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CORRECTION: This story was updated on Feb. 19, 2016. A previous version incorrectly claimed that a March 2015 report from Veolia, an environmental services company, advised Flint officials to treat Flint River water with orthophosphate to control corrosion. The report actually suggested adding polyphosphate to deal with iron corrosion responsible for the city's discolored water problems. The Veolia report did not discuss lead corrosion. Although orthophosphate can control both lead and iron pipe corrosion, polyphosphate is useful only for dealing with iron corrosion and could worsen lead corrosion.

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How Lead Ended Up In Flint's Tap Water

Without effective treatment steps to control corrosion, Flint's water leached high levels of lead from the city's pipes

*By **Michael Torrice***

Credit: Linda Parton/Shutterstock

When Virginia Tech researchers tested the water in LeeAnne Walters's home in Flint, Mich., this past summer, one sample had

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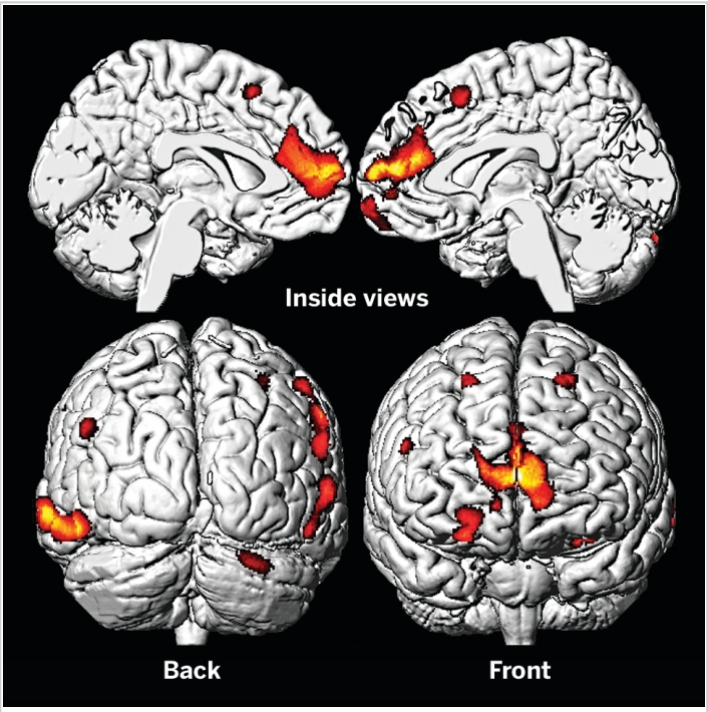
Lead levels that reached a staggering 13,200 parts per billion.

That's almost 900 times as high as the 15-ppb regulatory limit set by the Environmental Protection Agency. When lead levels exceed that threshold, water utilities must act to reduce concentrations of the toxic element.

"What was so scary about LeeAnne's house was not one sample," says **Marc A. Edwards <http://www.cee.vt.edu/profile/?pid=edwards>** , the Virginia Tech environmental engineer who led the team. "We took 30 samples over 20 minutes, and the average was over 2,000 ppb. And even after 20 minutes of flushing, it never got below 300 ppb."



<http://cenm.ag/crimelead>

Scientists worry about lead exposure in children because it can cause cognitive and behavioral issues. Read about how some researchers think the toxic metal is linked to criminal acts: **http://cenm.ag/crimelead <http://cenm.ag/crimelead>** .

Credit: Courtesy of Kim Cecil

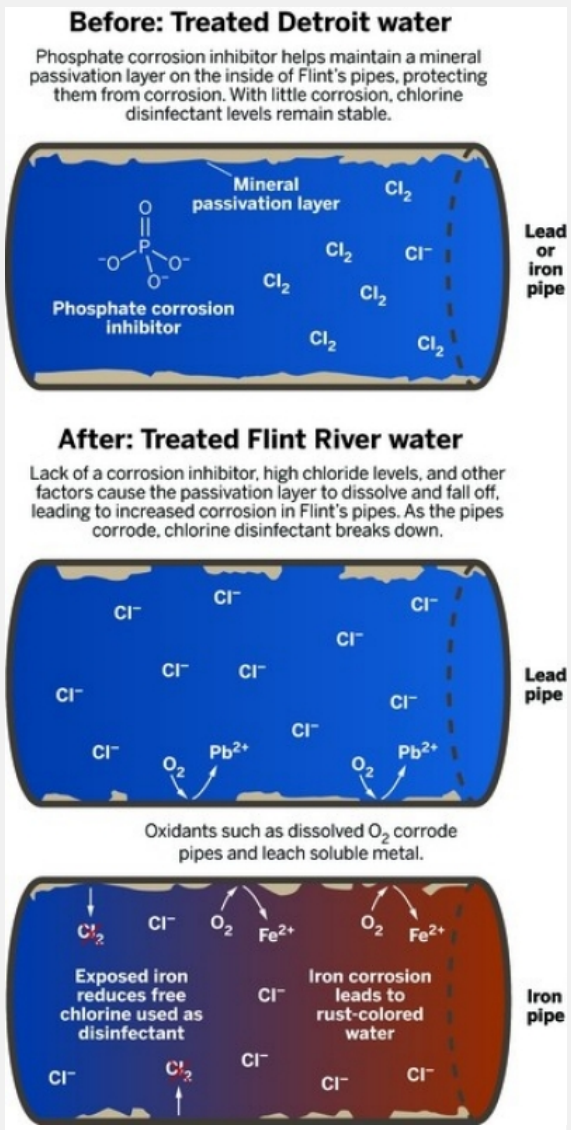
In terms of sustained high levels of lead in a home, Edwards had seen nothing like it before. "It was in a league of its own."

Lead contamination is the most troubling in a series of water problems that have plagued Flint since the summer of 2014. All of them were caused by corrosion in the lead and iron pipes that distribute water to city residents. When the city began using the Flint River as its water source in April 2014, it didn't adequately control the water's ability to corrode those pipes. This led to high lead levels, rust-colored tap water, and possibly the growth of pathogenic microbes.

Flint isn't the only city susceptible to these problems. The pipes in its old distribution system had seen the same water for decades. Switching water supplies in 2014 changed the chemistry of the water flowing through those pipes. When a switch like this happens, the water system is going to move toward a new equilibrium, says **Daniel Giammar**

http://eps.wustl.edu/people/dan_giammar , an environmental engineer at Washington University in St. Louis. "It could be catastrophic as it was in Flint, or it could be a small change."

Before 2014, Flint was getting its water from the Detroit Water & Sewerage Department, which would draw water from Lake Huron and then treat it before sending it to Flint. Looking to lower the city's water costs, Flint officials decided in 2013 to instead take water from the Karegnondi Water Authority, which was building its own pipeline from the lake. Shortly after that, Detroit told Flint it would terminate their original long-term water agreement within a year and offered to negotiate a new, short-term agreement. Flint declined the offer. As an interim solution, while waiting for the new pipeline to be finished, Flint began taking water from the Flint River and treating it at the city's own plant.



LOSS OF CONTROL
When Flint changed its water supply in 2014, the city didn't adequately control for corrosion, resulting in its water woes.

Problems with the city's tap water started the summer after the switch. First, residents noticed foul-tasting, reddish water coming out of their taps. In August and September, the city issued alerts about *Escherichia coli* contamination and told people to boil the water before using it. A General Motors plant stopped using the water in October because it was corroding steel parts. In December, the Michigan Department of Environmental Quality notified Flint that its water was in violation of national drinking water standards because it contained high levels of trihalomethanes, toxic by-products of chlorine disinfection.

Then, in early 2015, reports of high lead levels started making news. In January, it was Flint's University of Michigan campus; in February, it was the Walters home.

By early September, Edwards and his Virginia Tech team had sampled water from 252 homes and reported on their website, **flintwaterstudy.org <http://flintwaterstudy.org>** , that the city's **90th percentile lead level was 25 ppb**

//flintwaterstudy.org/2015/09/our-sampling-of-252-homes-demonstrates-a-high-lead-in-water-risk-flint-should-be-failing-to-meet-the-epa-lead-and-copper-rule/> . EPA's action limit is based on a 90th percentile calculation, meaning that if 10% of homes exceed the agency's 15-ppb threshold, then action is required.

That same month a team led by Mona Hanna-Attisha, a pediatrician at Hurley Children's Hospital, in Flint, released data showing that the number of Flint children with elevated levels of lead in their blood had increased since the water change. The percentage of affected kids went from 2.4% to 4.9%, according to a paper they published recently (*Am. J. Public Health* 2016, DOI: **10.2105/ajph.2015.303003 <http://dx.doi.org/10.2105/AJPH.2015.303003>**). In areas with the highest lead concentrations in the water, about 10% of the children had elevated blood levels of the element. Lead is neurotoxic and can disrupt children's development, leading to **behavioral problems <http://cen.acs.org/articles/92/i5/Crimes-Lead.html>** and decreased intelligence.

With evidence of lead contamination mounting, Flint switched back to the Detroit water in October.

So why did the switch to Flint's river water cause this catastrophe?

To understand the problem, consider that as water travels through the miles of pipes in a city's distribution system, molecules in the water react with the pipes themselves. "The distribution system acts like a geochemical reactor," says **Haizhou Liu <http://www.engr.ucr.edu/faculty/chemenv/haizhou.html>** , an environmental engineer at the University of California, Riverside. "There are miles and miles of pipes—some iron, copper, and lead—that get corroded." This corrosion occurs when oxidants, such as dissolved oxygen or chlorine disinfectant, react with elemental iron, lead, or copper in the pipes.

Cities no longer install lead pipes. But older cities such as Flint still rely on them, usually as service lines that connect water mains in the street to a home's water meter. A 1990 report from the American Water Works Association estimates there are millions of lead service lines in the U.S. To limit how much lead leaches into the water from these pipes and some homes' plumbing, EPA's **Lead & Copper Rule <http://www.epa.gov/dwreginfo/lead-and-copper-rule>** requires water utilities serving more than 50,000 people to establish a plan to monitor and control corrosion.

As part of these plans, utilities treat their water to maintain a mineral crust on the inside surfaces of their pipes. This so-called passivation layer protects the pipes' metal from oxidants in the water. The coatings consist, in part, of insoluble oxidized metal compounds produced as the pipe slowly corrodes.

If the water's chemistry isn't optimized, then the passivation layer may start to dissolve, or mineral particles may begin to flake off of the pipe's crust. This exposes bare metal, allowing the iron, lead, or copper to oxidize and leach into the water.

Environmental engineers that C&EN contacted say that, on the basis of how Flint treated the river water, the water chemistry was not optimized to control corrosion.

Most important, the treated Flint River water lacked one chemical that the treated Detroit water had: phosphate. "They essentially lost something that was protecting them against high lead concentrations," Giammar says. Cities such as Detroit add orthophosphate to their water as part of their corrosion control plans because the compound encourages the formation of lead phosphates, which are largely insoluble and can add to the pipes' passivation layer. By press time, C&EN was unable to get a comment from Flint city officials about why a corrosion inhibitor wasn't added to the river water.

The entire Flint water crisis could have been avoided if the city had just added orthophosphate, Edwards says. He bases his opinion, in part, on experiments his group ran on the treated Flint River water. The researchers joined copper pipes with lead solder and then placed the pieces in either treated Flint River water or treated Detroit water. After five weeks in the Flint water, the joined pipes leached 16 times as much lead as those in the Detroit water, demonstrating just how corrosive the treated Flint water was. But when the scientists added a phosphate corrosion inhibitor to the Flint water, the factor went down to four.

Still, orthophosphate isn't the only corrosion solution. Some water utilities treat water so it has a high pH and high alkalinity, Giammar says. Such conditions decrease the solubility of lead carbonates, which also contribute to the pipe's protective mineral layer.

The treated Flint River water had a relatively low pH that decreased over time. According to **monthly operating reports <https://www.cityofflint.com/public-works/utilitieswater/water-treatment-plant/>** from the Flint treatment plant, the city's water had a pH of about 8 in December 2014, but then it slowly dropped to 7.3 by August

Environmental engineers say that if water pH drifts too low in the absence of orthophosphate, the water can start to leach high levels of lead from pipes.

The pH drop over time seems to indicate that plant operators in Flint didn't even have a target pH as part of a corrosion plan, Edwards says. Water utilities usually find a pH that's optimal for preventing corrosion in their system. For example, in Boston, another city with old lead pipes, average water pH held steady around 9.6 in 2015, according to **reports from the Massachusetts Water Resources Authority**

TAP TROUBLES
Foul-tasting, discolored water started coming out of Flint's taps in the summer of 2014.
Credit: Flintwaterstudy.org

<http://www.mwra.com/monthly/wqupdate/qual3wq.htm> . By press time, C&EN wasn't able to get a comment from Flint city officials about whether they had a target pH for the water.

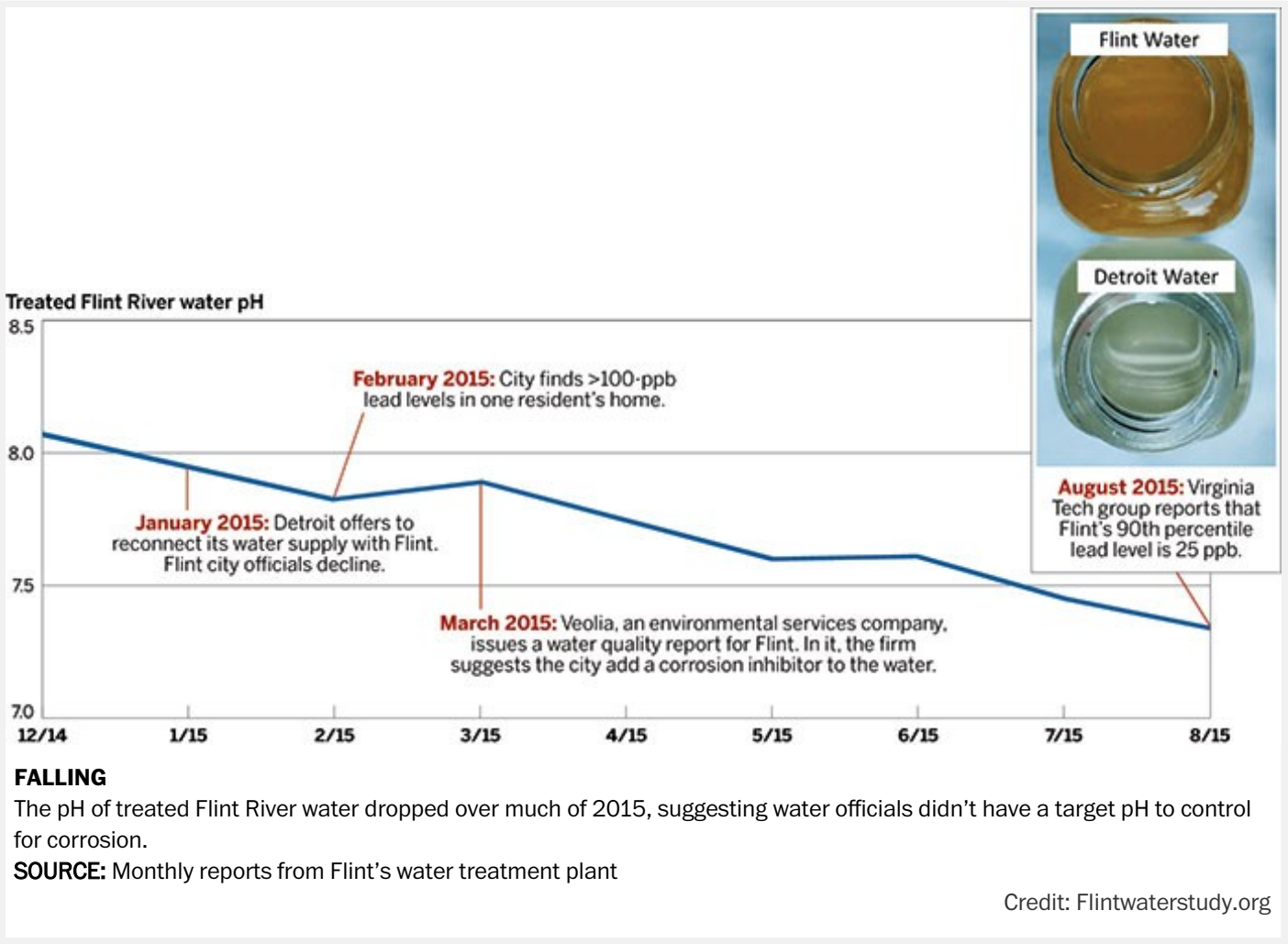
Another chemical factor that contributed to the treated river water's corrosiveness was its chloride concentration. The treated Detroit water's average chloride level was 11.4 parts per million in 2014, according to an **annual water quality report <http://detroitmi.gov/Portals/0/docs/DWSD/Water%20Quality%20Reports/2014Water** from the Detroit Water & Sewerage Department. Meanwhile, the treated Flint water had 85-ppm chloride in August 2015, according to a monthly operating report from the Flint treatment plant. The plant may have contributed to these high levels when it tried to address high levels of toxic trihalomethanes.

Disinfection by-products such as trihalomethanes can form through reactions between organic matter in water and chlorine disinfectant added at treatment plants. The Flint plant had increased the amount of chlorine it used in the summer of 2014 to combat the *E. coli* contamination problem. To reduce levels of trihalomethanes that formed, the plant removed organic matter from the water by adding ferric chloride, which coagulates organic matter, making it easier to filter out. Even though the treatment took care of the trihalomethanes problem, it increased the water's chloride levels.

Environmental engineers worry about high chloride levels because studies have shown that lead corrosion is more likely when the ratio of chloride to sulfate concentrations is greater than 0.58. Researchers at Virginia Tech **calculated the ratio for treated Detroit water <http://flintwaterstudy.org/2015/09/our-virginia-tech-research-team-wins-a-50000-grant-from-the-national-science-foundation-to-study-flint-water/>** as 0.45 and for treated Flint River water as 1.6.

Corrosion of lead pipes caused Flint's most serious water issue, but **corrosion of the city's iron pipes <http://flintwaterstudy.org/2015/09/research-update-corrosivity-of-flint-water-to-iron-pipes-in-the-city-a-costly-problem/>** also created problems. The chemistry that controls iron pipe corrosion is a little more complicated than the chemistry surrounding lead pipe corrosion, but some of the same factors play a role.

Problems with Flint's iron pipes started early: The rust color and bad taste of the water coming out of residents' taps in the summer of 2014 was a sign that the passivation layer on iron pipes was dissolving into the water.



FALLING
The pH of treated Flint River water dropped over much of 2015, suggesting water officials didn't have a target pH to control for corrosion.
SOURCE: Monthly reports from Flint's water treatment plant

Credit: Flintwaterstudy.org

For the issue that worries environmental engineers most about iron corrosion is that it could encourage the growth of pathogens in the distribution system. As the mineral layer in iron pipes falls off, it exposes bare iron that can reduce free chlorine added to the water as a pathogen-killing disinfectant. Walters's home—the one with lead levels that were almost 900 times as high as the EPA limit—had **no detectable chlorine levels <http://flintwaterstudy.org/information-for-flint-residents/chlorine-monitoring-in-flint-resident-ms-leeanne-walters-home/>** over 18 days of monitoring by the Virginia Tech team.

Susan J. Masten, an environmental engineer at Michigan State University, points out that the Flint water distribution system has another issue that could have worsened both the corrosion and disinfection problems. Much of the distribution system was built when the city's population was about 200,000 and Flint was a major manufacturing center. But the city now has less than half the population, and much of the industry, which used a lot of Flint's water, has left town. As a result, water usage has dropped significantly, while the system's capacity has remained the same.

RUSTED
A look inside Flint's pipes reveals different types of iron corrosion.

Credit: Flintwaterstudy.org

"That means water is residing in the distribution system for very long periods of time," Masten says. In some places, the water sits in pipes for more than six days before use, providing more time for reactions that corrode pipes and break down chlorine.

Although they acknowledge that they won't ever be able to directly prove it, the Virginia Tech researchers think that the *E. coli* contamination in 2014 could have been due to problems with maintaining sufficient chlorine levels in the water. Bolstering their case are two outbreaks of Legionnaires' disease, a waterborne respiratory infection caused by *Legionella* bacteria, in and around Flint—one starting in June 2014, and another in May 2015.

Now that Flint has switched back to the Detroit water, it may take months to a year for pipes to regain their passivation layers, for corrosion to slow to normal levels, and for lead concentrations to drop back into an acceptable range, say the environmental engineers that

contacted. The lesson from Flint, they say, is to continually monitor water chemistry, especially when switching between water supplies.

"What we learned here is when we collect data, we need to use those data," Masten says. She points out that the water utility officials were already collecting all the data they needed —pH, alkalinity, chloride levels—to determine if the water was too corrosive.

"Learning from Flint, I think the key message is to consider the connections between the stability of the water infrastructure and the chemistry of the water flowing through that infrastructure," UC Riverside's Liu says. "That will inevitably control the water quality at the tap."

Chemistry and the Flint Water Crisis - Speaking of Chemistry

How Chemistry Help Expose Flint's Water Crisis

C&EN covered the chemistry that let lead into Flint's water. Now, **Speaking of Chemistry <http://cenm.ag/speaking>** shows how analytical methods brought the problem to light.

Chemical & Engineering News
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Comments

William Platt **(February 9, 2016 9:46 PM)**

Do not let people such Hilliary Clinton condem anyone except for the responsible people at the treatment plant and the State health department enity. Politians do not treat water. It could have been prevented. If the politicos refused to spend the money after being told, then they deserve condemnation also. Cost cutting should never happen when it comes to public water.
» **Reply**

Michael Jankowski **(February 12, 2016 5:38 PM)**
When utilities say they need to raise rates to replace aging infrastructure, improve water quality (and wastewater treatment), etc, who balks? The users who pay for that public water.

Generally-speaking, utilities are forced to cut-costs to the bone. People will pay ridiculous amounts for bottled-water and gas, but when it comes to tap water...don't you dare raise my rates a few dollars per month!
» **Reply**

Robert Buntrock **(February 21, 2016 9:16 PM)**
Unnecessary politicization and irrelevance.
» **Reply**

William Filber **(February 10, 2016 10:43 AM)**
The catalyst or the start of this deadly problem was sparked many years ago by not being totally educated about the damages of lead. We must include the authority of local politicians into this discussion, such as the Flint City government which actually caused the City to enter into a legal state of Bankruptcy all because of self-greed and pride of many officials, we can see where this problem got life. It is shame that today we no longer accept responsibility for our actions, or standup for the values that made us civilized, we can easily today look across our nation. Or even the world and see how today entitlements and political correctness has removed the sense of responsibility, and accountability out of our mental conscious and social norm. Sorry got carried away, as for Flint and the high levels of lead in the City's pipes, words cannot express how sad and even angry I am over this issue, yes it should not have ever happen and must not happen today again anywhere. However unless we correct the political and social systems that started this health problem, we can be certain that it will happen again, our politicians across the state and in the City of Flint must take responsibility for this happening. Starting with the City of Flint government, people must look at the beginning to find the solutions and question the loud one-sided voices of our news media and those running for political office that are using this for there own personal gain. God Bless.
» **Reply**

Neil Plouff **(February 12, 2016 2:13 PM)**
William, before blaming "self-greed" and pride in city government for Flint's problems, it helps to understand municipal finances in Michigan. Cities are limited in the property taxes they can collect, both in overall rate and rate of increase. This is due to the 1978 "Headlee Amendment" to the Michigan Constitution. The bargain at the time was that cities would accept lower property taxes and in return receive higher state revenue sharing. But since then, the tax base in older Michigan cities has declined, especially in Flint, and so has revenue sharing, especially after school funding was largely shifted to the state. The fact is that no amount of cost-cutting will

make Flint's city government financially viable in the current environment, and many of Michigan's older cities are in deep financial trouble for the same reasons.
» **Reply**

D Peters **(February 10, 2016 1:57 PM)**
Thanks for this timely piece. I just described this chemical process to my son last night...he'll probably be surprised I got it right for once!

On the other hand, the local news here keeps showing an individual's home who clearly has a backed up sewage problem (brown water backing up into her traps) and this completely confuses the issue, in that lead tainted water can be perfectly clear.

Flint's water seems to have a lot of rust also for same reasons, no inorganic protection layer anymore!
» **Reply**

Rick Manner **(March 30, 2016 6:20 PM)**
You are correct that lead can be invisible and still at problematic levels. However, it may be that the news folks have it correct also. My take on the brown colored water that is so often pictured is that the tap water is so corrosive that rust and iron concentrations are so high as to be visible. I expect they filmed the water in a sink basin because it becomes more easily seen with a white background. This would be consistent with the extremely low pH for a drinking water supply.

Of course the ultimate irony is this visibly disgusting water can actually be less toxic than clear water with toxic levels of lead.

And the real shame is that many people, acting based upon a poor understanding of the issues, will be scared away from drinking their good old tap water that in first world countries is one of the safest things to drink.
» **Reply**

Patricia Egan **(February 10, 2016 2:12 PM)**
It is amazing how individuals and groups will ignore recommendation because of the cost. The old saying applies, pay now or pay later, looks like Flint Civic Leaders were very short sighted. They will pay the price not only in currency but reputation. The cost for the children and families of Flint is their long term health.

Let's hope it is a lesson that other learn from when completing a cost to benefit ratio.
» **Reply**

David Mauzzerall **(February 10, 2016 3:33 PM)**
Your article was very good, especially for a chemist. You explained the factors affecting the corrosion very well. However I was struck by the cost to add phosphate and alkalinity (via TSP presumably)to the water. It seems that $50K is an awful lot of money for such a treatment. Why the high cost which possibly made the Flint officials not do the treatment?
» **Reply**

Michael Torrice **(February 11, 2016 12:39 PM)**

Good question. Looked into how much other utilities spend on their phosphate treatment plans and $50,000 per year seems to be a reasonable rate. For example, Winnipeg spends $200,000 (Canadian dollars, so close to $140,000 U.S. dollars) annually on phosphate treatment. Their plant treats about 100 million gallons of water per day. Flint's treats about 20 million.

I think the cost comes down to volume of water treated. A few water treatment consulting firms estimate that it costs between 1 and 10 cents per 1,000 gallons of water for a phosphate treatment. At 20 million gallons per day, that would mean it would cost Flint between $200 and $2,000 per day. The $50,000 per year estimate from Veolia breaks down to $137 per day.

Thank you for your interest in the story!
» **Reply**

Joyce DeYoung **(February 10, 2016 4:24 PM)**
Excellent article that illustrates why chemistry matters to all of us every day.
» **Reply**

Michael Torrice **(February 11, 2016 1:14 PM)**
Thank you, Joyce!
» **Reply**

Thomas A. Kenat, Ph.D., P.E. **(February 10, 2016 4:34 PM)**
Thank you for your very informative article. It is good to see what the technical facts affecting this issue really are, as opposed the political football the media are making of it. It appears that the city of Flint changed their water source from Detroit to the Flint River as a temporary measure without first consulting competent Professional Engineers to determine whether there could be unexpected consequences. The complex chemical interactions that are clearly explained in this article show how dangerous it can be for officials with insufficient technical knowledge to make such decisions on the basis of cost savings alone. The consequences have been tragic.
» **Reply**

George Page **(February 10, 2016 4:38 PM)**
If it was up to me, the decision makers who let this disaster happen should be made to fix it- not using the tax money of the people they hurt. The town leaders should pay for the replacement of every lead pipe in the city out of pocket. Maybe then they will regain the trust of Flint.
» **Reply**

William Winter **(February 10, 2016 4:46 PM)**
It is curious that a scientist from Va Tech became involved. Aren't there any competent water chemists at U. Mich. or MSU?
» **Reply**

Gregg Horn **(March 7, 2016 2:46 PM)**
Dr. Edwards, the professor from Virginia Tech, has a background in studies of lead contamination of potable water systems. That is the tie-in.
» **Reply**

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Patricia White **(February 10, 2016 5:31 PM)**
Thanks for the explanation. I'd figured the chemistry was different and probably lower pH but didn't know about phosphate levels and the interaction of chlorine with the pipes. Great story.
» **Reply**

Patricia White **(February 10, 2016 5:32 PM)**
Thanks for the explanation. I'd figured the chemistry was different and probably lower pH but didn't know about phosphate levels and the interaction of chlorine with the pipes. Great story.
» **Reply**

Richard Ledesma **(February 10, 2016 5:32 PM)**
I assume that water usage in Flint has basically dropped to almost zero. If so, is there a plan for flushing the Flint system with the Detroit water so that the passivization of the piping can be done in a reasonable time frame? Does the "months to a year" estimate assume "normal" water flow? I hope that the water chemistry/experts will be involved with the decision making process and not just the politicians and bean counters.
» **Reply**

Donald Pullum **(February 10, 2016 7:21 PM)**
In the text it is stated that " Flint officials decided in 2013," It is my understanding that the officials were not Flint officials, rather it was Darnell Earley who was Flint's state-appointed emergency manager. Earley had near total control of day-to-day operations. "He was the third appointee to oversee the financially unstable city since 2011. According to a letter obtained by the American Civil Liberties Union of Michigan, it was Mr. Earley who made the final call." The quote if from America-Aljazeera's "Flint Who's Responsible" report. 12/19/15. A "2011 study that showed residents would be at risk of lead contamination if the water supply wasn't treated properly." That report was ignored. To poison one man is a crime; to poison a city population knowingly is a simple excusably error of judgement; really? I think not.
» **Reply**

Monica Keese **(February 11, 2016 10:23 AM)**
This indeed needs to be treated as a criminal case and not a mistake. We all rely on local water supply. A lot of the bottled water companies rely on the water supplied from their municipalities. The job of ensuring safe drinking water is supplied to homes and businesses shouldn't be taken lightly.
» **Reply**

Ellen Dannin **(February 17, 2016 11:30 AM)**
There are potentially several criminal or civil levels of misdeeds here, each with a specific type of sanction.

In the criminal category, the misdeed could be based on a malicious intent to cause harm. The punishment could involve varying amounts of jail time and / or financial sanctions.

In the civil area, the misdeeds could also have a malicious intent, and penalties could involve fines or other punitive actions.
» **Reply**

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Michael Torrice **(February 11, 2016 12:04 PM)**
Thank you for reading!

You are correct that the emergency manager–Ed Kurtz at the time–made the final decision in April 2013 to switch water supplies to the Karegnondi Water Authority. But the emergency manager wasn't the only one who wanted Flint to move to the KWA pipeline: A month earlier the Flint city council also voted to make the switch. Of course, the council had no power at the time.

And the KWA decision didn't necessarily mean Flint had to start taking water from the Flint River. Detroit offered to renegotiate a short-term deal with Flint while the KWA pipeline was under construction. In 2014, the emergency manager–then Darnell Earley–said no thanks and stuck with the plan to go with the river as an interim solution.

So the short explanation is that the decision to take water from the Flint River and treat it at the Flint plant was actually a series of decisions made by multiple people.
» **Reply**

Donald Pullum **(February 17, 2016 10:05 PM)**
Don Pullum, Flint College UofM 1st Gad Class 1958. In the 50s plating waste was routinely dumped directly into colorfully polluted Gilkey Creek..part of the Flint River Water shed. I suppose siltation is the solution to pollution. Flint River has a toxic history beyond Lead.

Mr Torrice, you stated, "Flint city council also voted to make the switch.".. tho "no power at the time." In a dictatorship lower, local officials are elected but have no real power; the Dictator Rules. Snyder has turned much of Michigan into a Dictatorship indeed. As you Mr T say "Of course, the council had no power at the time." Yet using the phrase "series of decisions made by multiple people." you are diluting the responsibility.

Dilution may be the historic solution to pollution, but not to apparent criminal liability. Logically extended, we can place the blame on the voters who elected the powerless officials; NO! That is a Logical fallacy, a tricks or illusions of thought. What happened to President Truman's Desk Motto... "The Buck Stops Here." Synider, please put you hands behind your back... Your Miranda Rights are... He knew, did not react, still is denying and saying we need to study it further... children close your eyes and wish... it will go away.

When supervising a TSDF and signing off on Treated Haz-Waste, the form stated that I - Personally, was responsible and fines and imprisonment could result!!! The Buck stopped with my name.
» **Reply**

Jerome Zoeller jzoeller2@hotmail.com **(February 10, 2016 9:57 PM)**
There seems to be a solution to the problem within the article. A shock of the entire system with a high pH solution, perhaps pH 10.2, followed by a short-term flush with a dilute chelate solution at pH 9.6, would in theory restore the water quality once the chelate flush was complete. Every household would have to run a specified amount of the water into the sewer. Such a treatment would necessitate facilities to collect samples of the flush waters from all over the system, and conduct real time analyses of the waters until it's free of lead and chelate, and is restored to an equilibrium pH of 9.6.
» **Reply**

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Ellen Levy **(February 11, 2016 8:49 AM)**
Thank you for this informative article. The chemistry is beautifully detailed and as you know, it is not easy to get serious scientific information about public health problems from the mainstream media. I am a high school chemistry teacher in the South Bronx section of New York City. We have just embarked on a study of the chemistry of ocean acidification. I am going to add a sidebar project on Flint, since the acidity issue is so paramount here. The lives of children compromised by the incompetence and greed of the officials in Michigan must be mourned in a way that matters; one way to do this is by increasing the scientific literacy of our next generation of leaders. Thanks again.

-Ellen J. Levy, Ph.D.
» **Reply**

DaveN **(March 28, 2016 3:49 PM)**
I don't know all of the facts, but I really don't see "greed of the officials" as the primary driver for this. I suspect there was a disconnect between the "engineers" who were treating the water from the "officials" who were making the decisions. This story describes part of the problems, but doesn't mention other aspects (for instance, the way the complaints were ignored, and the failure of management to get to the bottom of the issue in a timely fashion.) One key point made was the treatment system wasn't controlling pH adequately. This IS a systems failure (unless it can be shown that somebody suspended or ignored SOP or QA procedures). So, my questions are about the competence of the people in the decision making chain. If the "managers" relied on advice given by people not qualified to explain "best practice" (and the possible consequences of non-compliance), then they need to justify why these "experts" were relied on. Trust but verify. If the "technicians" pretended to an expertise they didn't possess, and willingly went along with the cost cutting because they didn't "know no better" then do we blame them or their management? It seems to me that no one in the Flint water management system was directly responsible for protecting the public. That, too, is a systems failure.
» **Reply**

Dr Al Wentz **(February 11, 2016 11:19 AM)**
pH monitoring and understanding the water systems reactions to it, could have avoided the costly solution, that must follow.
Where was the federal and state EPA during this period of indecision?
» **Reply**

John T. O'Connor **(February 11, 2016 12:11 PM)**
As a consultant to midwestern water utilities, I have been seeking answers to basic questions related to the operation of the Flint, Michigan water system and the resultant release of lead from its household plumbing systems.
What would explain a lead solubility as high as 13.2 mg/l? Was there any indication that much of this lead might be in particulate form?
It is, indeed, odd that “after 20 minutes of flushing, it (lead) never got below 300 µg/l”. Flushing of the tap for such long a long period should almost certainly have brought water into the home from the distribution main. Was the water from the distribution main providing the home with water having grossly elevated lead levels?
Did any other communities in Michigan experience coliform or trihalomethane violations during the summer of 2014 or was Flint unique in this regard?
To what degree did lead concentrations in household plumbing decrease with the return to use of the Detroit water source?

What were the copper concentrations and corrosion rates in Flint?
No detectable disinfectant residuals for eighteen days in the household exhibiting the most extraordinary lead concentrations? Not even when taps were run long enough to access water from the distribution main? Were there no disinfectant residuals in Flint's distributed water? Was there no routine monitoring of disinfectant residuals throughout Flint's distribution system?
I would appreciate links to sources that might provide information on the Flint River water; the treatment provided; the quality of the finished and distributed water; violations that were reported; and actions taken by the utility to respond to these violations.
» **Reply**

Michael Torrice **(February 11, 2016 1:12 PM)**
Thank you for your interest in the story.

The engineers I spoke with thought the lead was mainly coming from lead service lines leading from the distribution mains to Flint homes. So the water in the distributions system had the high lead levels to begin with. Lead in home plumbing probably contributed to the problem, but the Walters home–the one with the startlingly high lead levels–had plastic piping.

I don't know if other nearby communities experienced coliform or trihalomethane violations in 2014. But I think much of the rest of the county got water from Detroit, as Flint previously had. So I'm not sure other communities were using the Flint River as a source.

Data on Flint water quality and water treatment can be found on the Flint treatment plant's site: https://www.cityofflint.com/public-works/utilitieswater/water-treatment-plant/. The last report on there is from August 2015, and they only go back to December 2014. Hope that helps.
» **Reply**

John T. O'Connor **(February 14, 2016 5:11 PM)**
Michael,

Thank you for your response. Your links revealed a substantial quantity of data on the lead levels observed in 272 Flint households.

The useful data posted by the Virginia Tech team confirms that there was no lead in the water supplied through the distribution mains, but was recruited from the service connections and household plumbing.

By sampling at various times, the researchers also demonstrated that, when household sample taps were flushed for two minutes, elevated lead concentrations decreased to less than 1.8 µg/l in more than half the homes sampled.

Alternately, a dozen homes still exhibited exceptionally high levels of lead, even after two minutes of flushing. These homes, and similar ones yet to be found, clearly require bypassing of their service connections until a permanent solution can be implemented.

Finally, I wondered if any those severely affected homes were utilizing ion exchange softeners.

John
» **Reply**

ronald michalak **(February 28, 2016 7:20 PM)**
I appreciate these comments, the poster has an understanding of the situation that confirms his background. My question is one of simple math, maybe I am not understanding something. If a million ppm is 1, then why isn't 13,200 ppm 1.32%? If I am right, the lead content in that house's water is 13.2 g/L, not 13.2 mg, off by a factor of 1000. If I am right I think it is important to correct from a legacy perspective. If I am wrong, don't bother to post this reply.
» **Reply**

ronald michalak **(February 29, 2016 6:00 AM)**
Sorry, I see my mistake, I'm used to dealing with ppm, not ppb, I just glossed over that part too quick, 13.2 mg it is!
» **Reply**

Jeff McKinley **(February 11, 2016 5:27 PM)**
I was an operator at the Flint water plant in 2014-15. To answer your question about a target pH, it was 8.5-9.0. I would add that Flint utilized lime softening so the pH was raised to a target range of 11.0-11.6 and subsequently reduced through the addition of carbon dioxide.

As far as the decision to not implement optimized corrosion control, that was a decision by committee including the city, their engineering firm and the Michigan DEQ. It was the DEQ that misinterpreted the Lead and Copper Rule requirement for communities with over 50,000 residents to implement corrosion control immediately after a source water change. Instead, the DEQ allowed Flint to conduct the two consecutive six month monitoring periods first.

I would also add that Flint had used the Flint River as its primary source until 1967 when they switched to Detroit water. They maintained it as a backup source until 2014 when they switched back to the primary source. The difference was that aluminum sulfate was the primary coagulant used during the previous years and the plant switched to ferric chloride a few years before the water crisis. It was never tested properly throughout the distribution system, only at the plant as the plant was generally run about 20 days per year in a backup role. Had they examined the CSMR, chloride sulfate mass ratio, they would have been alerted to the dramatic increase in corrosivity by switching from alum to ferric chloride.

I would note that nothing was preventing Flint from doing the right thing and implementing corrosion control. Despite the DEQ signing off, the city water experts and their engineering firm could have submitted their proposal to include it. Instead, they took the minimalist approach and we've seen the results.
» **Reply**

Michael Jankowski **(February 12, 2016 5:47 PM)**
Thanks for your interesting first-hand contribution.

Most people seem to ignore or be unaware that the Flint River used to be the primary source of raw water and remained as the backup source. This was a temporary measure that had very unintended consequences.

While this article states Dr. Edwards' research as reducing the lead leachrate from 16 times that of the Detroit water to only 4 times with phosphate added, I have seen another report that stated Dr. Edwards' tests showed a reduction in corrosivity from 19 times that of the Detroit water to 16 times after phosphate was added - seemingly negligible. Those are measuring two slightly-

different things but still seem conflicting. That report singled-out the corrosivity of the Flint River source being the result of water having 8 times the salinity of the Lake Huron source water that feeds Detroit.
» **Reply**

Anthony Kiszka **(March 8, 2016 1:55 PM)**
Jeff McKinley, thank you for the explanation, as I am not expert in municipal water systems is the CSMR testing required? Optional? or best practice when making a chemical change?
» **Reply**

Jeff McKinley **(April 9, 2016 11:10 PM)**
CSMR is another tool in the toolbox. Not a requirement. The EPA can take credit for complicating this issue. Their guidance is very confusing concerning corrosion control, even to trade professionals. The Safe Drinking Water Act dictates that the public must be protected at all times. Yet the EPA stipulates that a water utility that changes a water source should NOT continue the identical process used previously. Rather they should first conduct two six month monitoring periods and collect data to determine if an optimized corrosion control program is necessary. This is what Flint did. It meets the legal standard. The DEQ failed in its oversight role but only from a best practices perspective. Government failed at all levels because they were attempting to meet minimum legal standards rather than providing the best possible product.
» **Reply**

Chip Kilduff **(February 11, 2016 5:52 PM)**
Michael, Great article, very informative, well researched and well written. A minor issue with the Loss of Control figure. Chlorine undergoes hydrolysis to form hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). These are the chlorine species that should be shown in the figure, not Cl_2.
» **Reply**

Michael Torrice **(February 18, 2016 5:28 PM)**
Hi Chip. Glad you enjoyed the article.

For that diagram, our goal was to quickly depict the key types of chemical species relevant to the corrosion issues. To avoid making a diagram that was hard to follow, we stuck with representations for the different species. So we didn't show the hydrolysis of Cl_2 into HOCl or OCl^-, or the various lead and iron compounds produced by the corrosion process. It was meant to be more of a big picture illustration than a detailed outline of the chemical reactions taking place.
» **Reply**

Stephanie Rathsack **(February 24, 2016 9:00 PM)**
Do you have a source for those specific, detailed chemical reactions? This is an amazing article. I have been looking for this EXACT type of article for a while. I am a chemistry teacher and have been discussing the Flint Water Situation with my students continuously. We are just starting to talk about types of chemical reactions and the unit will culminate in creating our own model of what happened. Any advice from anyone or any links to help with further chemistry would be greatly appreciated.
» **Reply**

c&en

Fred Welfare **(February 11, 2016 11:48 PM)**
A few questions immediately come to mind: what was the budgetary reason for switching the water source?

Also, were daily water samples taken and analyzed? If so, were the levels reported to the appropriate officials, and if so, what did they do?

Lastly, this sounds like a common problem that can only be addressed by switching out the pipes and using pipes that do not leach chemicals into the water!
» **Reply**

Frank C. DiLego **(February 15, 2016 11:07 AM)**
I think your questions are basic to understanding the problem. I'm sure that samples were analyzed daily. What happened to the results? Is it possible that the water was sampled in such way that the high lead levels did not show up? I have not seen any answers to these questions.
» **Reply**

Michael Torrice **(February 15, 2016 6:52 PM)**
One of the problems with the lead testing in Flint was that the officials weren't following the EPA's Lead & Copper Rule. That rule states that at least 50% of the homes tested must be homes at high risk for lead issues–meaning they are connected to lead service lines or their internal plumbing has sources of lead, such as older brass fittings or lead solder. When officials tested the water in Flint, they didn't do that mainly because they didn't have easily accessible records that would have allowed them to find such at-risk homes. There were also problems with how they told residents to collect the water. So those missteps contributed to officials missing the lead problem.
» **Reply**

Peter Evans **(February 12, 2016 3:54 AM)**
I think tap water should be banned from drinking altogether. Miles and miles of lead filled pipes with water erosion alone transferring high levels of lead...for what? To not drink out of a bottle? The cost of water is 50 cents per person per day or $200 a year at most.
» **Reply**

Bob Faulkner **(March 5, 2016 2:44 PM)**
The problem with bottled water, I have read, is that there is an awful lot of pollution caused by making/recycling the plastic bottles and then trucking them to your local store.
» **Reply**

Brian Howells **(February 12, 2016 8:52 AM)**
Mr. Torrice,
Thank you for the very informative story, it made me aware of the chemistry that happens after the water leaves the treatment facility. From the story I inferred that routine monitoring of water quality downstream of the distribution network (at the tap) was not required although from Mr. McKinley's comment I see that monitoring is done when deemed appropriate. Is that correct? Given that I now know that the distribution network is not passive but an active player in water quality I would want

periodic monitoring for, at the very least, harmful elements and bacteria. Testing can be tailored to monitor for known weaknesses in the system (the composition of the pipes, water treatment chemicals used, seasonal variation in source water pH, etc).
» **Reply**

Rick Manner **(March 30, 2016 6:44 PM)**
Mr. Howells,

You might be happy to hear that the regulations around drinking water do take into account that some parameters change in the distribution system. Bacteria and lead and copper samples are collected both at the treatment plant (to understand baseline inputs) and in the distribution system. Lead and copper samples are intentionally collected as first-draw samples to capture the high concentrations that may result from water sitting in pipes and fixtures.

Many components are not expected to be changed in the distribution system. These are tested only at the water plant.

The frequency of testing is also based upon prior test results and the probability they will change. For example volatile organic chemicals are tested frequently at first. But after several clean samples, can be reduced in the frequency of testing - especially if the utility is using a groundwater source, which is unlikely to change rapidly.
» **Reply**

Richard Silver **(February 12, 2016 9:18 AM)**
I know one solution which has been used for damaged or corroded pipes is a polyethylene liner which can be pushed into the pipe at one or several entry points without digging up and replacing the old pipes. Pressure drop may actually decrease even though the ID is reduced due to the smoother surface. This is much less costly and disruptive than replacing the pipes. It also may avoid future corrosion problems. Has anyone examined this for Flint or other affected cities?
» **Reply**

Ivy **(February 13, 2016 12:30 PM)**
Thank you for writing this. I am a high school chemistry teacher, but I did not feel like I had enough information to explain why there were problems in Flint. The mainstream news organizations glossed over the science, and I didn't have time to research it myself. This was very informative. I assigned it as reading for my students and shared it with my friends.
» **Reply**

Raymond Baumer **(February 15, 2016 9:03 AM)**
Thank you for the well researched article. You state that the "American Water Works Association estimates there are millions of lead service lines in the U.S." The terminology implies a pipe made entirely of lead. A more complete description and even history of the materials typically in the composition of metal water pipes would be really helpful. Similarly, a discussion of the composition of common metal drinking water fixtures. Even a short history of the solder used on copper pipe would be great. People look at a "chrome" faucet and "galvanized iron pipe" and do not see any source for lead.
» **Reply**

Carter B **(March 3, 2016 11:07 PM)**

I really like the science behind the article and the poor situation that is going on in Michigan. This is a very well done project and research on this article. The information is very crucial so people understand and can avoid situations like this in the future.
» **Reply**

Thomas E. Hopkins, Jr., P.E. **(March 4, 2016 6:49 PM)**
This is a very a good refresher on corrosion control and lead contamination. I left the State of Georgia's drinking water program in 1993 and got as rusty as Flint's water!
» **Reply**

Bob Faulkner **(March 5, 2016 2:53 PM)**
Looks like a very nice article...a lot to read in one sitting. I hope my questions were nor addressed in the article or comments already.

1) I have always heard that phosphates in rivers are bad. This water is flowing to the homes; but, won't the added phosphates flow in the waste water back to the river or lake? Is it removed at the waste-water treatment plant?

2) An article on the Huffington Post suggests that phosphates may not be all too healthy to consume.

3) Is it that difficult to add phosphates at the Flint water plant as opposed to switching back to Detroit water?
» **Reply**

John **(March 10, 2016 9:19 AM)**
As a wastewater professional I can answer the 1st question, at least for my area (Georgia). Wastewater treatment plants (WWTP) do in fact treat and remove phosphorus. As new permits are issued the levels allowed are being greatly decreased. In rural areas the issue of phosphates in the rivers isn't coming from the WWTP but from runoff of non-point source pollution (farmers/golf courses/suburban lawns). Even if WWTPs released zero phosphates it would only have a minimal effect on river phosphate levels.
» **Reply**

Toomas Parratt **(April 7, 2016 12:24 PM)**
Can you please show the study that indicates that adding an orthophosphate would have reduced the lead from the Flint water? All the studies I have read by Edwards state

"As indicated in this work, orthophosphate will not reduce lead leaching from all lead plumbing sources. On the basis of our extensive experience, we would only expect modest improvements to water lead levels if orthophosphate was added."

http://flintwaterstudy.org/2015/09/test-update-flint-river-water-19x-more-corrosive-than-detroit-water-for-lead-solder-now-what/
» **Reply**

Cindy **(May 9, 2016 7:30 AM)**
I'm trying to figure out polyphosphate related to iron/manganese- please correct me if I'm wrong. This is my research after talking with water specialists and reading articles like this:

1) Polyphosphates bind to iron/manganese to help keep acceptable levels in our water.
2) These polyphosphates bind so tightly that filters with water softeners, and reverse osmosis installed at our sink cannot break the bonds to filter them out of our water.
3)heat/Ph can break the bonds - thus exposing phosphates, iron and manganese in our water heaters and bond breaking in our body.
4) Anything that is not consumed or heated - gets flushed down the sink/toilet - and the polyphosphate can rip the calcium lining of PVC pipes (older pvc pipes)thus exposing the asbestos lining of the PVC.
5) The asbestos lining of the pipes gets into our wastewater thus exposing our ground water to cancer causing chemicals - and we in turn drink this water.

So:
1)what are the health effects of the polyphosphates, iron, manganese - once our bodies break down the bonds??
2)what is in our water heaters when these bonds are broken and the sediment is at the bottom of the heater?
3)what is in our ground/wastewater as a result of exposed asbestos?

Why are we using polyphosphates??? That's right - to stay within acceptable levels of iron and manganese without properly filtering it out at the plant well site.

» **Reply**

mo **(June 29, 2016 11:43 AM)**
Chlorine is the culprit in addition to state water engineers who regulate the amount of chlorine residual. Sometimes it is necessary to increase the chlorine to combat increased sediments, but this is when the tthms rise as well as the corrosion.
WA state ordered an arbitrary 750% increase in our residual and ignored our complaints and pleas of damage and health concerns for nearly two years until they learned the septic systems lost their biotic action. Now one of us even has tpll, a type of leukemia lab animals get from consuming high levels of chlorine!!
They finally admit that the tthms and lead levels are most certainly too high but also say because of the size of our system, we don't have to test, and they don't have to order it. They obviously don't believe they have responsibility to warn us of the harm.
» **Reply**