



Phosphorus - A Holistic Approach to Corrosion Control and Water Quality

NJ Water Association Training

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OUR MISSION

EVERYONE DESERVES CLEAN WATER





Ancient Rome invented plumbing
and had the same problems.

The UK can provide a glimpse
into our future problems.



Cause & Effect

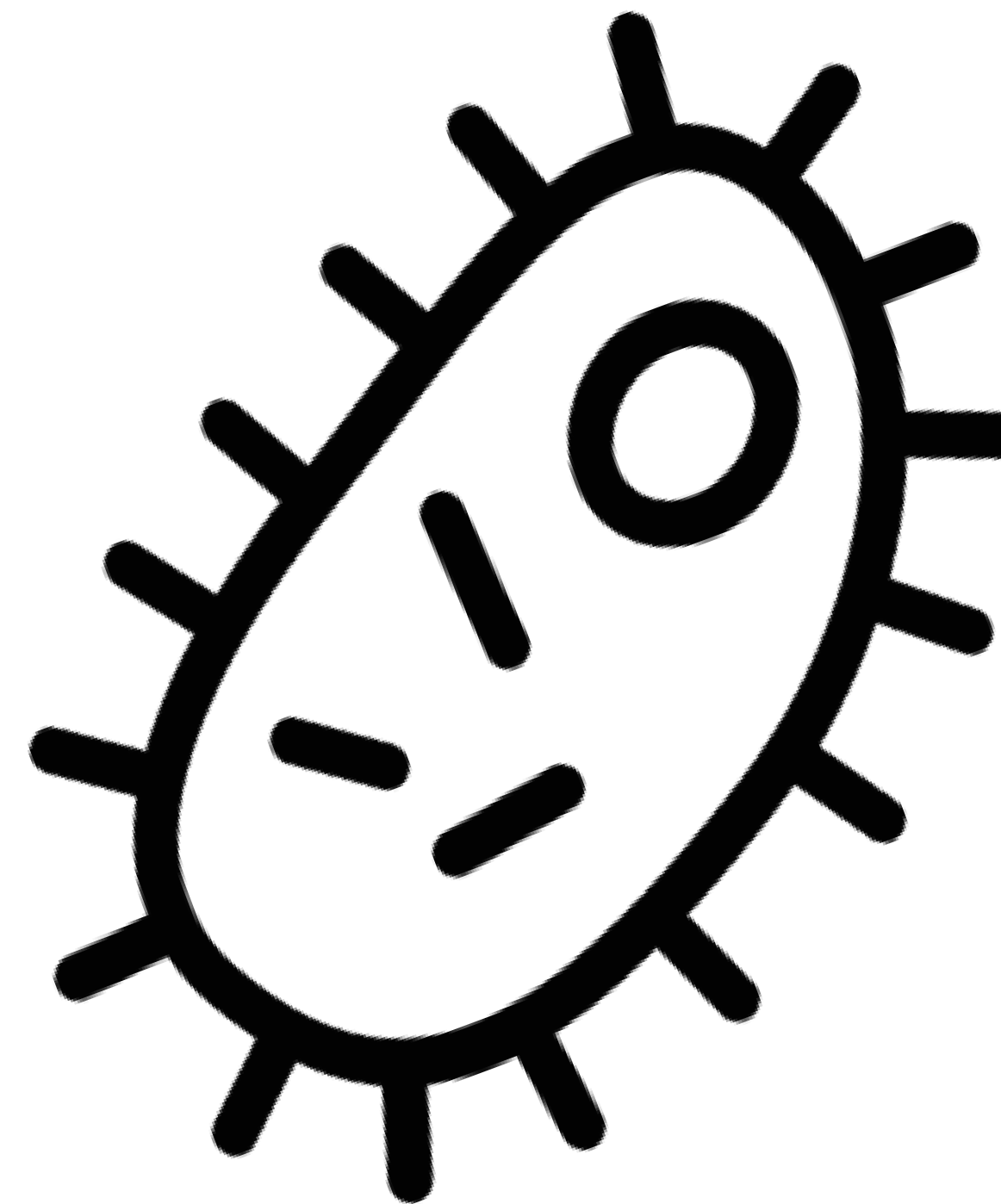




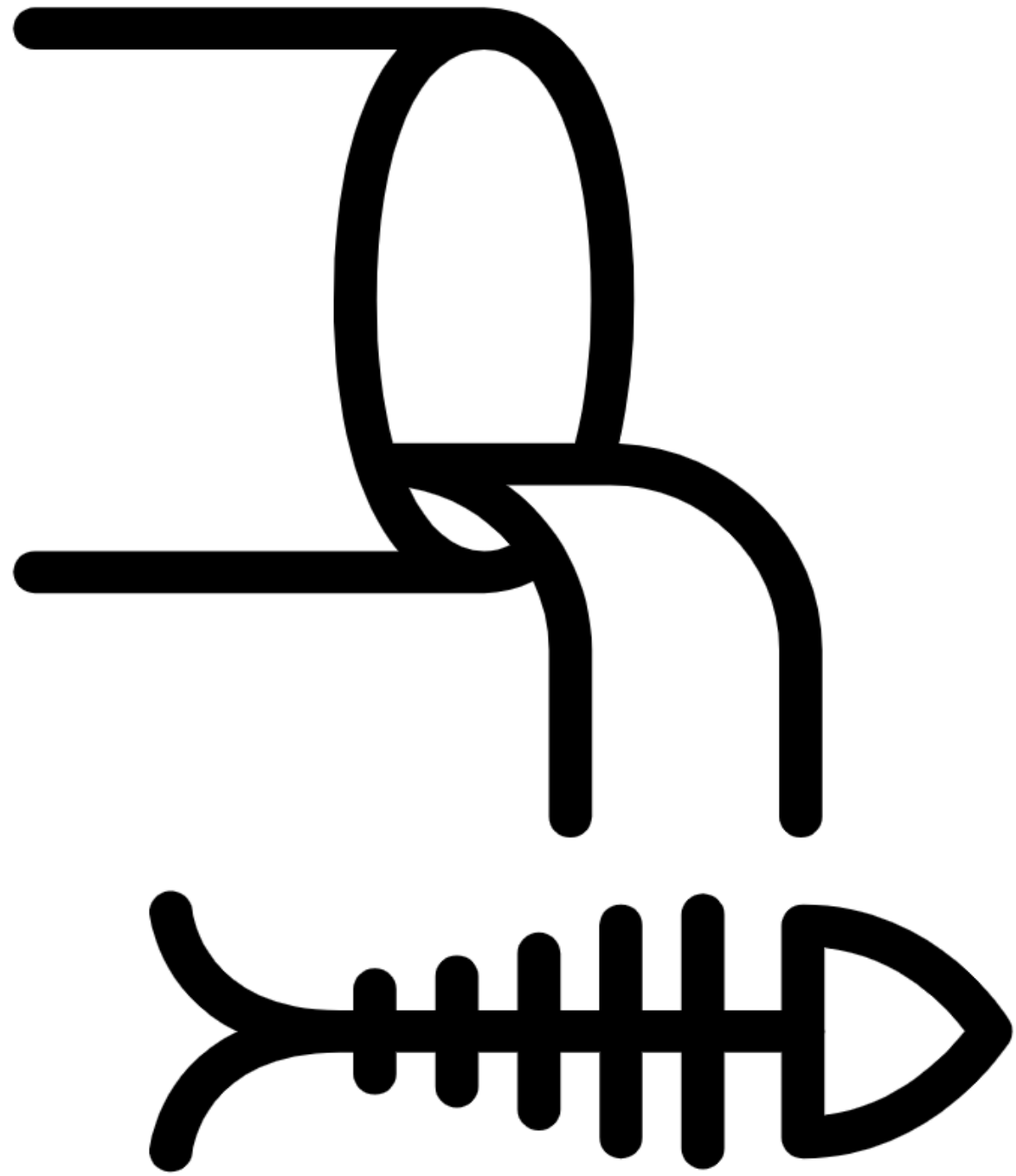
Revised US Lead & Copper Rule...

“The water system must evaluate the effect of the chemicals used for corrosion control treatment on other drinking water quality treatment processes.”

Corrosion of infrastructure leads to iron in the water, which reacts with chlorine resulting in lower residuals



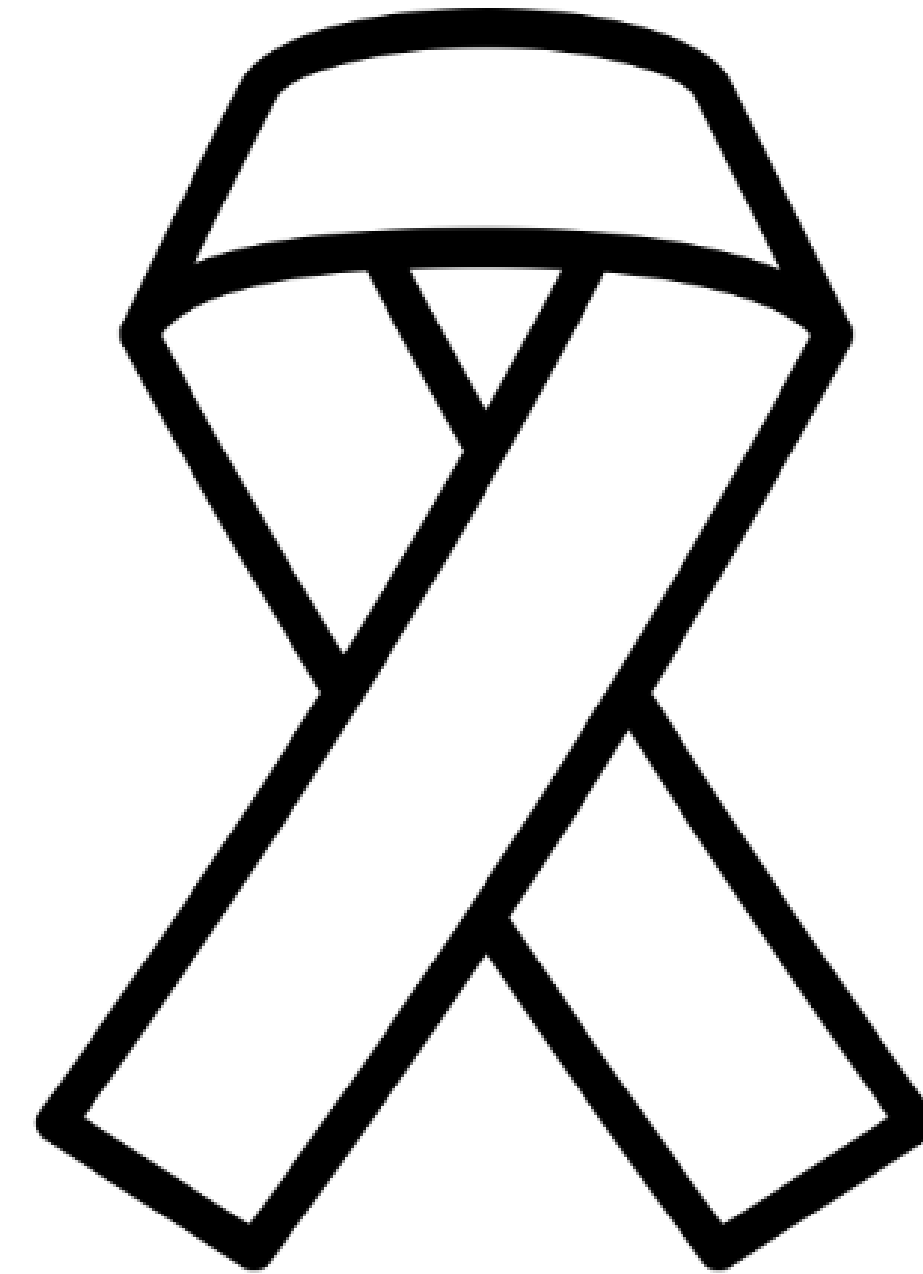
**Low Chlorine
Residuals**



A study cited by EPA concluded as much as 35% of the phosphorus load on wastewater plants comes from corrosion control products for drinking water

Phosphorus Discharge

When low residuals are encountered, more chlorine is added which leads to oxidizing more organics, which leads to excess disinfection byproducts



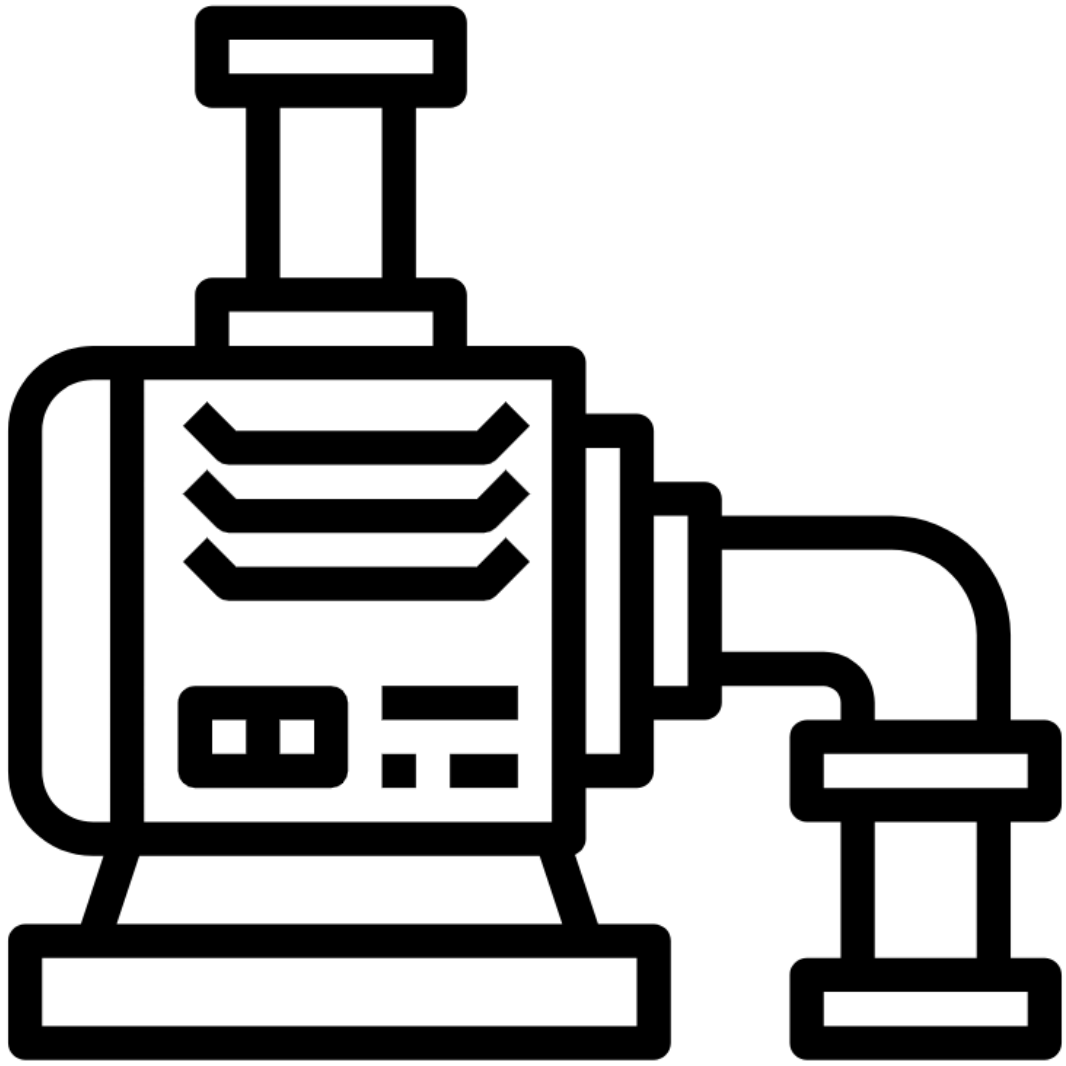
Disinfection Byproducts



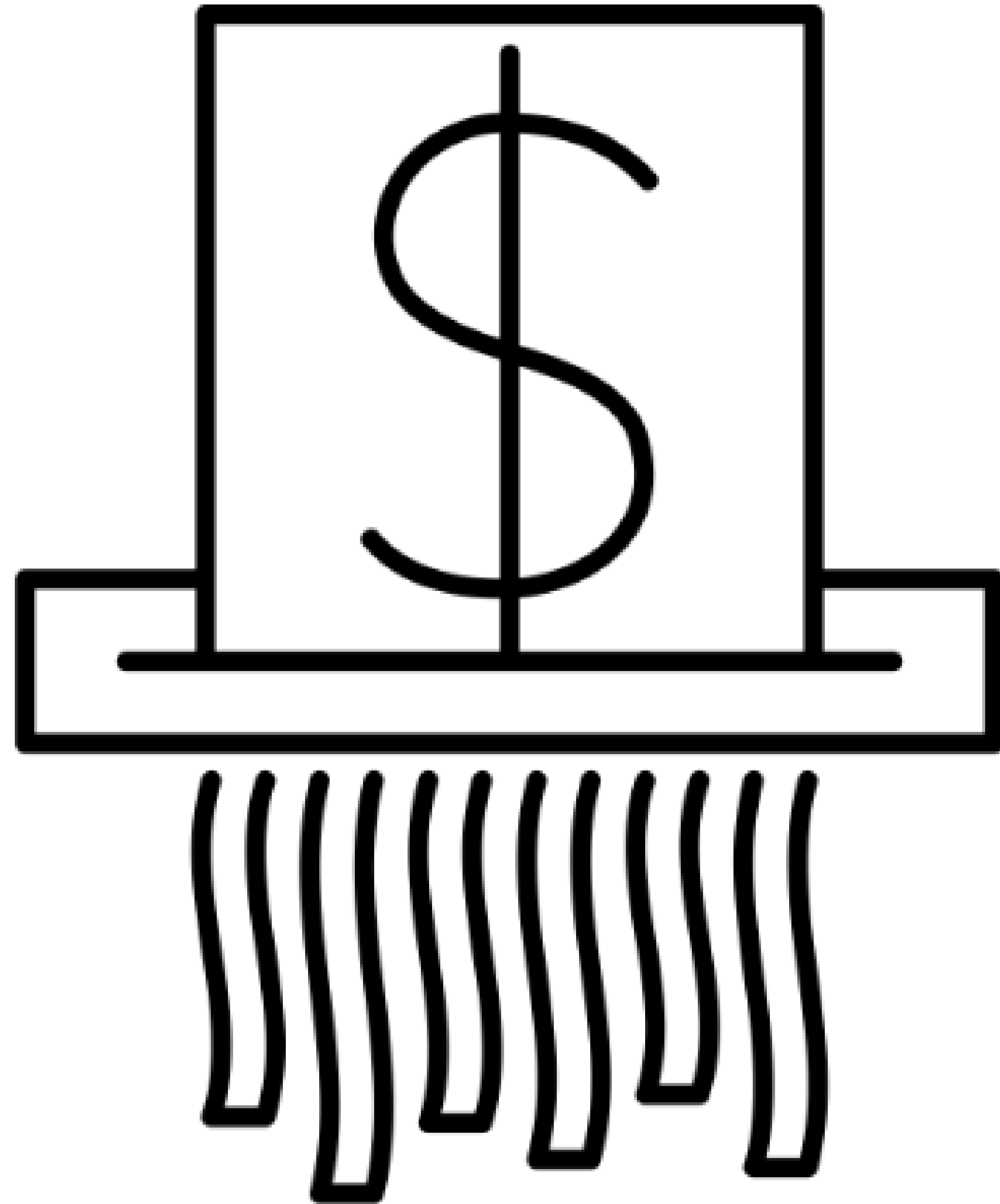
Dangerous Chemicals

Utilities should minimize use and potential exposure to dangerous chemicals, such as phosphoric acid, sodium hydroxide & calcium hydroxide

When pipe walls aren't clean, it takes more energy to pump the same amount of water, leading to excess cost and premature equipment failure



Extra Pumping & Electrical Cost

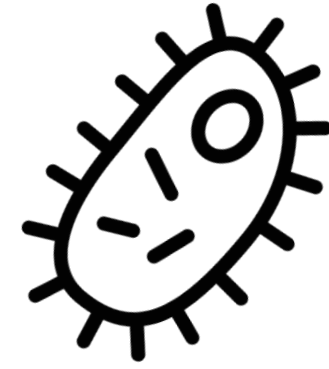


Expensive Chemicals

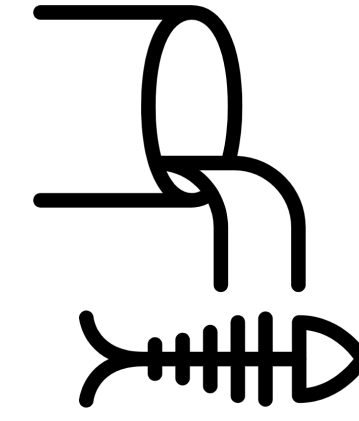
“In cases where more than one treatment option can meet OCCT, systems may want to consider cost factors.”

-EPA, 2018

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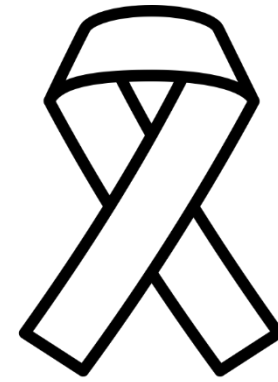
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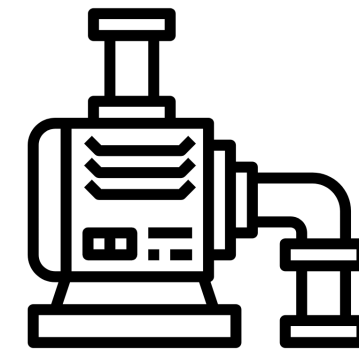
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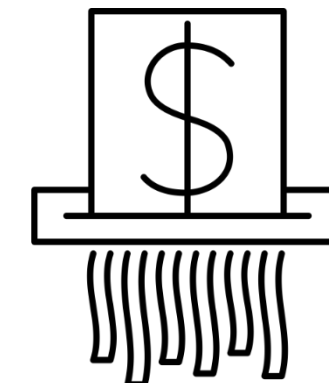
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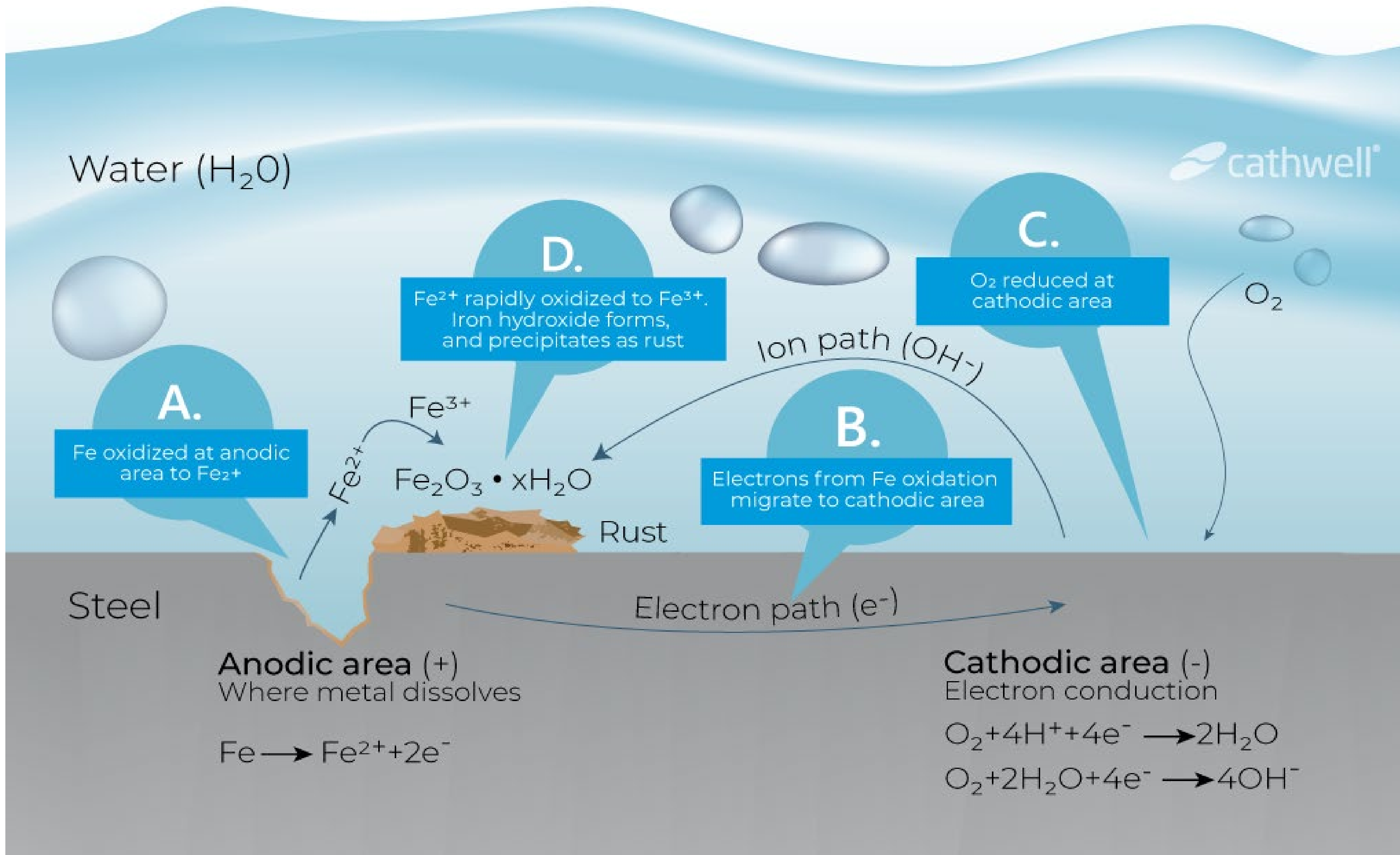
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SEAQUEST

Drinking Water Treatment – Introduction to Corrosion Control

Why is there Corrosion?



Cathodic Protection?

Anodic Protection?

Oxygen Barriers?

Coatings?

Sacrificial Anodes?

Charge?



Building Mineral Scale is the Answer!



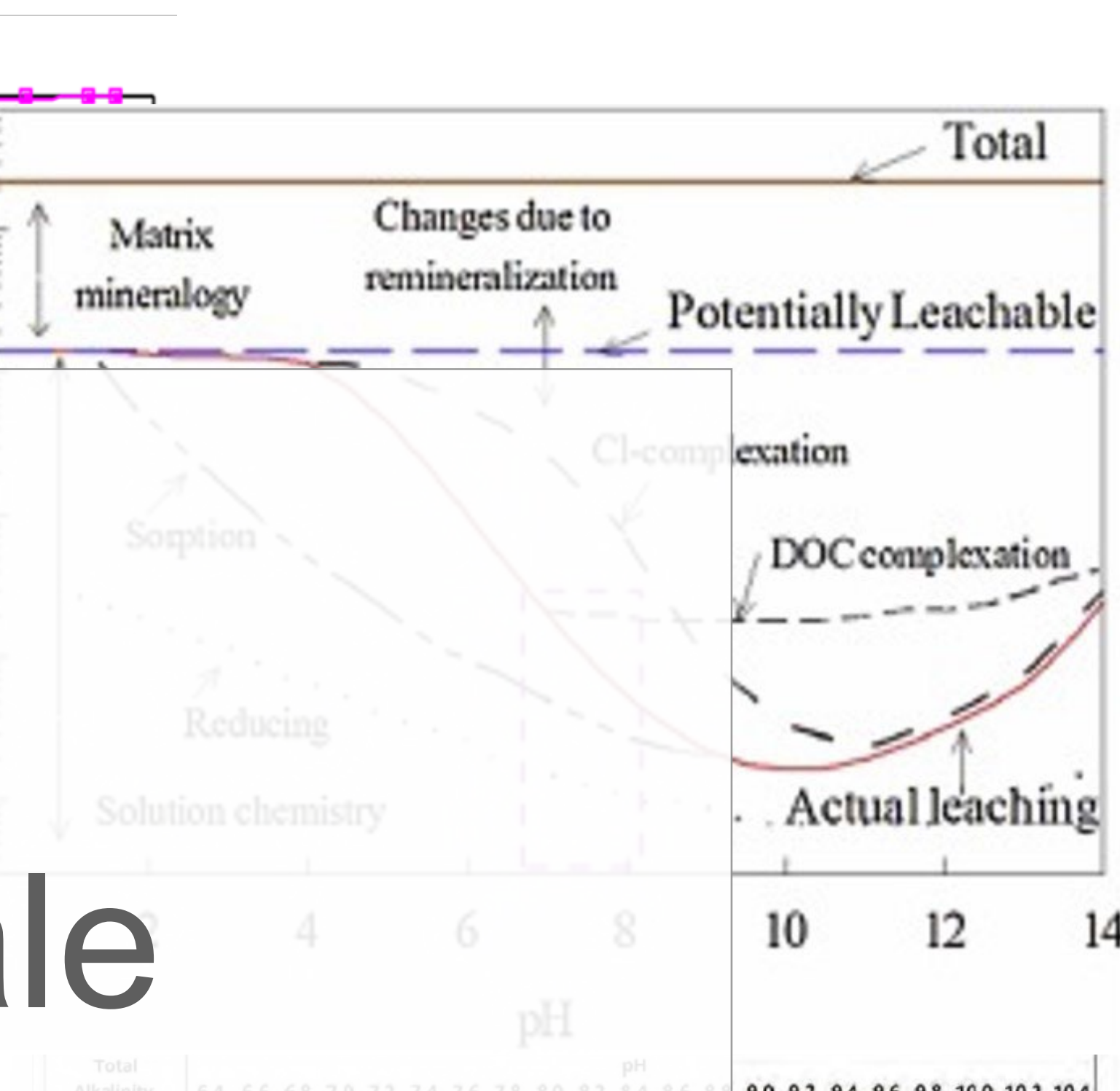
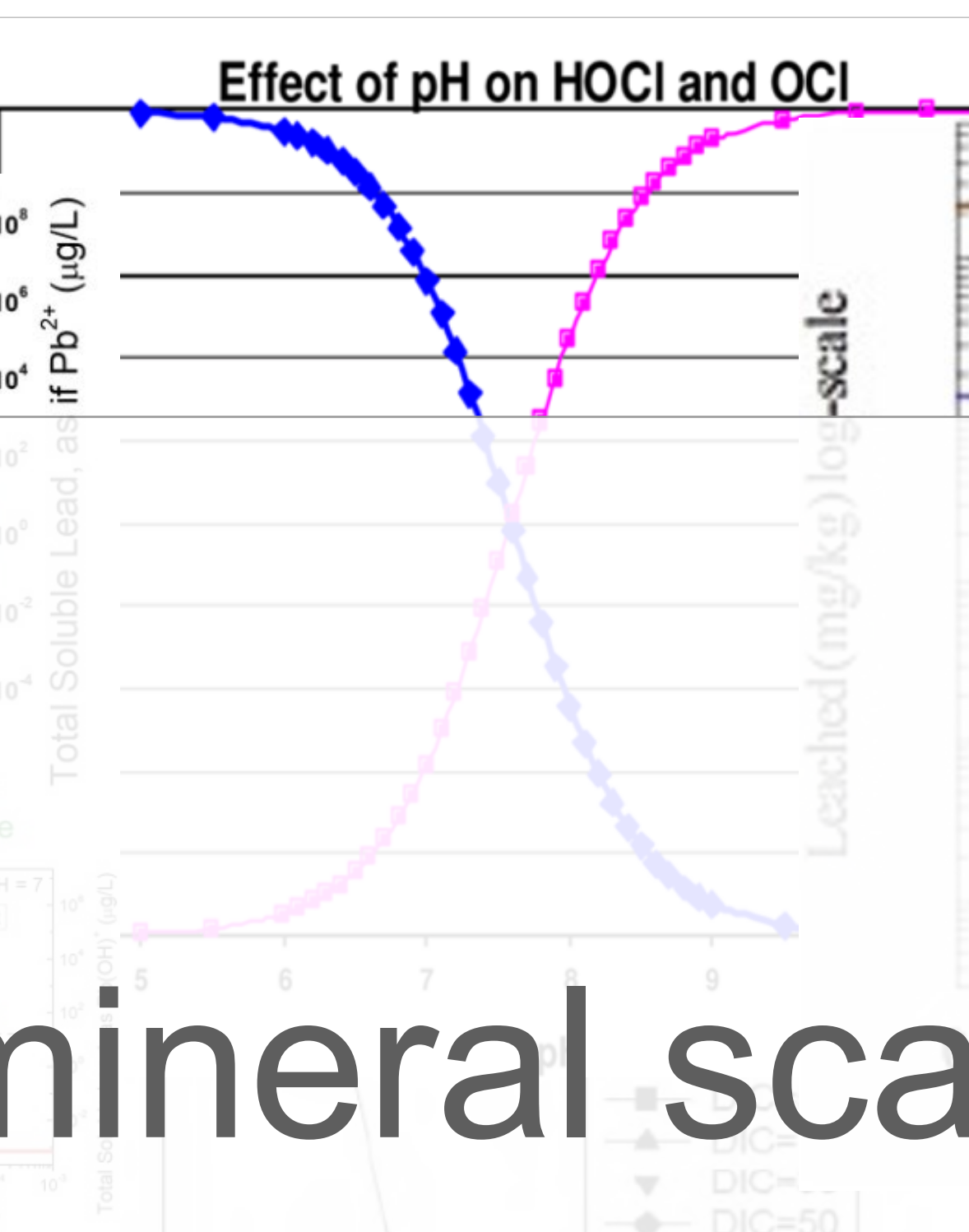
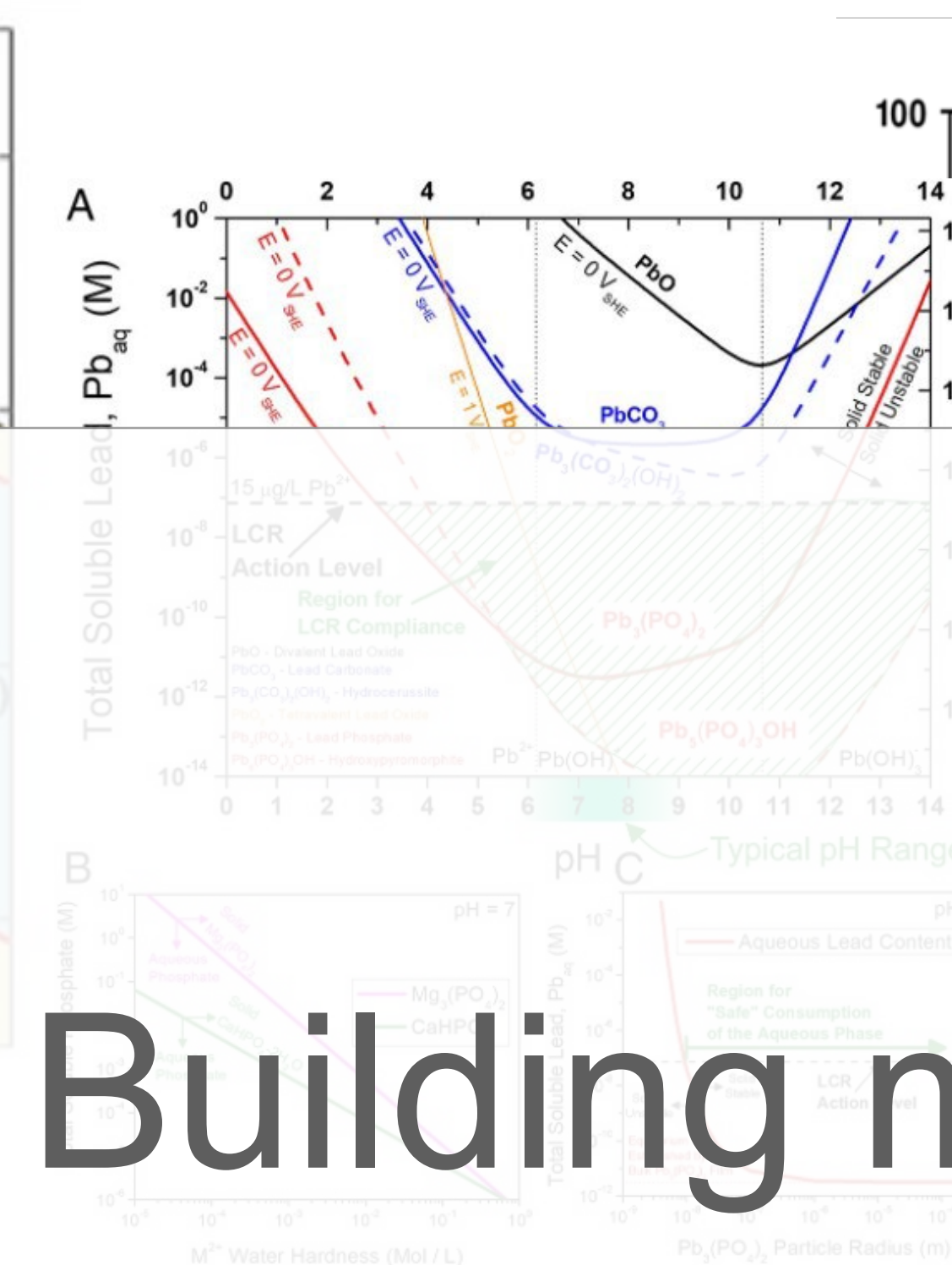
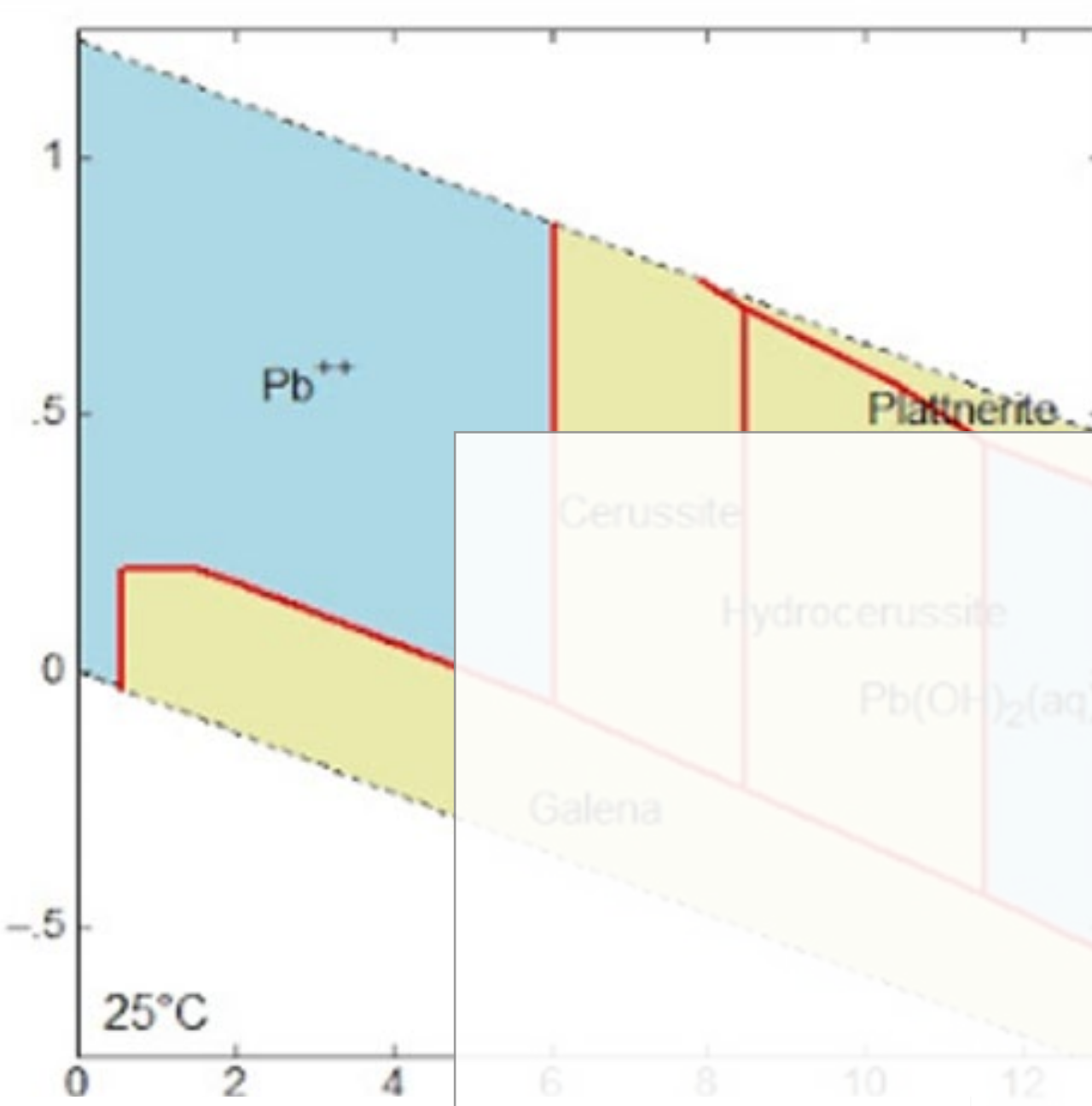
pH Control = Carbonate Scale

Ortho/Zinc Phosphate = Phosphate Scale

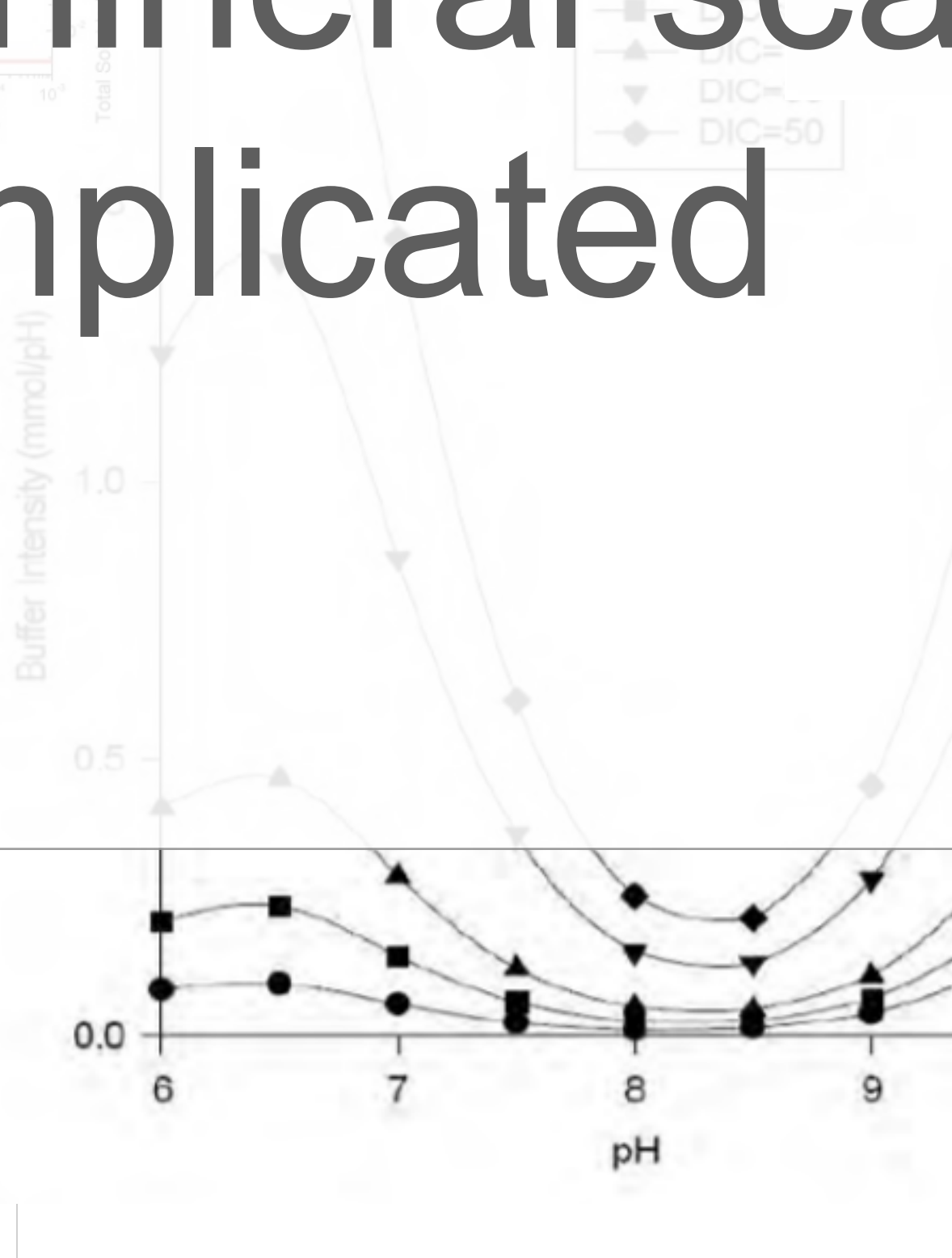
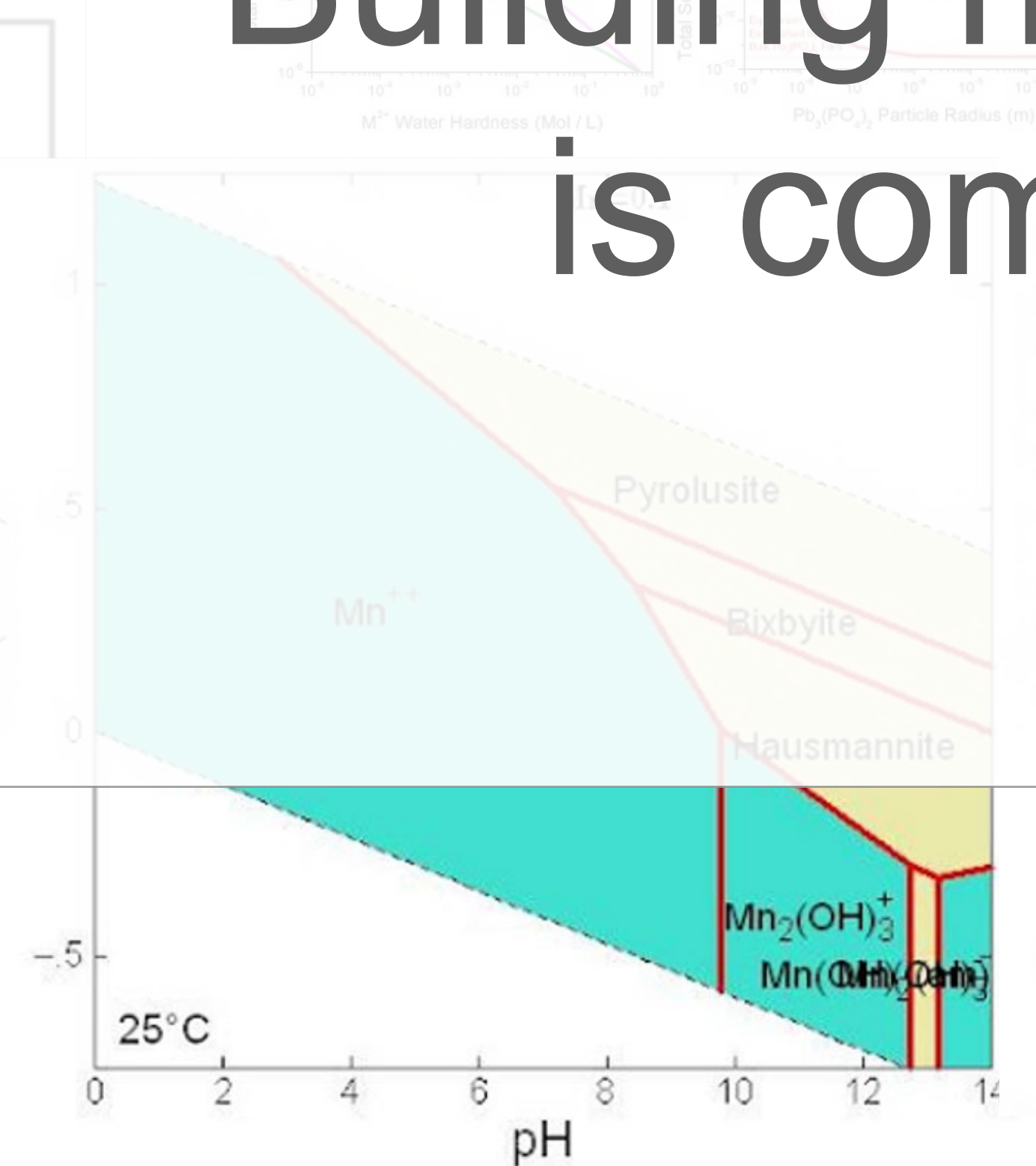
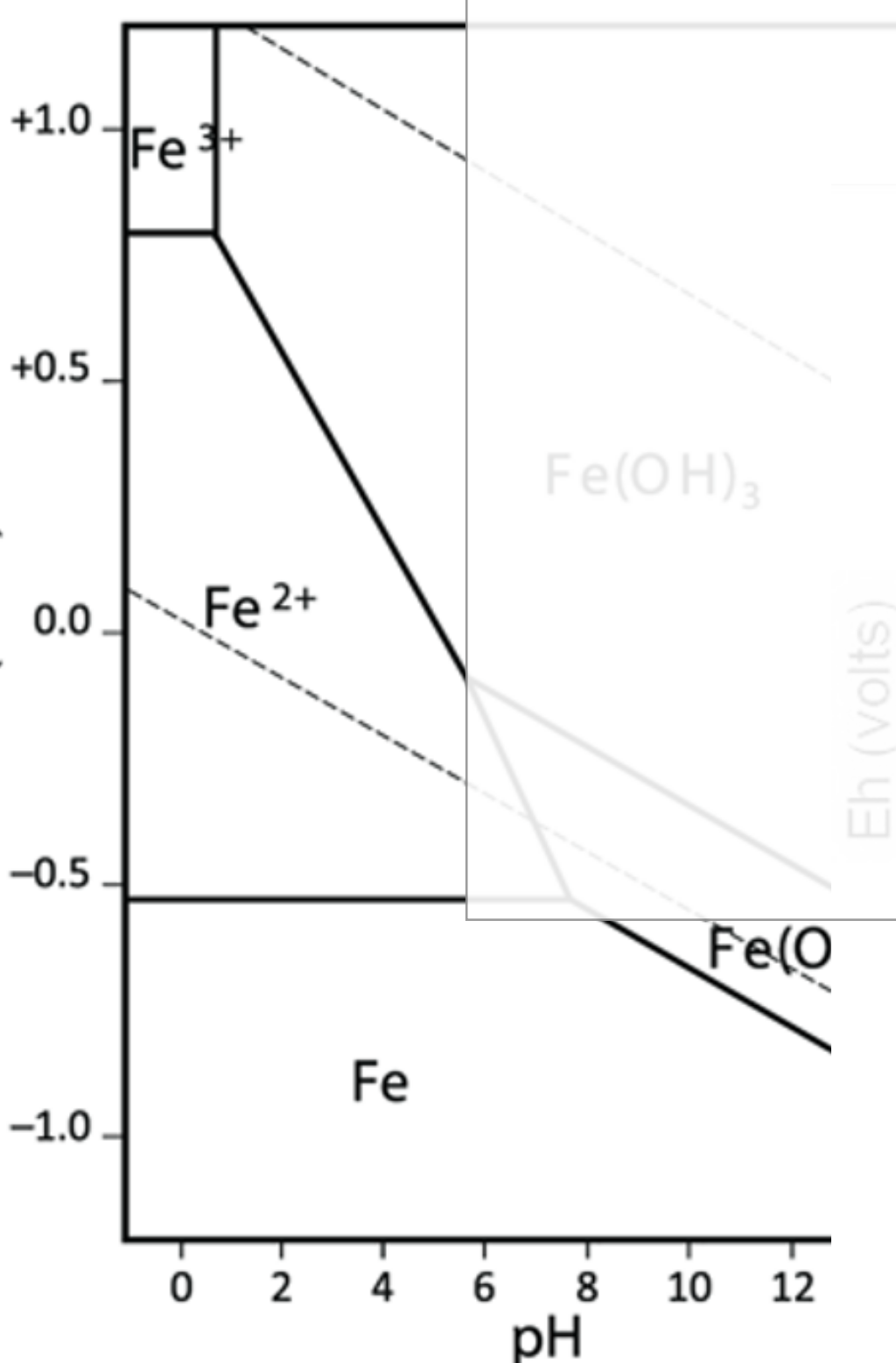
Blended Phosphate = Phosphate Scale

Silica = Silica Scale

Pictured from left to right are a lead pipe, a corroded steel pipe, and a lead pipe treated with protective orthophosphate. Orthophosphate creates a film coating inside of lead pipes that can act as a barrier, reducing at least somewhat the amount of lead that gets into tap water.



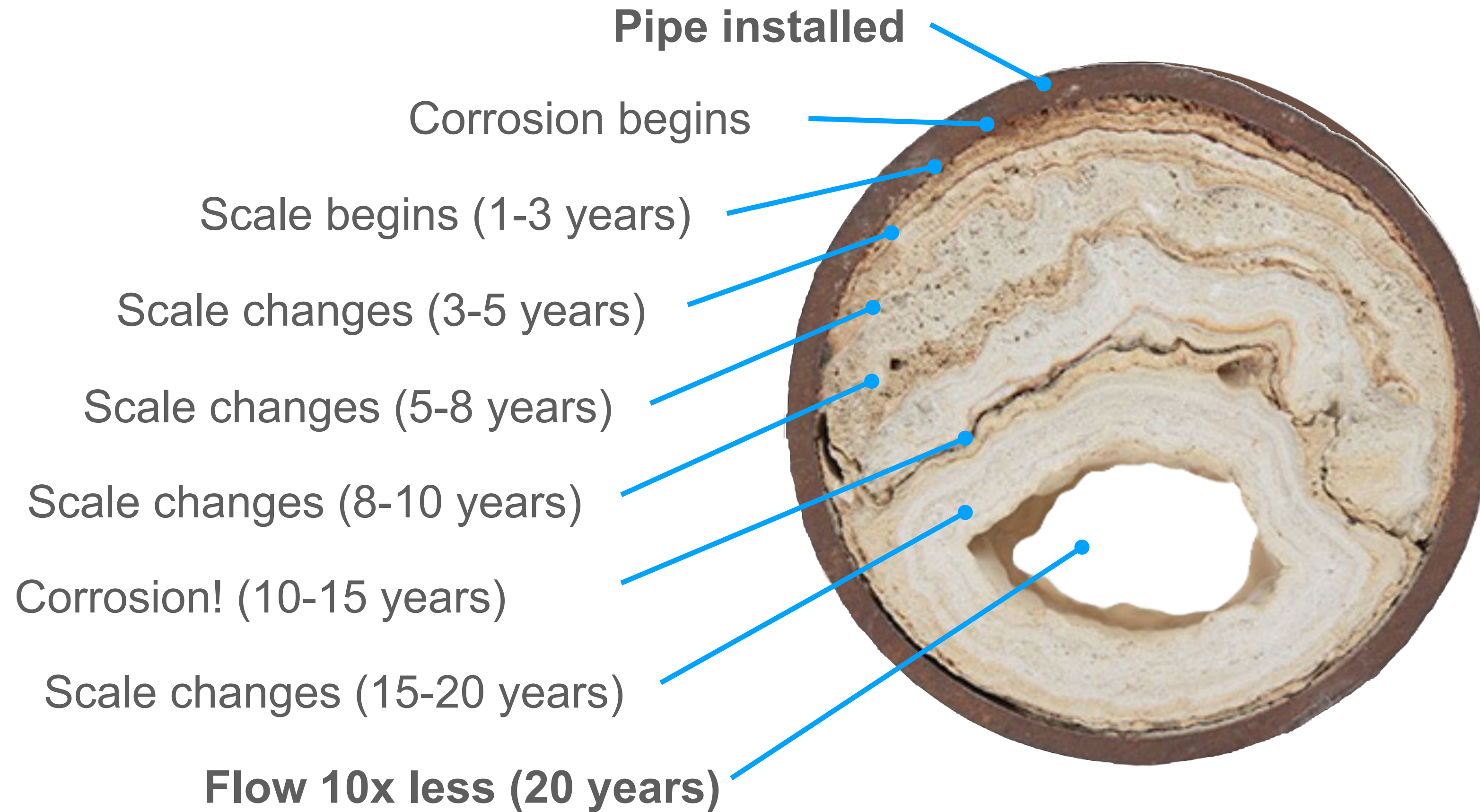
Building mineral scale is complicated



Total Alkalinity	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	
0	0													0	0	0						
2	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0						
4	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0			
6	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0			
8	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	0		
10	4	4	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	0		
12	5	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	1	1	
14	6	5	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	2	2	1	1	0
16	7	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	2	2	1
18	8	7	6	5	5	5	5	4	4	4	4	4	4	4	4	4	4	3	3	2	2	1
20	9	7	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	3	3	2
22	10	8	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	4	4	3
24	11	9	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	5	5	4
26	11	10	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	5	5	4
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55	24	20	18	16	15	14	14	14	14	14	14	14	14	14	14	14	14	13	13	12	12	11
60	26	22	19	17	16	16	15	15	15	14	14	14	14	14	14	14	14	13	12	12	11	10
65	29	24	21	19	18	17	15	16	16	16	15	15	15	15	15	15	15	14	14	13	12	11

OCCT Evaluation Technical Recommendations for Primary Agencies and Public Water Systems

Conditions continuously change



Scale must *continuously* change to keep up with environmental factors

(such as flow, temperature, pH, chlorine, minerals, electrochemical potential...)

Hint: all of this was invented for industrial water treatment where conditions can be controlled

Corrosion happens underneath



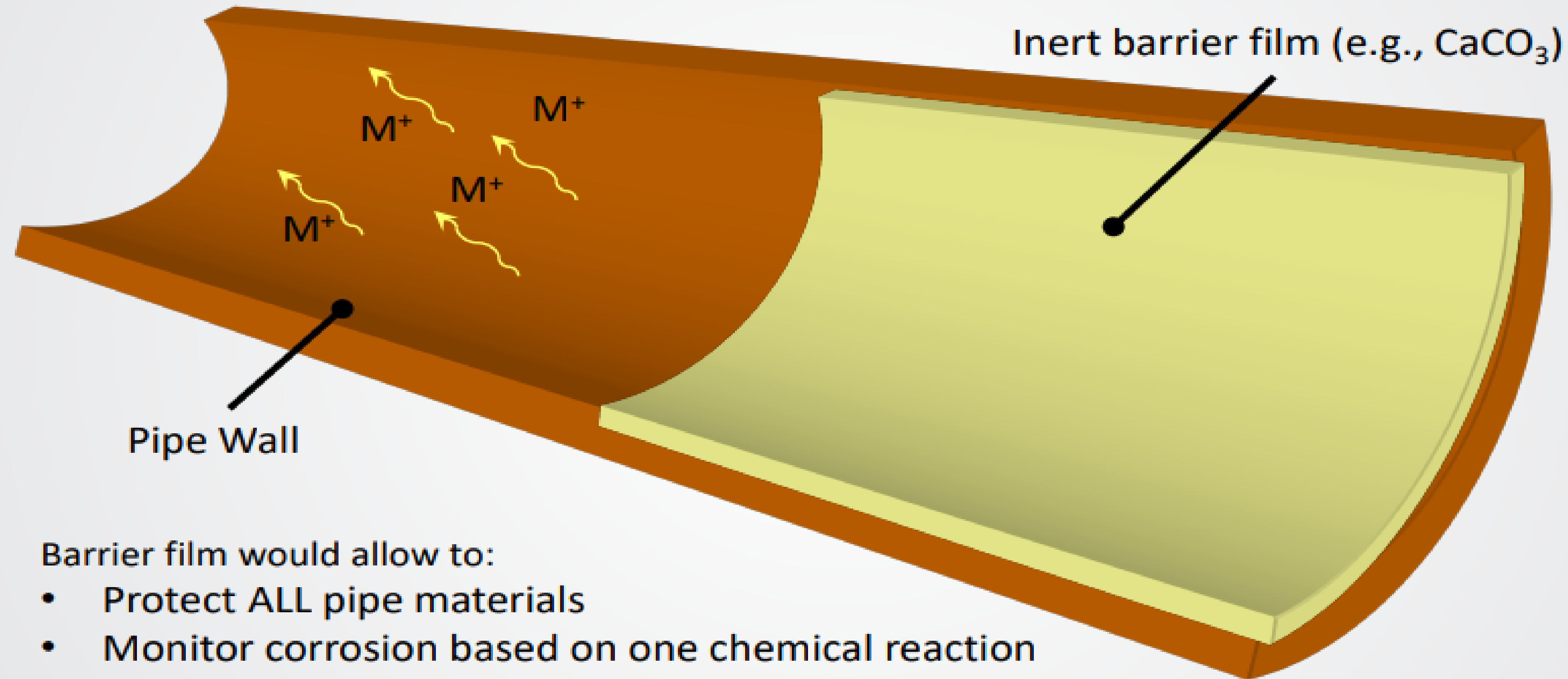


“Scale can be very complex in practice.”

“Variety of scale coatings analyzed at EPA:
heterogeneous, several layers, amorphous,
many constituents.”

-Chemistry of Lead Corrosion and Release;
EPA Small Drinking Water Systems Webinar, Feb 2021; S. Triantafyllidou

How Scale Theoretically Works (EPA)



Schematic: Marc Edwards

Barrier film would allow to:

- Protect ALL pipe materials
- Monitor corrosion based on one chemical reaction

Although barrier film would be convenient for important reasons, the $CaCO_3$ hypothesis has not been proven

What Actually Happens (EPA)

Barrier film is a complex scale* that reacts with water constituents

Pipe Wall

- Heterogeneous
- Several layers
- Pb & non-Pb compounds
- Amorphous & crystalline

*Scale layer illustration, for an LSL sample analyzed at ORD

L1

L2

L3

L4

Fe/Mn crust

PbO₂

Harmon et al., 2021

Although barrier film would be convenient for important reasons, the CaCO₃ hypothesis has not been proven and scale is overall more complex

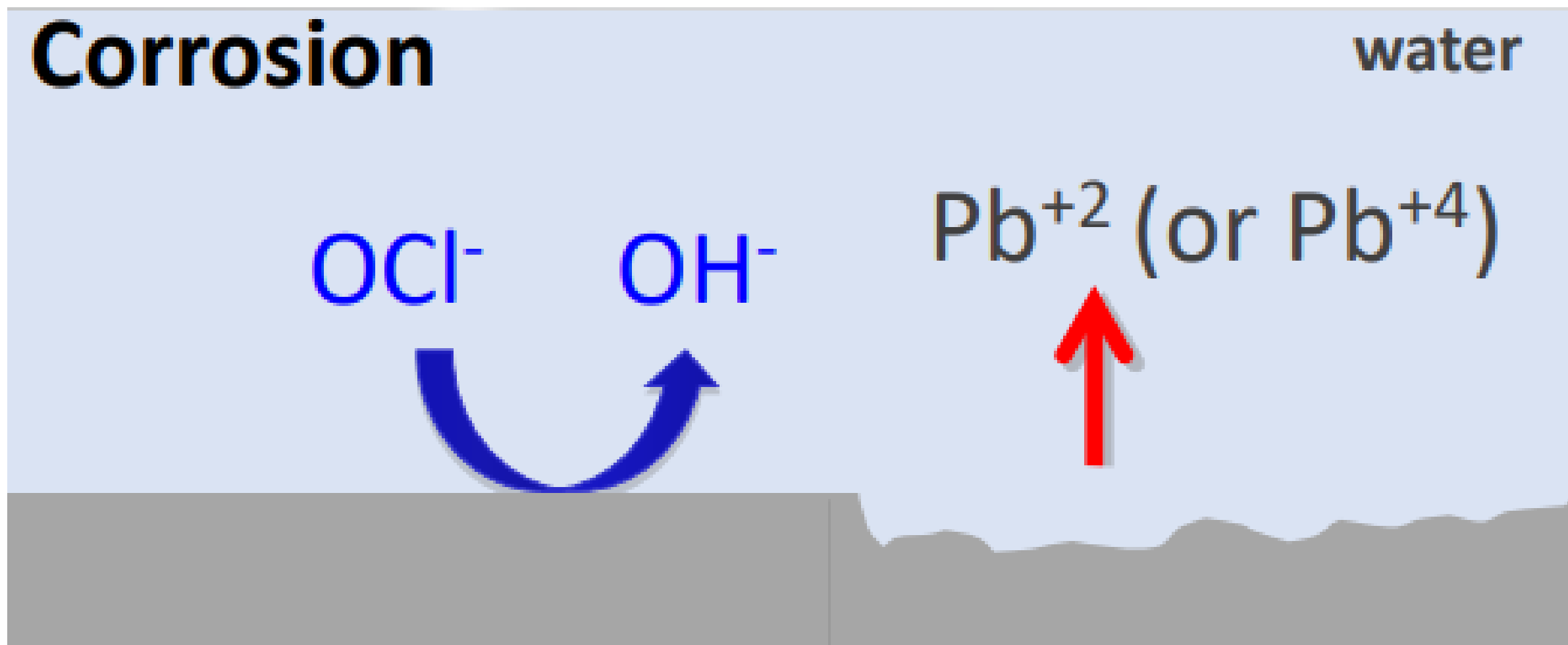


Theoretically is Possible...

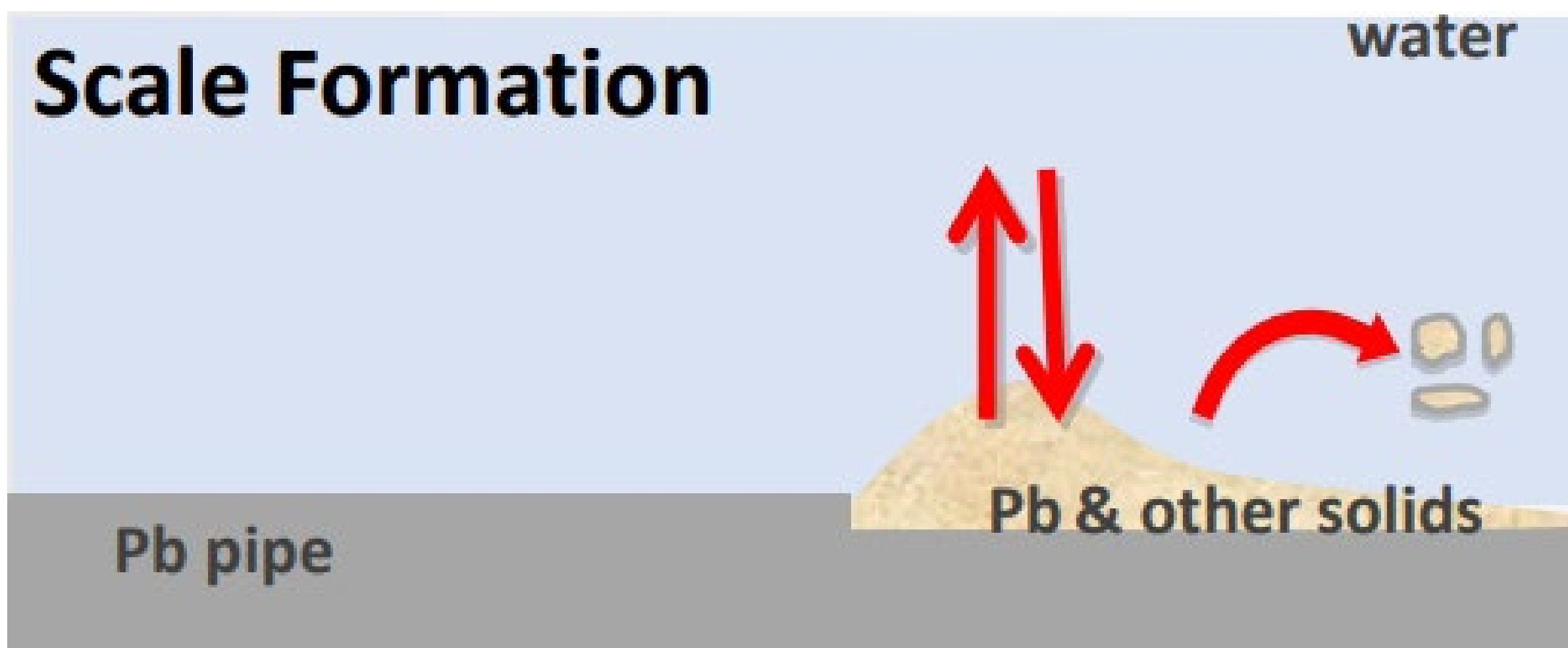
Practically is Difficult...

Could Only Work on Clean Pipe
Under Controlled Conditions...

Why add Orthophosphate?



Unreacted $\text{Pb}(+2)$ is soluble and dangerous.



Both $\text{Pb}(+4)$ oxide and $\text{Pb}_3(\text{PO}_4)_2$ are insoluble.

Orthophosphate is not a corrosion inhibitor.

Lead corrodes, and orthophosphate is used to control the harmful byproducts (Pb^{+2}) by reacting with them and becoming insoluble.

“The majority of distribution system pipes are composed of iron material: cast iron, ductile iron and steel.”



Iron corrosion byproducts are different than lead.

Tubercles are formed (rust), which is comprised of metal, minerals and organic material.

Any scale building corrosion technology (carbonate index calculations, orthophosphate, silica, etc...) does not work because the metal surface is not clean and the water chemistry is dynamic.

This fundamental problem impacts many other areas of water treatment.



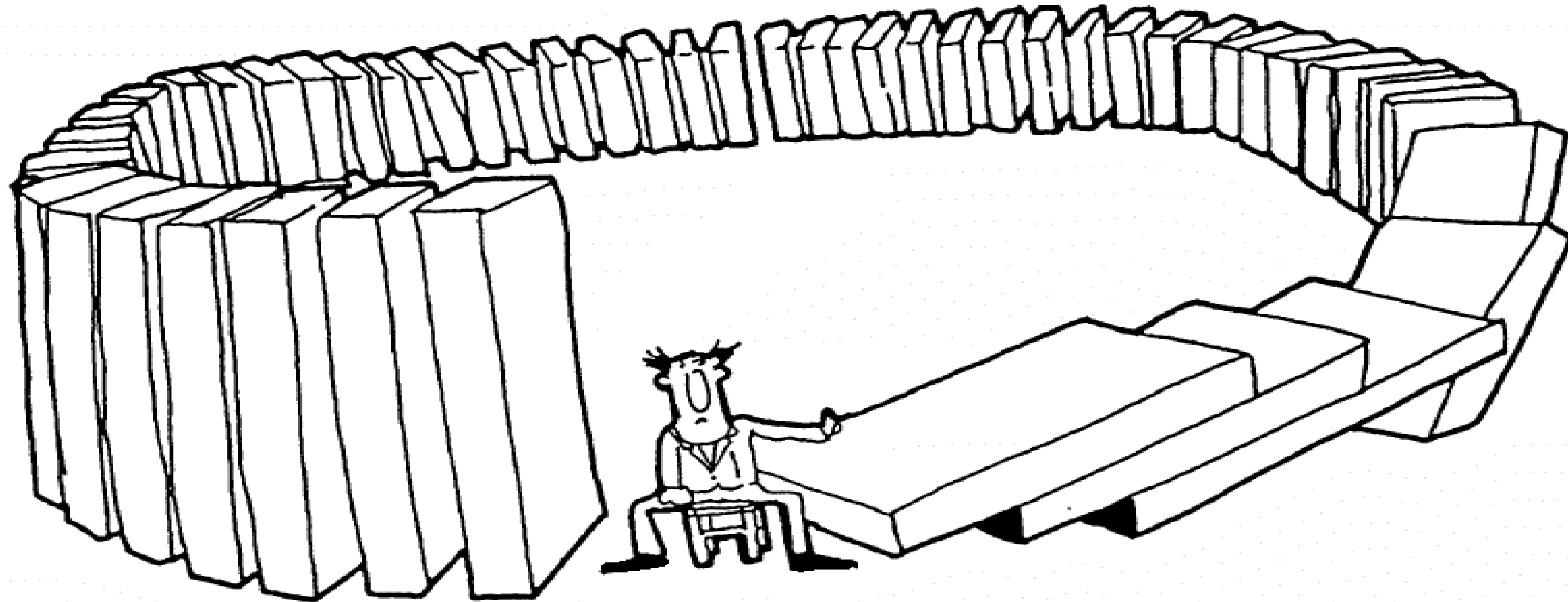
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Corrosion Control – Environmental and Wastewater Effects



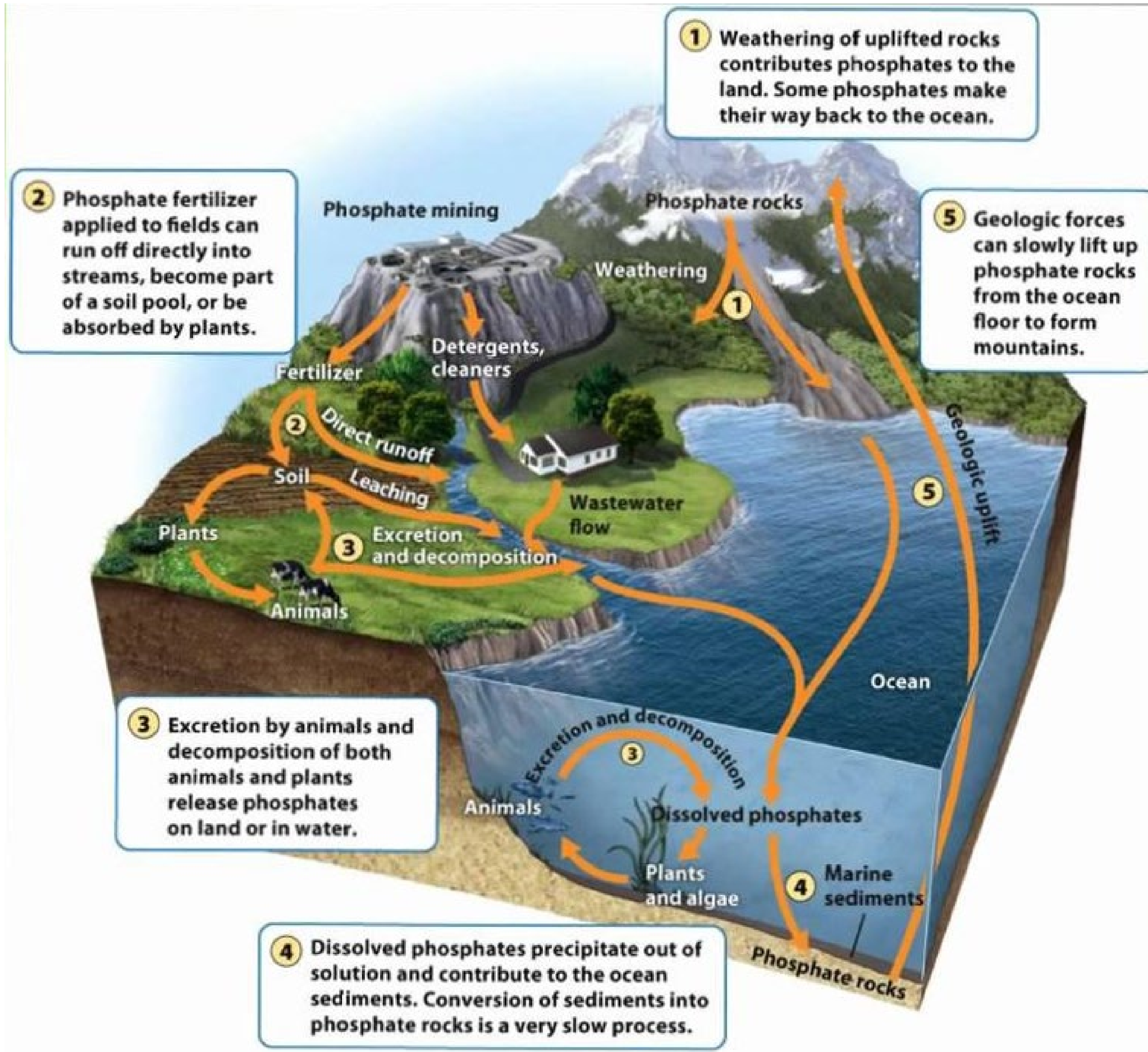
“[L]ife can multiply until all the phosphorus is gone, and then there is an inexorable halt which nothing can prevent. We may be able to substitute nuclear power for coal, and plastics for wood, and yeast for meat, and friendliness for isolation—but for phosphorus there is neither substitute nor replacement.”

Isaac Asimov (1974)



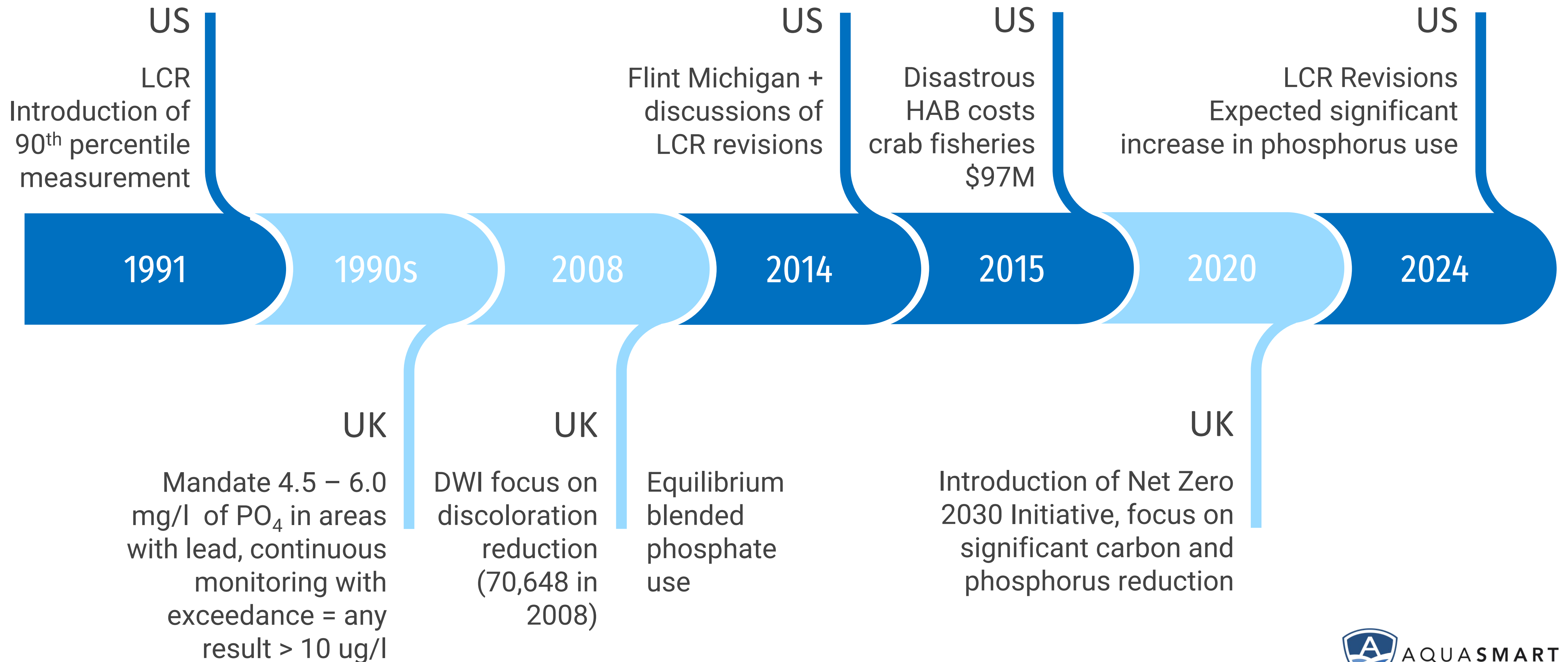
.....an example of unintended consequences
and what we can learn from the UK

Phosphorus



- Cannot be manufactured and there is no substitute for it
- Is essential for all living matter
- Equilibrium cause / effects from too much in the wastewater supply
- Discharge from waste treatment plants is regulated
- As much as 35% of wastewater flow can be due to corrosion control in drinking water (Rogers, 2014)

Phosphorus Timeline in Water



Wastewater vs Corrosion Control



Corrosion Control:

- Increased, more sophisticated monitoring is likely to result in greater number of lead exceedances
- Systems with 90th percentile lead results >10 ug/l will be out of compliance
- The result will be a significant **increase** in the amount of phosphorus used

Wastewater Treatment:

- Harmful algae blooms are likely to continue escalating in frequency and severity
- Mandated use of non-phosphorus ingredients is likely to increase beyond personal care
- The result will be a significant **decrease** in the amount of acceptable phosphorus discharged

After Flint, the EPA began the process of amending the lead & copper rule based on a White House white paper.

Mandating the use of significant levels of phosphate, like in the UK, was proposed.

The Chesapeake Bay Watershed is especially sensitive to phosphorus discharge.

A study was presented at The University of Virginia in 2014 to predict the impact high levels of phosphate corrosion control use would have on local wastewater treatment plants.



\$39,967 per MG in Added Costs!

88% More Aluminum Sulfate!

83% More Total Solids!

33% Higher Solid Phosphorus Content!

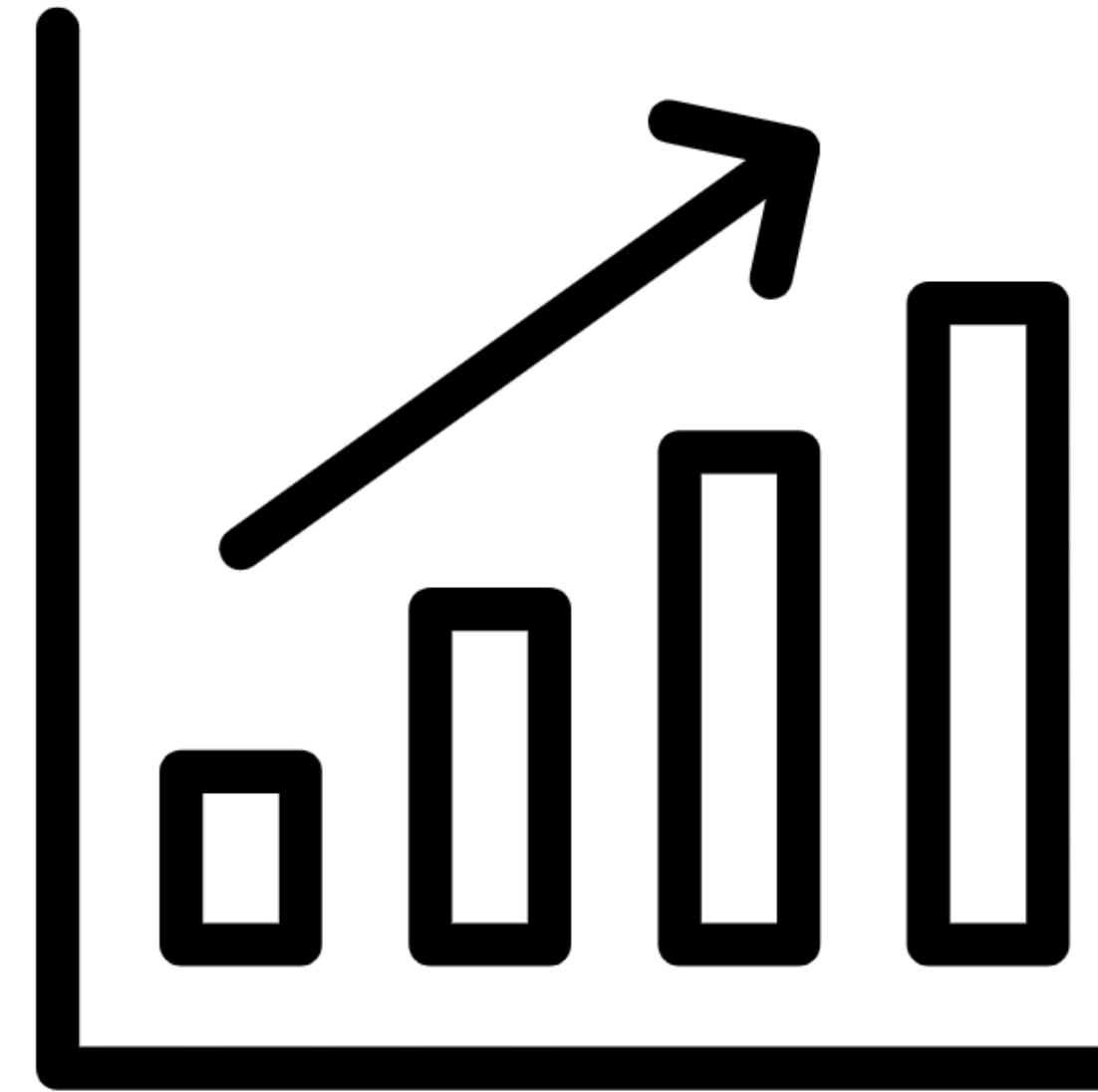
Wastewater treatment is possible, but with significant added costs



In 2020, wastewater phosphorus discharge levels in the UK were reduced to 0.25 mg/l...

The full impact of this change on how wastewater treatment plants are managed is only now becoming apparent

The number of sites in the UK requiring phosphorus treatment is increasing by 70%



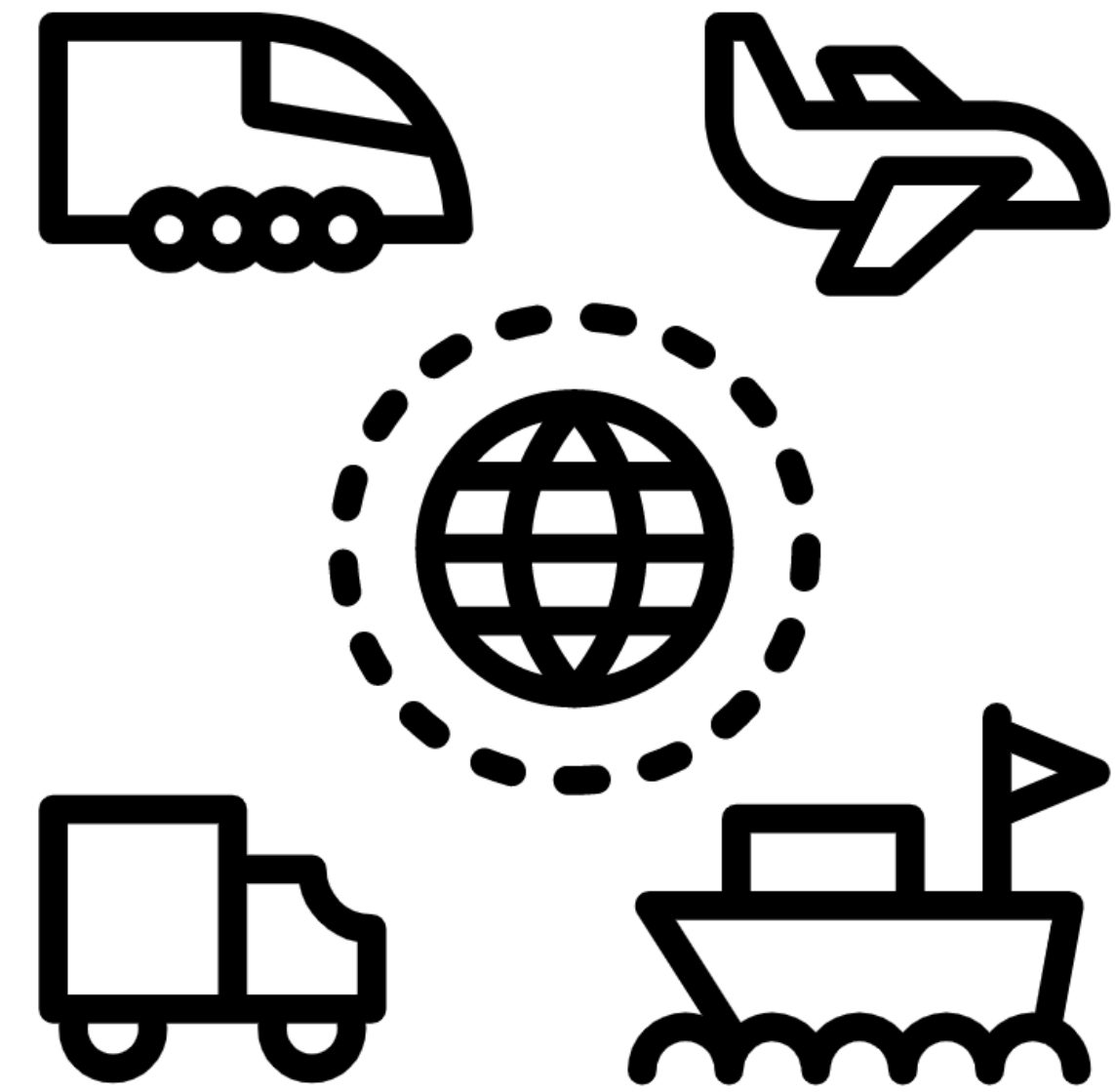
More Sites Require Treatment



Increase in Sludge Output

A significant increase in sludge production is creating cost and complexity to manage

Most of the new sites requiring treatment are small, requiring more complex logistics



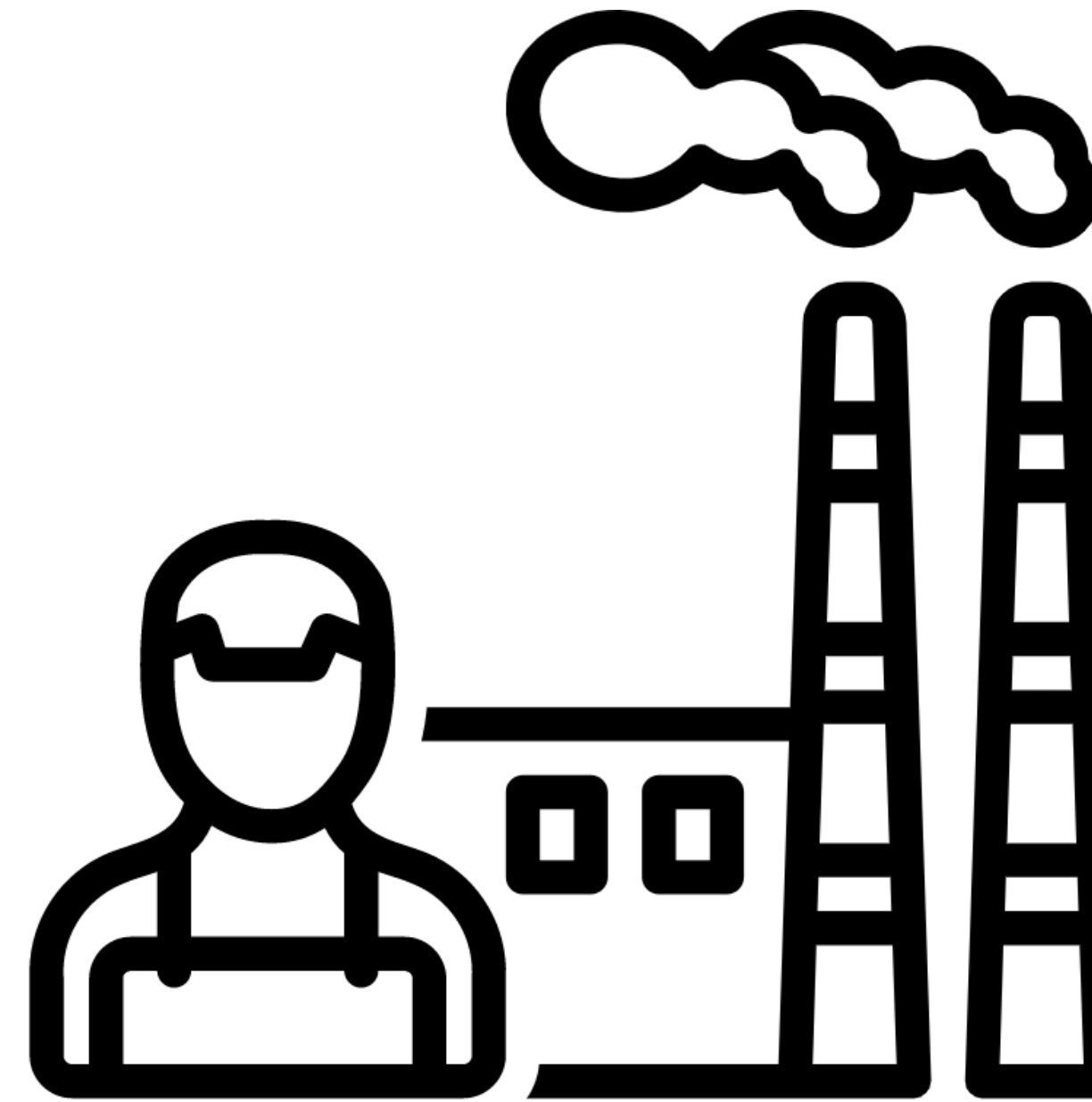
Complex Logistics



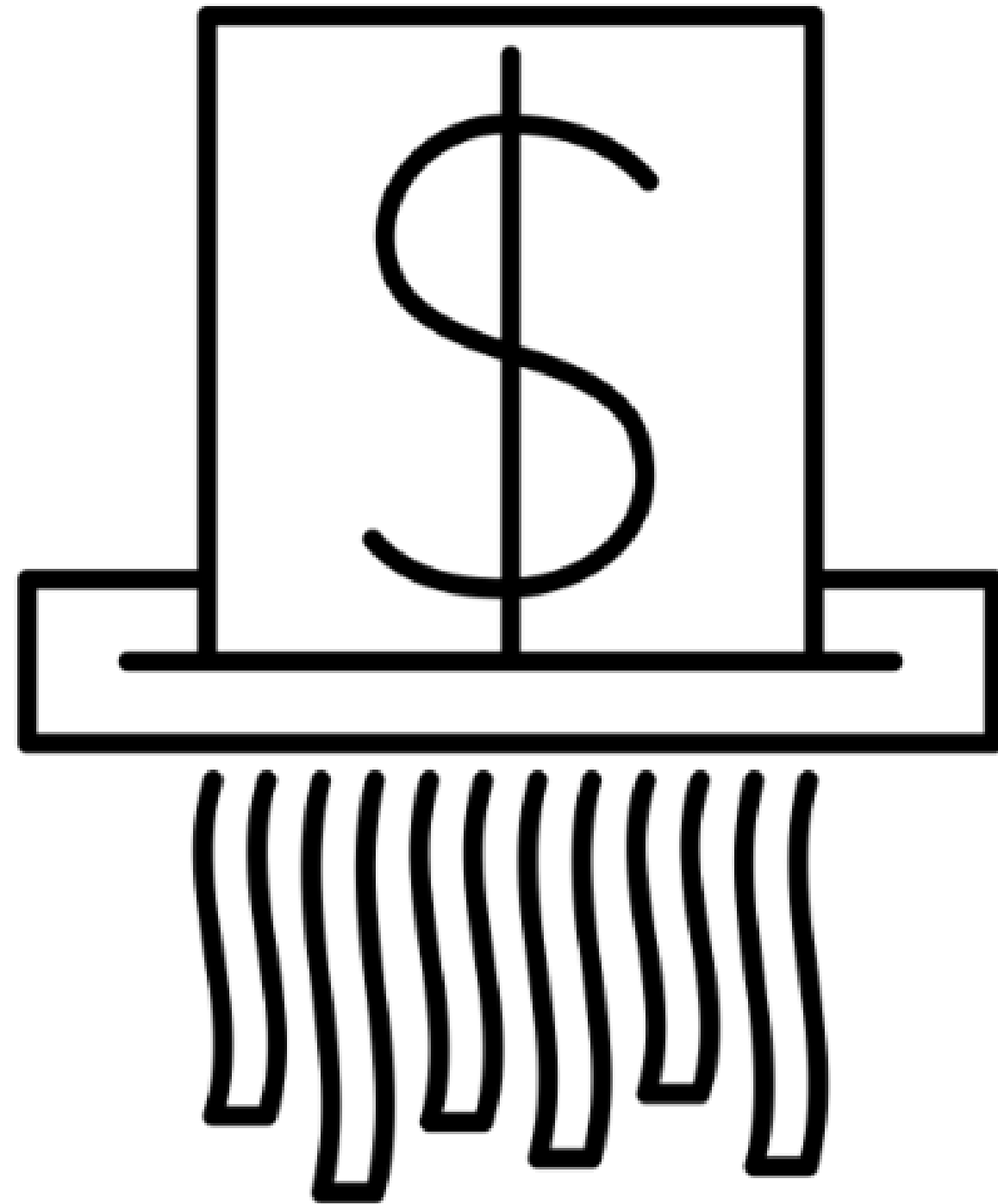
Dangerous Chemicals

Increased use and handling of
coagulants and excess sodium
hydroxide for pH control

Coagulant use is increasing
by >75% requiring additional
UK manufacturing capacity



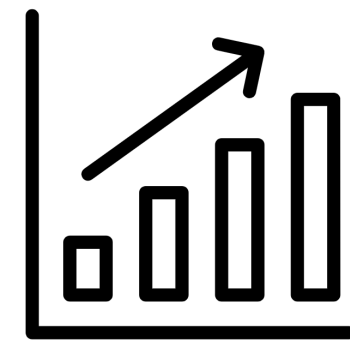
Increased Chemical Use



Expensive Chemicals

The overall use, and direct raw material cost of chemical continues to increase

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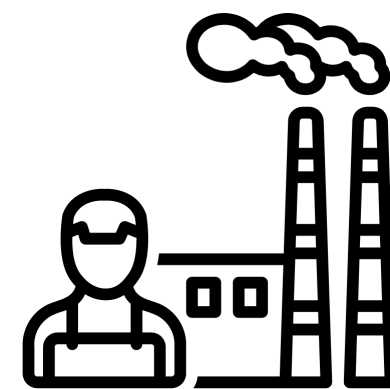
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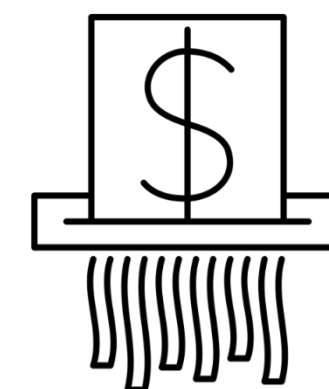
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Wessex Water

Highlighted 24 small wastewater treatment sites impacted by increased costs due to lower phosphorus discharge regulations:

- Equipment (pumps, dosing plant, etc.)
- Storage of raw materials
- Emergency showers and other safety requirements
- Site upgrades and improved access for chemical deliveries
- Costs for managing increased sludge production

These costs were concluded to be “disproportionately expensive”



“The anticipated UK demand by regulated water companies for ferric and ferrous salts needed for phosphate removal in wastewater is expected to grow significantly in the next five to ten years and could exceed the current levels of UK production”


-Water Industry Journal 2021

“Water companies face chemical supply disruption”

-BBC Sept 7th 2021

“Water treatment rules eased due to chemical supply failures”

-CIPD Sept 2021

A hand is shown from the bottom, cupping a glowing digital globe. The globe is composed of a network of white and orange nodes connected by thin lines, with a bright orange glow emanating from the center. The background is dark with some bokeh light effects.

Predicting the Future (Part 3)

- In the UK, technologies to control corrosion using less phosphorus, and technologies to remove phosphorus using less chemicals (generating less sludge) are being explored
- In the US, many states are interpreting the revised lead copper rule as a mandate to use larger amounts of phosphorus to control lead
- Wastewater phosphorus limits continue to be reduced, and available supply of chemicals continues to be challenging
- Phosphorus use for water treatment is the second least valuable market for phosphorus producers

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Wastewater Treatment



The Sewage Treatment Process



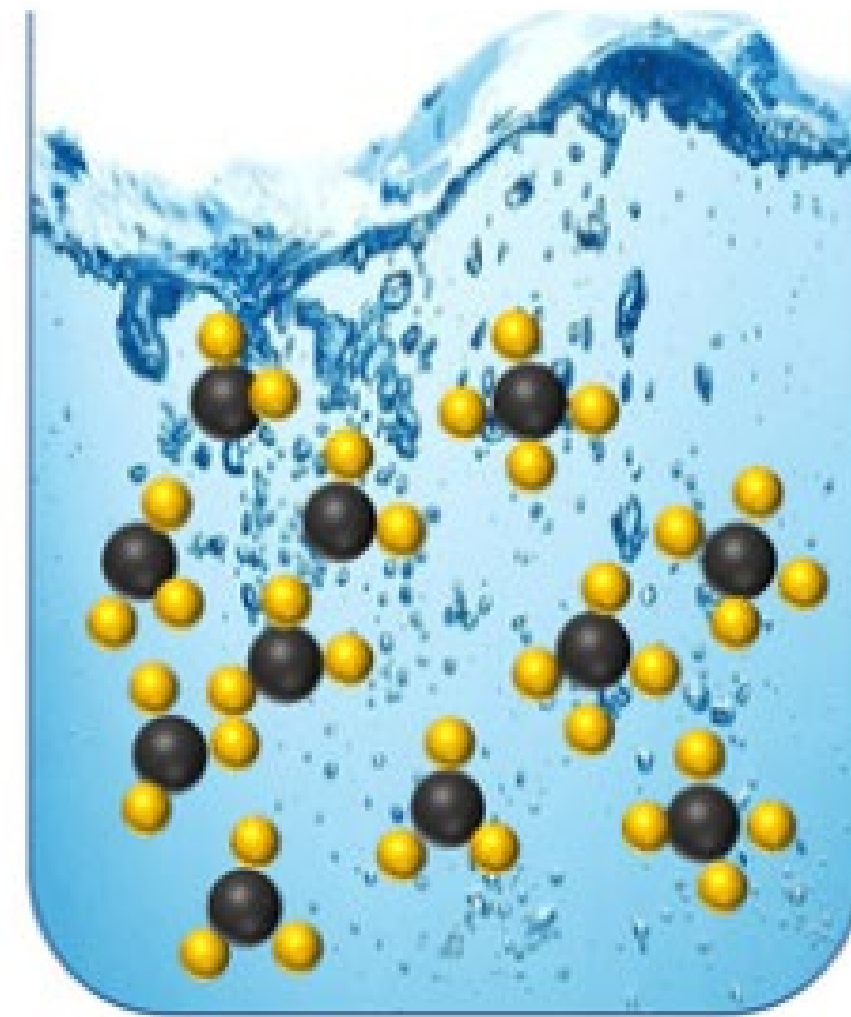
How does Coagulation Work?

Without Coagulant



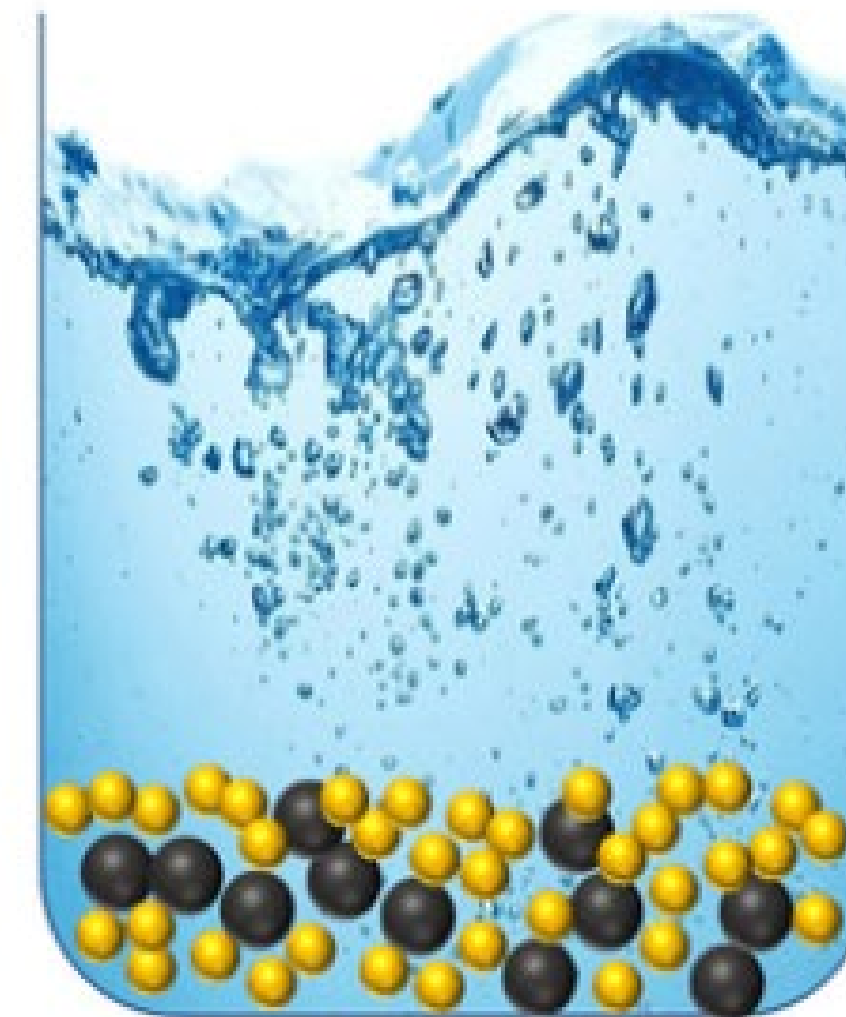
● Pollutant

Precipitate Formation



● Coagulant

Settlement



● Floc

Primary coagulants neutralize the charge of pollutants so they can bind together easier

Coagulation aides (flocculants) add density (particle agglomeration) so the sludge survives downstream and settles more rapidly

About Coagulants...

Charge:

Different types of pollutants carry many different attributes, which govern the selection and use of treatment process and additives. Coagulants are available with the following charges so the appropriate match to corresponding pollutant charge can be made:

- Cationic (positive)
- Anionic (negative)
- Nonionic (neutral)

About Coagulants...

Type:

- Coagulants are either metallic salts or polymers
- In some cases (typically industrial use) blends are utilized
- The most common coagulants used in municipal wastewater treatment are:
 - $\text{Al}_2(\text{SO}_4)_3$ - aluminum sulfate (alum)
 - FeSO_4 - ferrous sulfate
 - $\text{Fe}_2(\text{SO}_4)_3$ - ferric sulfate
 - FeCl_3 - ferric chloride
 - $\text{Al}_n(\text{OH})_m\text{Cl}(3_{n-m})_x$ - polyaluminum chloride (PAC, PACl, ACH, PACH)

Alum

- One of the earliest coagulants developed
- Typically produced as 8.3% active liquid or 17% active solid
- Readily dissolves with water and does not produce staining in chemical feed equipment
- Alum is typically effective only at specific pH range 5.8 - 6.5
- In some waters it can be difficult to achieve proper flocculation
- Significant over-use of alum frequently occurs
- As an inorganic coagulant with zero basicity
 - Will decrease alkalinity of the water
 - pH will decrease



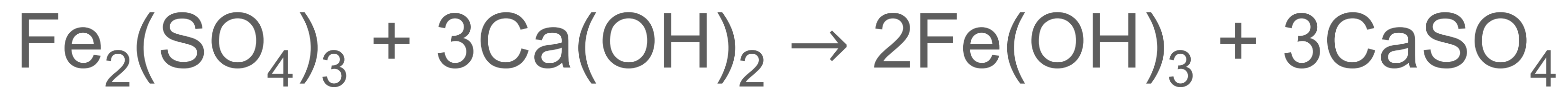
ALUM

LIME

FLOC

Ferric

- Ferric hydroxide is formed at low pH values
- Possible to use as low as pH 4.0
- Ferric floc is typically heavier and settles faster than alum floc
- Ferric hydroxide floc does not redissolve at higher pH values
- Ferric is often used for color removal when oxidizers are used
 - Potassium permanganate → iron & manganese
- As an inorganic coagulant with zero basicity
 - Will decrease alkalinity of the water
 - pH will decrease



FERRIC SULFATE

LIME

FLOC

PAC and Engineered Coagulants

- Manufacturing process and degree of polymerization determines:
 - Length of the polymerized chain
 - Type (PACl, ACH, PACH)
 - Molecular weight
 - Basicity
- Lower basicity products (25-45%) are used for phosphorus removal
- Use of PACs consume less alkalinity than inorganic coagulants such as ferric and alum
 - Broader pH working range
 - Less reduction of finished water pH
- Effective dosages are typically lower → Less sludge



Cool Things to Know

- Industrial coagulants do not depress pH and generate very little sludge
 - Examples: polyDADMAC, polyamine, Tannins
 - Not typically used in municipal water treatment
 - Underperform metallic coagulants in removing color and organic material
- Sodium hypochlorite typically raises the pH of the finished water
 - May eliminate post-coagulant lime feed for PACs

Cool Things to Know

- Included in the structure of a metallic coagulant is basicity
 - Basicity is the measure of the number of hydroxyl ions
 - The higher the basicity the less impact on finished water pH
 - Alum has zero basicity since there are no OH-
- Flocculants can be used for rapid settling or to add strength to the sludge
 - Examples: Bentonite, Calcium Carbonate, Sodium Silicate, Anionic & Nonionic Polymers (various molecular weights)

SEAQUEST

Practical Impacts of Holistic Corrosion Control Treatment



“YOUR SCIENTISTS
WERE SO
PREOCCUPIED
WITH WHETHER OR
NOT THEY COULD
THAT THEY DIDN’T
STOP TO THINK IF
THEY SHOULD.”

-JURASSIC PARK

Chlorine Residuals & Selection

Chlorine Added

Initial chlorine concentration added to water

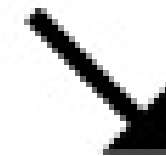
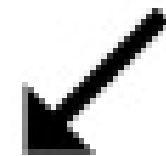


Chlorine Demand

Reactions with organic and inorganic material, metals, other compounds present in water prior to disinfection

Total Chlorine

Remaining chlorine concentration after chlorine demand of water is met



Free Chlorine

Concentration of chlorine available for disinfection

Combined Chlorine

Concentration of chlorine combined with organic and inorganic nitrogen compounds in the water. Not as effective for disinfection.

Corrosion of infrastructure



Contribute metals (typically iron) into the water



Oxidizer consumption



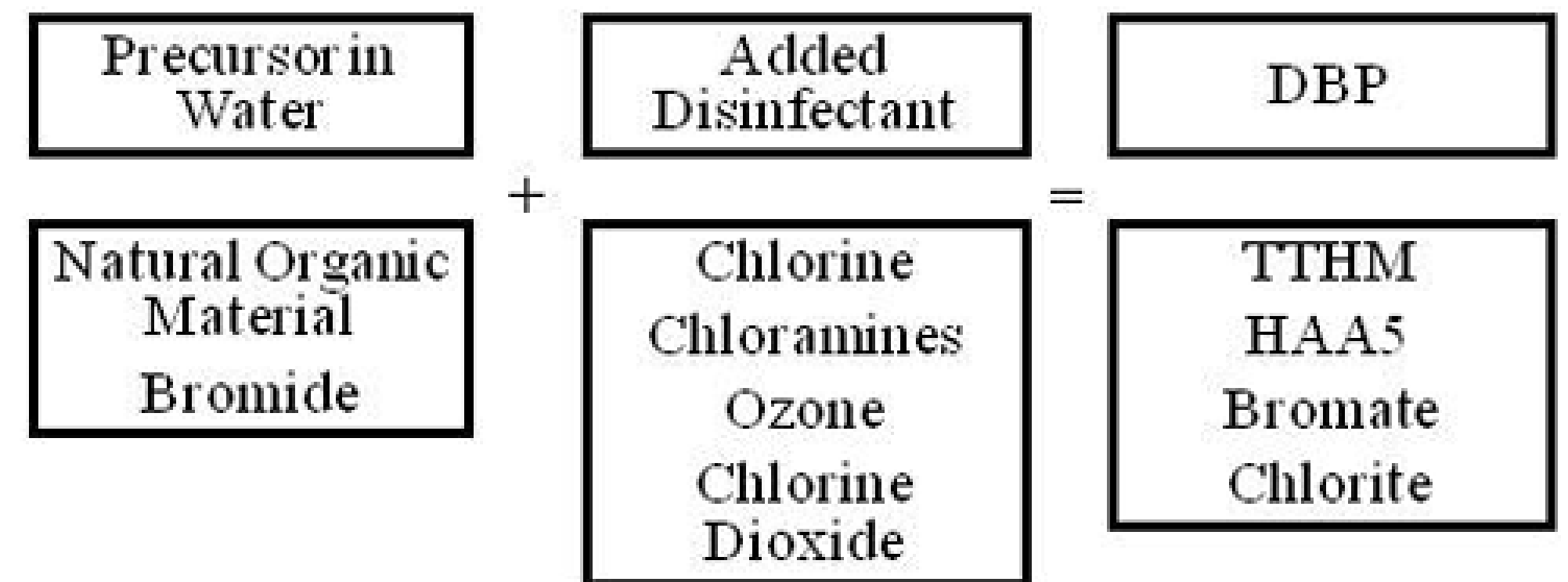
Reduced chlorine residuals



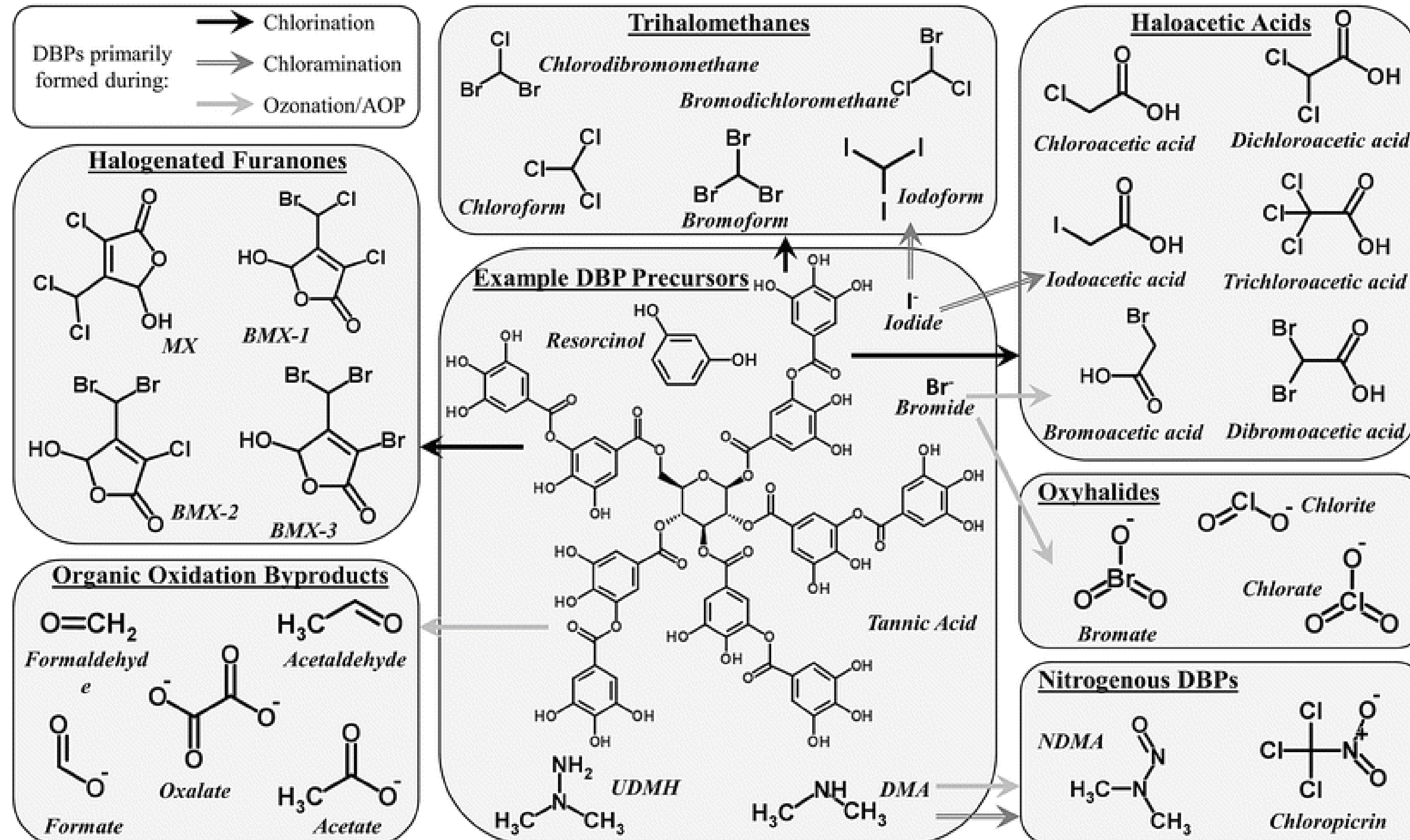
Change in pH / Change in Oxidizer

Disinfection Byproducts

- Starting just after 1900, chlorine disinfection of municipal drinking waters largely vanquished the outbreaks of cholera, typhoid, and other waterborne diseases in the developed world by the 1940s
- Chlorination of drinking water represents one of the greatest achievements in public health
- In 1974, analytical chemists discovered that trihalomethanes (THM4; chloroform, bromodichloromethane, dibromochloromethane, and bromoform) forming as byproducts of chlorine reactions with natural organic matter (NOM) reached concentrations up to ~160 µg/L in finished drinking waters
- Unlike most drinking water contaminants; formed as part of the treatment process
- Exist as different species; based on disinfection process used and NOM species in source
- pH can affect type of DBP along with amount
- Chlorine can be 80 times less effective at pH over 7.5



Disinfection Byproducts



Corrosion of infrastructure

↓

Contribute metals (typically iron) into the water

↓

Oxidizer consumption

↓

Reduced chlorine residuals

↓

Increased oxidizer use

↓

Increased THMs

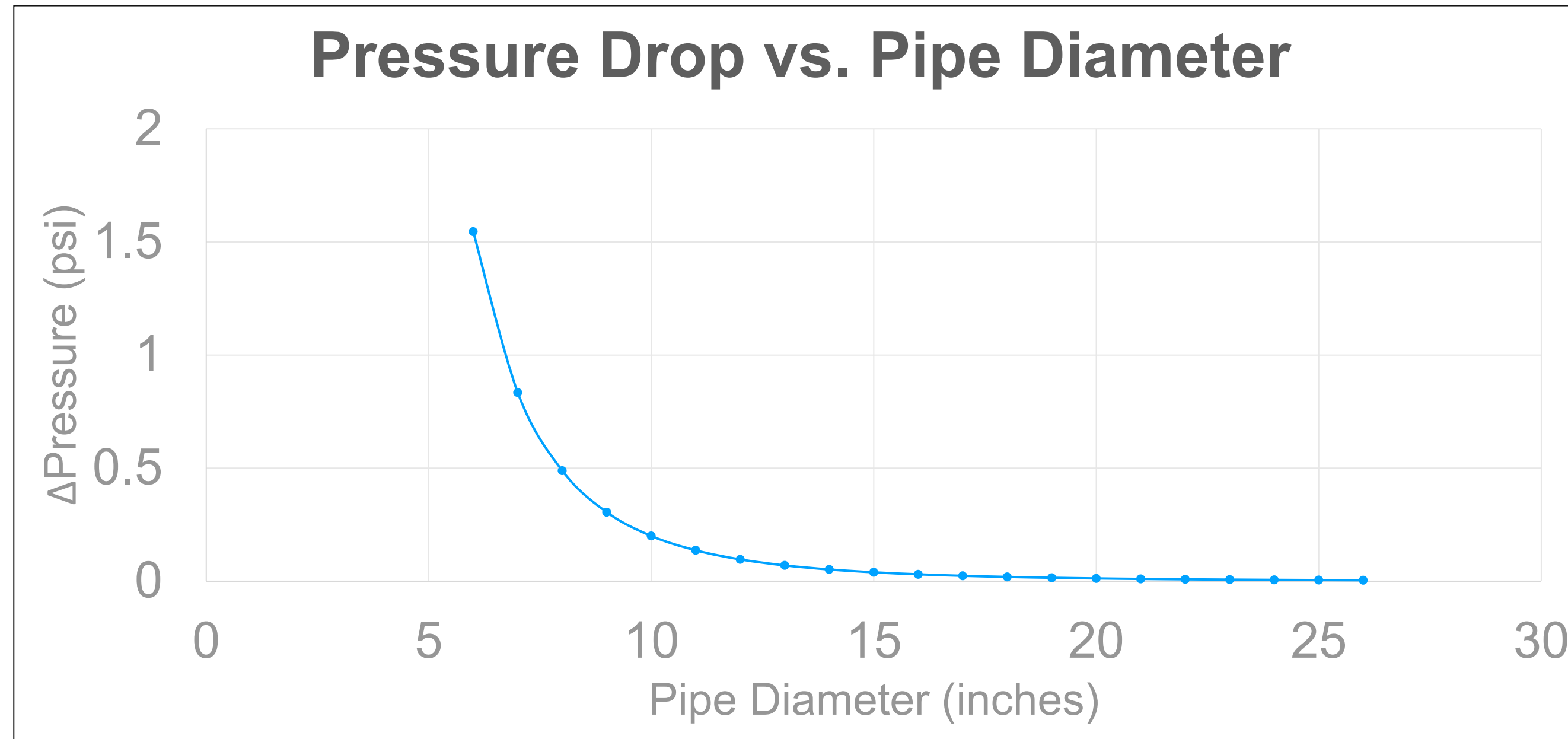
Phosphorus & Zinc Discharge



EPA OCCT RECOMMENDATIONS

- Phosphate loading from drinking water accounts for 10 – 35% of phosphate loading at wastewater plants
 - Median loading was 20% (Rodgers, 2014)
 - The potential phosphate load at the wastewater facility should be considered before selecting a phosphate-based corrosion inhibitor
 - Using zinc orthophosphate can increase zinc loading at WWTP
-
- Study by Schneider et al (2011) found most zinc in zinc orthophosphate makes its way to WWTP
 - Zinc may also inhibit biological wastewater treatment processes
 - Particularly nitrification and denitrification
 - EPA limits on zinc in processed sludge that is land applied

Electricity / Flow



Hagen-Poiseuille equation: $\Delta P = (8 * \lambda * L * Q) / (\pi * d^4)$

λ = dynamic viscosity

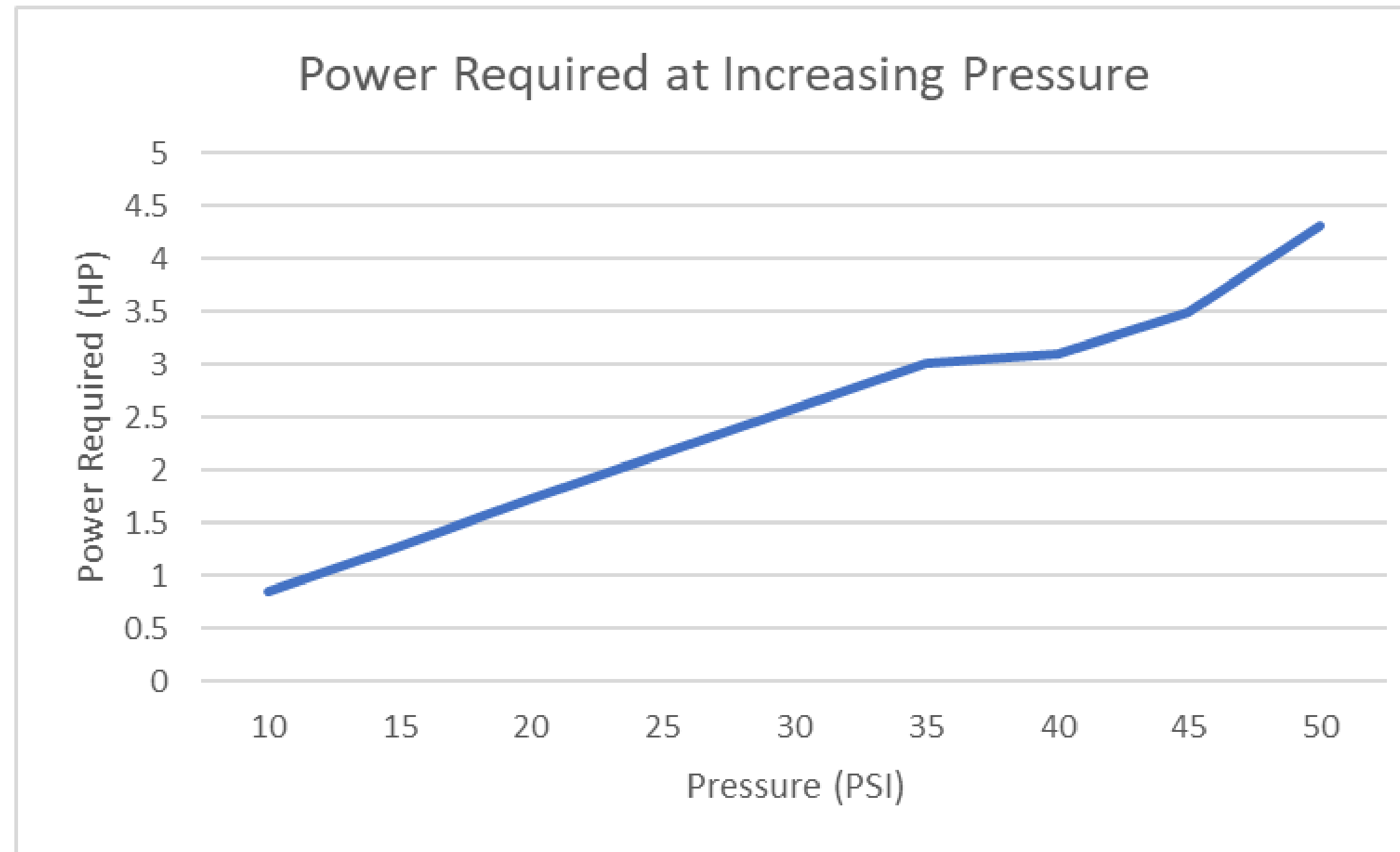
L = length of pipe

Q = flow rate

d = pipe diameter

- Pipe diameter and pressure have an inverse relationship

Electricity / Flow



Power = flow rate * ΔP

Where: flow rate = Q (mass or volume flow rate) ΔP = the pressure difference across the pipe

It can also be represented as: Power = Q * (P1 - P2)

Where: Q = flow rate P1 = Pressure at the inlet of pipe P2 = Pressure at the outlet of pipe

Workplace EHS



Phosphoric acid burns



Sodium hydroxide burns

<https://www.sciencedirect.com/science/article/pii/B9780323476614000393>

<https://www.ehs.com/2014/04/sodium-hydroxide-lye-safety/>

<https://www.ehs.com/2015/06/phosphoric-acid-safety-tips/>

SEAQUEST

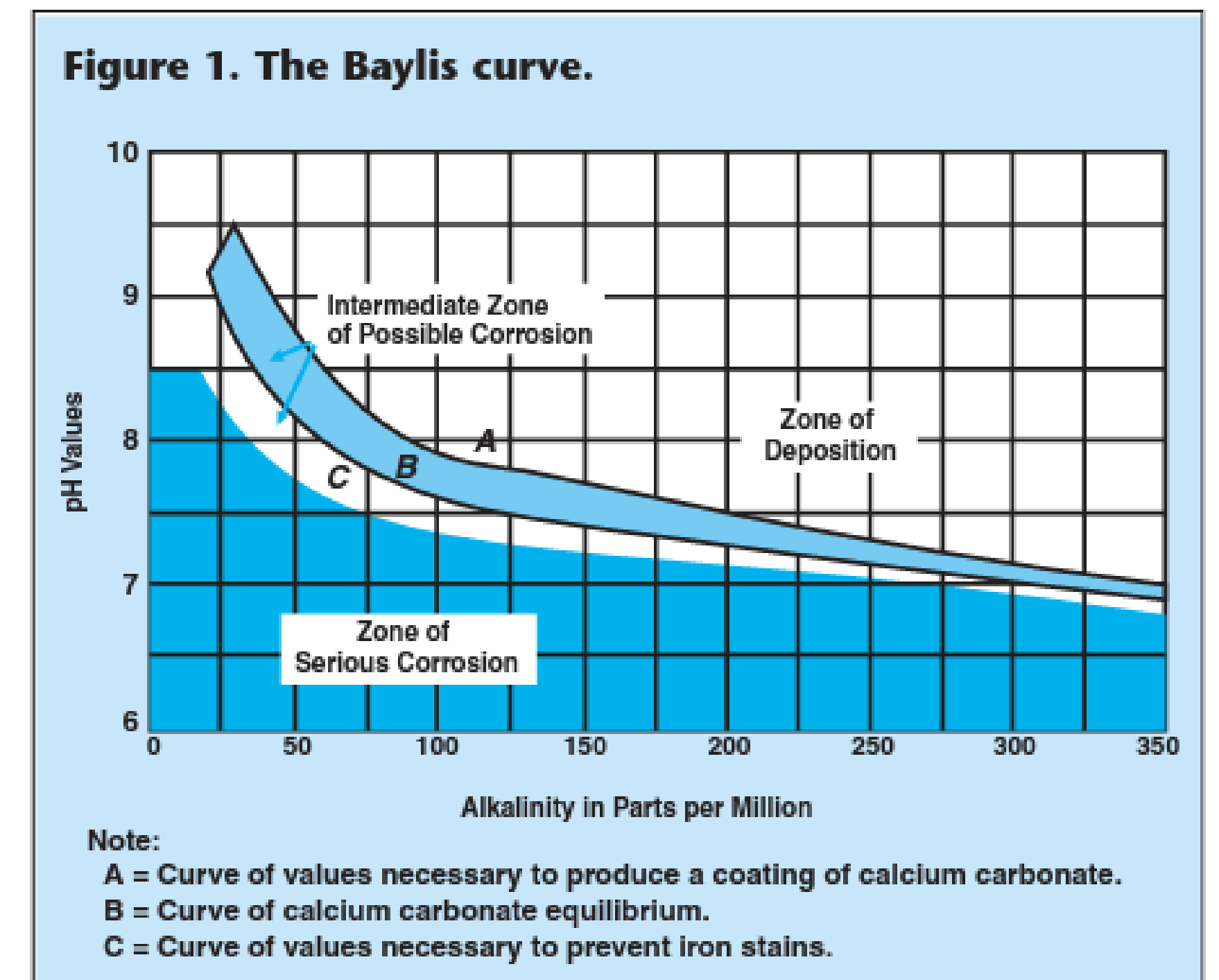
Balancing Chemical Usage in Drinking Water

Why do we raise pH?

- Water is naturally more corrosive at lower pH
- Alkalinity also affects water's ability to corrode or create scale
- If water has high hardness; then pH is raised to cause calcium carbonate precipitation
 - Hardness is primarily the sum of calcium and magnesium in water

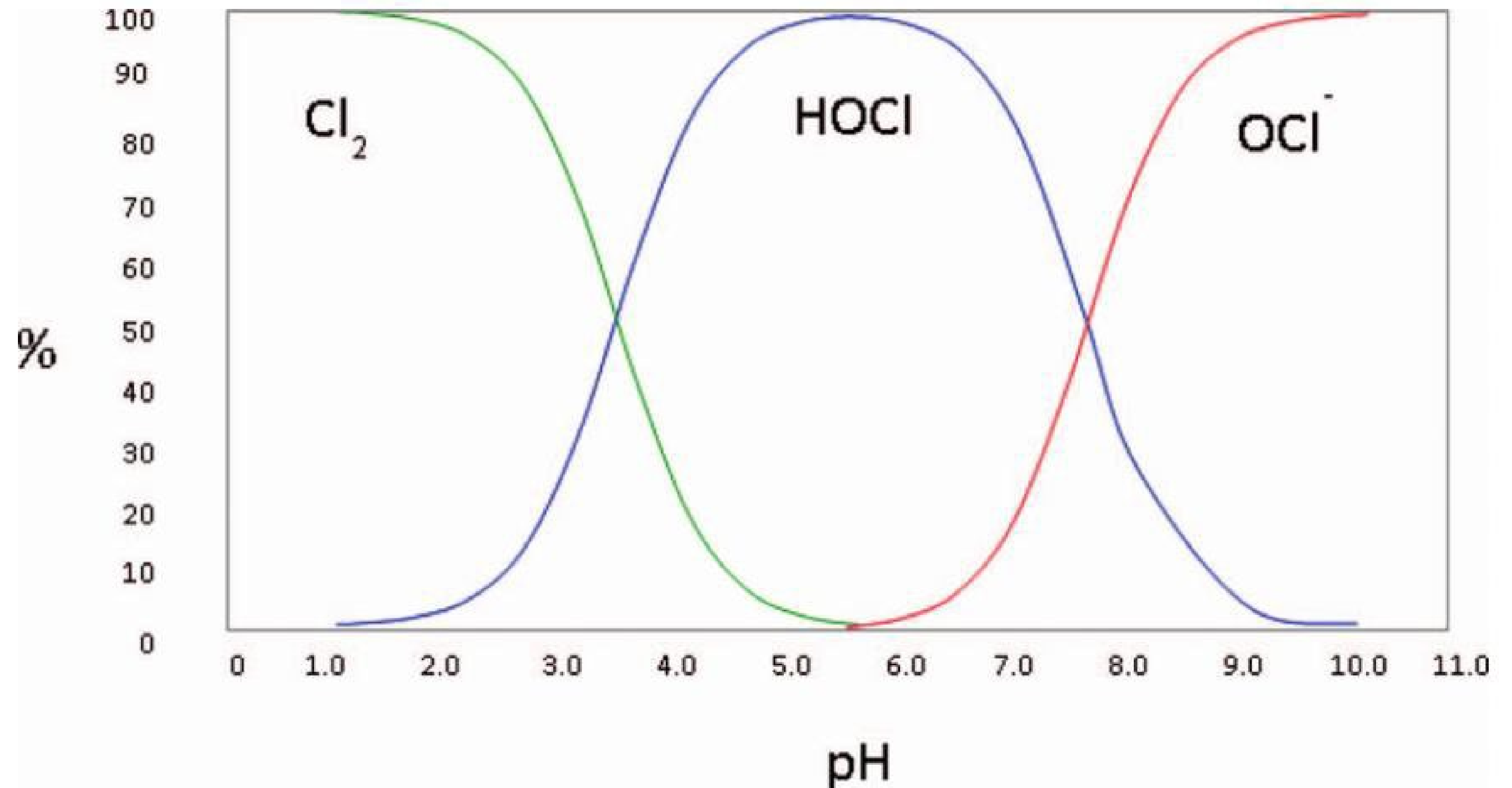
Theoretically this could work but doesn't in practice because systems are too dynamic, and pipes are already too corroded.

- Orthophosphates work by binding with lead +2 so they cannot precipitate
 - Orthophosphates have a minimum pH of 7.2; most plants operate between 7.5 – 8.2
- pH can be volatile throughout a distribution system due to dissolved oxygen and typically varies
 - pH can also be difficult to properly measure and verify across different instruments
- pH can be adjusted for disinfection purposes (ammonia)



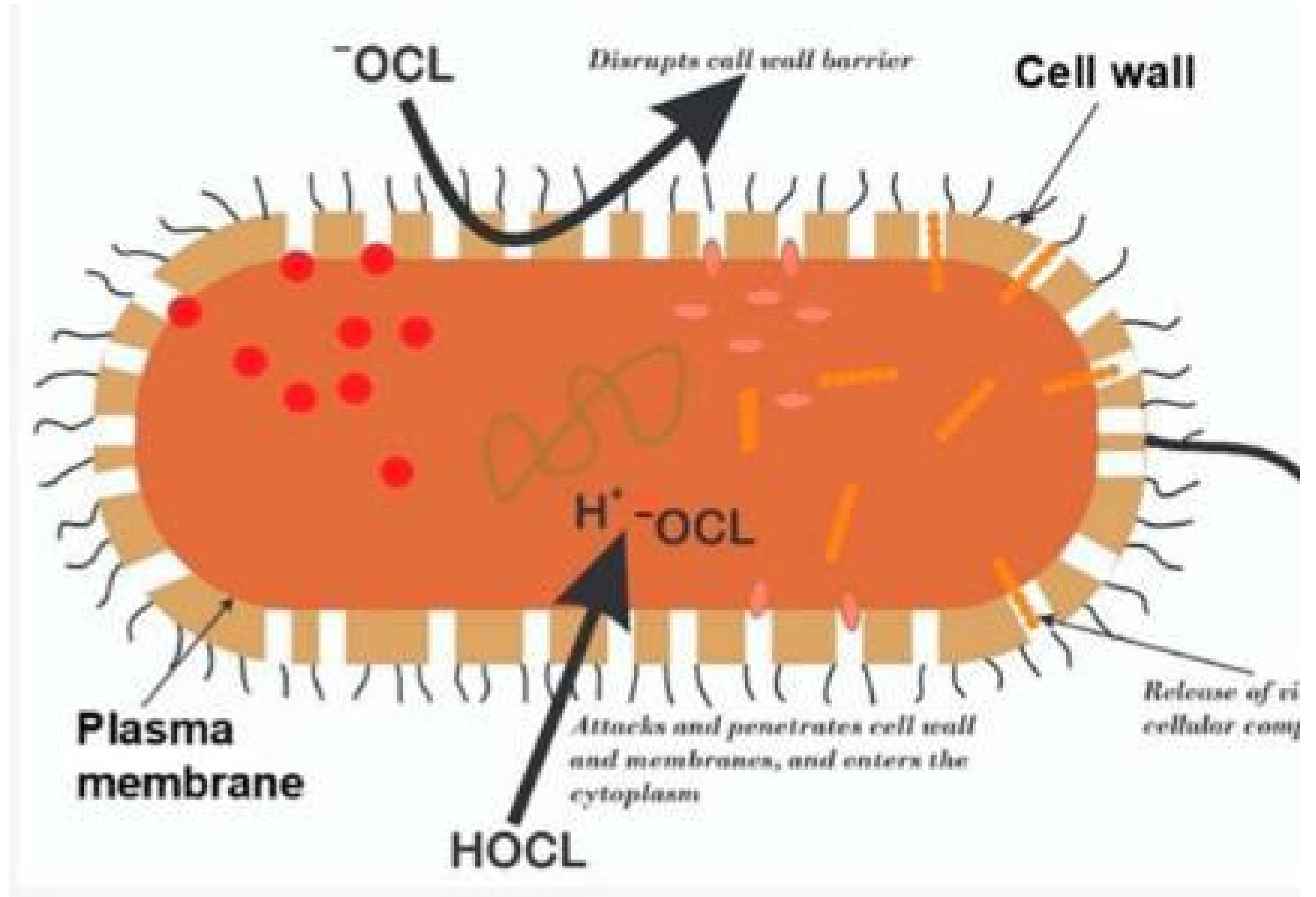
What happens to chlorine at increased pH?

- Between pH 5 – 10 hypochlorous acid (HOCl) and hypochlorite ion (OCl⁻) disassociate
- At pH 7: 78% is HOCl and 22% is OCl⁻
- At pH 8: 78% is OCl⁻ and 22% is HOCl



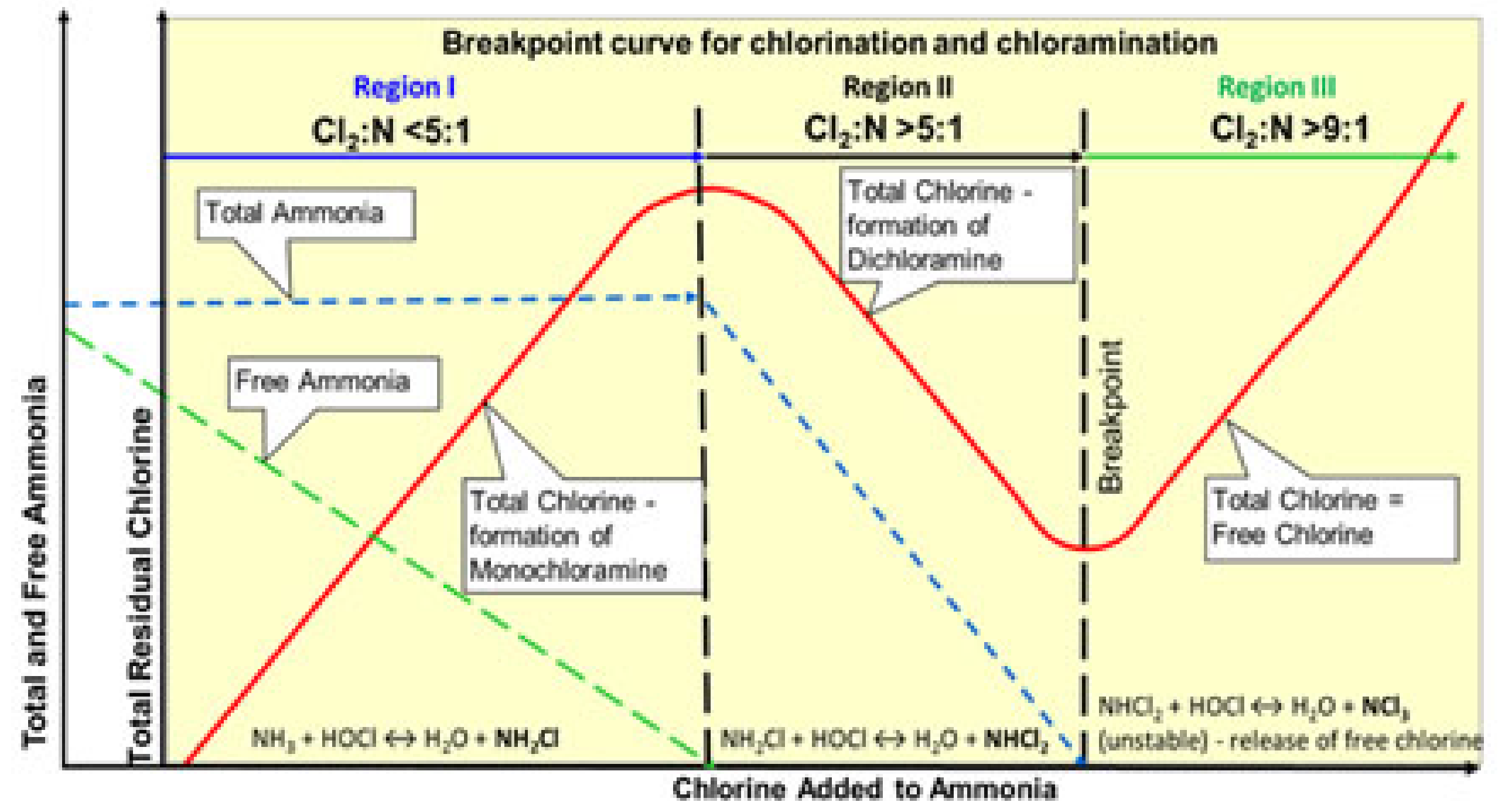
Why is chlorine less effective at increased pH?

- Bacteria have an external slime coating that must be penetrated by disinfectant to effectively kill the cell
- HOCL penetrates the cell wall of bacteria, and OCL does not. HOCL can be up to 80-120 times more effective than OCL
- The lower the pH the more HOCl present and the more effective chlorine becomes



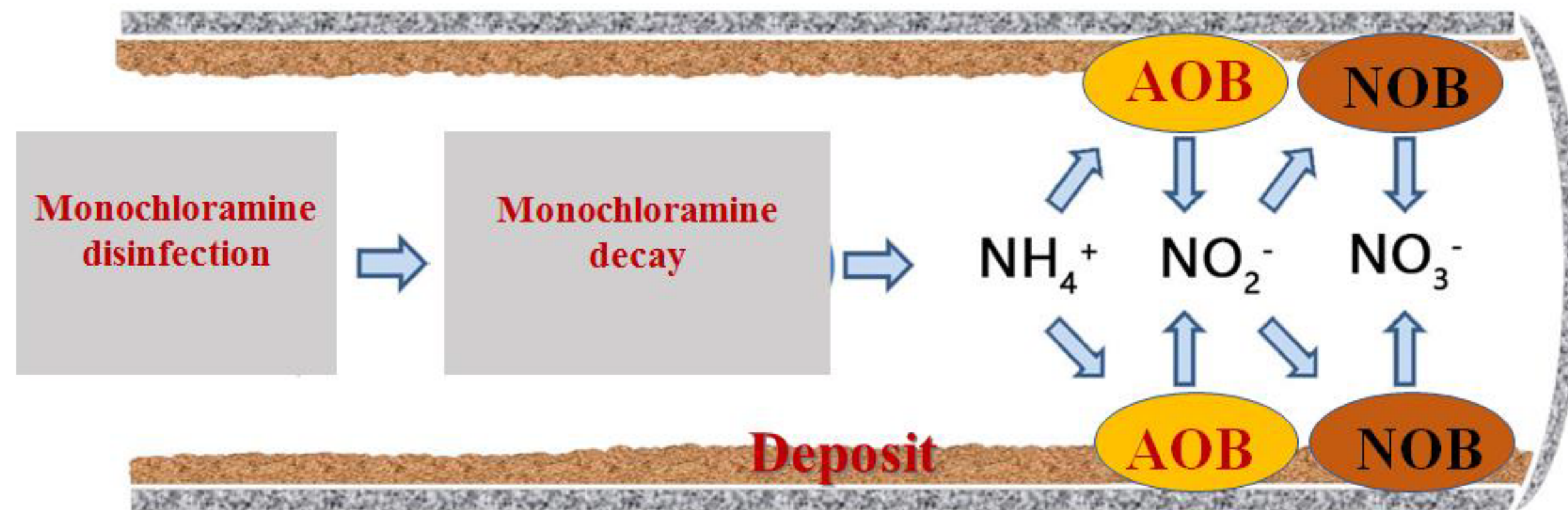
Why do we add Ammonia?

- Have been used in public water systems since 1930
- The Stage 1 DBPR was published in the Federal Register on December 16, 1998, and the Stage 2 DBPR was published in the Federal Register on January 4, 2006
- DBP have been linked to liver, kidney, central nervous system problems, and reproductive effects
- Monochloramines produce lower concentrations of regulated DBP because it is less reactive with natural organic matter
- The formation of disinfection byproducts is influenced by source water type and the type of disinfection used.
- Formation can vary daily with the amount of natural organic material in the water, temperature, rainfall, and distance from the treatment plant or other factors influencing water chemistry.
- Nitrification is a possibility



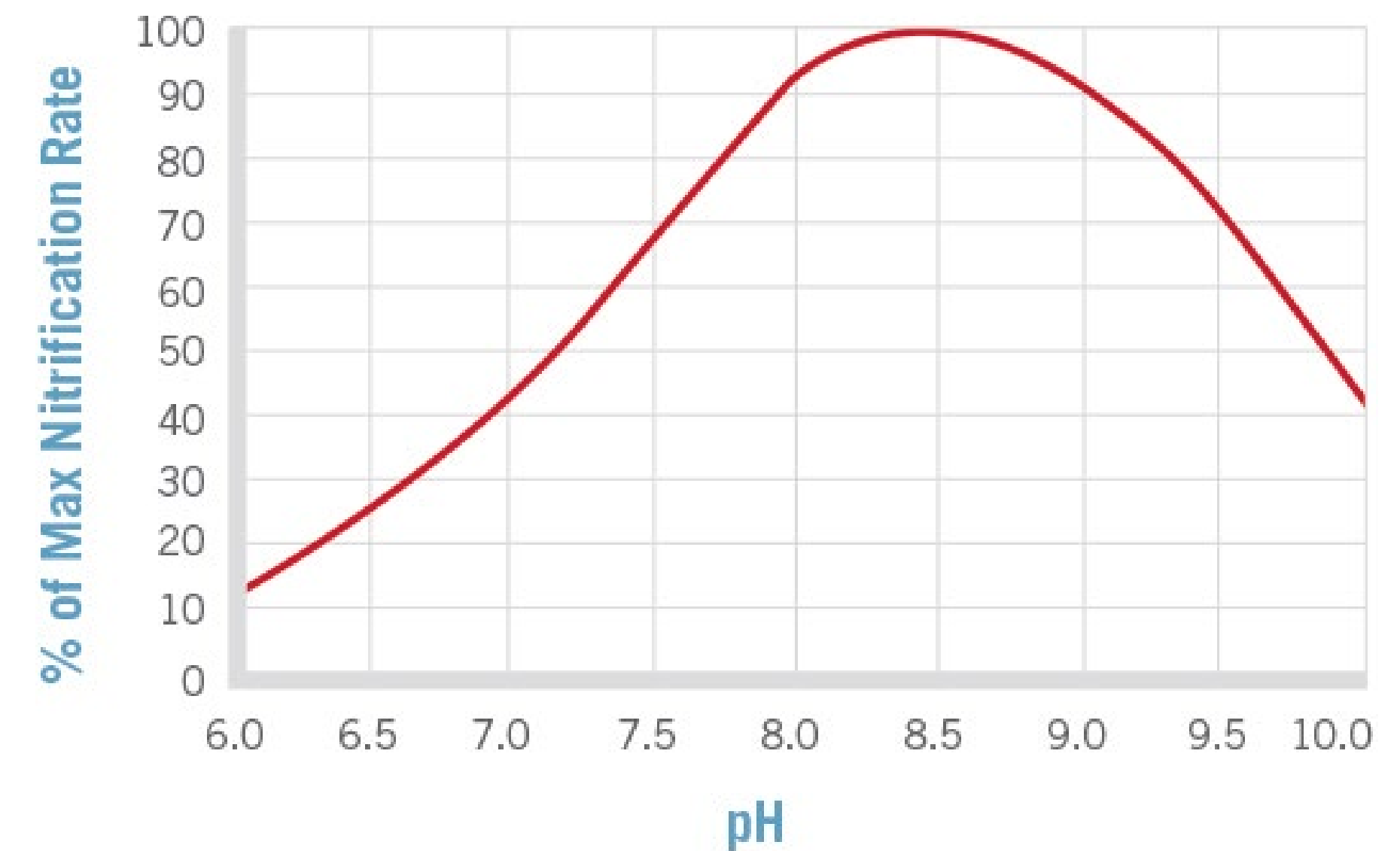
What is nitrification?

- Ammonia + Temperature + Oxygen + Bacteria = Nitrification
- Nitrification results in undesirable loss of disinfectant residual
- Heterotrophic bacteria growth is increased
- This causes adverse affects on water quality, causing taste, odor, and health issues
- Optimum pH range is 8.0 – 8.5



Nitrification activities within deposit sediment of drinking water supply system

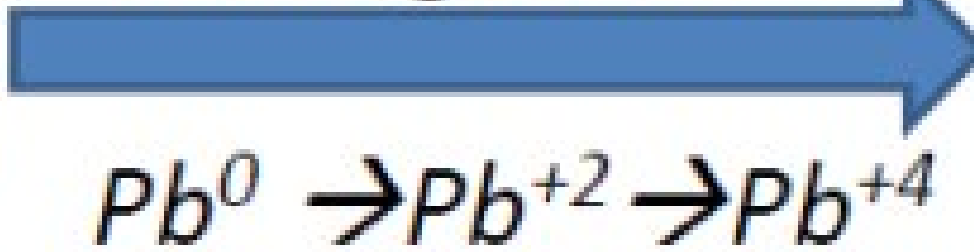
pH VS NITRIFICATION RATE AT 68 °F



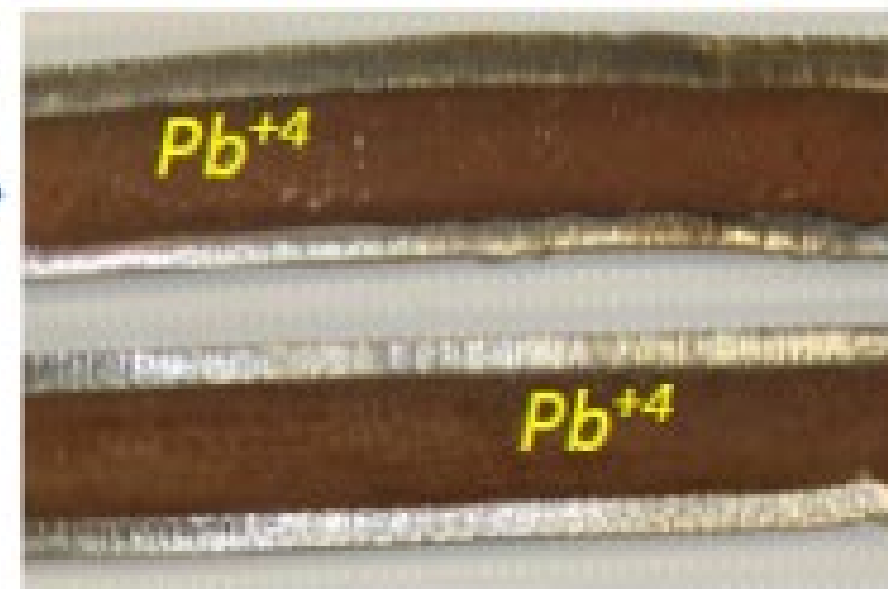
The link between weak oxidation and lead

Chlorine
Disinfectant

Strong Oxidant



Stable Corrosion Layer

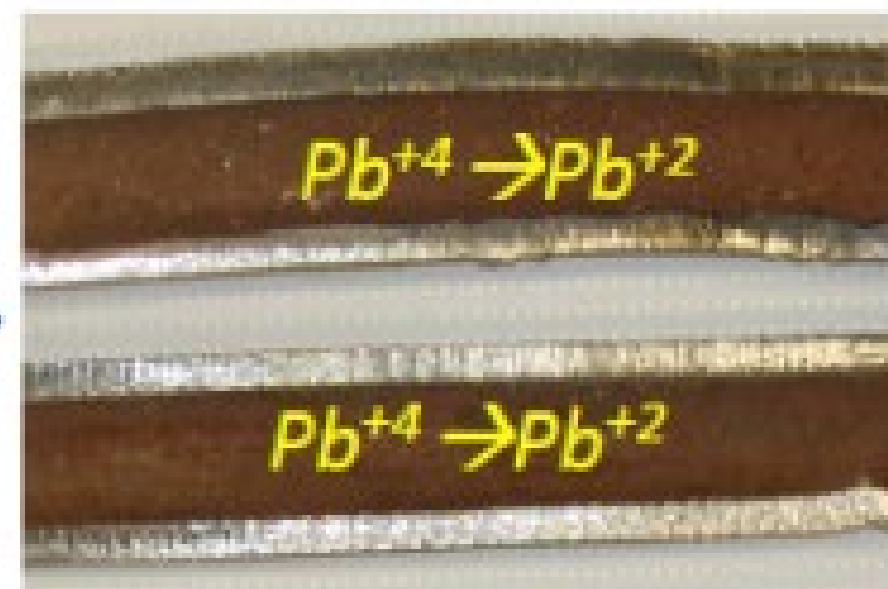


Chloramine
Disinfectant

Weak Oxidant



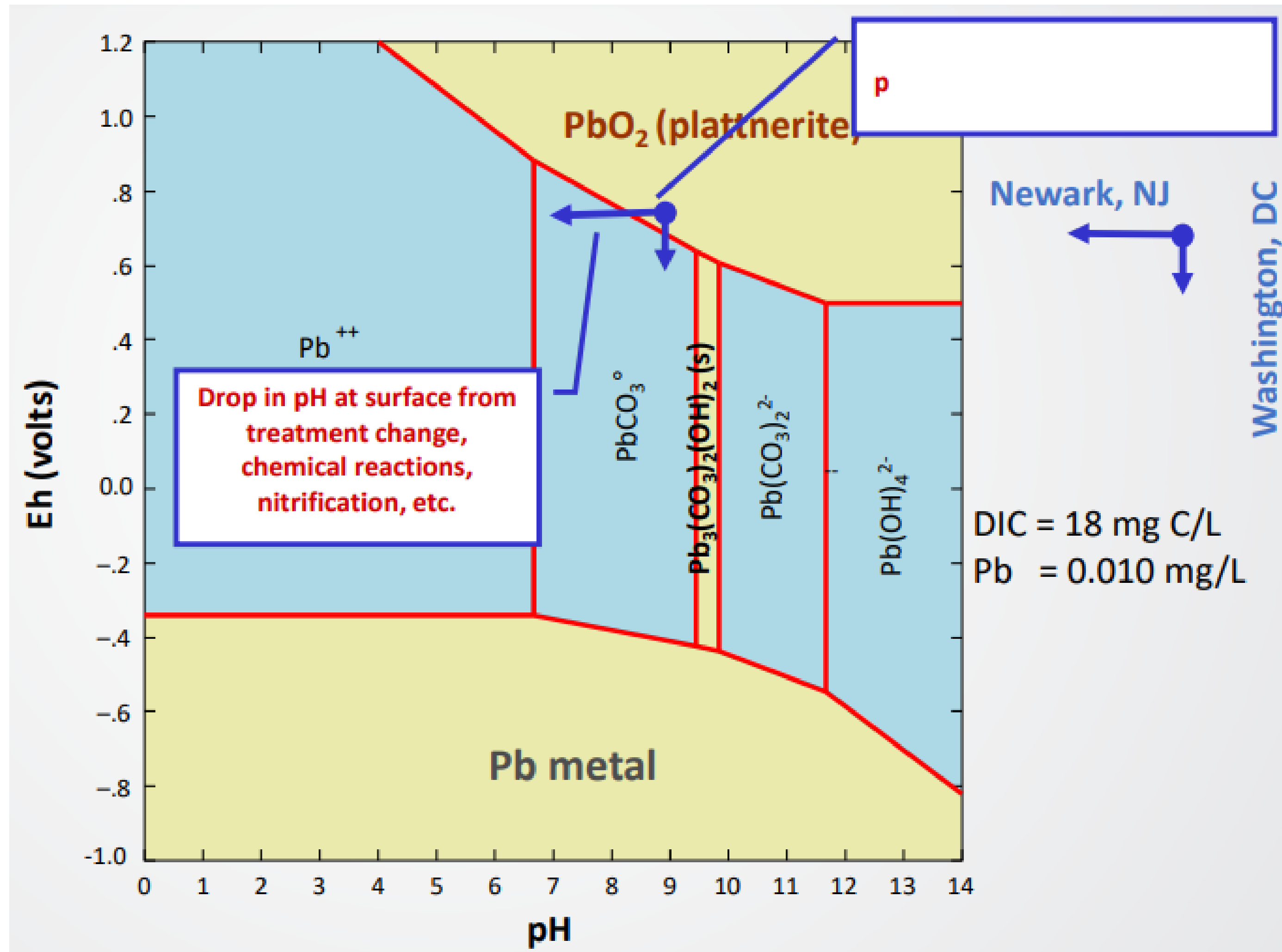
Unstable Corrosion Layer



Weak oxidation from the switch to chloramines was responsible for the Washington DC "lead-in-water crisis" from 2001-2004

Photo of Cut Lead Service Line from M. Schock

Remember Pourbaix Diagrams?



- Describe conditions in which metals oxidize, and which oxidation species (scale) is most common across pH and voltage potential of the bulk water
- Eh = the energy potential of the electrolyte solution (in our case, the water). Stronger oxidation = higher Eh potential (or ORP potential)
- Newark NJ example of passive scale changing due to water chemistry changing (including nitrification)

Goal should be to stabilize pH in the distribution system (avoid swings) and hold high levels of chlorine (strong oxidation)

Total Cost

“Systems should consider operability, reliability, system configuration, and other site-specific factors when evaluating CCT alternatives. In cases where more than one treatment option can meet the OCCT definition of the rule, systems may want to consider cost factors including costs for **capital equipment, operations, and maintenance.**”

DIRECT COST

- Corrosion inhibitor use cost

INDIRECT COST

- Oxidizer efficiency
- Oxidizer selection
- Operating pH window selection
- Capital feed equipment lifecycle / capex
- Flushing man hours

SECTION 2

Lead / Copper Rule

- Optimum Corrosion Control Treatment (OCCT)
 - *“Optimal corrosion control treatment, for the purpose of [subpart I of this part](#) only, means the corrosion control treatment that minimizes the lead and copper concentrations at users' taps while ensuring that the treatment does not cause the water system to violate any national primary drinking water regulations”*
 - Utilities should utilize the technology that provides corrosion control treatment (CCT) as measured by the lowest level of lead and copper
 - The revision to the lead and copper rule is taking a holistic approach to water treatment when accounting for CCT
 - *“Any water system that complies with the applicable corrosion control treatment requirements specified by the State under [§§ 141.81](#) and [141.82](#) shall be deemed in compliance with the treatment requirement contained in [paragraph \(d\)\(1\)](#) of this section.”*

141.81 Applicability of corrosion control treatment steps to small, medium, and large water systems:

- Defines small (<10,000 people), medium (10,000 – 50,000), and large (>50,000) systems
 - Provides guidance on how systems can be deemed to have OCCT
 - Guidance for small and medium-size water systems without CTT
 - Treatment steps and deadlines for:
 - *re-optimizing CCT*
 - *systems without CCT*
 - *small community waters and non-transient non-community water systems electing CCT*
- *Most systems are in compliance and are not expected to be triggered into corrosion control optimization/reoptimization...*

141.82 Description of corrosion control treatment requirements:

- Sets forth requirements for systems and states in the designation of OCCT that is optimizing or reoptimizing CCT
 - CCT recommendations for systems that do not contain LSL and systems that contain LSL but do not exceed the lead action level
 - Guidance for states on how to apply OCCT to different plant sizes and absence/presence of LSL
 - Performance of corrosion control studies
 - State designation of OCCT guidance
 - Installation of OCCT
 - State review of treatment and specification of optimal water quality parameters
 - Continued operation and monitoring of OCCT
- *When states are designating OCCT, they must consider the following effects:*
- *water quality parameters*
 - *CCT on other drinking water quality treatment processes*

Testing Guidance (2016):

- [Optimal Corrosion Control Treatment Evaluation Technical Recommendations | US EPA](#)
- Different checklist for population < > 50,000
- Some states may be using this incorrectly. It is meant for testing guidance if there is a trigger
- Some states are using it to justify change when there is no trigger

141.82 Description of corrosion control treatment requirements:

- When evaluating CCT options system must evaluate
 - *alkalinity and pH adjustment*
 - *orthophosphate- or silicate-based corrosion inhibitor at a concentration sufficient to maintain effective corrosion inhibitor residual*
 - *orthophosphate at 1 mg/L*
 - *orthophosphate at 3 mg/L*
- *This is a minimum list of items that must be tested, not a list of approved treatments.*

141.82 Description of corrosion control treatment requirements:

- Can be evaluated as follows:
 - *pipe rig/loop using harvested LSL pipes*
 - *metal coupons*
 - *partial-system tests*
 - *analyses based on documented analogous treatments with other systems based on:*
 - *size*
 - *water chemistry*
 - *distribution system configuration*
- *There are levels of compliance and what needs to happen based on a lot of factors once lead > 0.010, but CCT testing is almost always the first thing required*
- *“(d) State designation of optimized optimal corrosion control treatment and re-optimized optimal corrosion control treatment. When designating optimal corrosion control treatment, the State must consider the effects that additional corrosion control treatment will have on water quality parameters and on other drinking water quality treatment processes.”*

141.86 Monitoring requirements for lead and copper in tap water:

- Sample site location
- Sample collection methods
- Number of samples
- Timing of monitoring
- Monitoring of initial or re-optimization CCT, installation of source water, and addition of new sources
- Monitoring after state specifies water quality parameters for OCCT
- Reduced or additional monitoring regarding 90th percentile
- Rules on waivers

141.86 Monitoring requirements for lead and copper in tap water:

- All tap samples must be first draw
- All first draw samples will be tested for lead and copper unless only lead is required
- All first draw samples must be:
 - 1 liter wide-mouthed bottles
 - stood motionless for 6-hours
 - no instructions on removing aerators and cleaning or flushing
 - acidification can be conducted 14 days after sampling
 - collect 5 consecutive samples

141.90 Reporting requirements:

- For tap water
 - Source water monitoring & treatment
 - CCT
 - LSL inventory & replacement
 - Public education program
 - Additional monitoring data
 - Reporting the 90th percentile lead and copper concentrations
 - Reporting for schools and public education facilities
 - Small system compliance flexibility options
-
- *If there is an addition of a long-term change in water treatment or source, then monitoring will take place for two consecutive 6-month periods*
 - *The state can determine if the change is significant enough to warrant testing*
 - *The state can decide that additional monitoring is not required when changing or adding water treatment*

141.92 Monitoring for lead in schools and childcare facilities:

- 5 sample per school
- 2 samples per childcare facility
- Water systems must collect samples from cold water tap:
 - *sample must be first draw*
 - *250 mL in volume*
 - *water must have been stationary from 8 – 18 hours*
 - *samples must be analyzed using acidification*
- Sampled from 20% of schools and childcare facilities
- All must be sampled at least once in the 5 years following the compliance date

- **Revised Lead and Copper Rule**
 - Details of the upcoming rule are still being discussed
 - Lead and Copper Rule Improvements (LCRI) rule to be released later this year (2023) as draft

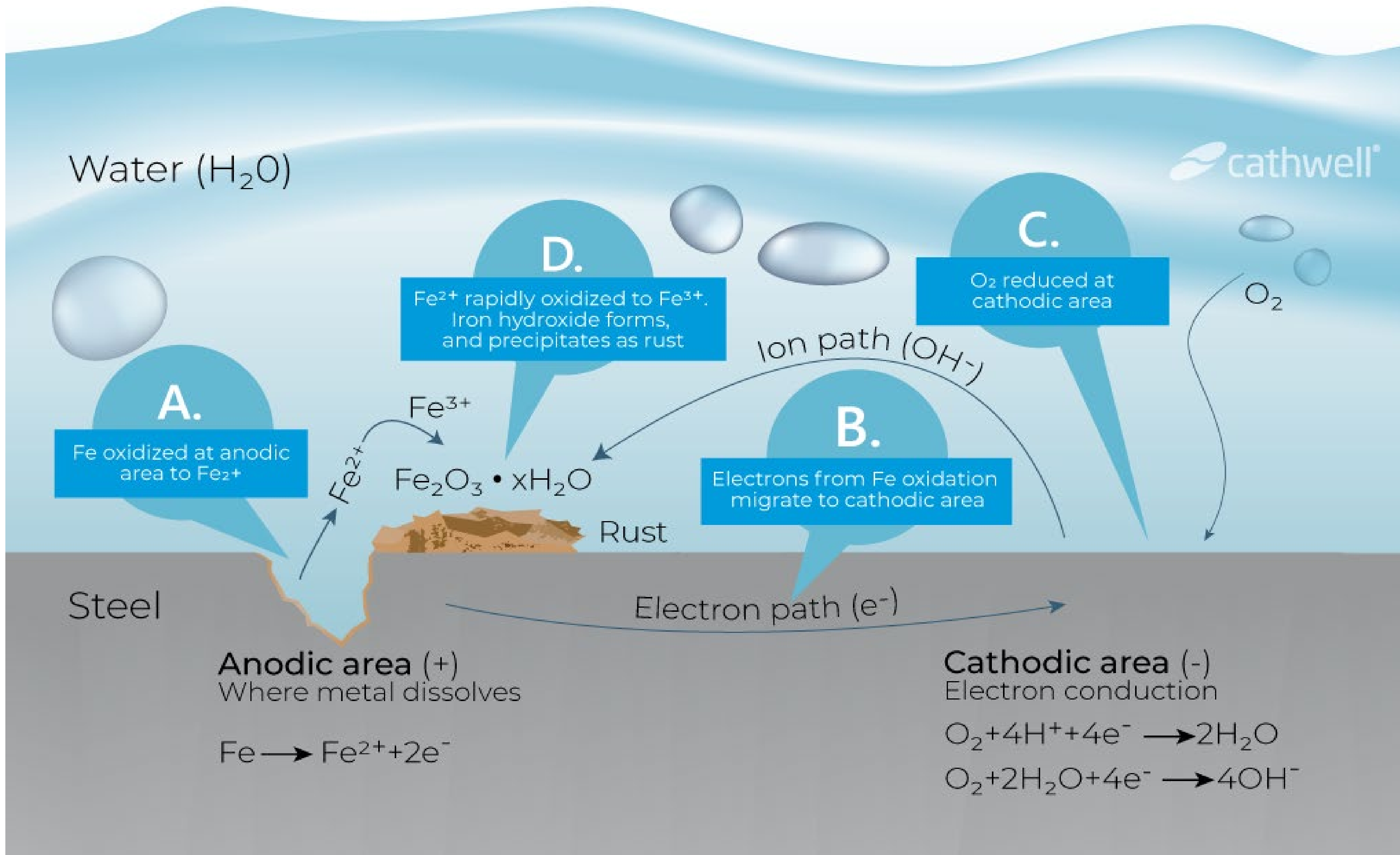
HOLISTIC

The more
chemicals and *complexity*
the *harder* this all gets.

SEAQUEST

A Holistic Approach to Water Quality

Why is there Corrosion?



Cathodic Protection?

Anodic Protection?

Oxygen Barriers?

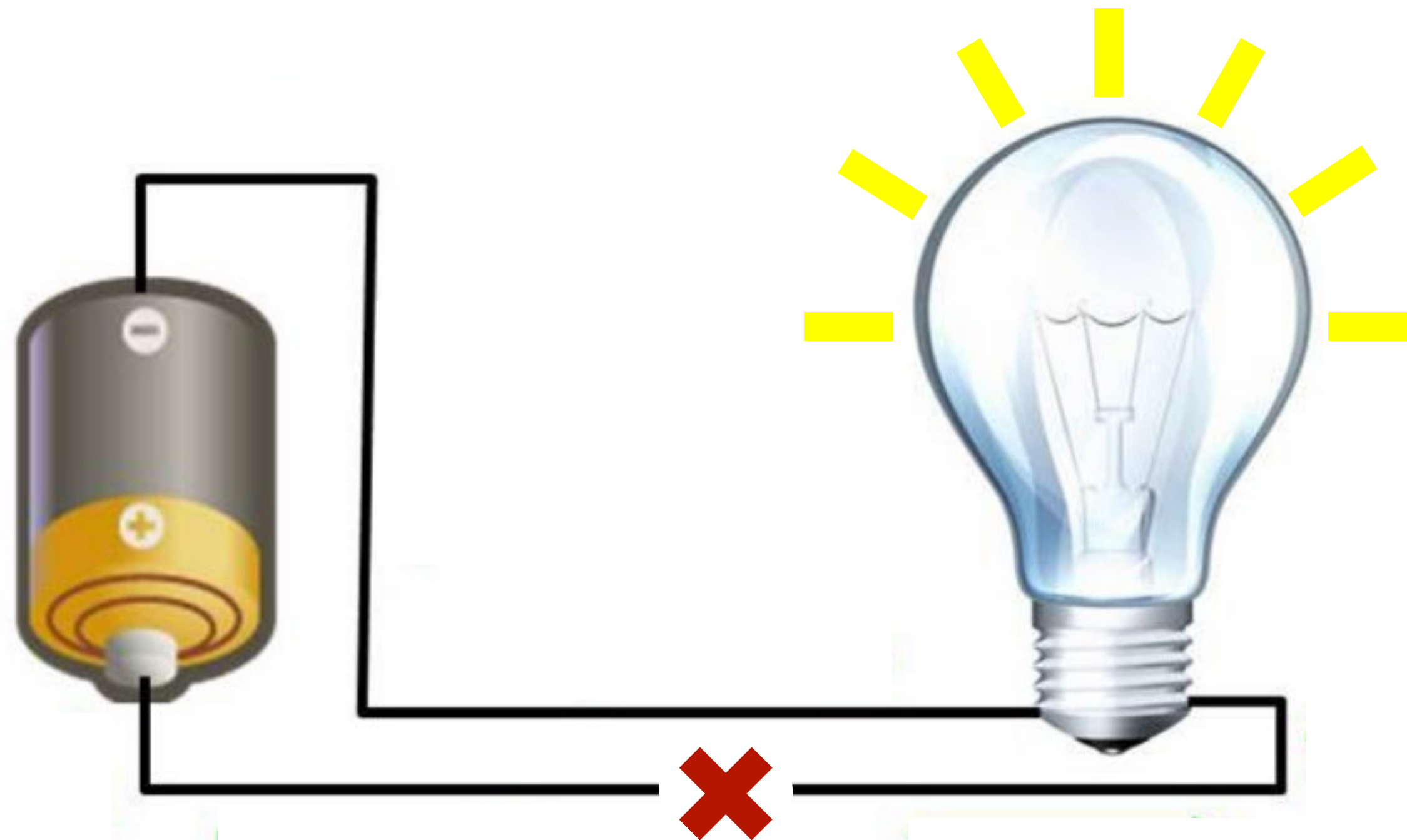
Coatings?

Sacrificial Anodes?

Charge?



Why is there Corrosion?



- What would be a better way to turn off the light?
- Cover the light in electrical tape
 - Stop the flow of electrons between the anode and the cathode

Demonstration Phosphates in Equilibrium



HOW IT WORKS

1. Two samples of tap water one with SeaQuest
2. Iron is added
3. Bleach is added to oxidize the iron



Sequestration vs. No Sequestration



**Corrosion Control Treatment
Equilibrium Blended Phosphate vs Without**

pH Control

- Measure of hydrogen ions in water, logarithmic scale
- The less free hydrogen ions, the less reactive water is to metal
- Generates scale on the inside of the pipe
- Calcium carbonate films rarely adhere to lead and copper pipe walls
- Calcium carbonate films are not considered an effective form of corrosion control

Silica

- No longer typically in use
- *“Information on the use and effectiveness of silicate-based corrosion inhibitors continues to be limited and more research is needed.”*
- *“The mechanisms by which silicate inhibitors control lead and copper release have been debated in the literature. Silicates may form an adherent film on the surface of the pipe that acts as a diffusion barrier. Silicates will also increase the pH of the water, which may reduce lead and copper release.”*

Orthophosphate

- Reacts with divalent metals, such as lead and copper to form scale
- Orthophosphate is available as:
 - Phosphoric acid
 - In a salt form (potassium or sodium)
 - Zinc orthophosphate
- Scale formation is dependent on:
 - Orthophosphate concentration (1.0 – 6.0 mg/L PO₄)
 - pH (7.2 – 7.8 for lead control)
 - Dissolved inorganic carbon (can't be measured)
 - Characteristics of existing corrosion scale (type of metal)
- Use can contribute 10 – 35% of phosphorus load at WWTP
- Does not sequester metals in water (iron and manganese)

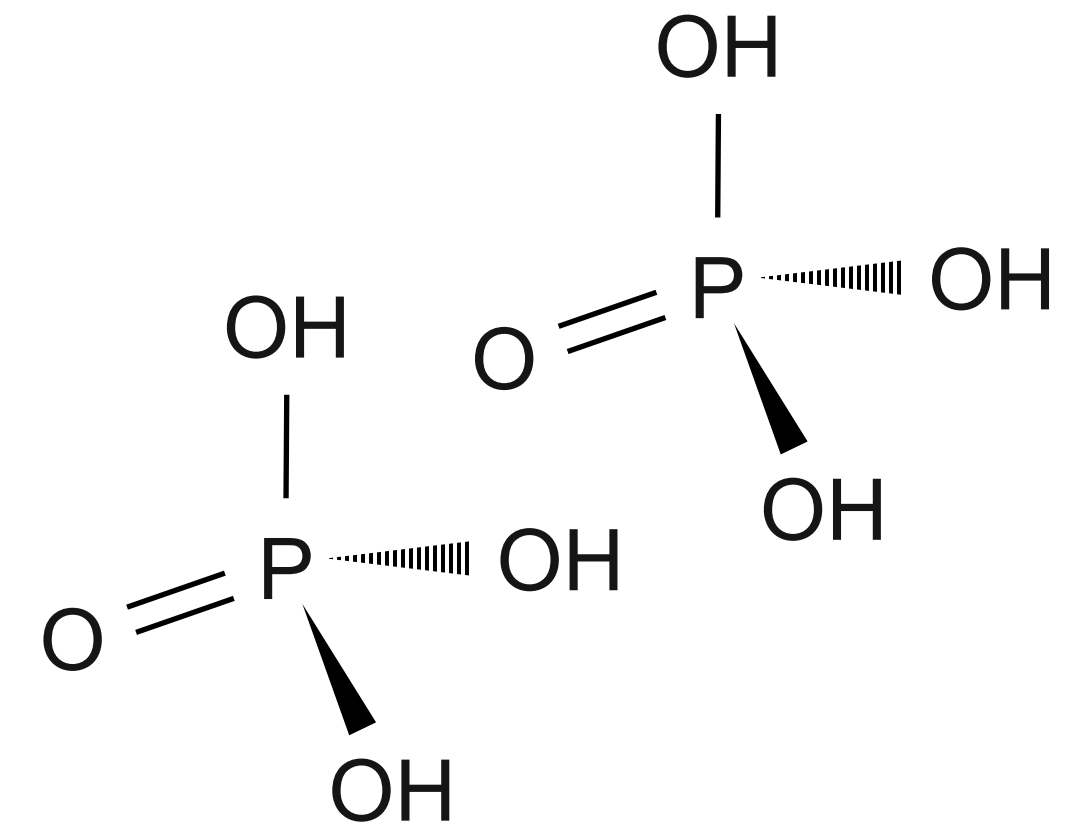
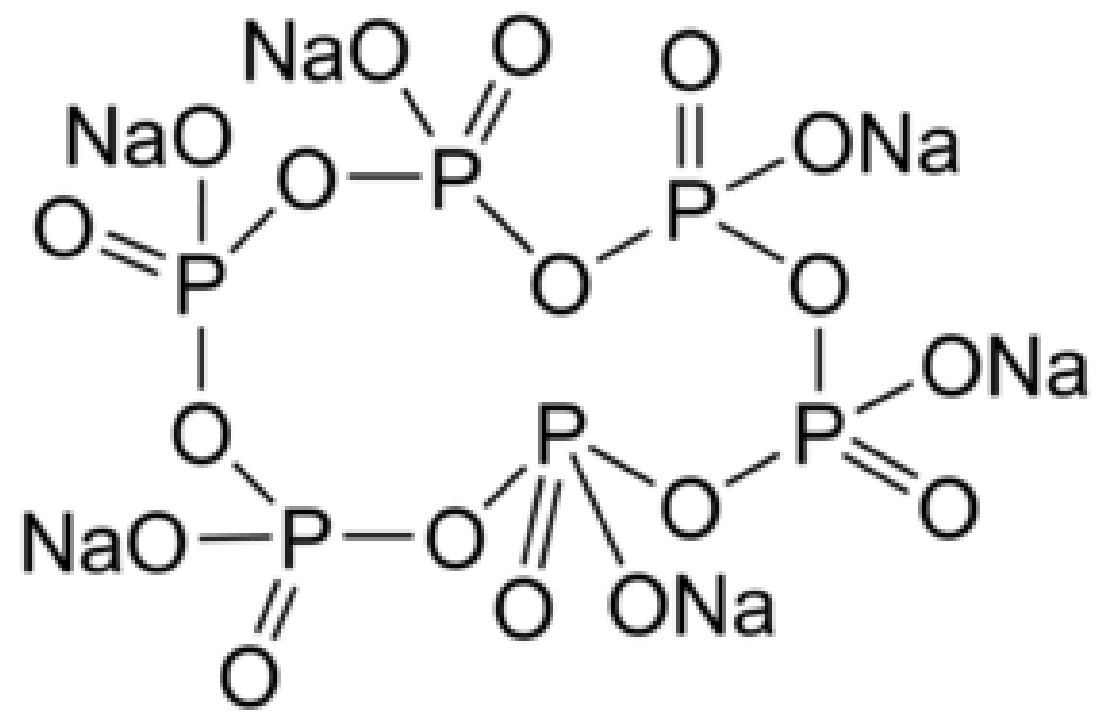
Traditional Blended Phosphates

- Contain some ratio of polyphosphate and orthophosphate
 - 50/50, 70/30, 20/80, etc....
 - Over 6.4 billion combinations
- *“It is possible that blends can provide both sequestration of metals and reduce metals release (Hill and Cantor, 2011).”*
- *“....blended phosphates may not function as corrosion inhibitors strictly on the basis of concentration and relative amount of orthophosphate.”*
- Polyphosphate exists to sequester metals
- Orthophosphate exists to form scale
- Balance is tricky and needs to be customized to water
- Calcium and aluminum play a role in effectiveness

Equilibrium Blended Phosphates

- Takes advantage of biological and chemical conditions at the interface of the pipe and water
- Chemical catalyst is used to drive a continuous reaction that maintains equilibrium between ortho- and polyphosphate which disrupts the corrosion process electrochemically
- Mechanism is non-scale forming which uses less overall material
- Longer sequestration ability in the presence of strong oxidizers
- Not dependent on bulk water pH; assists in optimization of other water treatment processes

PHOSPHATES IN EQUILIBRIUM



Traditional Selection Criteria

	Lead Release	Copper Release	Steel Corrosion	Color / Appearance	Typical Dose	Product Cost
Equilibrium Blended Phosphate	☹☹☹	☹☹☹	☹☹☹	☹☹☹	☹☹☹	☹☹
pH Control	☹☹☹	☹☹☹	☹	☹	☹	☹☹☹
Silica	☹☹	☹☹	☹☹☹	☹	☹	☹☹☹
Ortho Phosphate	☹☹☹	☹☹	☹☹	☹	☹	☹☹☹
Traditional Blended Phosphates	☹☹	☹☹	☹☹	☹☹	☹☹	☹☹

- ☹ Poor Performance
- ☹☹ Acceptable Performance
- ☹☹☹ Excellent Performance

Holistic Approach Selection Criteria

	Phosphorus Discharge	Chlorine Residuals	Disinfection Byproducts	Electricity / Water Flow	Workplace EHS	Total Use Cost
Equilibrium Blended Phosphates	☹☹	☹☹☹	☹☹☹	☹☹☹	☹☹☹	☹☹☹
pH Control	☹☹☹	☹	☹	☹	☹	☹☹
Silica	☹☹☹	☹	☹	☹	☹	☹
Ortho Phosphate	☹	☹	☹	☹	☹	☹
Traditional Blended Phosphates	☹	☹☹	☹☹	☹☹	☹☹☹	☹☹

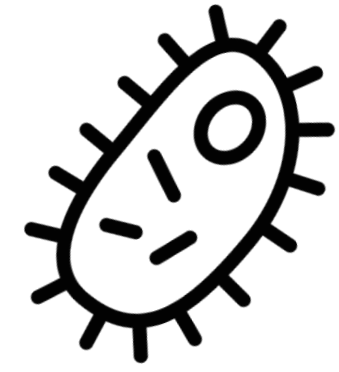
- ☹ Poor Performance
- ☹☹ Acceptable Performance
- ☹☹☹ Excellent Performance



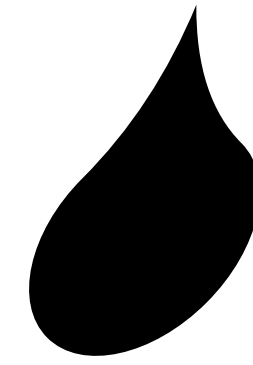
Lead /
Copper



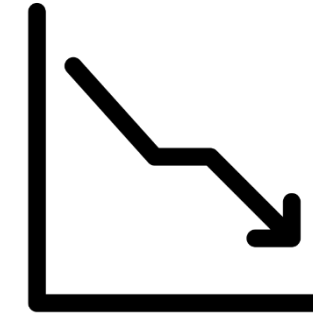
Rogue
Water Loss



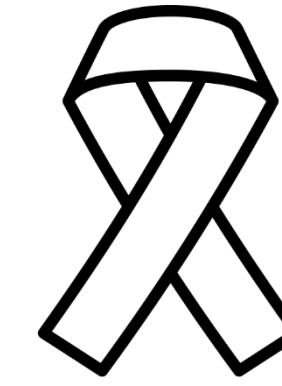
Biofilm



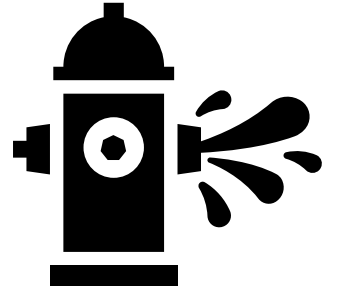
Dirty
Water



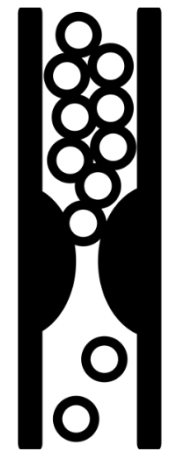
Low
Chlorine



Disinfection
Byproducts



Excess
Flushing



Clogged
Pipes

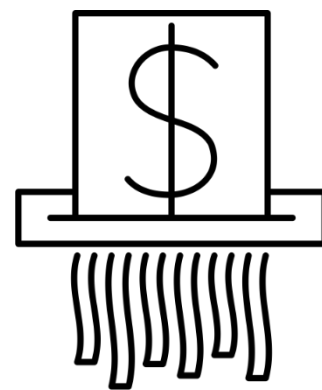
Equilibrium Blended Phosphate
addresses every issue.



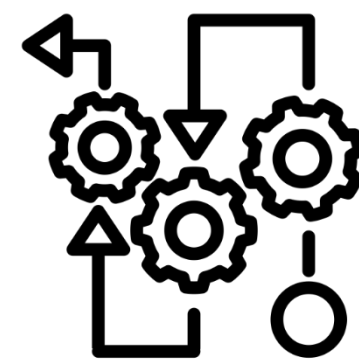
Well
Productivity



Dangerous
Chemicals



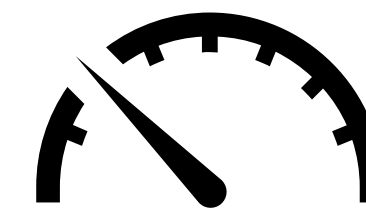
Expensive
Chemicals



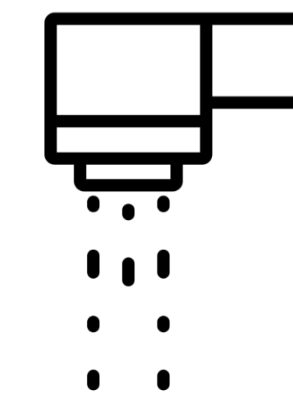
Hard-to-Feed
Chemicals



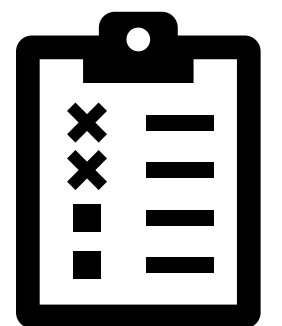
Hard-to-Control
Chemicals



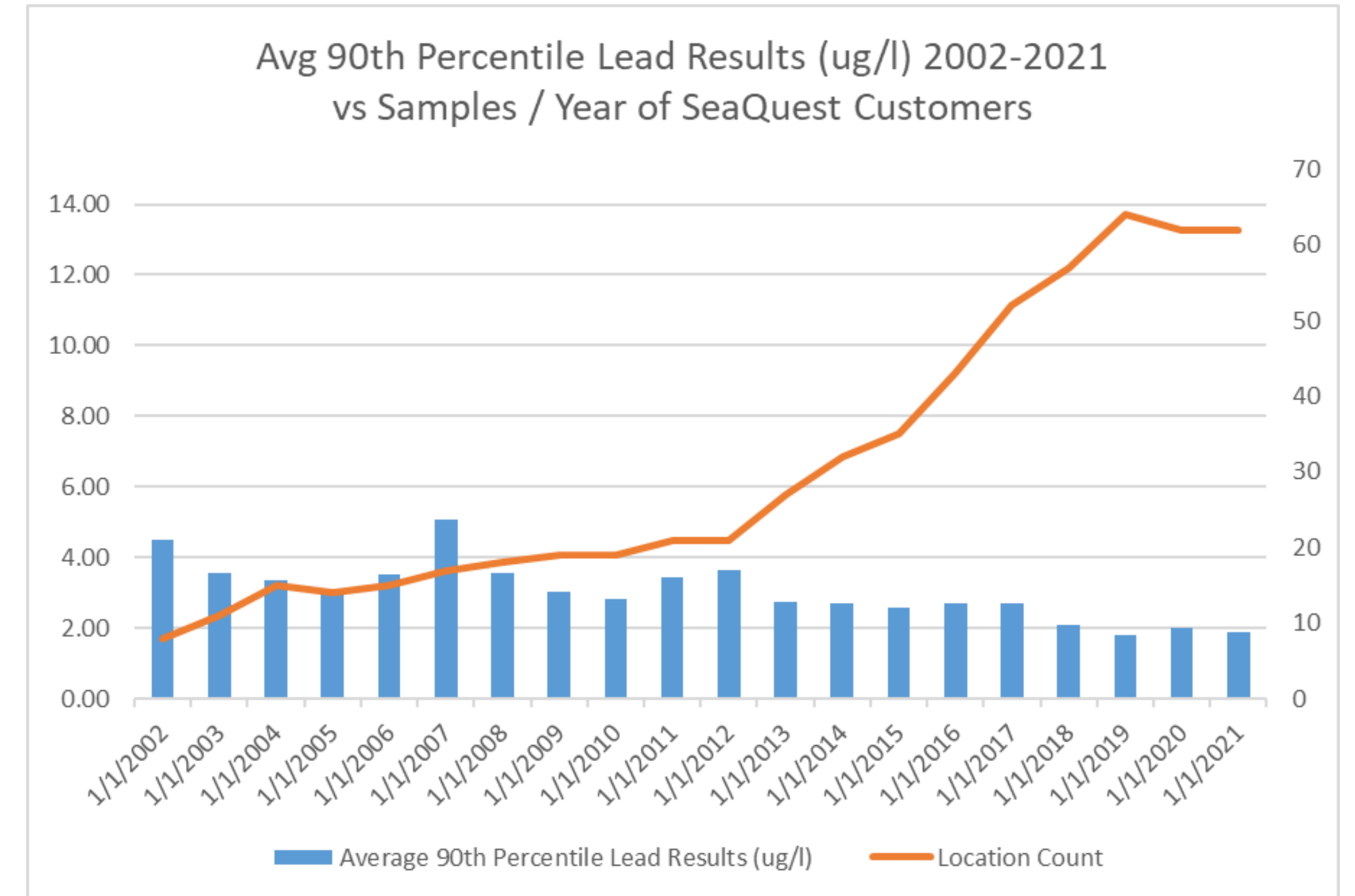
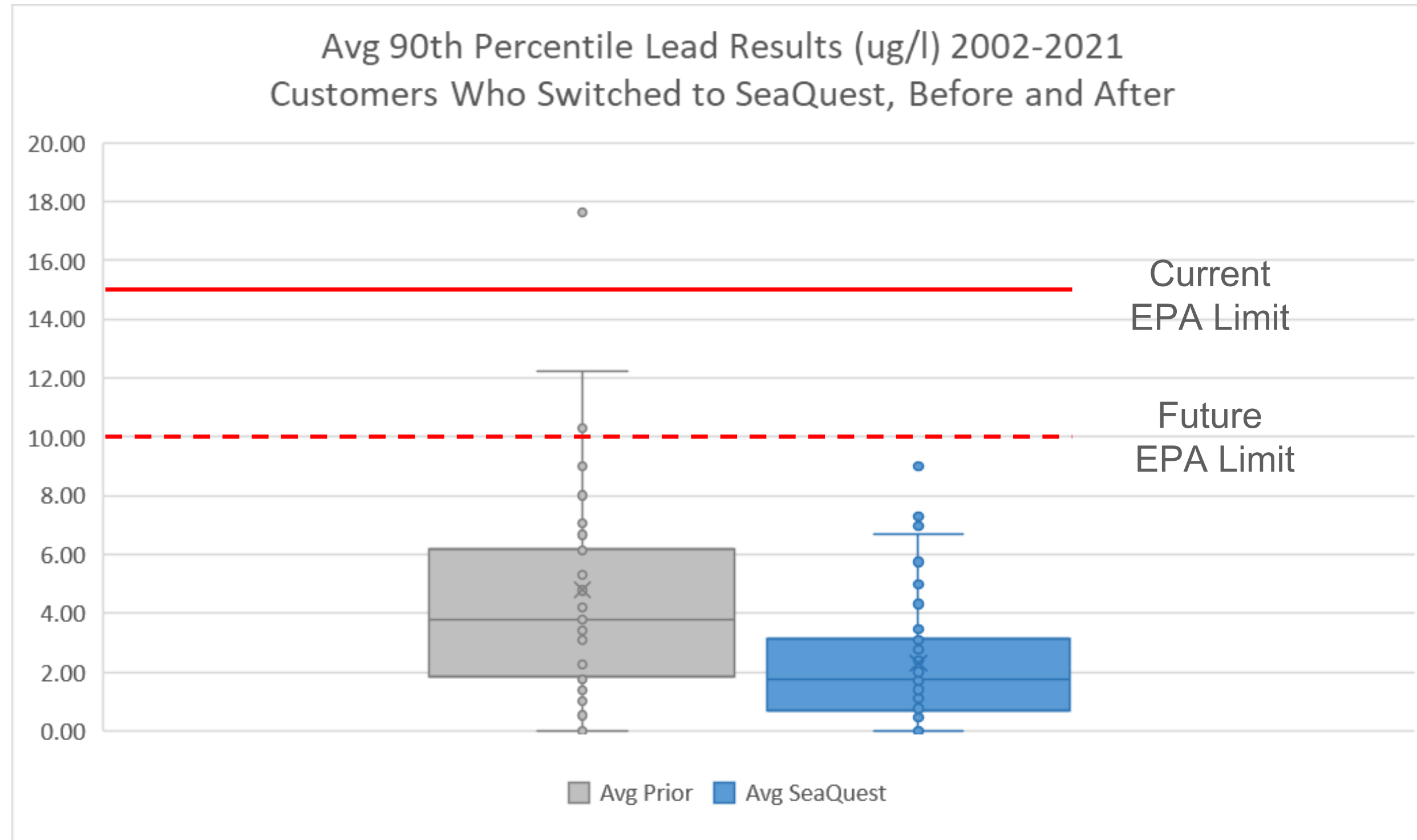
Low Bill
Rates



Low
Pressure



Regulatory
Compliance



63 customers were sampled who switched to an equilibrium blended phosphate from a different type of corrosion inhibitor since 2002:

- Average 90th percentile lead concentrations were reduced from 4.8 ug/l to 2.3 ug/l

87 customers were sampled who used an equilibrium blended phosphate since 2002:

- Average 90th percentile lead concentrations remain compliant and are continuously reduced

	Total Cost (GBP/Yr)	Total Phosphorus Generation (KG/Yr)	Total Carbon Footprint (KG CO2e/Yr)
Ortho-Phosphate	£3,371,540	146,267	3,844,292
Equilibrium Blended Phosphate	£2,449,577	32,449	3,270,632
Equilibrium Blended Phosphate + Eliminate Lime	£1,237,122	32,449	537,640

While:

- Eliminating red water complaints
 - Increasing chlorine residuals
- Reducing EHS risk
- Using minimal capex

SEAQUEST

Case Histories



Problem

- High levels of phosphoric acid used for lead control where high levels of lead service lines are present
- Waters typically mix from different treatment works into different distribution zones
- Discoloration complaints began being regulated more heavily in 2017
- Equilibrium blended phosphate had been used in West Region, and was deployed in East Region to address discoloration
- Lead concentrations in distribution system are taken continuously, and any level $>10 \text{ ug / l}$ is an exceedance

About SEW

2.2 Million Customers

540 MI/d Average Supply (142 MGD)

9,000 Miles of pipe

83 Treatment works

275 Boreholes

198 Service Reservoirs

10 Water Towers

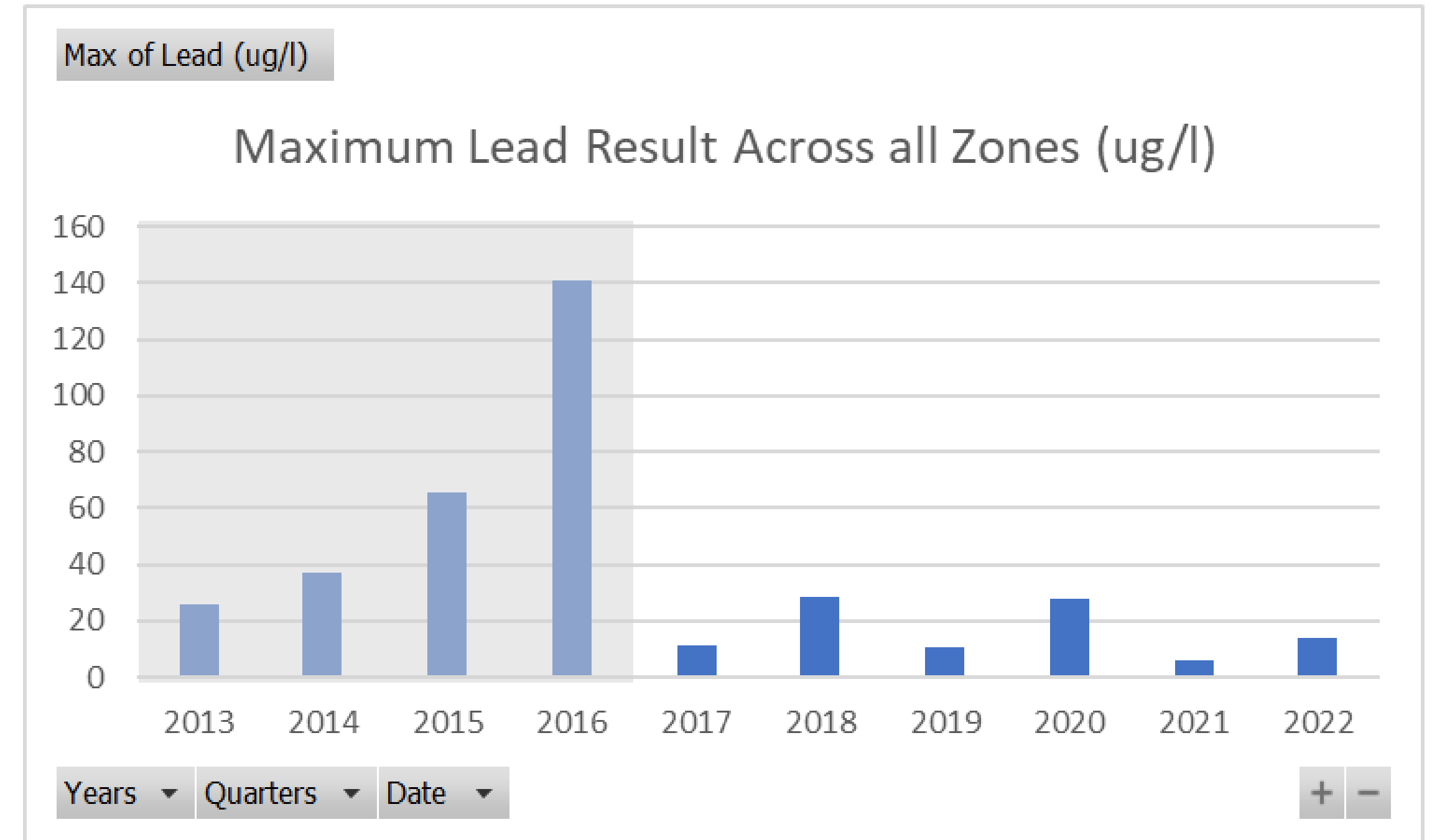
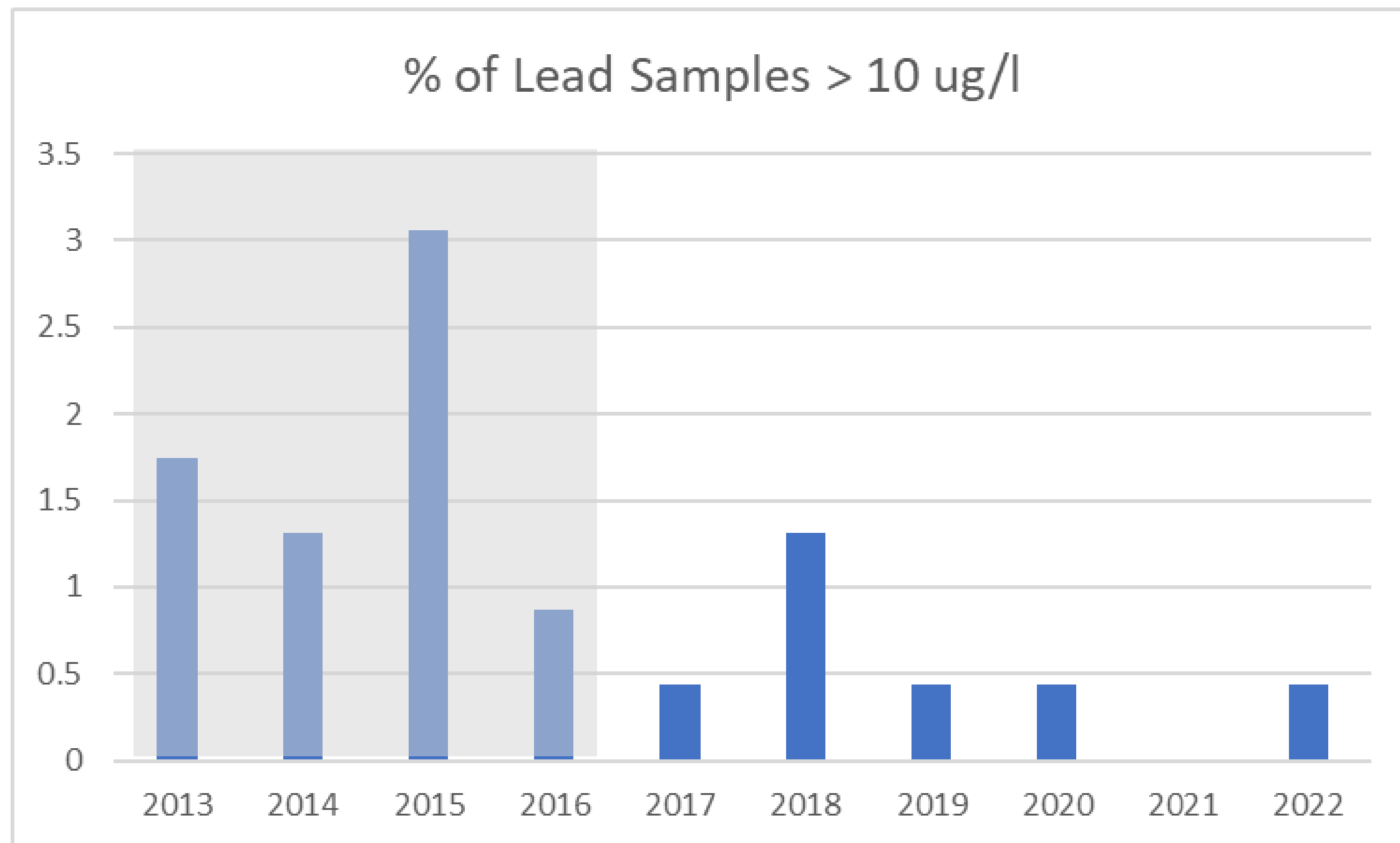
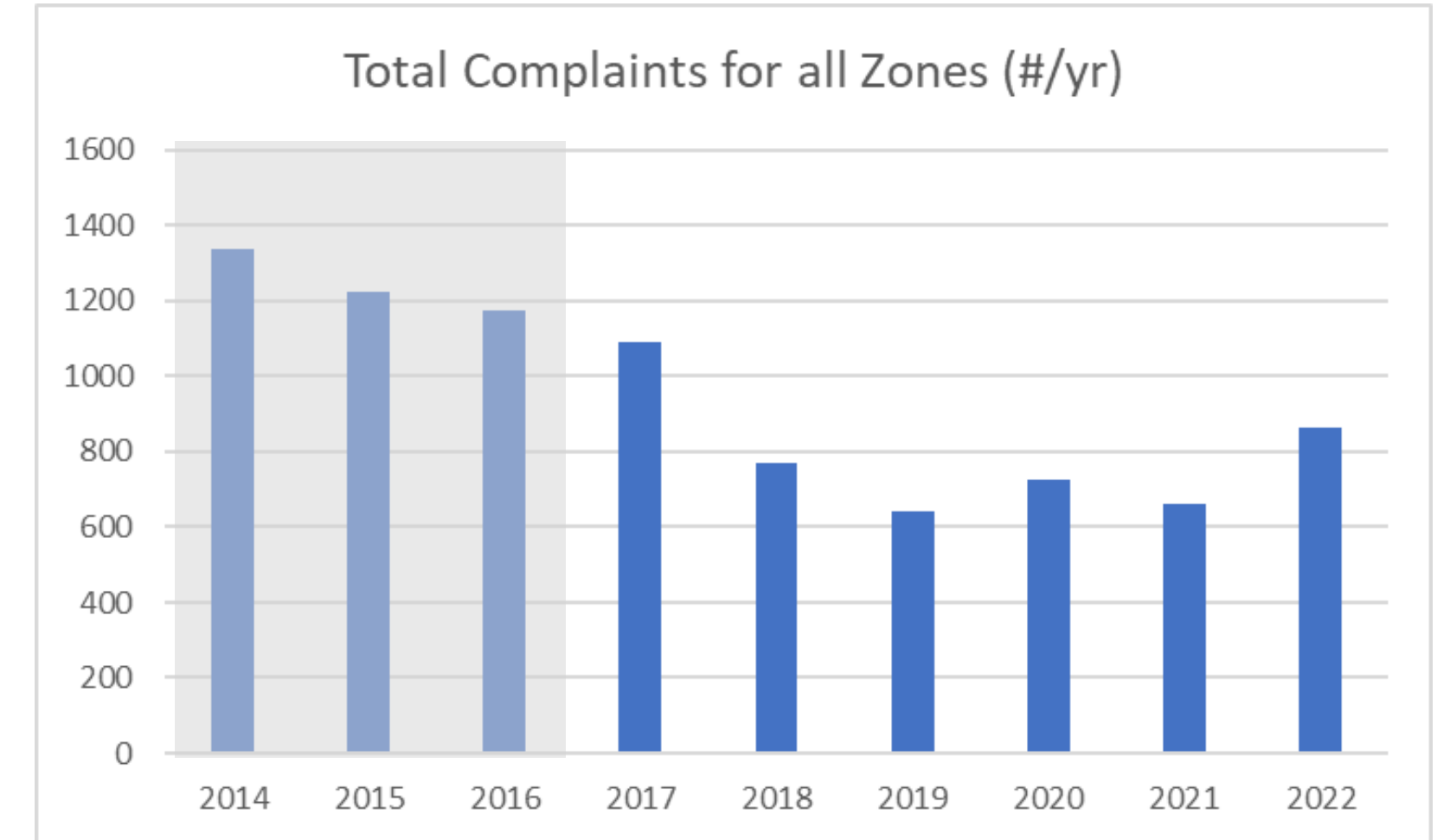
4 Surface Water Reservoirs



Treatment Works	Water Source	Avg. Hardness (mg/l)	Iron (ug/l)	Manganese (ug/l)	Avg Daily Flow (liters / second)	Disinfection
Arlington WTW	Surface	33.9	8.9	2.1	122	Chlorine Gas
Barcombe 1 WTW	Reservoir (shallow issues) / River / Treated Cow Wish (barely used)	38.7	8	2.3	126	Chlorine Gas
Barcombe 2 WTW	Reservoir (shallow issues) / River / Treated Cow Wish (barely used)	38.3	8.7	2.3	491	Chlorine Gas
Bewl WTW	Surface / Bore Hole 10:1	30	13.4	5.3	171	Chlorine Gas
Bray Gravel WTW	Shallow Bore Holes (River Thames)	116.2	7.3	1.7	214	Chlorine Gas
Crowhurst Bridge WTW	Bore Holes – occasional river (up to 25%)	32	55.6	3.9	68	Chlorine Gas
Forstal WTW	Bore Holes – occasional springs (up and down 5-50%)	137.3	7.3	1.7	130	Sodium Hypochlorite
Greatham WTW	Bore Holes	51.6	18.5	1.8	51	Sodium Hypochlorite
Headley WTW	Bore Holes (system not always on)	48.5	7.4	1.7	84	Sodium Hypochlorite
Keleher WTW	Surface - River Thames	101.8	7.3	1.7	444	Liquid Bleach
Oakhanger WTW	Bore Holes	45.1	7.3	1.7	54	Sodium Hypochlorite
Pembury WTW	Reservoir fed by Bore Holes and Springs	29	7.6	2.1	104	Chlorine Gas
Trosley WTW	Bore Holes	99	7.5	1.7	147	Chlorine Gas

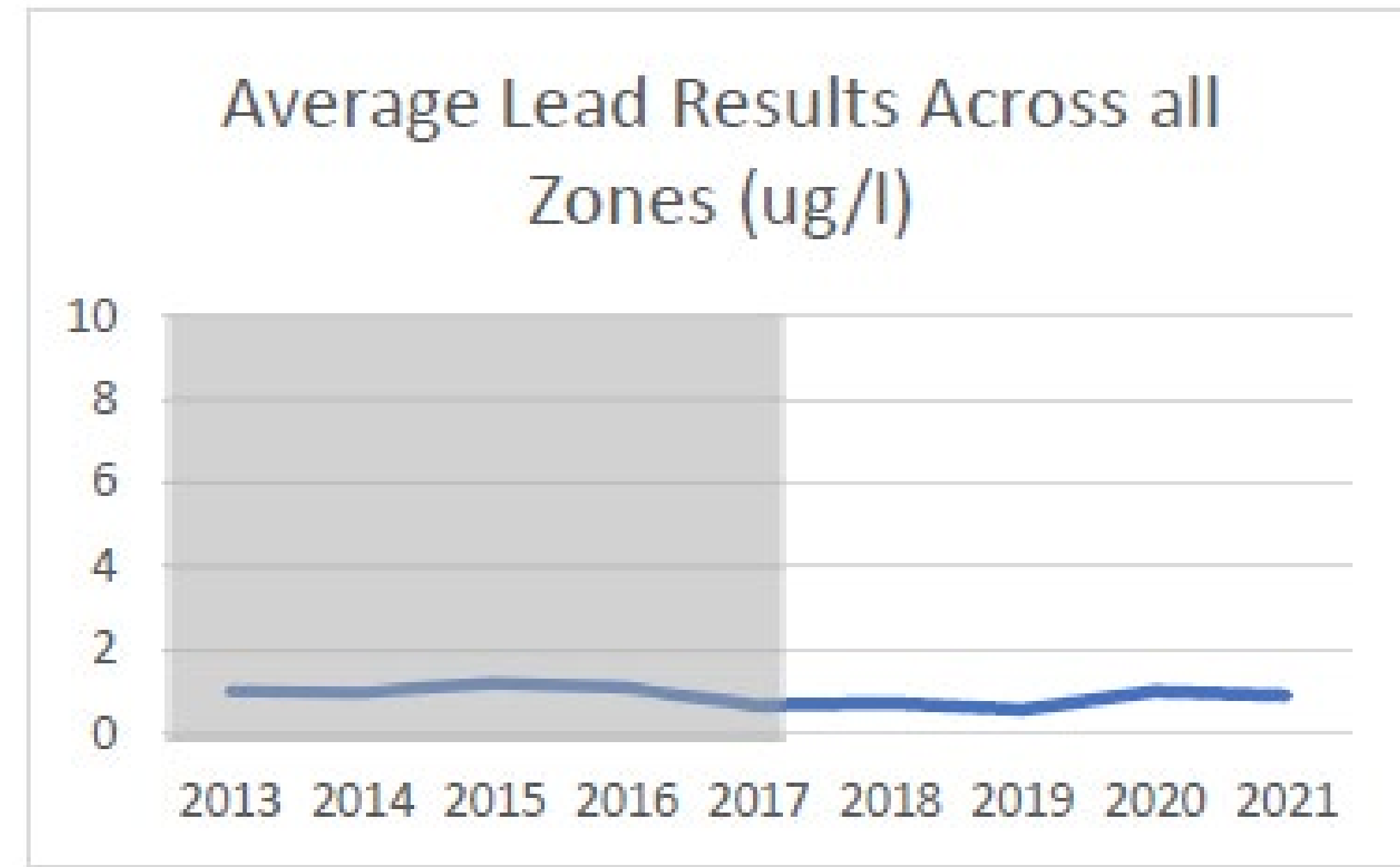
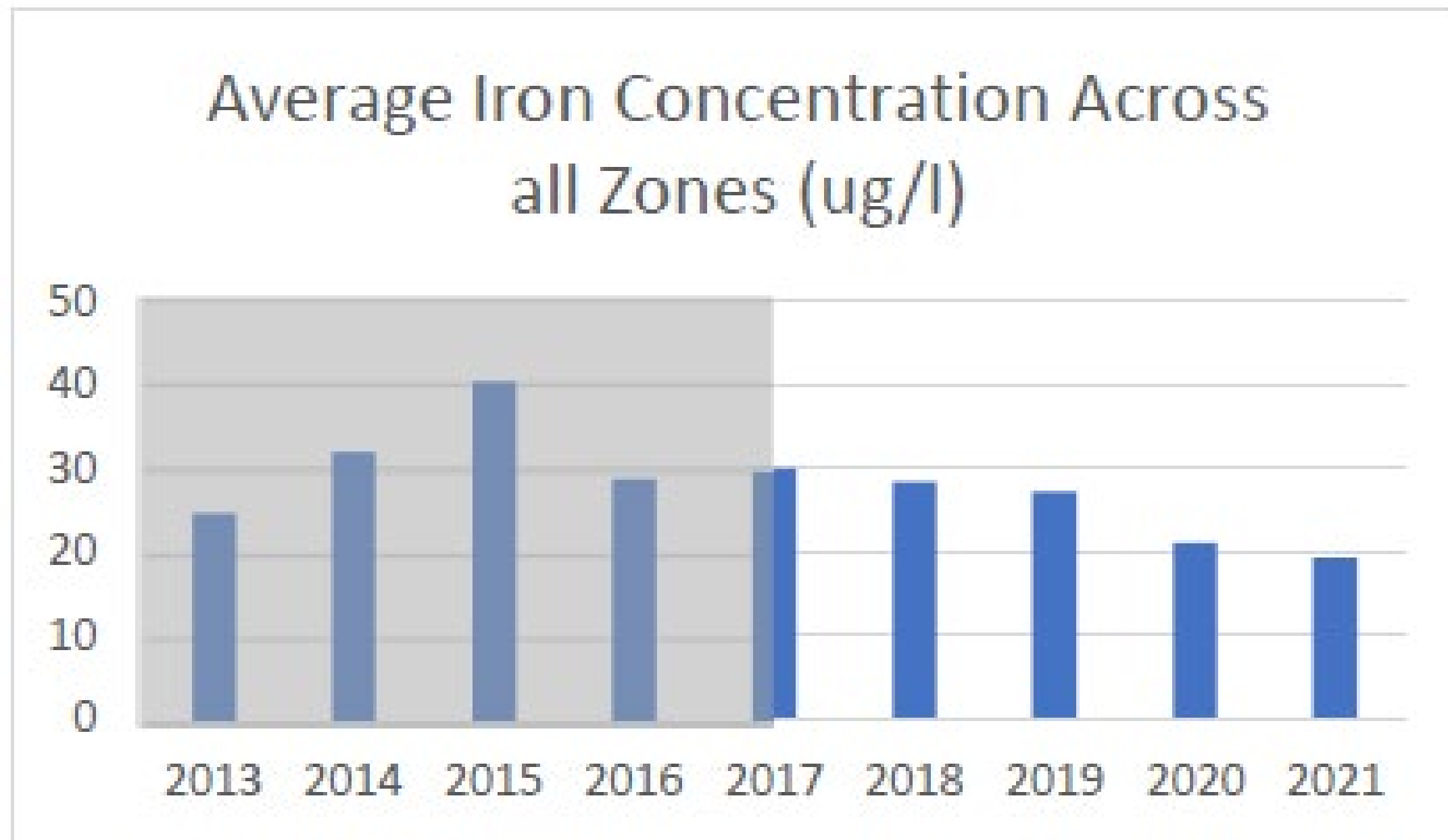
Discussion:

- Overall reduction in complaints; increase in 2020 and 2022 due to iron filter pass-through and water supply issues
- Reduction in max lead results (single value per year)
- Reduction in % of samples > 10 ug / l (avg. 612 samples per year)
- Results achieved with passive dose (possible to optimize based on changing water quality)



Discussion:

- Gradual reduction in iron levels as steel corrosion is reduced
- Average lead numbers slightly reduced
- Samples measured 2 – 3 times per month
 - Iron = 9,688 samples
 - Lead = 5,561 samples
- Both graphs indicate average corrosion for both metals reduced

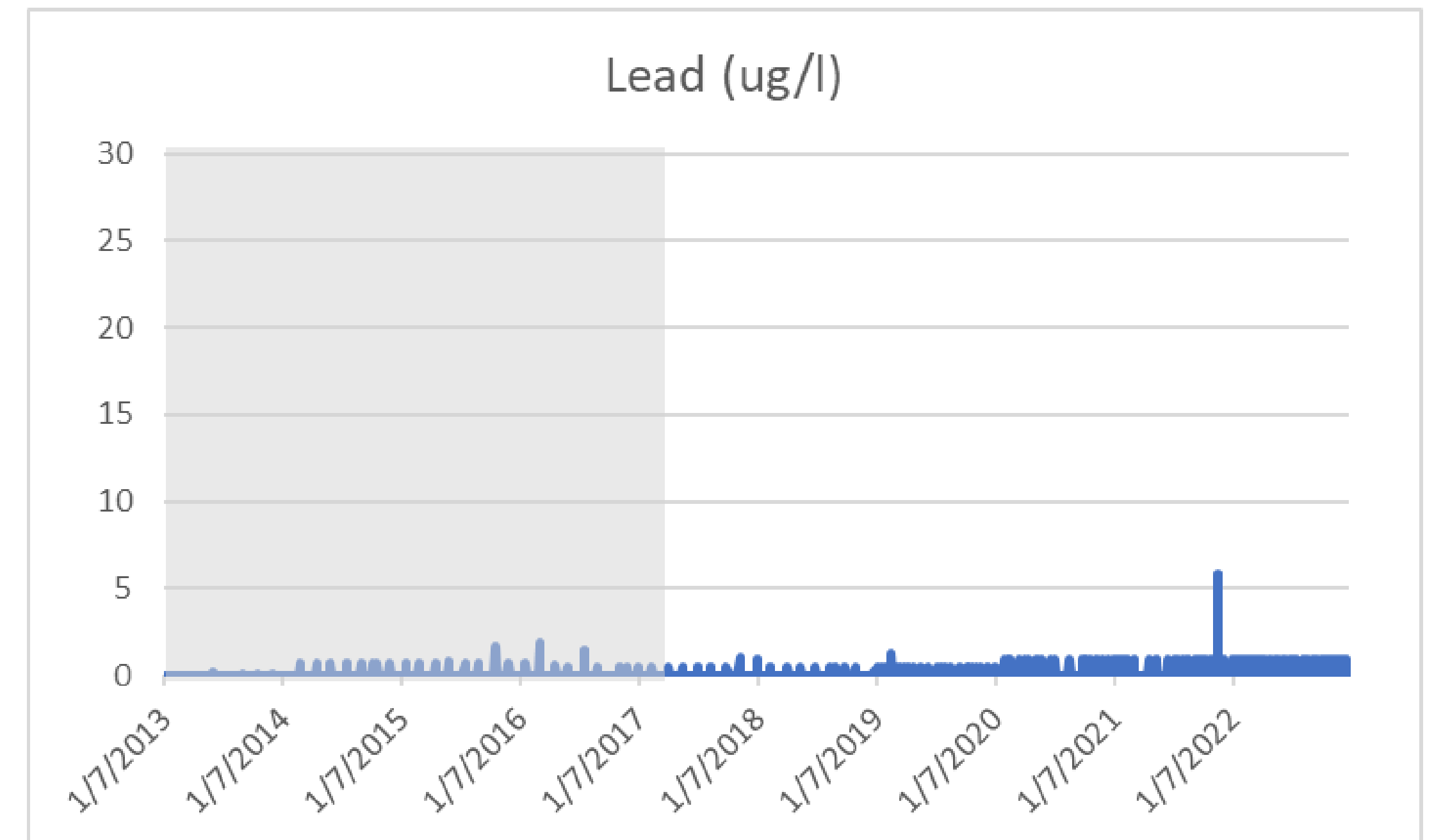
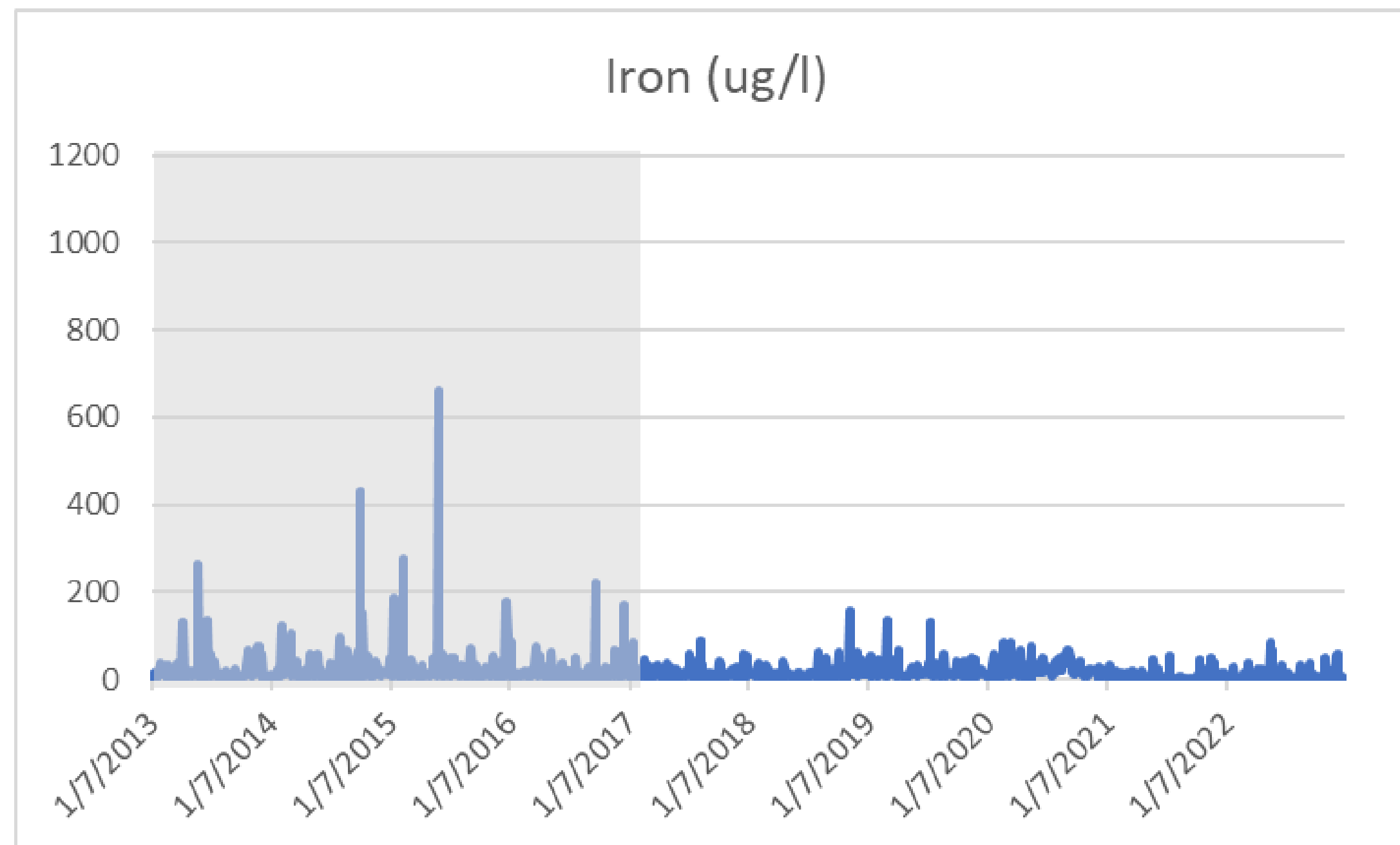
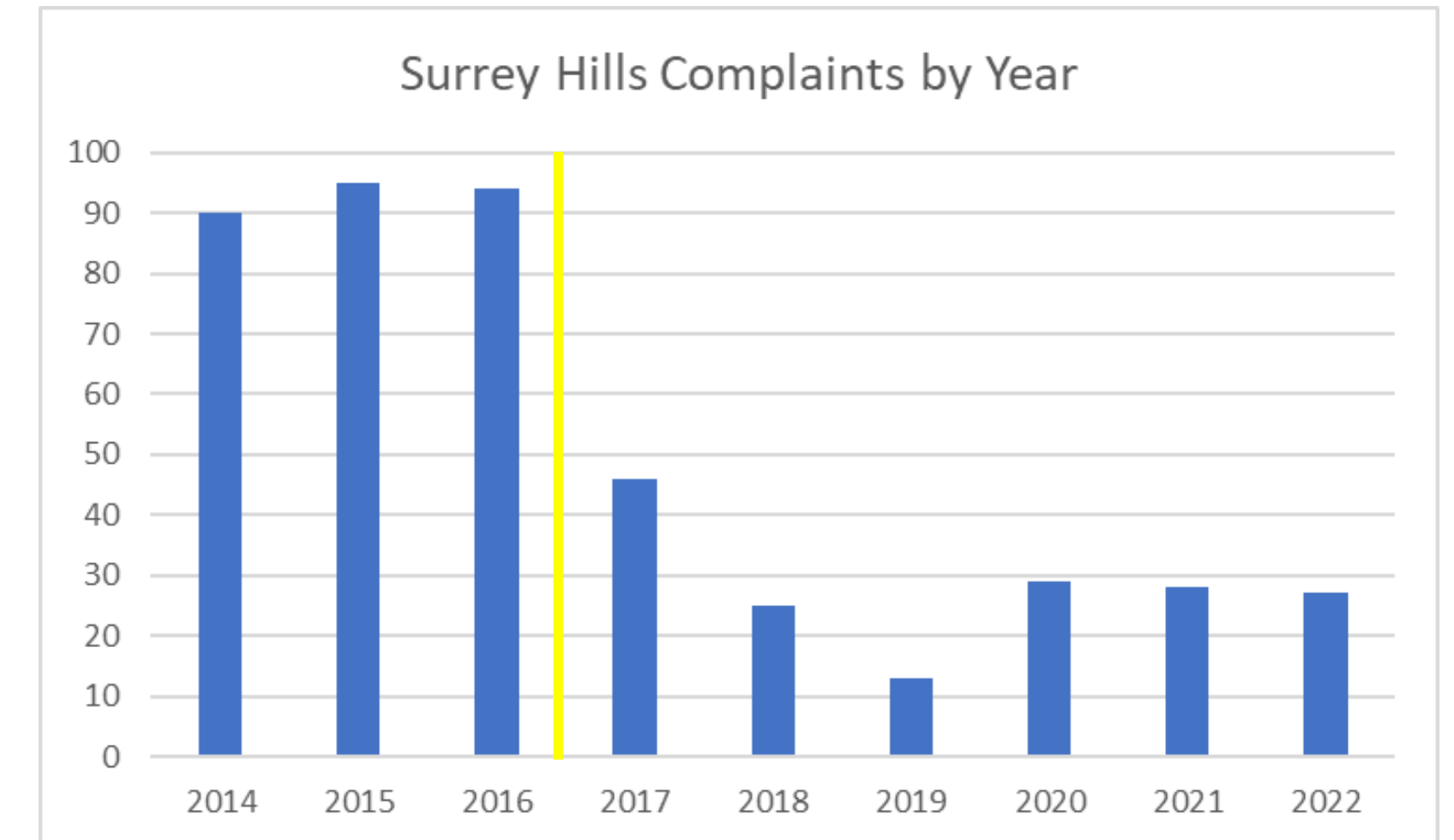


Supplied By:

- Keleher
- Bray Gravel
- Beenham (non)
- Affinity (Non)
- Gray well (non)

SeaQuest Use Started:

- Jan 2017 (Kel.)
- Feb 2017 (Bray)

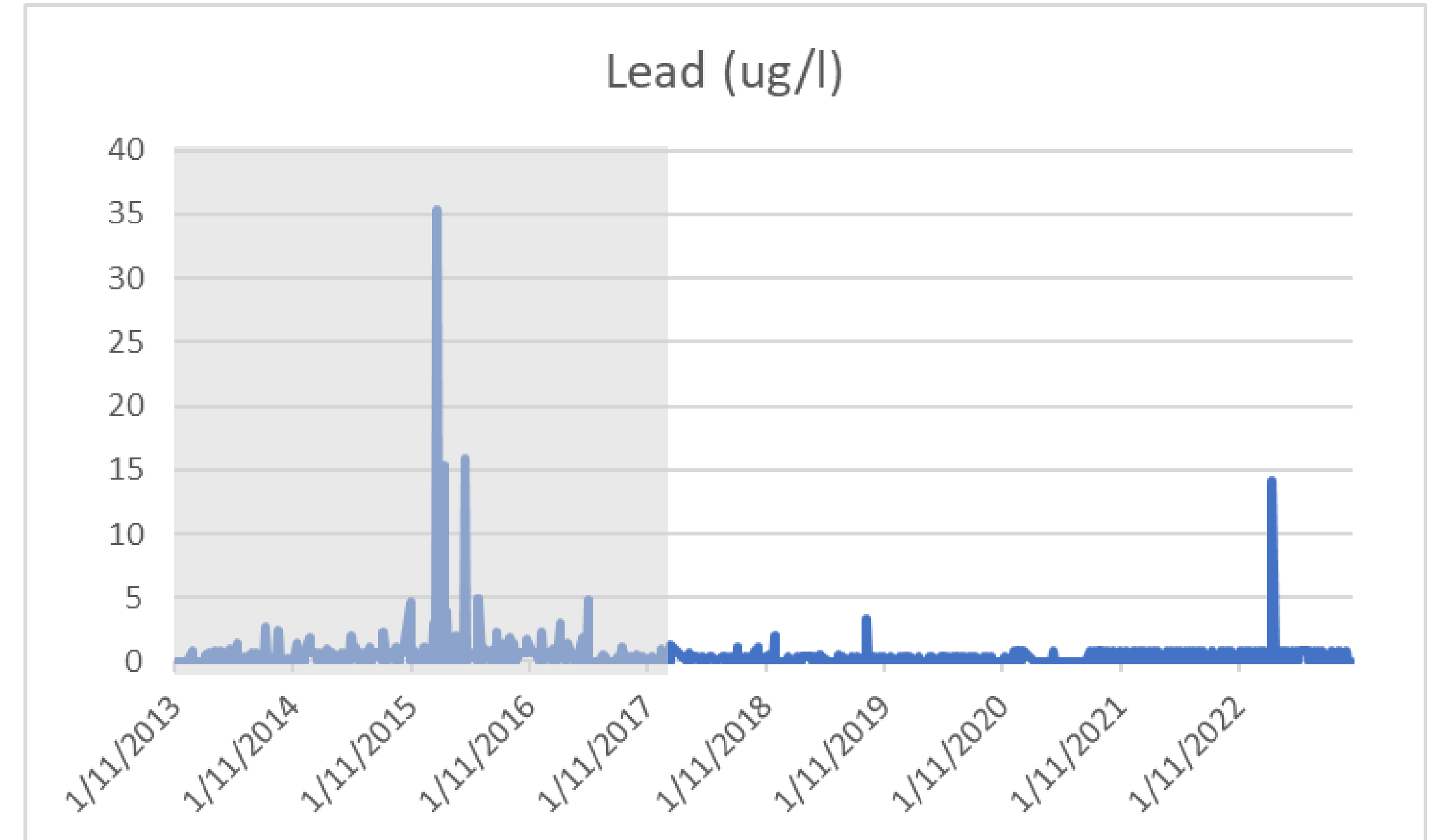
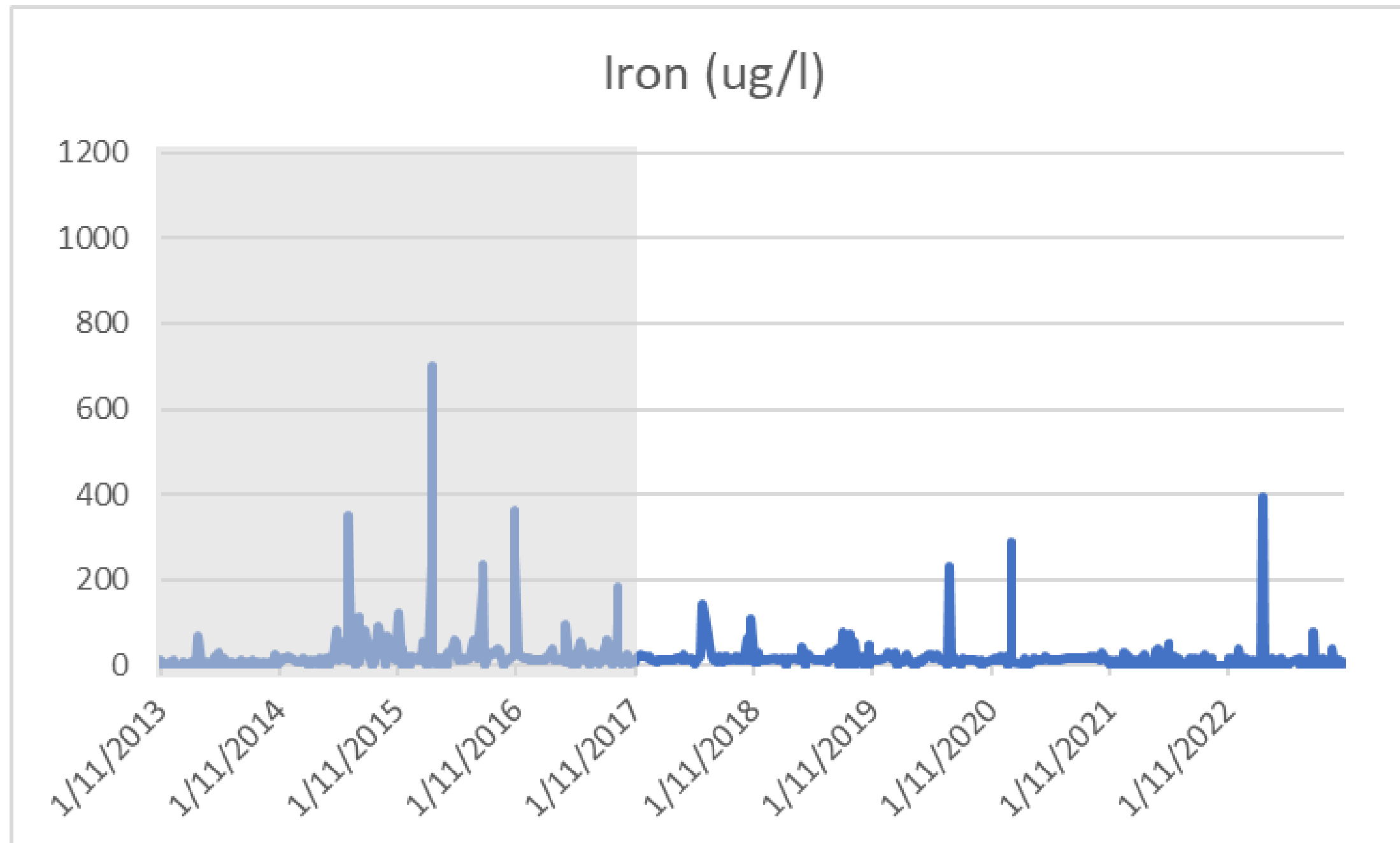
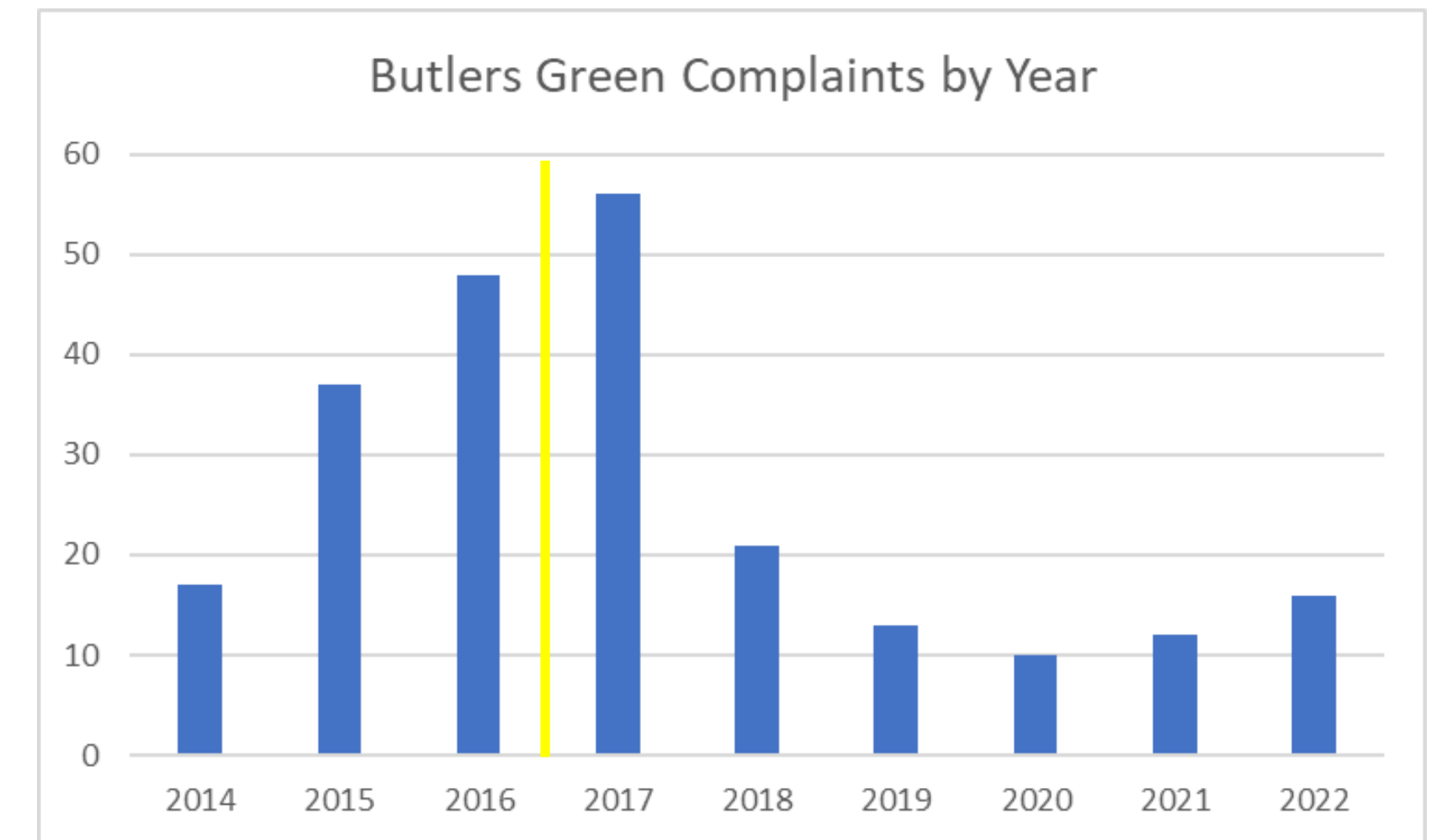


Supplied By:

- Barcombe 1
- Barcombe 2

SeaQuest Use Started:

-Jan 2017



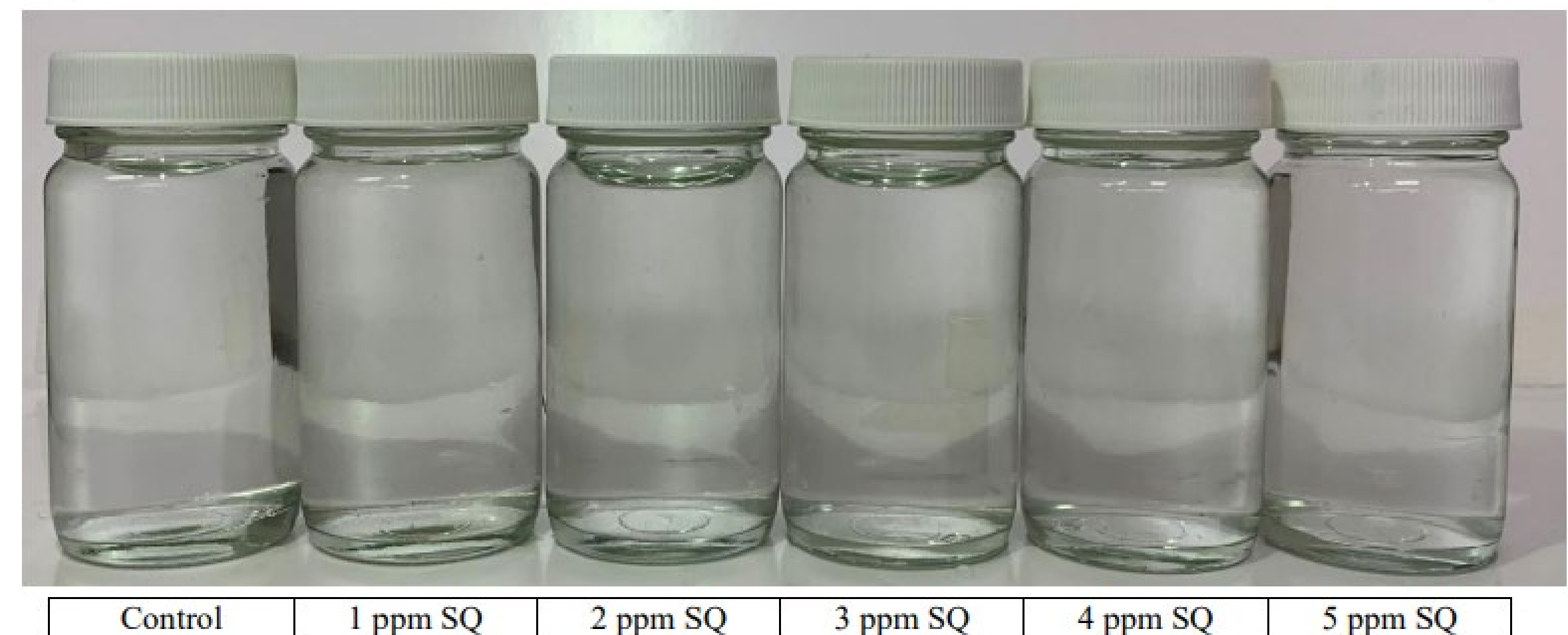
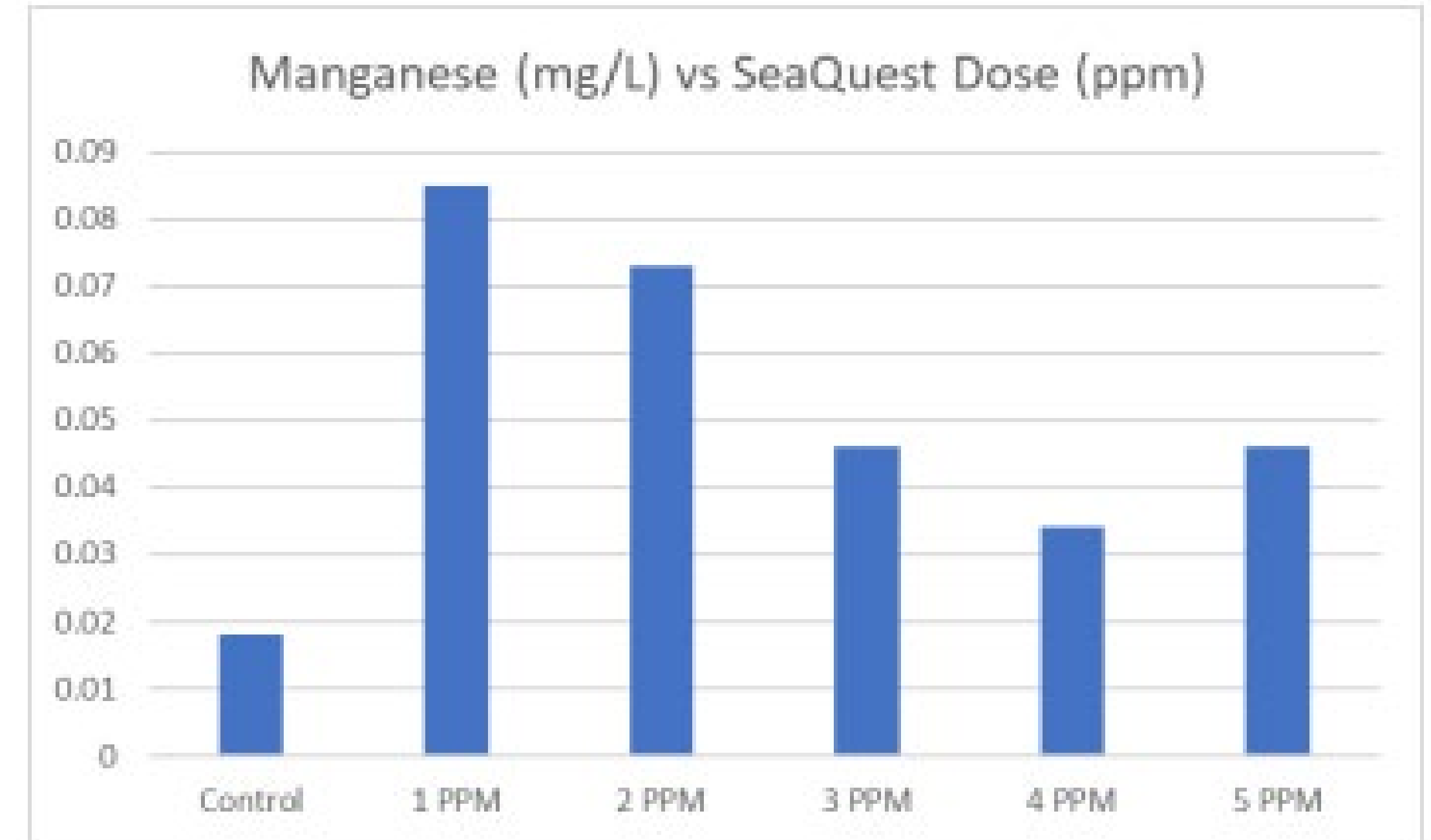


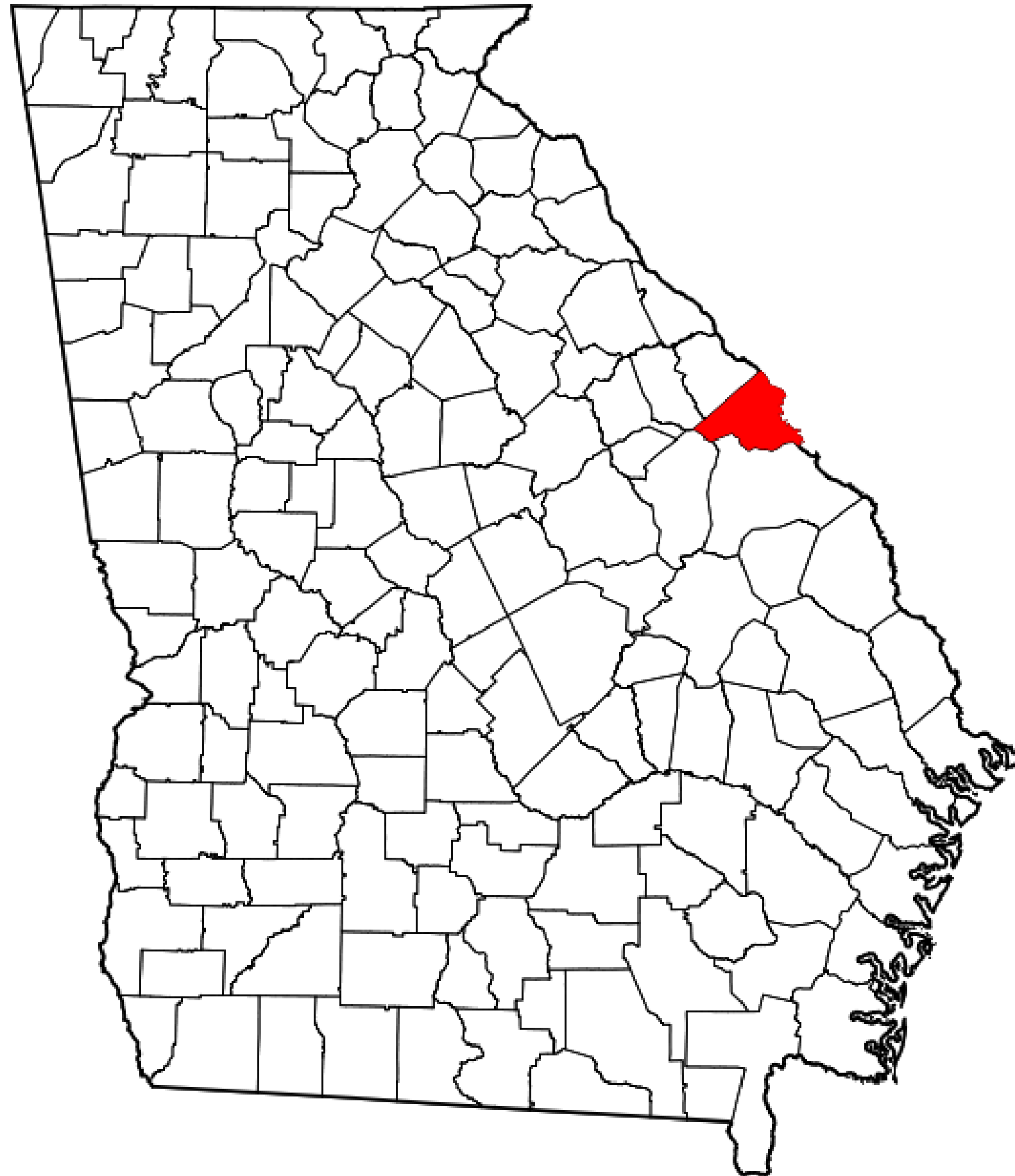
Problem

- Periods of manganese release when the bayou turns over twice per year
- The system is all PVC
- Treatment plant was designed for 0.5 MGD with a demand of 1.2 MGD
- Potassium permanganate used for manganese removal does not achieve complete removal due to minimal residence time

Solution

- Experiment performed to identify the dose of equilibrium blended phosphate required to:
 - Remove manganese deposits from the PVC
 - Keep the manganese soluble
 - Eliminate complaints
- Field trial was performed in Q4 2021
 - Dose rate = 3.0 ppm of equilibrium blended phosphate
 - During the spring bayou changeover black water complaints were eliminated
 - Equilibrium blended phosphate dose is being further reduced to optimize economically





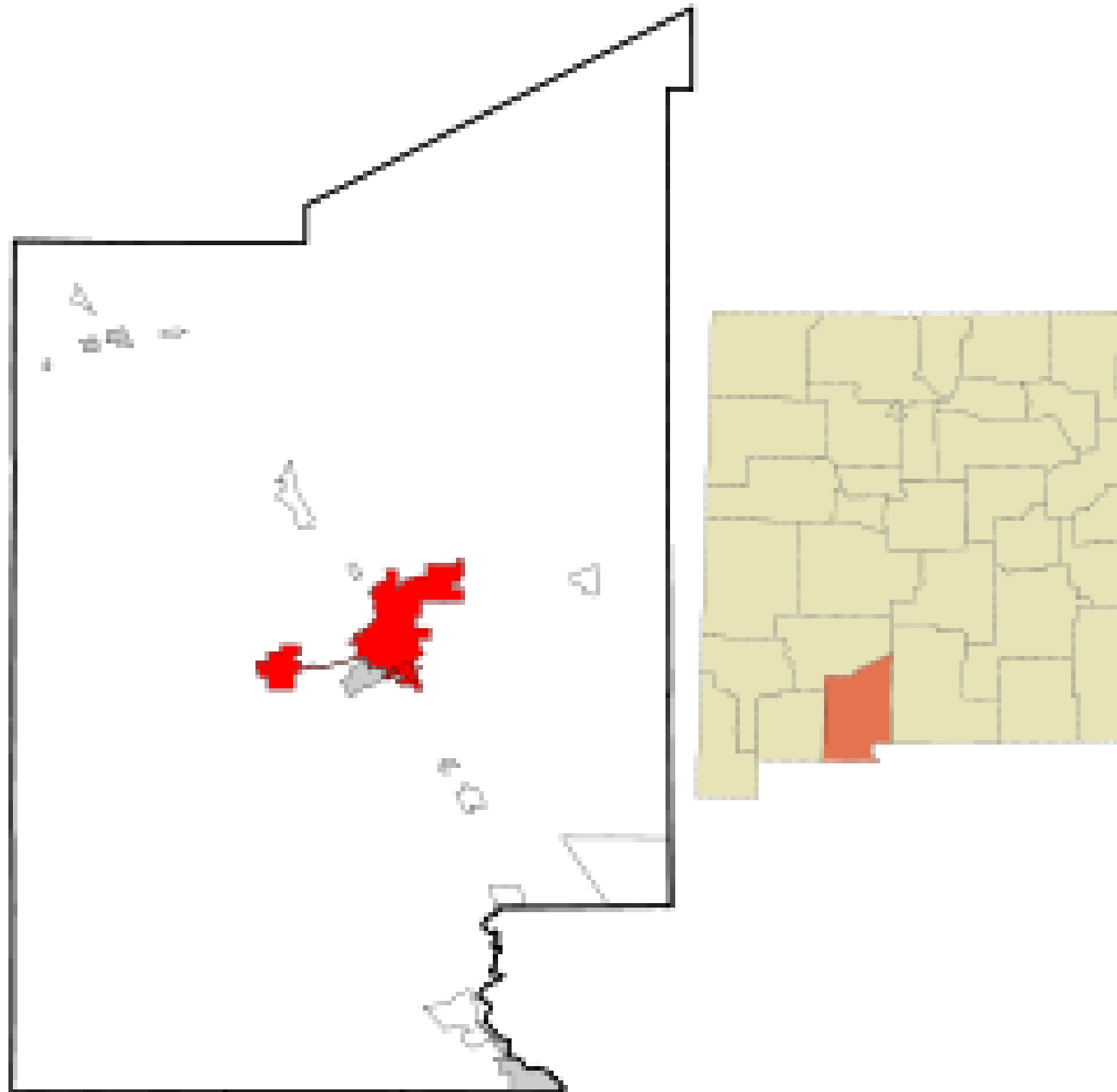
Problem

- Other phosphate-based chemicals were used
- Inconsistent chlorine residuals and finished water pH
- Bids were awarded based on price / pound rather than performance
- Excess chemicals (and cost) were observed
- Substantial red water complaints due to system wide corrosion
- New chemical evaluation protocol was developed to accurately mimic field performance

Solution

- Moved to a performance-based specification with a dose rate guarantee
- Switched to equilibrium blended phosphate
- \$14,000 per year was saved in the ground water plant
- \$55,000 per year was saved in the surface water plant
- All copper and lead tests remain in compliance
- Less pH adjustment was required since the distribution water was more stable
- Less chlorine was used
- Customer complaints were reduced dramatically



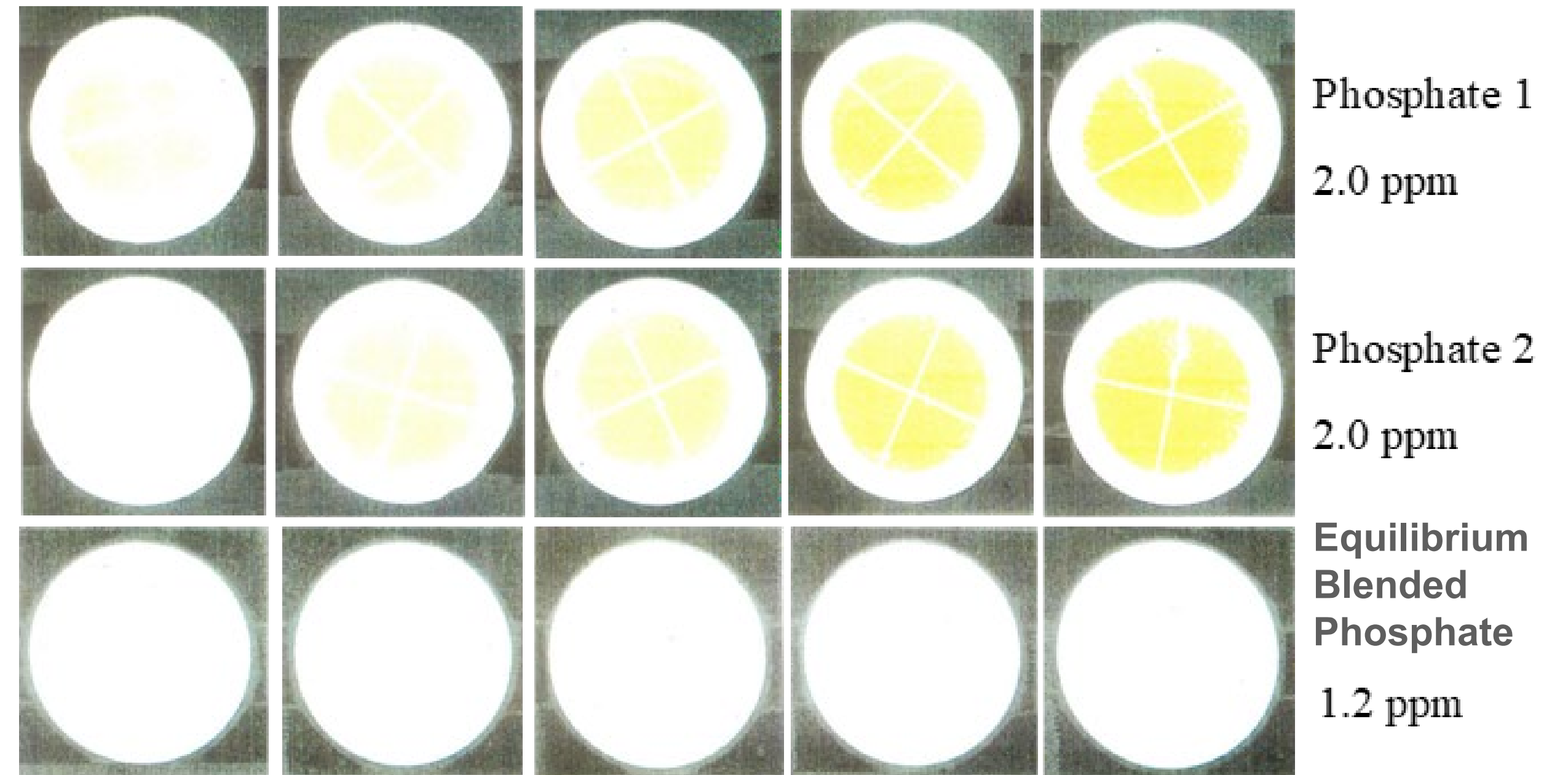


Problem

- High levels of iron / manganese in their source water
- Routinely suffered from dirty water complaints
- ~\$120,000 / year in costs
- Various phosphates were sourced through a traditional bidding process
- Often resulted in over-use and excess cost without reducing the complaints
- New chemical protocol developed to accurately mimic field performance

Solution

- Raw water containing iron and manganese was oxidized before and after the addition of phosphate and then filtered at 0.45-micron
- Failure occurred when a visible amount of iron was observed on the filter pad
- Equilibrium blended phosphate was selected for use vs traditional blended phosphates
- Selection based on highest performance and lowest use cost
 - Within one-year complaints were reduced from ~800 to ~75
 - The amount of equilibrium blended phosphate needed did not increase from the original dose
 - ~10,000 less man hours were spent flushing



Filter pads from 1hr to 5 hrs showing iron oxidation and sequestration

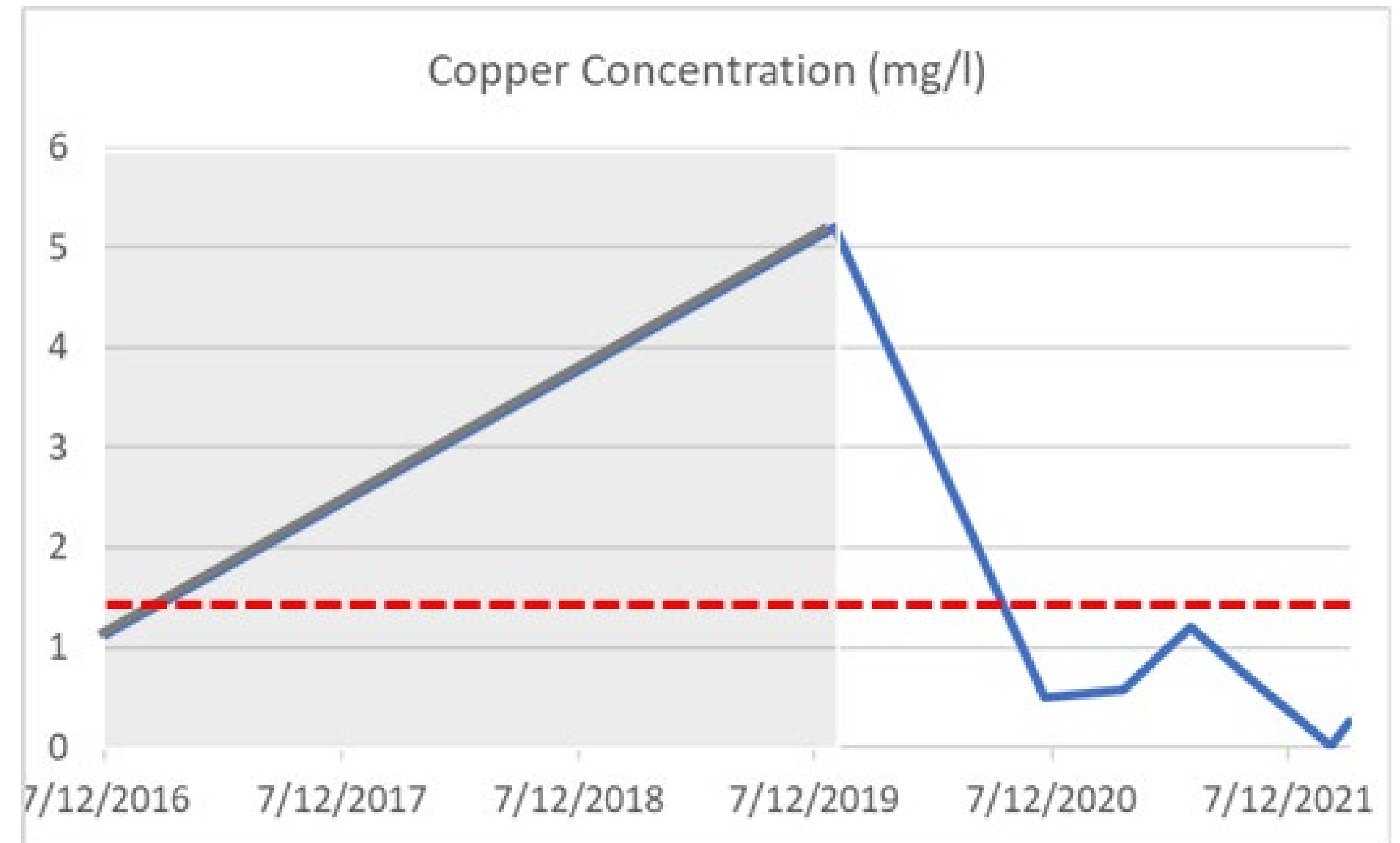


The Problem:

- A former orphanage was repurposed to a DFACS shelter for families fleeing violence
- The facility experienced periods of neglect which resulted in inconsistent water treatment
- Several lead and copper exceedances occurred from 1995-2016
- In 2019 the 90th percentile copper measured 5.2 mg/l and lead measured 15 ug/l
- During an inspection DFACS noted the blue/green staining of sinks and bathtubs

The Solution:

- A new contract operator took over the facility to gain control of the water
- Chlorine was stabilized and equilibrium blended phosphate was installed for corrosion control
- Due to small size of system installing liquid caustic was deemed too dangerous
- pH of the water ranged from 6.7 – 7.1
- After installing equilibrium blended phosphate:
 - Copper corrosion was immediately controlled
 - Copper levels were reduced from 5.2 mg/l to 0.5 mg/l
 - Lead levels were reduced from 15 ug/l to 0 ug/l
 - The facility is now fully compliant with all regulations





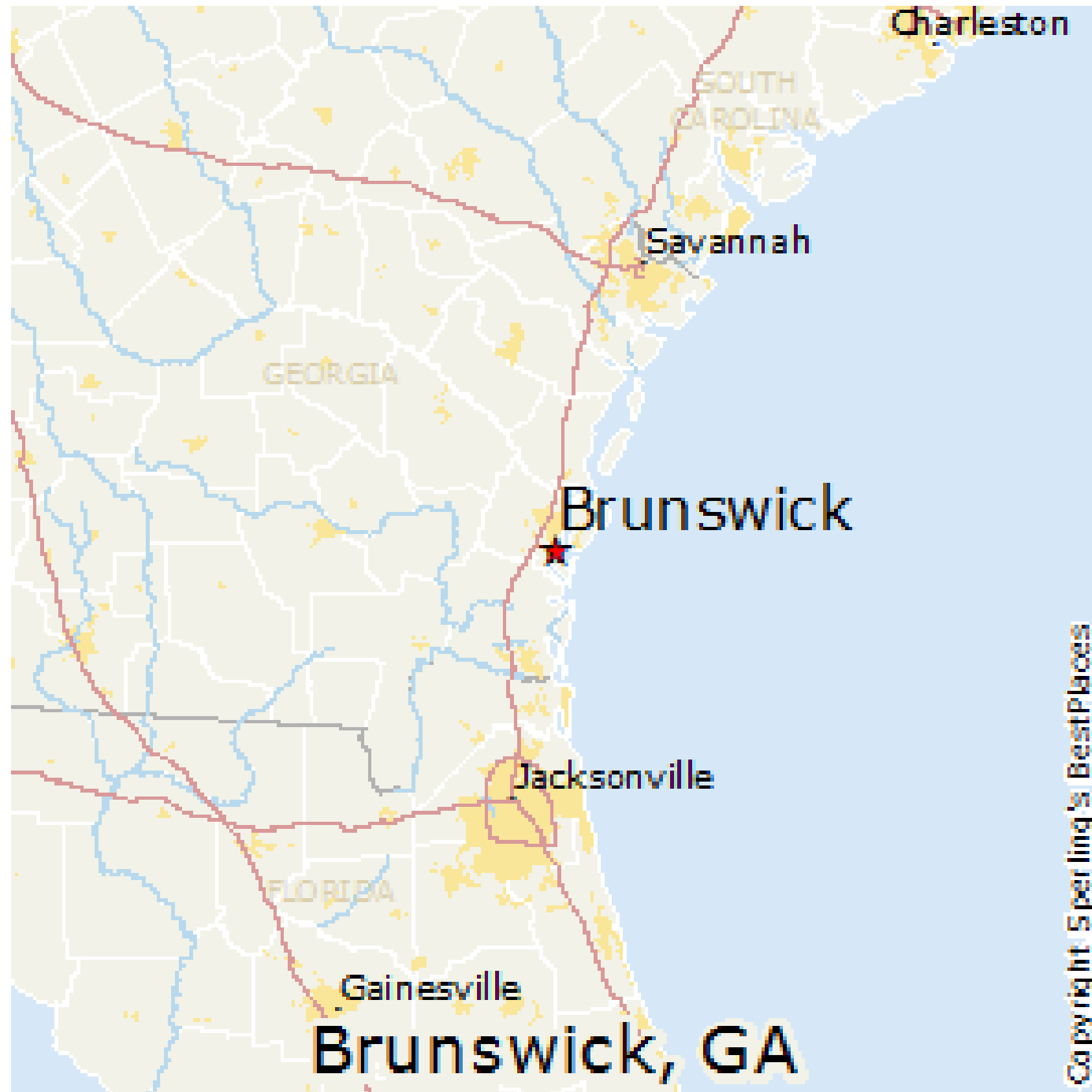
Problem

- Surface water plant built in 1904
- 100-year-old cast iron pipes in distribution system
- Experienced scale buildup throughout distribution system

Solution

- Started using equilibrium blended phosphate in 2004
- Pipe was cut out in May of 2004 as reference
- Comparison pipe was cut out in May of 2009
- Pipe opening improved 300%
- Chlorine usage reduced 29%
- Flushing reduced by 50%
- Flushing staff required reduced by 50%
- Flushing uses 66% less water





Problem

- Used several different types of traditional blended phosphates over 15-year period
- A 50-year-old 4" pipe was clogged to $\frac{3}{4}$ "
- Flow rates were down to 40 – 50 gpm
- Office received 2 calls each month about red water
- Began using equilibrium blended phosphate in 2009
- Pipes were pulled in May 2009, 2010, & 2011

2009



2010



2011

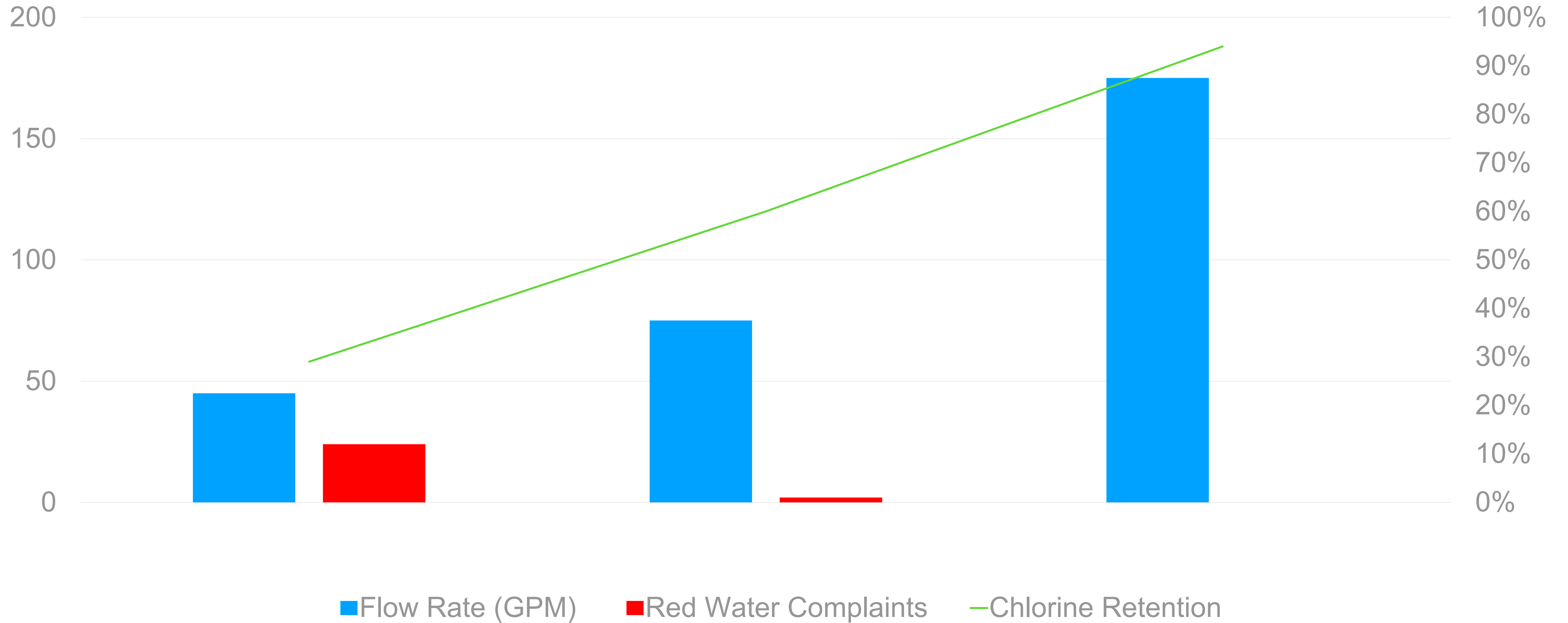


Year 1

- Flow rate improved nearly 100%
- Red water complaints dropped to 2 per year (from 2 per month)

Year 2

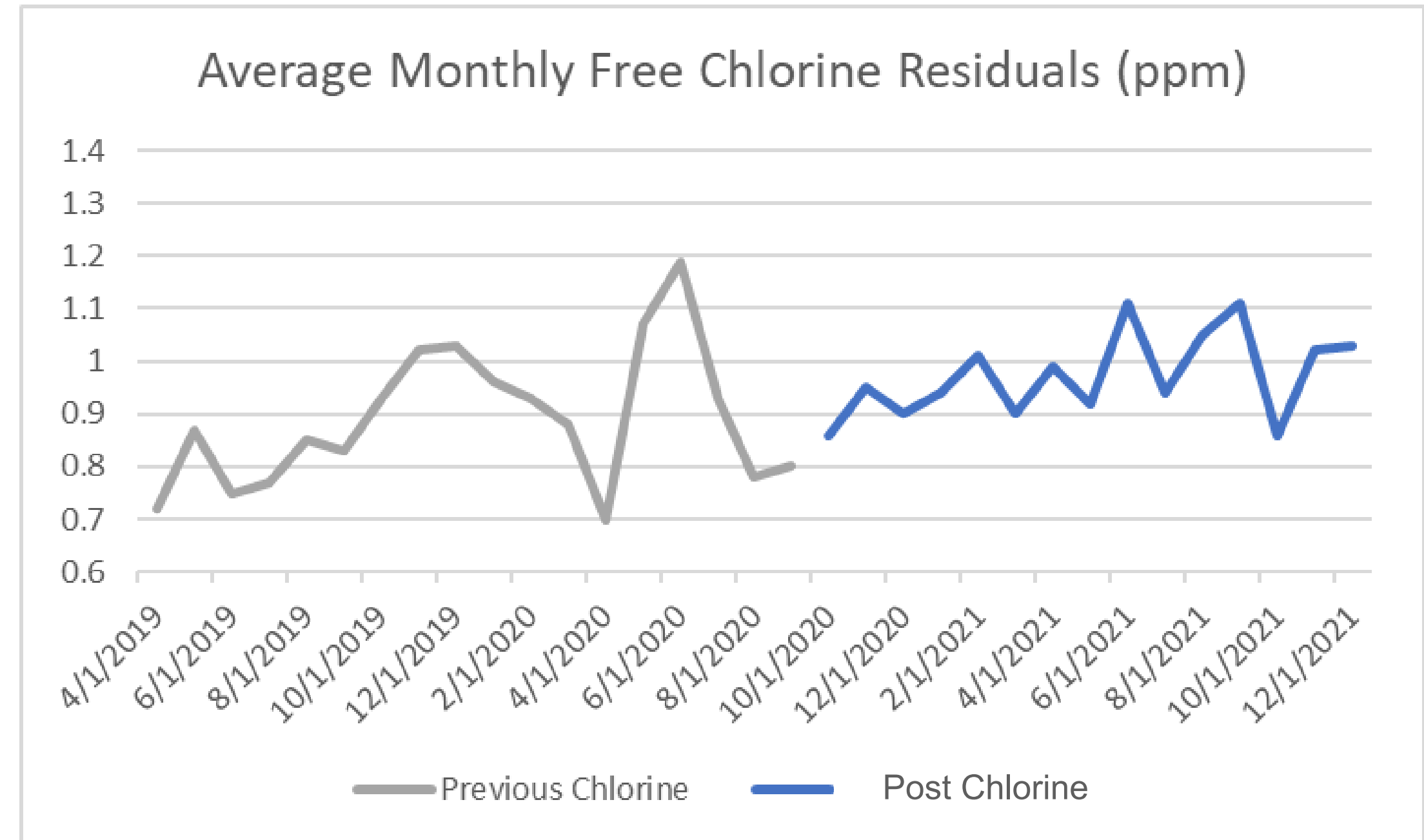
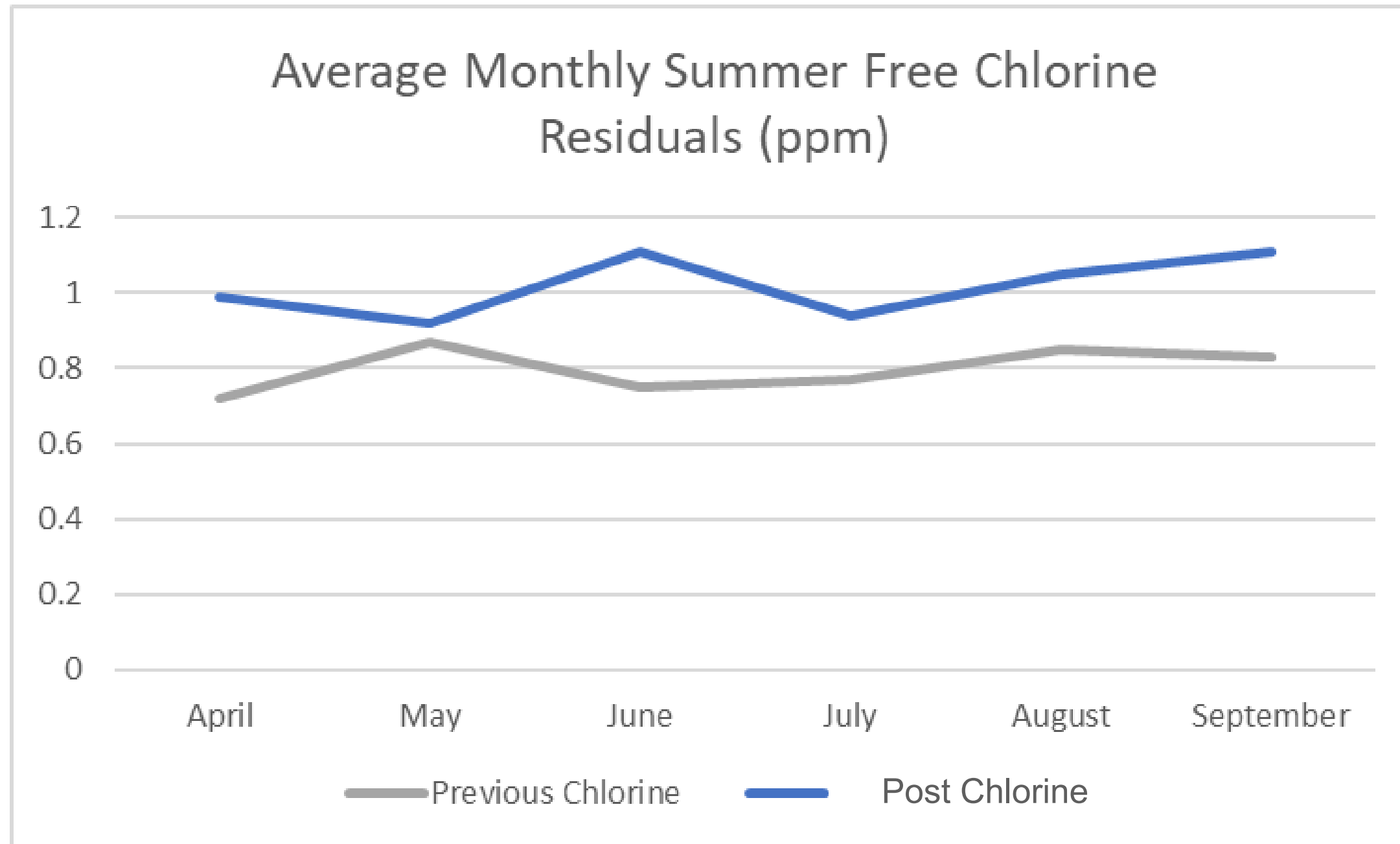
- Flow rate improved 400%
- Chlorine usage dropped 33%
- Chlorine residuals more than doubled. Red water complaints stopped (zero calls)





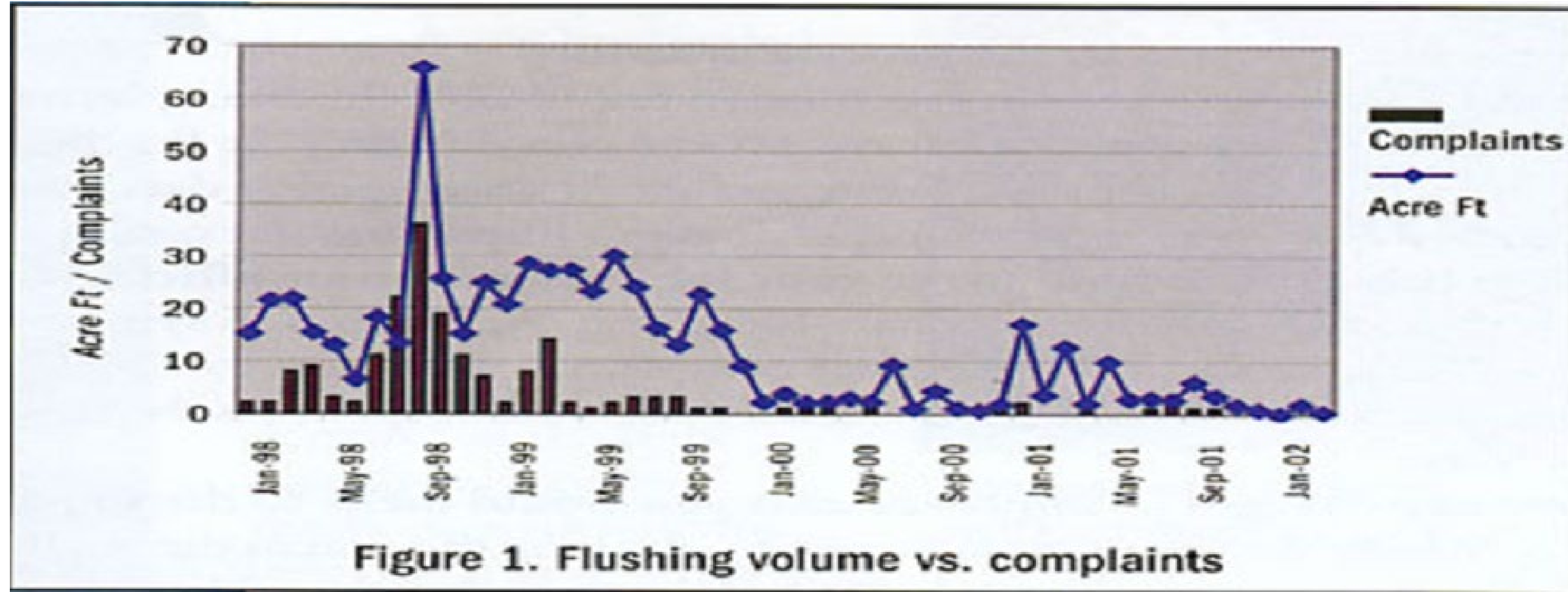
Problem

- Was using traditional blended phosphates
- Plant averaged 0.4 MGD of production
- The finished water pH is 7.3
- Was having issues maintaining consistent chlorine residuals in the distribution system
- Was also having issues maintaining a consistent phosphate dosing
- Summer months were particularly challenging due to higher bacterial loads



Solution

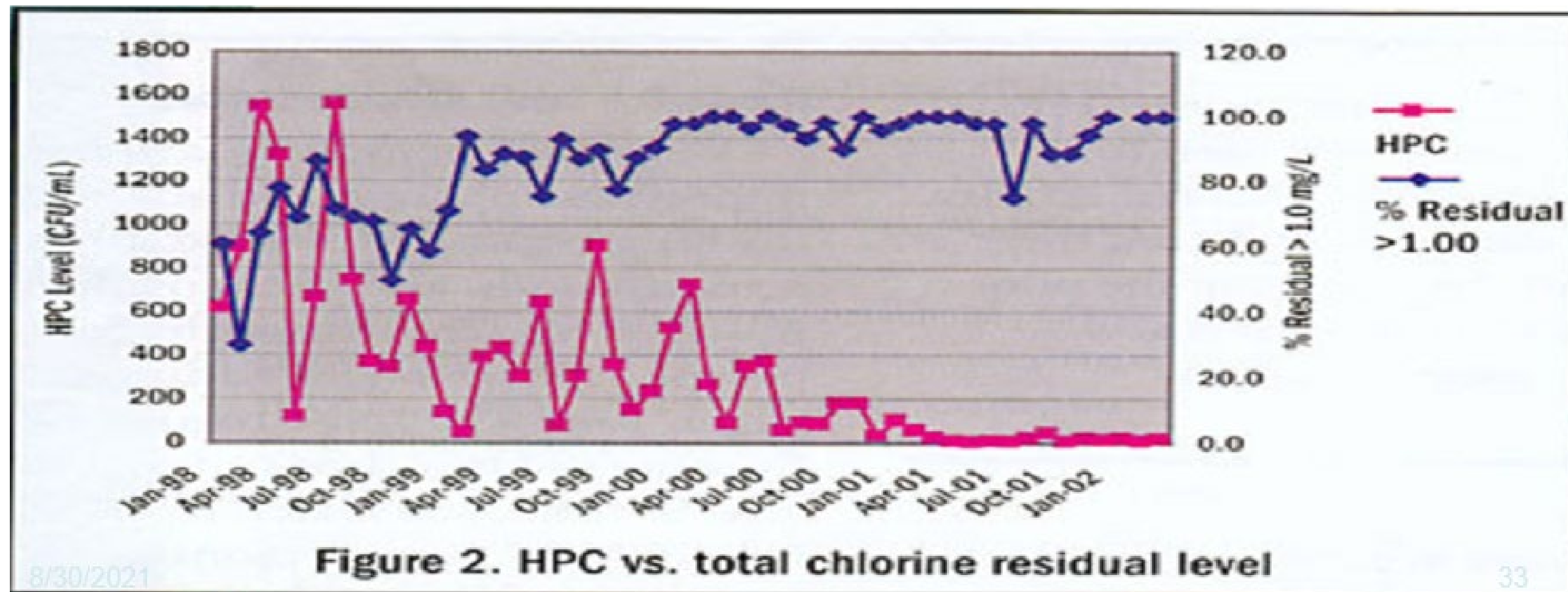
- Switched to an equilibrium blended phosphate October 2020
- MOR data was reviewed and summarized
- An overall 10% increase in average free chlorine residuals in the distribution system
- An overall 16% increase in average free chlorine residuals in the distribution system in the summer months from April to September
- A 74% improvement in the consistency of product quality



Summary:

A large utility in California was facing significant biofouling complaints and had to flush extensively.

They switched to equilibrium blended phosphate, and both the flushing program and complaints were reduced.



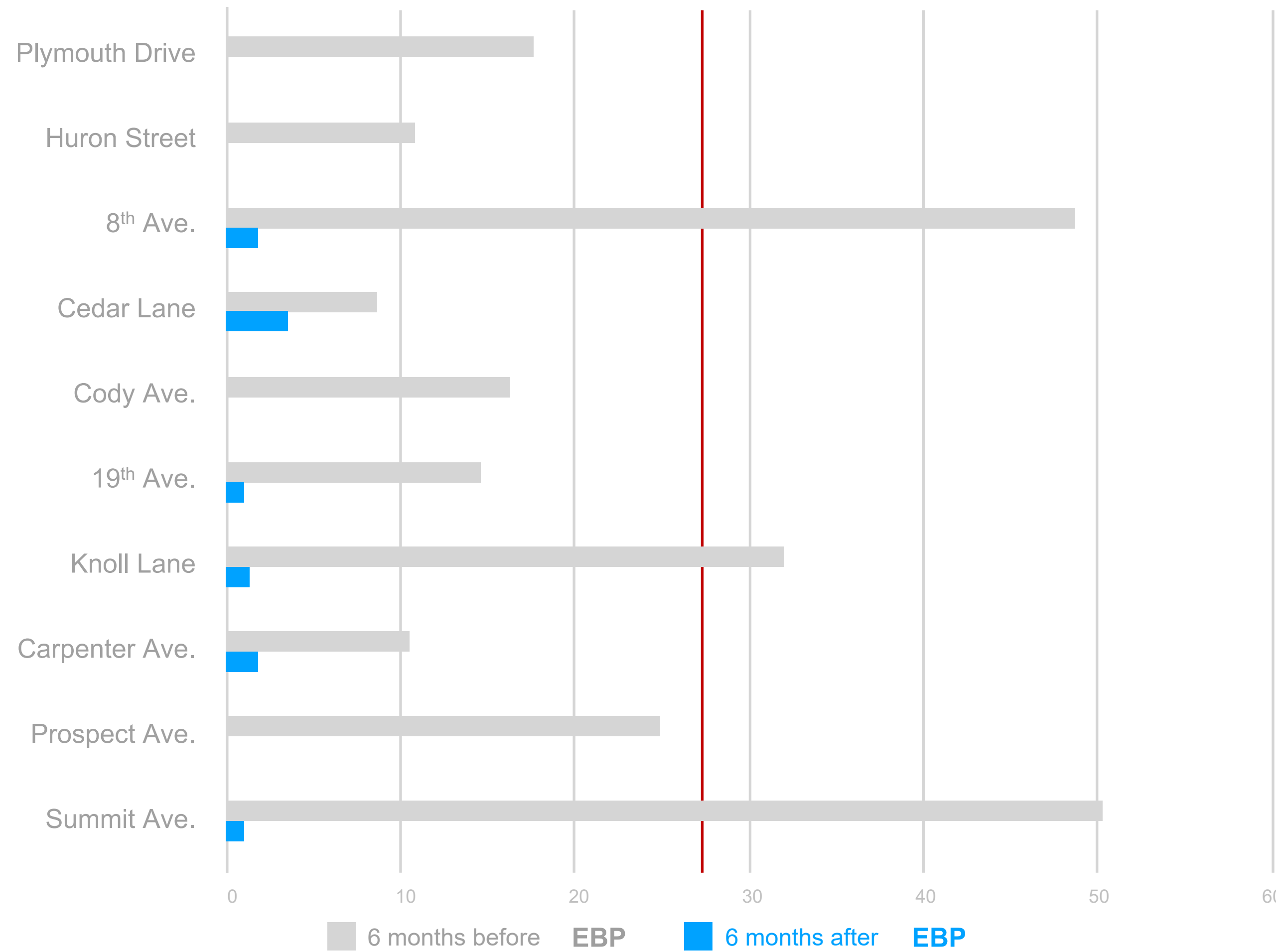
With equilibrium blended phosphate, chlorine residual in distribution was able to build consistently, which reduced HPCs, biofouling and black water.



Background:

- Compliance issues resulted in NY DEP forcing a review and change to CCT
- Previous treatment 3.0 ppm sodium hexametaphosphate + pH increase
- The lead results achieved were dangerously close to violation levels
- 90th percentile lead results were 14.7 ppb
- A single additional location >15 ppb would result in an exceedance
- Reviewed top 10 highest lead locations equilibrium blended phosphate before and after
- 2 locations had lead service lines which were not replaced

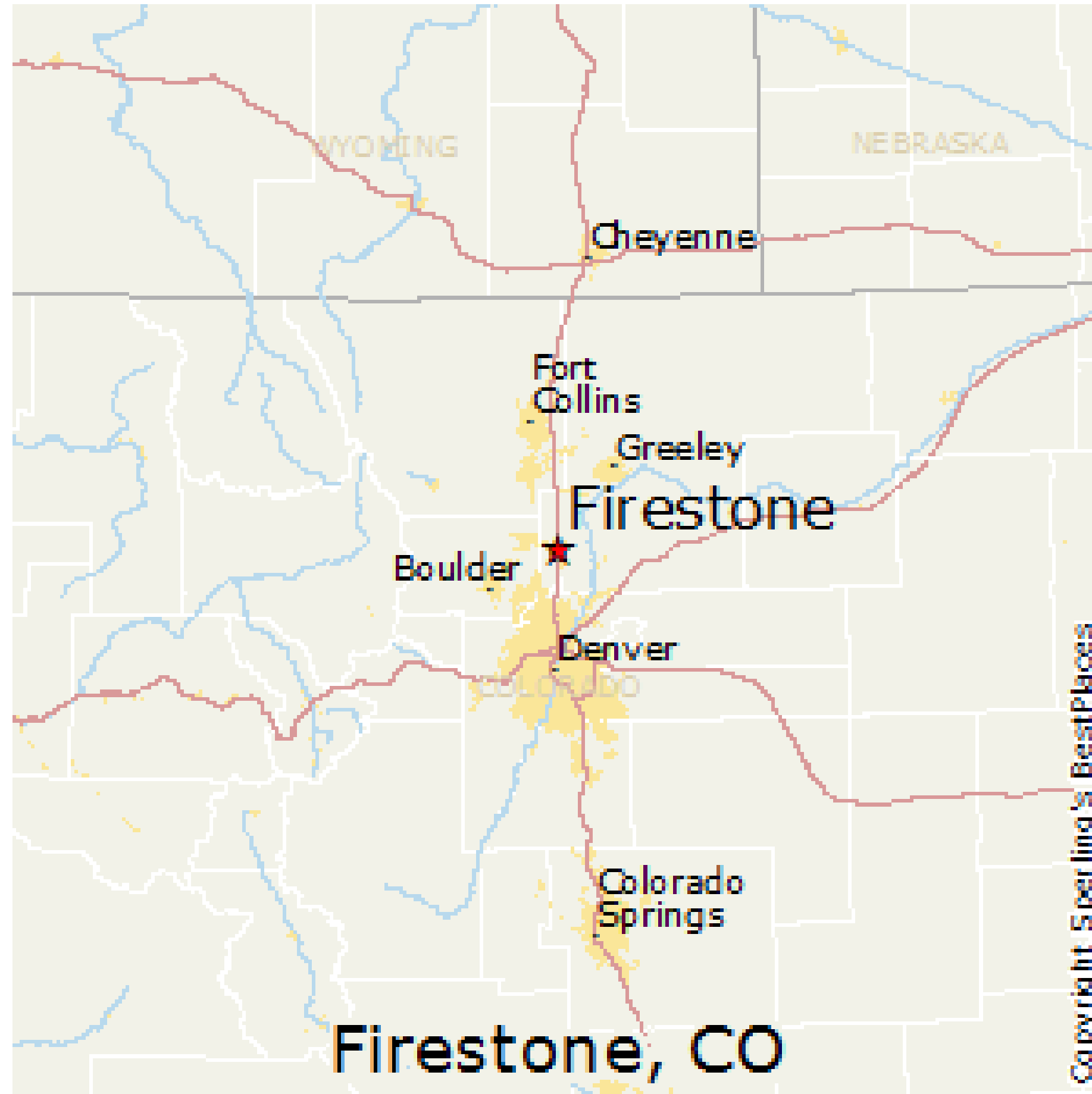
Top ten highest lead locations in Sea Cliff, NY (ppb)



Solution:

- Zero red water events
- 90th percentile lead results reduced from 14.7 to 1.2 ppb
- Zero locations exceeded copper
- 75% cost reduction switching to equilibrium blended phosphate

Firestone, CO was on track to be the next Flint, MI

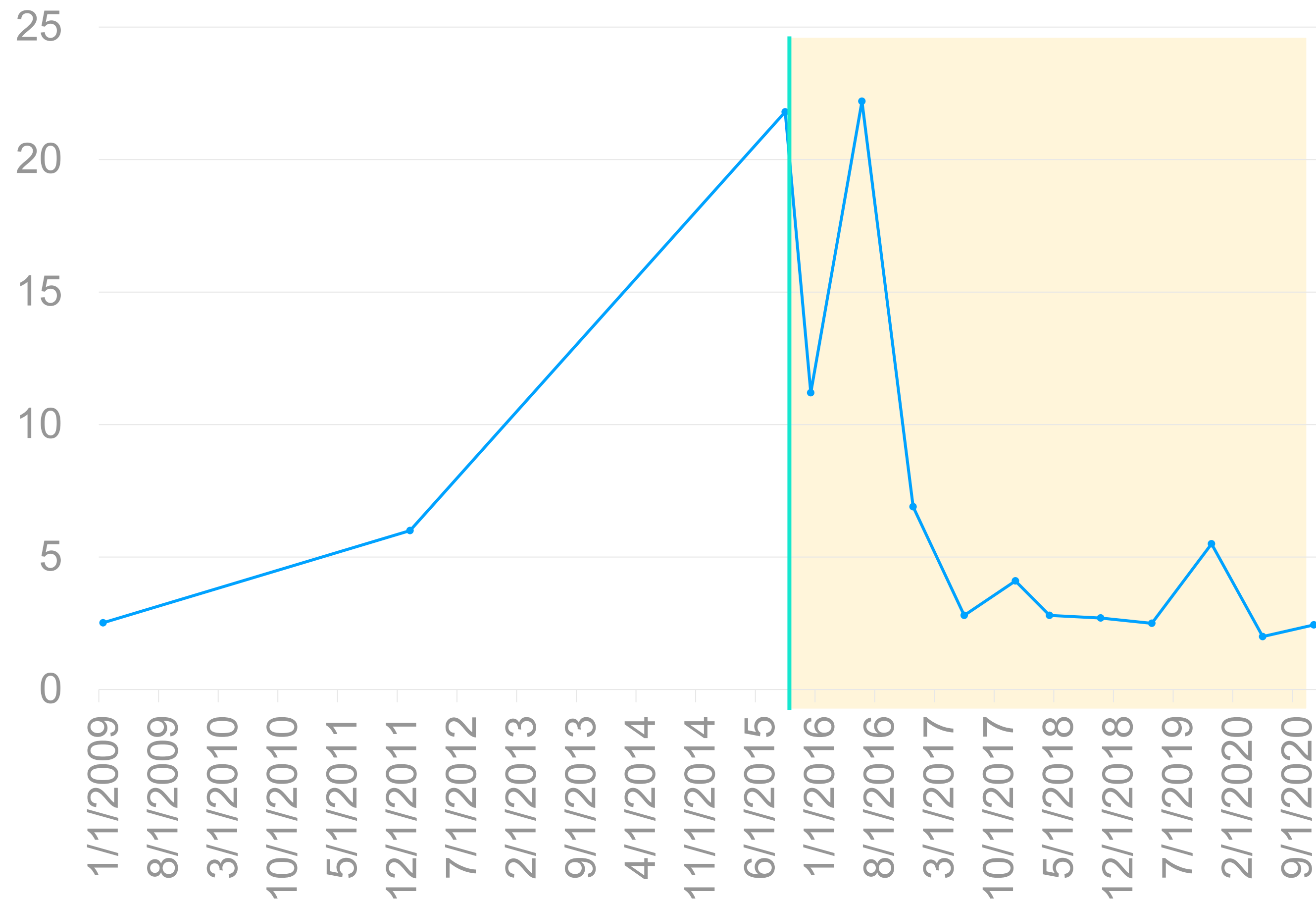


Background:

- Experienced a lead spike of 23 ppb
- Event was covered in the USA Today in 2016
- 40 homes were tested built in 1985
- July 2015: 11 tested > 15 ppb
- System needed to be installed to inject equilibrium blended phosphate

Firestone, CO was on track to be the next Flint, MI

Lead Concentration over Time (ppb)



Solution

- By December 2015, 6 out of 40 homes tested >15 ppb
- Increased monitoring confirmed a continual reduction in lead release
- By January 2019, all 40 homes tested below 15 ppb

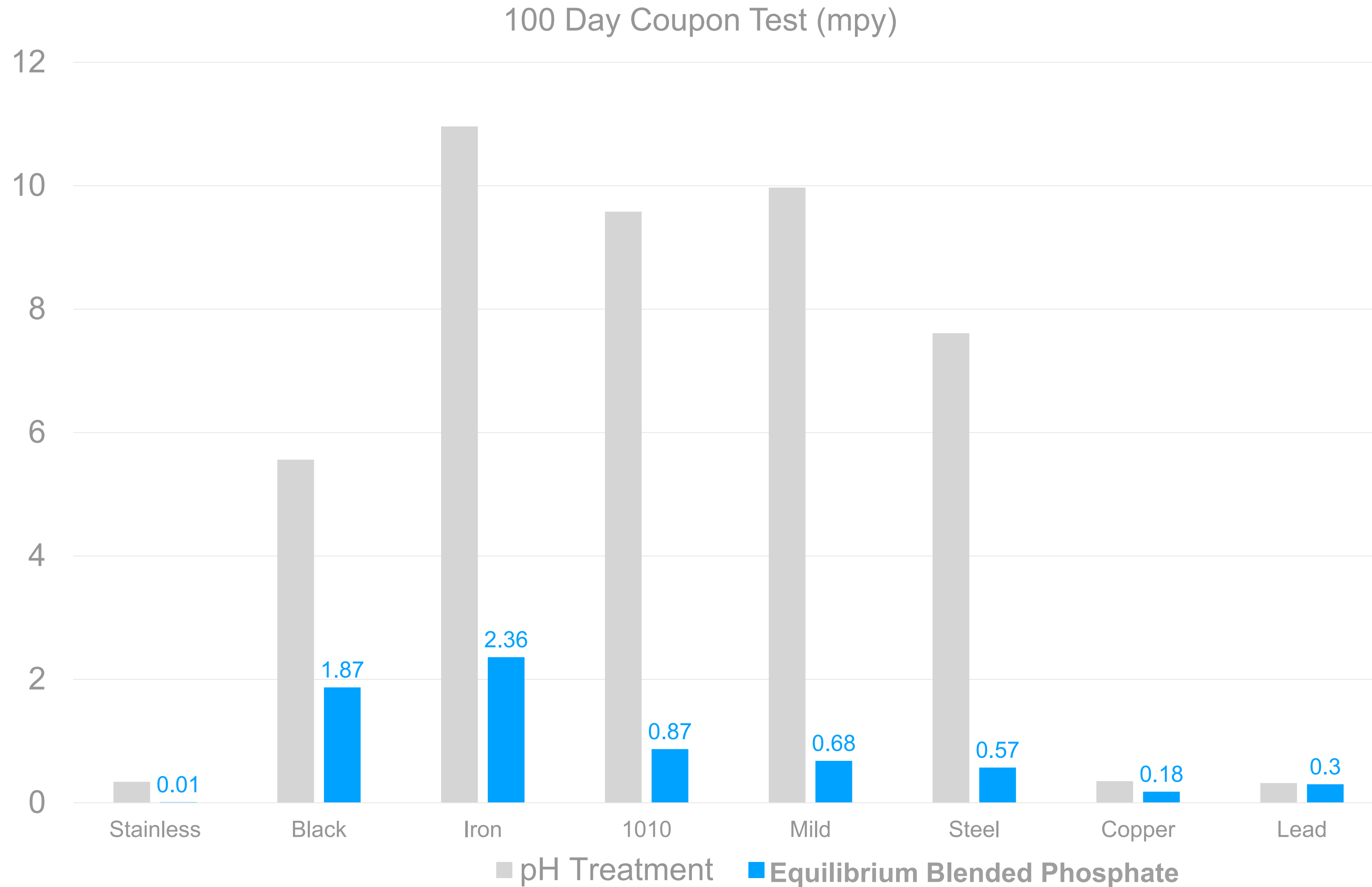
“You know Flint was a disaster all the way around. There’s many other ways to deal with that issue in a safe and proactive way. And our water providers in our region are doing that.”

- Tom Cech,
M.S.U Denver One World One Water
Center

SEAQUEST

Lead Data

Example Corrosion Coupon Study

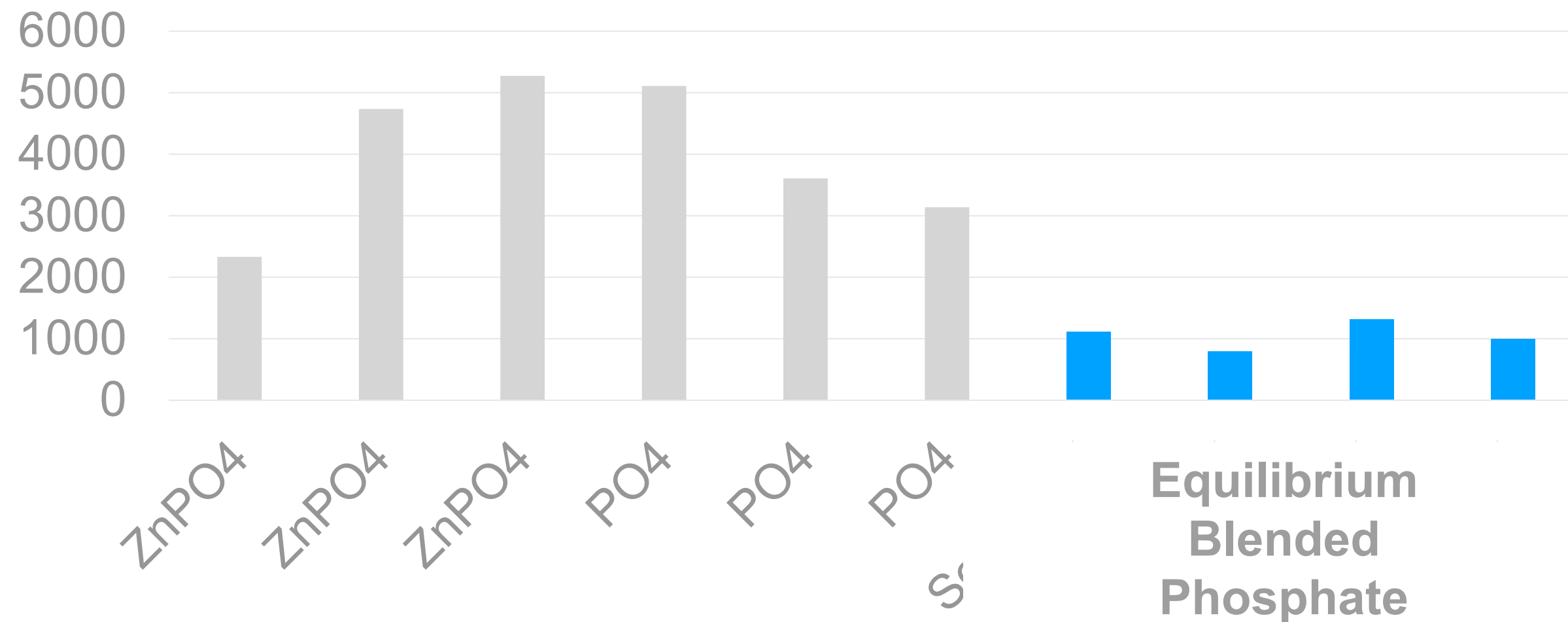


Equilibrium Blended Phosphate performs well in corrosion coupon studies.

In the proposed lead/copper rule, these studies can be used instead of a full pipe loop in certain areas to justify CCT changes.

17 Day Coupon Soak Test

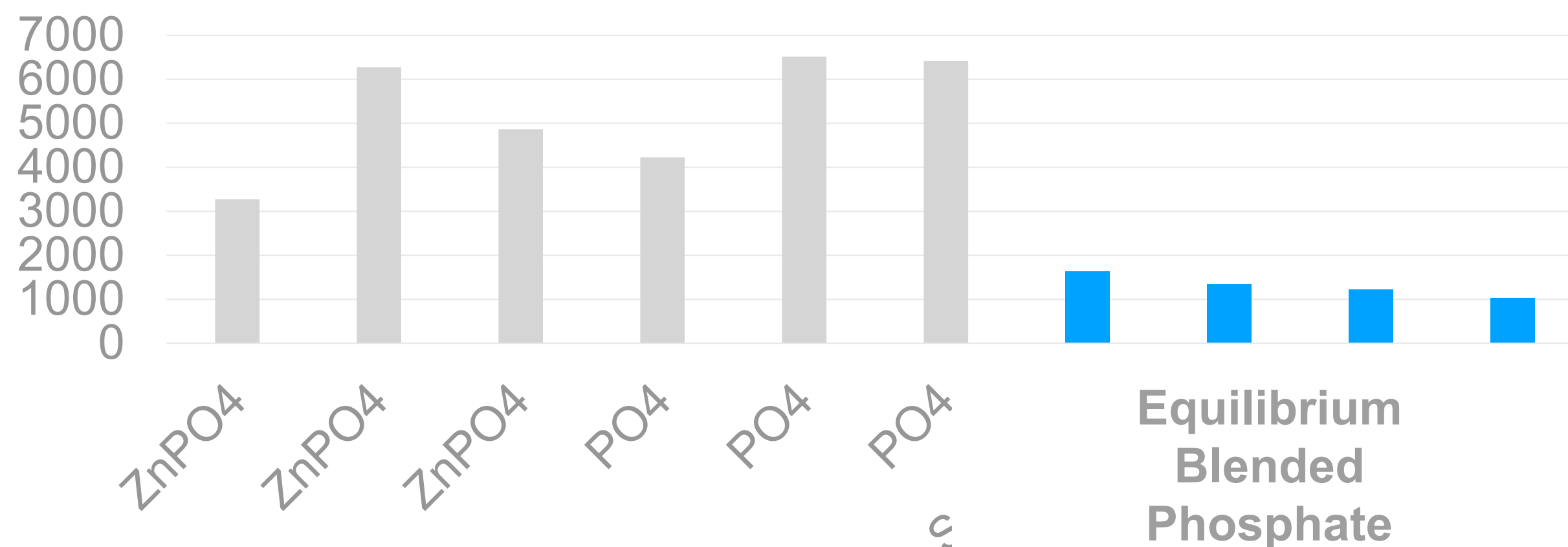
Lead (ug/l) at pH 7.6



Equilibrium Blended Phosphate performs well in soaked coupon tests, which are more aggressive than standard coupon tests.

In this test, the Equilibrium Blended Phosphate shows better control of lead leaching than orthophosphate and zinc orthophosphate.

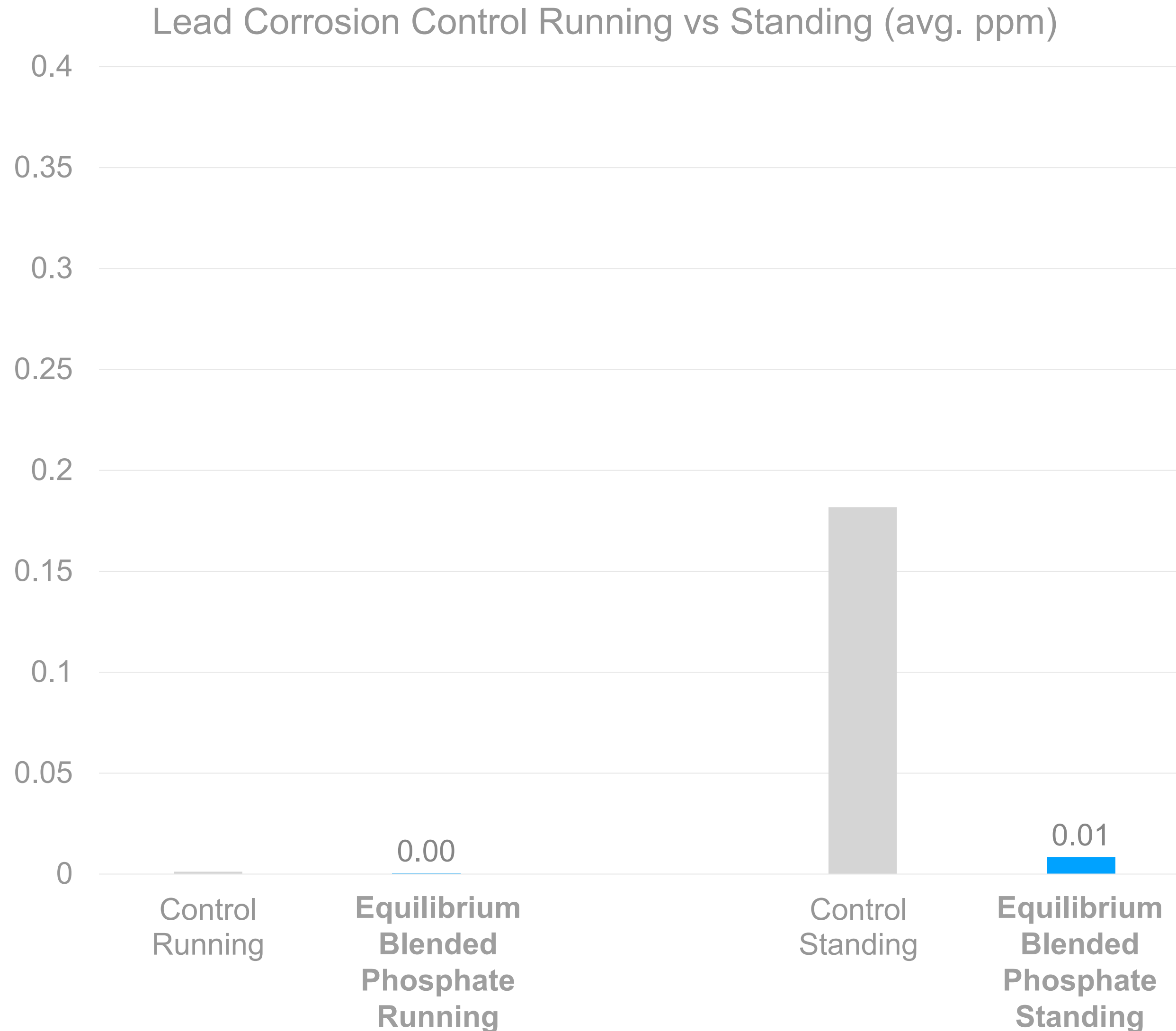
Lead (ug/l) at pH 7.1



The doses range from 0.5-2.0 mg/l for the orthophosphates and 0.5-5.0 mg/l for the Equilibrium Blended Phosphate.

The Equilibrium Blended Phosphate outperforms all doses of both orthophosphates at both pH conditions, even at a low dose of 0.5 mg/l.

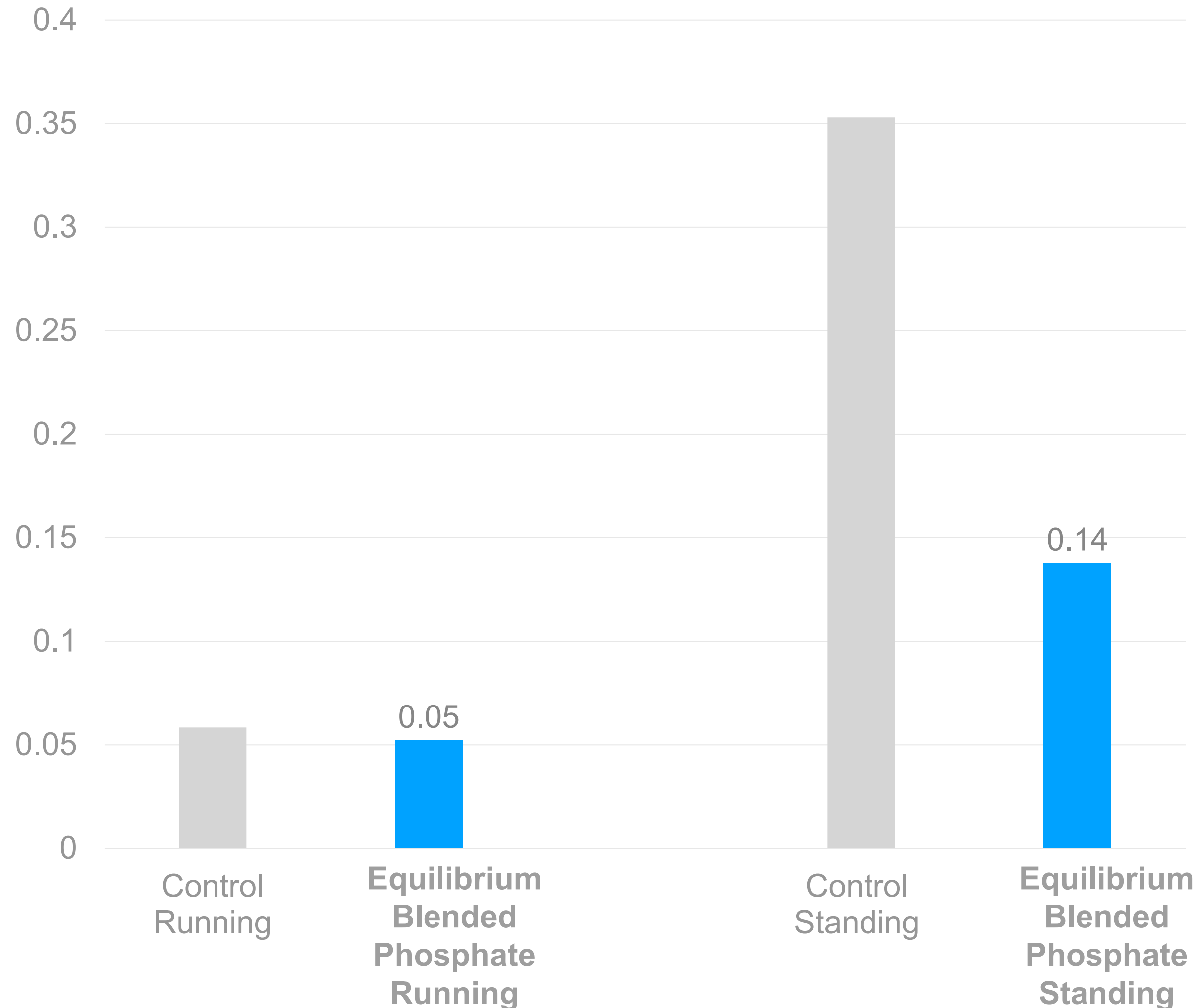
Standing vs Running Pipe Loop Testing



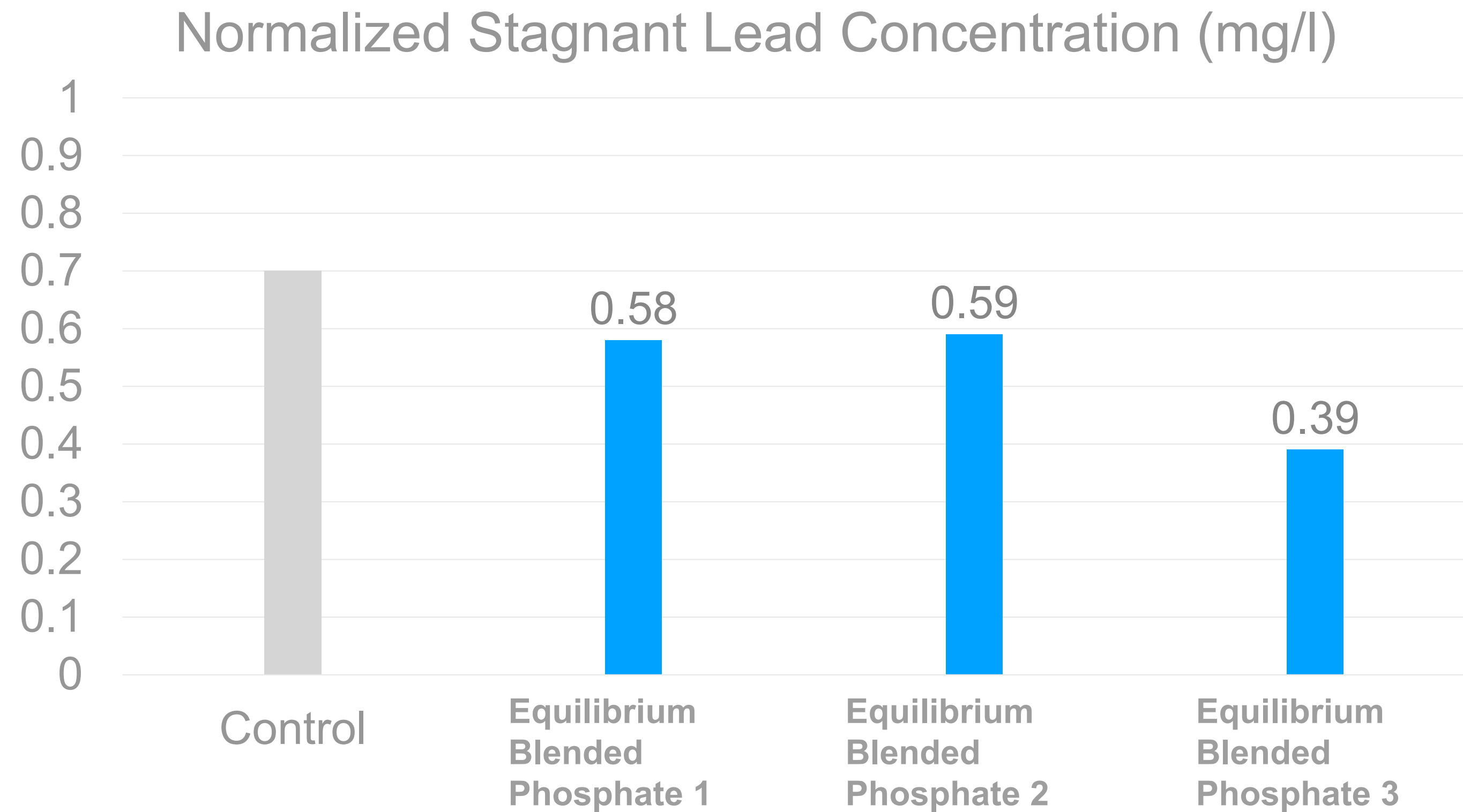
- Test shows the difference between a standing and running pipe loop test
- Equilibrium blended phosphate dosed at 0.5 mg /l
- Zinc orthophosphate control dosed at 2.0 mg/l
- Equilibrium blended phosphate controlled for lead similarly as zinc orthophosphate while running
- Equilibrium blended phosphate controlled for lead better than zinc orthophosphate while standing

Standing vs Running Pipe Loop Testing

Copper Corrosion Control Running vs Standing (avg. ppm)



- Test shows the difference between a standing and running pipe loop test
- Equilibrium blended phosphate dosed at 0.5 mg /l
- Zinc orthophosphate control dosed at 2.0 mg/l
- Equilibrium blended phosphate controlled for copper similarly as zinc orthophosphate while running
- Equilibrium blended phosphate controlled for copper better than zinc orthophosphate while standing

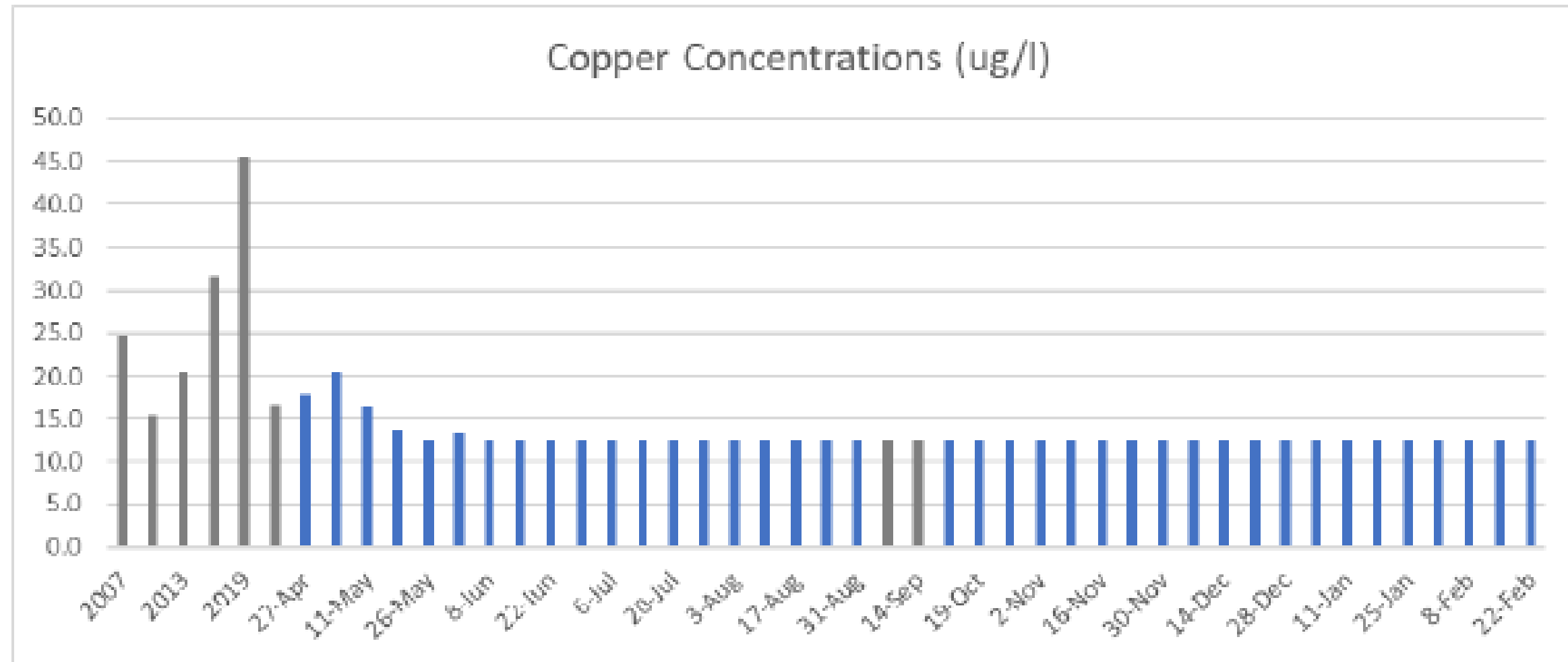


This test shows the effect of equilibrium blended phosphate vs orthophosphate at controlling lead release from lead solder, typically found in homes.

Equilibrium blended phosphate loop 3 shows effectiveness at low dose and at natural pH.

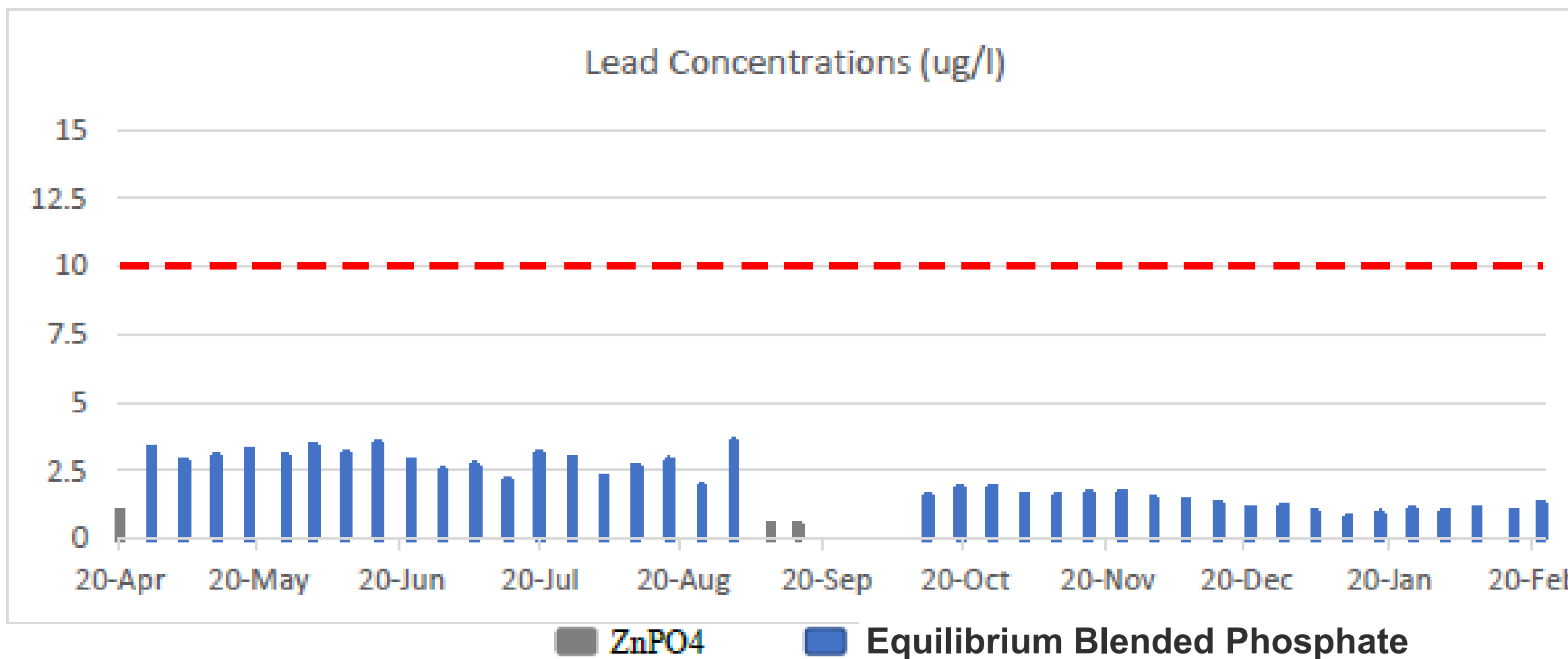
Conditions	Procedure
Loop 1 = 2 ppm Ortho, pH 7.2-7.4	a. 2 Weeks conditioning at pH 7.2-7.4
Loop 2 = 0.6 ppm EBP pH 7.2-7.4	b. 30 Days treatment at baseline current conditions (2 ppm ortho, pH 7.2-7.4)
Loop 3 = 0.6 ppm EBP pH 7.2-7.4	c. Lead analyzed during conditions for baseline to normalize data
Loop 4 = 0.6 ppm EBP pH 6.8	d. Stagnant for 6- and 24-hour periods to simulate home use for 90 days ; 23 24hr samples, 6 6hr samples

Harvested Lead & Copper Pipe Single Pass



Copper and lead pipes previously treated with zinc orthophosphate were harvested from the field and run through a single pass pipe loop.

- Harvested copper concentrations were compared to 2007-2019 average copper customer tap sampling results
- Harvested pipe study lead concentrations vs future 90th percentile target (10 ug/l)
- 2007-2019 customer tap sampling results average < 5 ug/l
- Based on previous test method detection limit of 5 ug/l



What this test shows is the effect equilibrium blended phosphate can have in establishing control over a lead and copper pipe, and that during the changeover from ortho-phosphate to SeaQuest there is not significant lead or copper release.