hydroxycarbonate (hydrocerussite, Pb$_3$(CO$_3$)$_2$(OH)$_2$) can passivate the lead surface.

- If phosphate is present then chloropyromorphite Pb$_5$(PO$_4$)$_3$Cl or hydropyromorphite, Pb$_5$(PO$_4$)$_3$OH can form; these minerals are less soluble than cerussite or hydrocerussite.

- If the chlorine levels are high and the organic matter content of the water is low, then plattnerite (PbO$_2$) can form.
Corrosion index for lead

- No saturation index similar to LSI
- Chloride-sulfate mass ratio (CSMR) is the most widely used index

\[ CSMR = \frac{\text{Conc. of } Cl^- \cdot \frac{mg}{L}}{\text{Conc. of } SO_4^{2-} \cdot \frac{mg}{L}} \]
It is assumed
- if CSMR < 0.58 corrosion is limited
- if CSMR > 0.58 corrosion could be a problem

Empirical. Based on utility survey. 100% of utilities surveyed with CSMR < 0.58 met US EPA action limit of 15 µg/L. Only 36% of utilities with CSMR > 0.58 met the action limit

No sound theoretical underpinning. It is thought sulfate may aid formation of passive layer
CSMR in Flint water

As reported by Edwards (2015)

- **DWSD water**
  - Chloride (mg/L) 11.4
  - Sulfate (mg/L) 25.2
  - CSMR 0.45

- **Treated Flint River water**
  - Chloride (mg/L) 92
  - Sulfate (mg/L) 41
  - CSMR 1.6
What went wrong in Flint?

- Lead and Copper Rule was not followed
  - DEQ did not require corrosion control program
  - Sampling protocols stated in LCR were not followed
    - Pre-flushing
      - Used bottles with small opening, so the tap was not run fast enough
    - Tier 1 site - No easily accessible records; over 45,000 index cards
  - 15 ppb action level was misinterpreted (not a health-based standard)
What went wrong in Flint?

- Flint River has a high chloride level
  - (average: 48 mg/L)
- Used ferric chloride rather than alum, because they were worried about disinfection by-product formation and that increased the chloride concentration by 30-40 mg/L)
- Chlorine gas was added to the water
  - \( \text{Cl}_2(\text{g}) \leftrightarrow \text{Cl}_2(\text{aq}) + \text{H}_2\text{O} \leftrightarrow \text{OCl}^- + \text{Cl}^- + 2\text{H}^+ \)
- As a result of softening the water, they did not have sufficient alkalinity in the treated water

Water was corrosive to iron and lead piping
So what went wrong in Flint?

- Low chlorine residuals
  - Resulted in boil water alerts during Summer 2014 (3 in 22 days)
- Reasons
  - Reaction with organic matter in water
  - pH and temperature
  - Long water age
  - Reaction with corrosion products or metal pipe

http://flintwaterstudy.org/page/2/
So what went wrong in Flint?

- Focus was on
  - THMs
  - Microbials
- Ignored corrosion problems
CITY OF FLINT MAJOR WATER INFRASTRUCTURE
WATER AGE & WATER SAMPLE LOCATION MAP
January 21, 2016


Source: Hanna-Attisha (2016)
Legionnaire’s Disease

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.

(http://www.huffingtonpost.com/entry/flint-water-legionnaires-lead-crisis_us_569d09d6e4b0ce4964252c33)
Serious corrosion of pipes

- And most likely serious damage to the infrastructure
What is next?

- Medical intervention for those with high BLL
- EPA Region 5 to Audit State of Michigan's Drinking Water Program
- EPA looking to revise federal Lead and Copper Rule
- Multiple lawsuits filed against City of Flint and State
Questions?