



# INFRASTRUCTURE CORROSION DRINKING WATER

**Patty Baron**

Drinking Water Program

Florida Department of Environmental Protection, South District

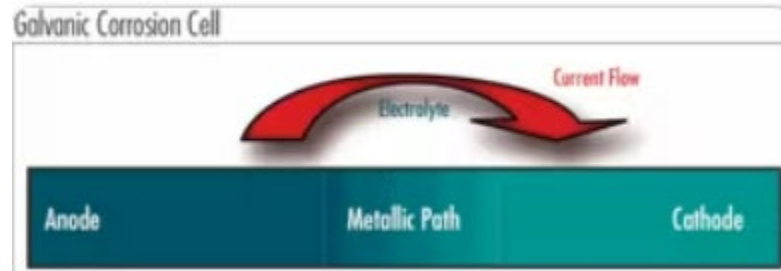
| 8/3/22



# Corrosion Definition

Corrosion is defined as the chemical or electrochemical interaction between a metal surface (i.e. pipe wall) or solder and water

- This interaction causes the oxidation of metals
- Once oxidized, metals are transferred to the water (metal release) or another location on the pipe surface as metal ions



The type and rate of metals release depends on many factors: physical, chemical, and biological properties of the water and the metal surface





# Oxidation/Reduction of Metals

When exposed to Oxygen or corrosive conditions:

- Metals that are more reactive (Magnesium, Zinc, Aluminum) lose electrons before the metals that are less reactive
- Metals that are more reactive protect metals that are less reactive
- The metals that are more reactive have higher oxidation potentials



Magnesium is more reactive than Zinc  
Zinc is more reactive than Aluminum  
Aluminum is more reactive than Cadmium  
Cadmium is more reactive than Cast Iron  
Cast Iron is more reactive than Carbon Steel  
Carbon Steel is more reactive than Stainless Steel  
Stainless Steel is more reactive than Lead  
Lead is more reactive than solder  
Solder is more reactive than Tin  
Tin is more reactive than Copper





# Pipe Corrosion- Why Does It Matter?

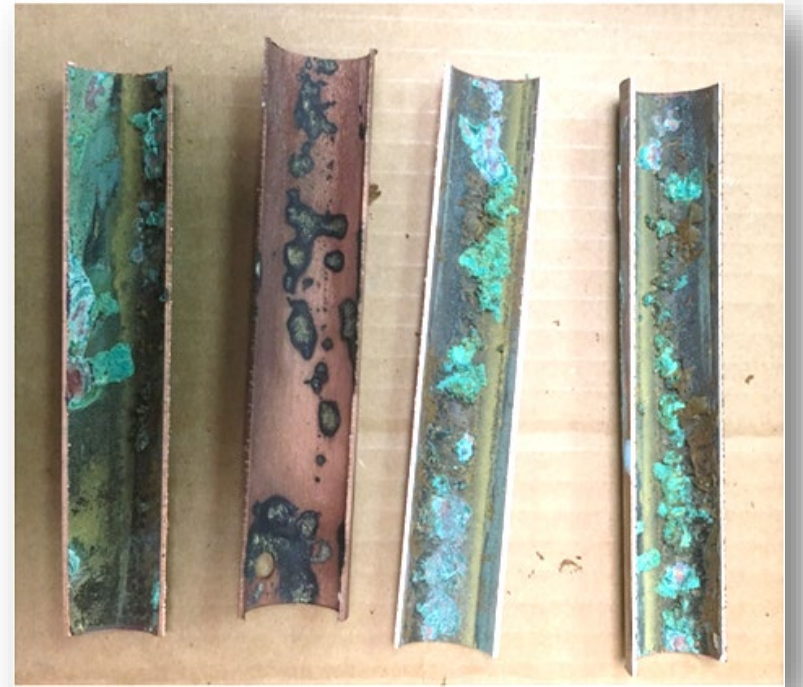
- Corrosion can be a concern because it can lead to the leaching or **RELEASE** of metals from the inside of pipes, service lines, or plumbing fixtures into the drinking water supply.

Ductile Iron, Cast Iron water mains

Copper Service Lines, Copper or Brass fixtures

Lead Service Lines, Lead Solder

Calcium from Asbestos Cement Mains

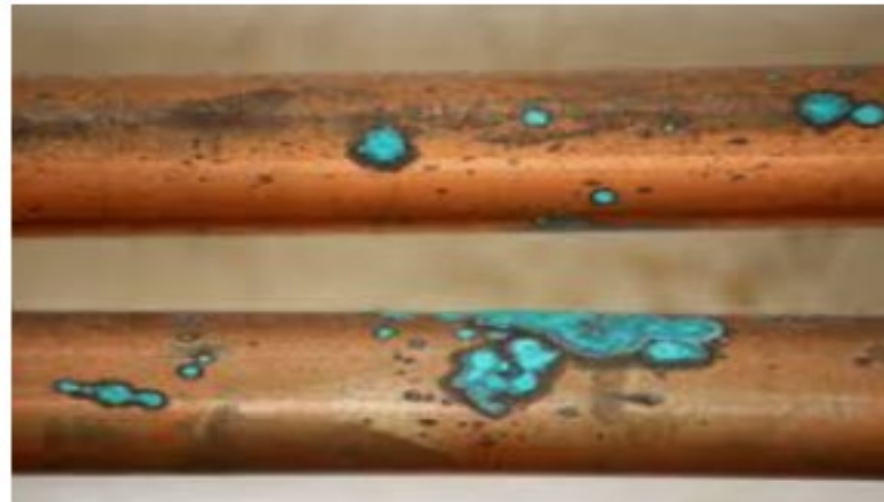




# Types of Corrosion

## Corrosion Types

- Uniform
- Non-uniform
- Galvanic







# Problems Corrosion Can Cause

- Premature failure of water mains or service lines
- Discolored water
- Complaints
- Pinhole leaks in pipes





# Regulatory Perspective

From a regulatory perspective, corrosion can be a major concern because of the potential for the release of Lead and/or Copper

- Action Level Exceedances of the Lead and Copper Rule
- Health Effects of Lead and Copper
- Erosion of Consumer Confidence

## Released forms of Lead and Copper

- Dissolved
- Colloidal
- Particulate (calcium, iron, manganese, aluminum)





# Health Effects Lead

## The health effects of lead in children include:

- Impaired mental development.
- IQ deficits.
- Shorter attention spans.
- Low birth weight.



An EPA civil engineer shows how corrosion control treatments can affect lead pipes. The one on the left was treated, the middle one was not, and the one on the right is a new pipe. Lauren Chapman / IPB News, File Photo





# Health Effects of Copper

- Stomach and intestinal distress
- Complication of Wilson's Disease.
- Chronic exposure can cause liver disease in genetically predisposed individuals.





# Methods of Corrosion Control

## Precipitation

Adjusting the pH, Alkalinity, and/or Calcium Carbonate equilibrium so that Calcium Carbonate precipitate forms

## Passivation

**Carbonate Passivation**-Modifying the pH and/or Alkalinity to form less soluble compounds with the metal on the pipe wall (metal carbonates)

**Corrosion Inhibitor Passivation**-Adding orthophosphates to form less soluble metal complexes on the pipe wall (metal phosphates)





# Problems Precipitation of Calcium Carbonate Can Cause

- Calcium Carbonate scales via precipitation only rarely form on Galvanized (zinc coated) Iron or Steel, Lead, or Copper pipe
- Can create an uneven layer of precipitation and an uneven layer of corrosion protection
- Can create Hydraulic Stress in over-precipitated areas
- Prevents valves from sealing properly
- Areas with very light coating of scale can be easily dislodged from pipe wall if there is drastic change in flow volume or direction





# Problems Oversaturation of Calcium Carbonate Can Cause

- Hard water reduces the life of clothes, decreases the life of hot water heaters, toilet flushing units, water faucets, dishwashers.
- Leaves spots on dishes/glassware.
- Studies show Copper adsorbs onto pipe scale, when scale is dislodged copper particles get trapped in aerator faucet screens.







# How to Prevent Corrosion

Preventing or minimizing corrosion centers around several main strategies.

- **Adjusting the water system's pH and/or Alkalinity.**  
Increasing the scale forming potential of water to create a thin coating inside the pipe wall.
- **Adding an Orthophosphate**  
Creating a passivating film inside the pipe wall by adding chemicals at the treatment plant.

Ultimately want scale that is: Adherent  
and  
Insoluble





# Is Your Water Corrosive, Scale Forming, or Stable?

Non-carbonate hardness-Calcium & Magnesium Chlorides and Sulfates

Carbonate Hardness-Calcium and Magnesium Carbonates and Bicarbonates

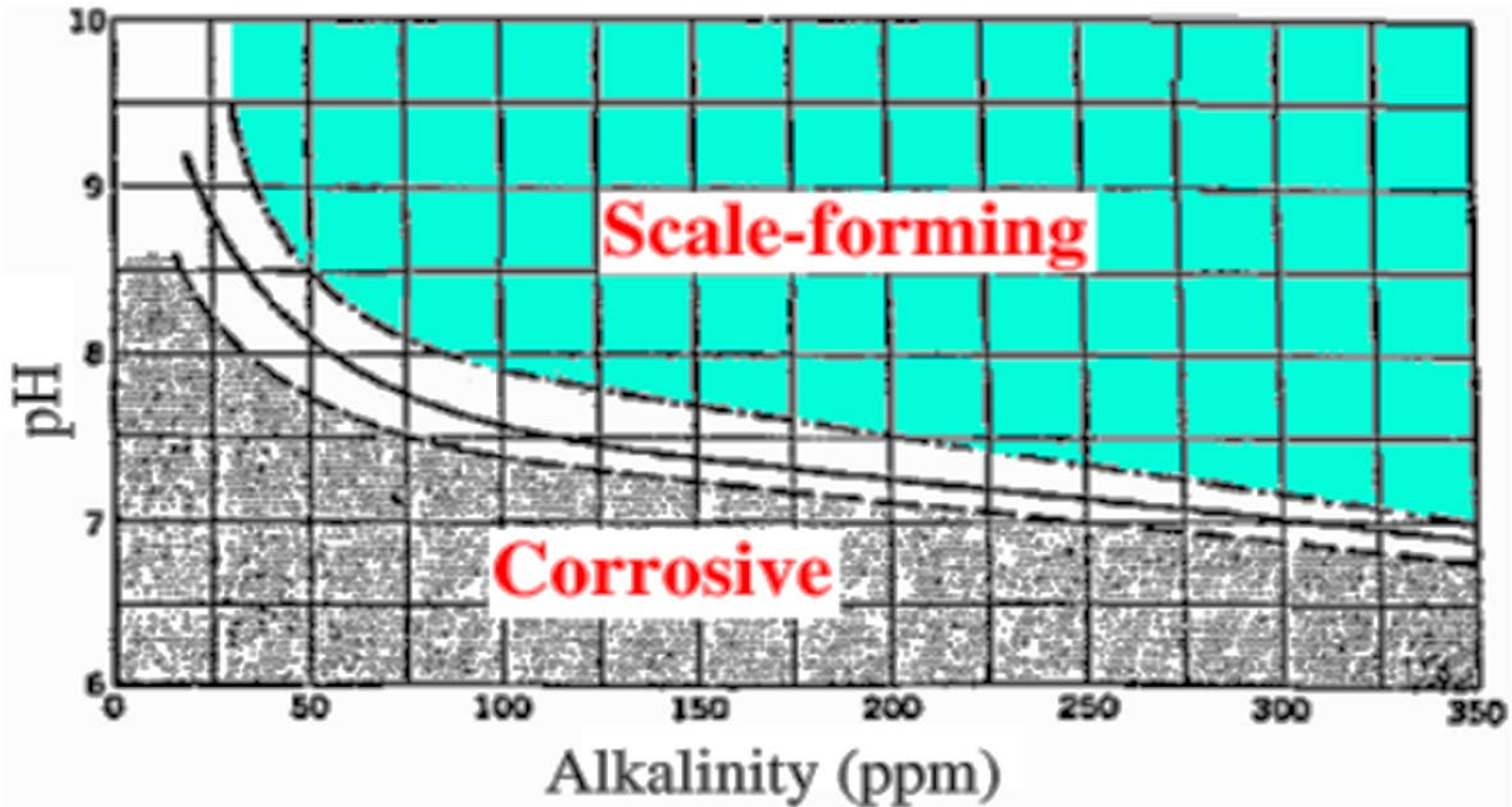
Corrosive Water	Scale-forming Water
<ul style="list-style-type: none"><li>● low pH</li><li>● soft or with primarily noncarbonate hardness</li><li>● low alkalinity</li></ul>	<ul style="list-style-type: none"><li>● high pH</li><li>● hard with primarily carbonate hardness</li><li>● high alkalinity</li></ul>





# Baylis Curve

The graph shown below is known as the Baylis Curve. It shows the relationship between pH, alkalinity, and water stability. Water above the lines is scale-forming while water below the lines is corrosive. Stable water is found in the white area between the lines.

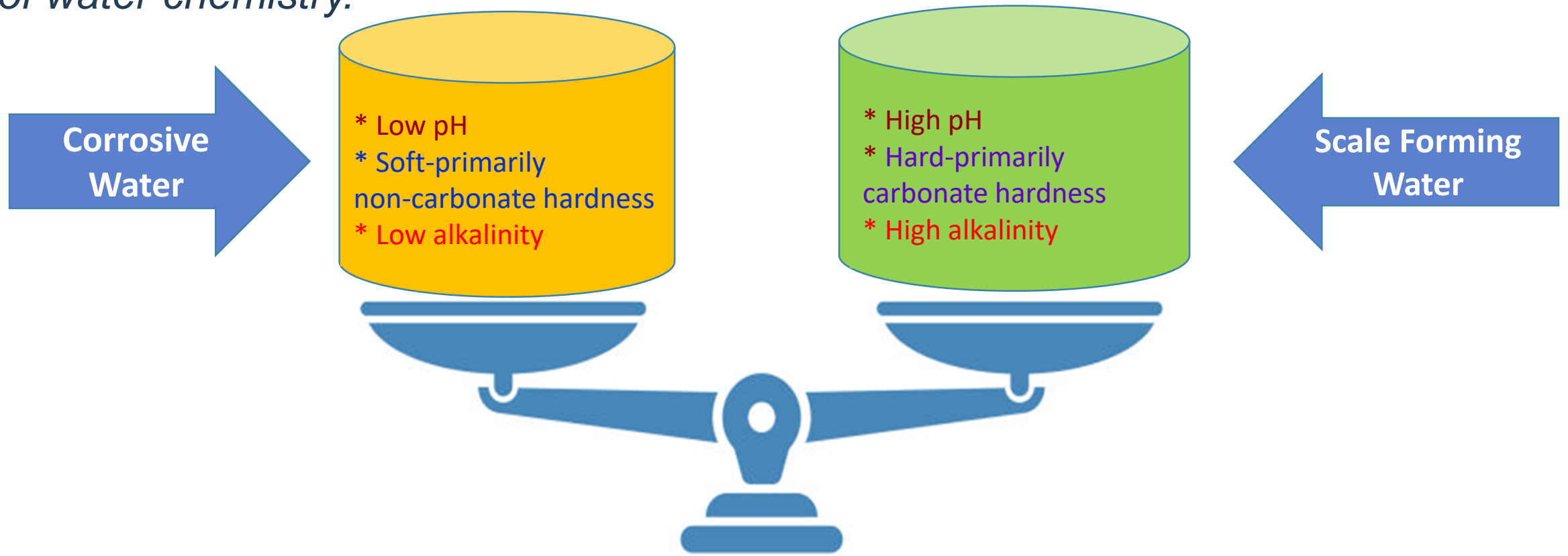




# Balancing Water Chemistry

There is a fine line between decreasing metal solubility and precipitating just enough metal carbonate on pipe wall to prevent corrosion.

*Need to find the right balance between the two, but first you need a basic knowledge of water chemistry.*





# Chemical Factors Influencing Corrosion

## Primary Factors that Influence Corrosion

- pH
- Alkalinity
- Dissolved Inorganic Carbon (DIC)
- Buffering Intensity
- Hardness
- Total Dissolved Solids (TDS)
- Chlorides and Sulfates
- Dissolved Oxygen
- Oxidation Reduction Potential (ORP)





# pH

- pH affects almost every chemical process at a water treatment plant.
- pH identifies the intensity of acidity of a solution but does not identify how much acid or base is present.
- At pHs <7 metal solubility (especially Lead & Copper) increases.
- At pHs >8 precipitation of  $\text{CaCO}_3$  increases.





# pH

## pH stands for potential Hydrogen ion (H<sup>+</sup>) concentration



pH is a measure of the Hydrogen ion activity

Acids are those compounds that release a proton (H<sup>+</sup> ion)

Bases are those compounds that accept a proton (H<sup>+</sup> ion)

Aeration-one of the only non-chemical means of raising pH

CHEMICALS THAT LOWER pH	CHEMICALS THAT RAISE pH
GAS CHLORINE	SODIUM HYDOXIDE (Lye)
SULFURIC ACID	CALCIUM HYDROXIDE (Lime)
MURIATIC ACID	SODIUM BICARBONATE (Baking Soda)
CARBON DIOXIDE	SODIUM CARBONATE (Soda Ash)
ALUM	SODIUM HYPOCHLORITE
FERRIC CHLORIDE	CALCIUM HYPOCHLORITE
HYDROFLUOROSILICIC ACID	





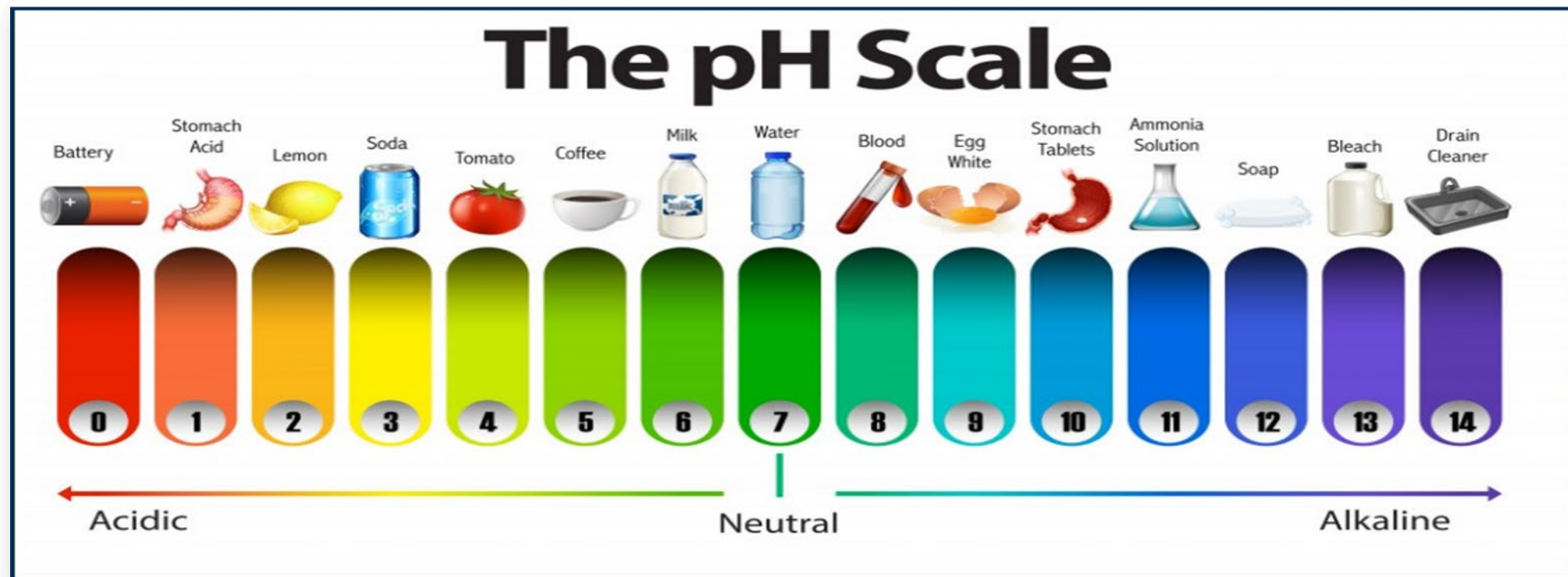
# pH

pH is on a log scale.

A change of only 1 pH unit = a 10-fold difference in activity.

pH 7 to pH 6 is 10 times more acidic.

pH 7 to pH 5 is 100 times more acidic.







# Alkalinity

- Alkalinity is expressed in mg/L as Calcium Carbonate ( $\text{CaCO}_3$ ).
- Alkalinity is the ability of a solution to resist changes in pH or its buffering capacity.
- The more Alkalinity a solution has, the higher its buffering capacity and its ability to resist changes in pH.





# Buffer Intensity

- Buffering Capacity comes from:

Carbonate ions

Bicarbonate ions

Hydroxide ions

- Buffer Intensity is dependent on pH and Alkalinity.
- Buffer Intensity is lowest at pH 8-8.5



# Dissolved Inorganic Carbon

- DIC is Dissolved inorganic Carbon is expressed in mg/L of C
- DIC is made up of: **Free CO<sub>2</sub> (gas)**  
**Bicarbonate Ions**  
**Carbonate Ions**
- DIC and Alkalinity are closely related-both have bicarbonates and carbonates and influence buffering (acid) neutralizing capacity of water  
EPA flow charts for optimizing corrosion control use DIC instead of Alkalinity
- DIC can be determined by knowing the Alkalinity and pH





# Buffer Intensity as a Function of pH

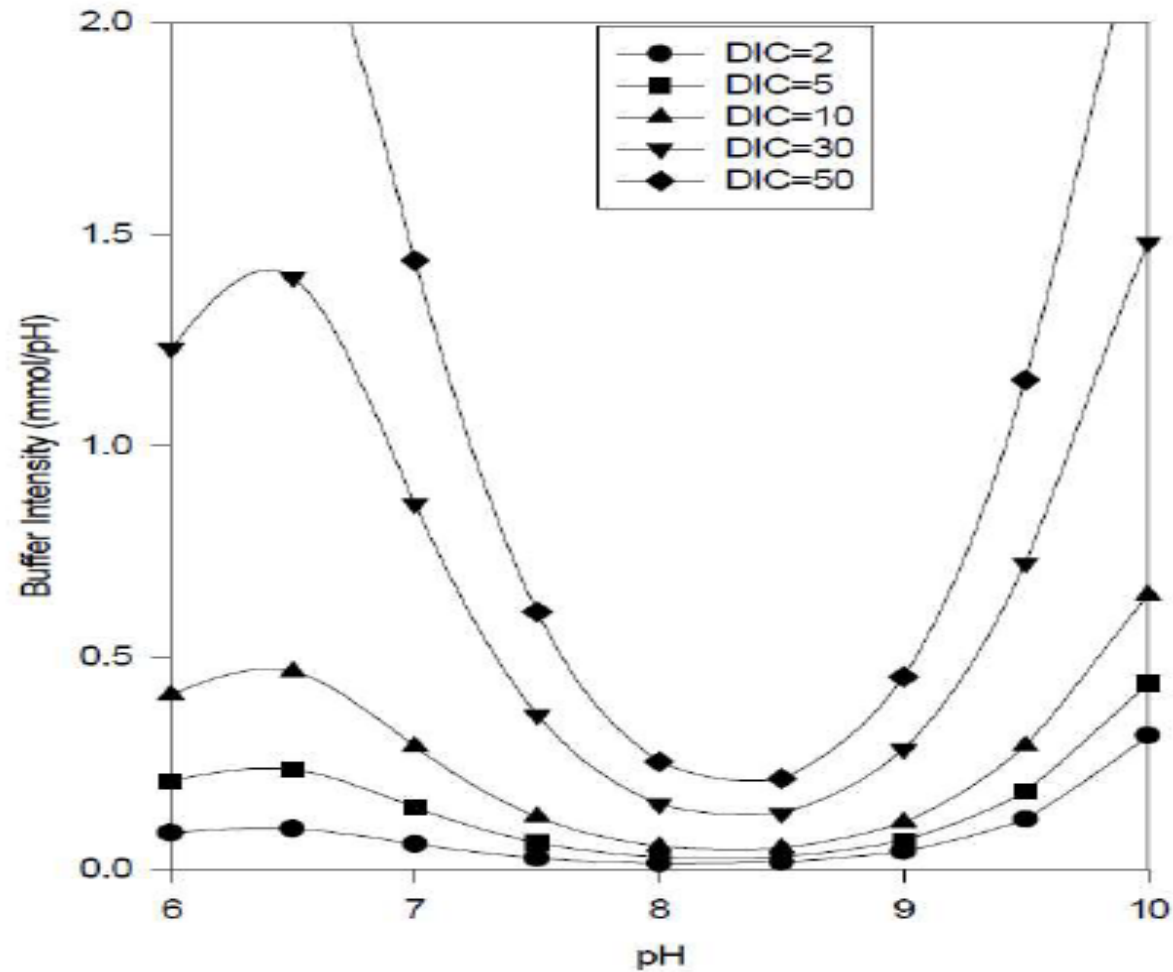


Exhibit 2.3: Buffer Intensity as a Function of pH at Different DIC Values (Clement and Schock, 1998, Figure 1)



# Hardness

- Hardness like Alkalinity is expressed in mg/L as CaCO<sub>3</sub>.
- Hardness is mainly made up of Calcium and Magnesium Ions.
- Hardness can also be expressed as grains/gallon.

(1 grain/gal=17.1 mg/L as CaCO<sub>3</sub>)

- **SOFT:** <17.1 mg/L (<1 grain/Gallon)
- **SLIGHTLY HARD:** 17.1-60 mg/L (1- 3.5 grains per gallon)
- **MODERATELY HARD:** 60-120 mg/L (3.5-7 grains per gallon)
- **HARD:** 120-180 mg/L (7-10.5 grains per gallon)
- **VERY HARD:** >180 mg/L (>10.5 grains per gallon)





# Total Dissolved Solids

- **TDS is the total concentration of dissolved substances in water. This includes inorganic salts, and a small amount of organic matter.**

Inorganic Salts: CATIONS Calcium Magnesium Sodium Potassium

ANIONS Carbonates Bicarbonates Nitrates Chlorides Sulfates

- **TDS is closely related to conductivity.**

What is the difference between conductivity and TDS? Conductivity tells you how well electricity is passing through a substance. TDS indicates the amount of dissolved solids within a liquid, accounting for both conductible and non-conductible particles.

- **In most cases corrosion rates increase as conductivity increases.**

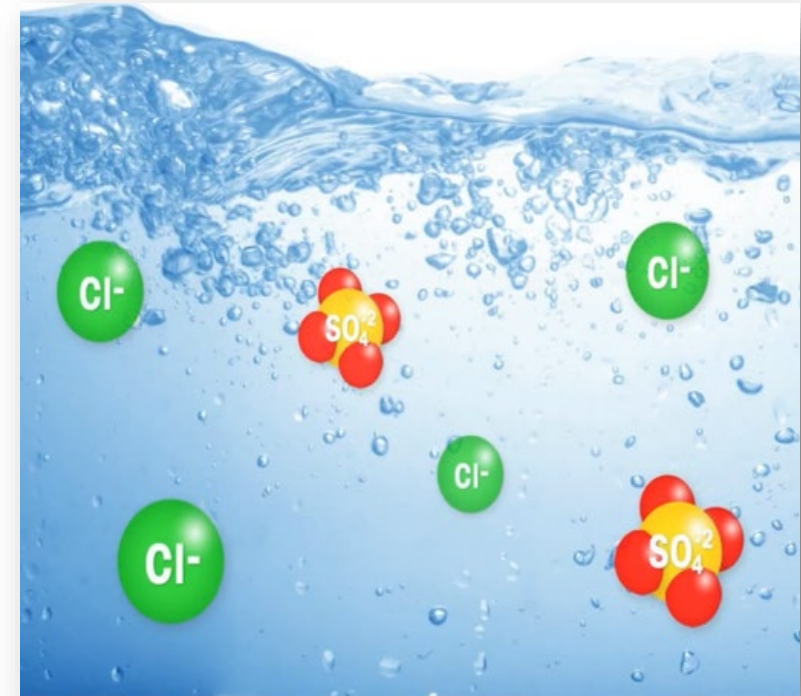






# Chlorides and Sulfates

- Chlorides and Sulfates are aggressive anions that disrupt the internal protective surfaces of pipes.
- Chlorides are made up of the element of chlorine with a negative charge  $\text{Cl}^-$  or any compound with chlorine in its chemical composition (salts or even acids).
- Chlorides can cause corrosion on passive materials such as Aluminum or Stainless Steel (pitting), Brass, Bronze, Copper (classic green staining).





# Chlorides and Sulfates

- Sulfates are aggressive to Copper and can also be associated with the staining of Brass, Bronze, Copper and zinc coated steel.
- Sulfates can also act synergistically with Chlorides to accelerate corrosion on metal surfaces.
- Sulfates are a source of sulfate reducing bacteria.



# Dissolved Oxygen and Oxidation Reduction Potential

## Dissolved Oxygen

- Dissolved Oxygen is low in soils containing clay or in stagnant water
- Dissolved Oxygen is higher in sandy soil and aerated water
- Water with higher DO forms more protective Lead Oxide scales
- Water with higher DO accelerates copper corrosion

## Oxidation Reduction Potential

- Oxidation Reduction Potential varies with pH, temperature, and DIC
- ORP is driven mainly by the type of disinfectant used and the DO concentration
- Free Chlorine has higher ORP than Chloramines
- Reducing the pH or ORP can cause potential Lead release (Lead IV converts to Lead II)



# Making Water More Scale Forming

## Chemicals That Raise the pH or Add Alkalinity

- Caustic Soda Adds 1.25 mg/L as CaCO<sub>3</sub> per mg/L.
- Lime Adds 1.35 mg/L as CaCO<sub>3</sub> per mg/L.
- Soda Ash Adds 0.94 mg/L as CaCO<sub>3</sub> per mg/L.
- Sodium Bicarbonate Adds 0.6 mg/L as CaCO<sub>3</sub> per mg/L.







**Exhibit 3.1: Typical Chemical Processes for pH/Alkalinity/DIC Adjustment**

Chemical	Use	Composition	Alkalinity Change	DIC Change <sup>1</sup>	Notes
Baking Soda, NaHCO <sub>3</sub> (sodium bicarbonate)	Increases alkalinity with moderate increase in pH.	98% purity. Dry storage with solution feed. <sup>2</sup>	0.60 mg/L as CaCO <sub>3</sub> alkalinity per mg/L as NaHCO <sub>3</sub> <sup>2, 3, 4</sup>	0.14 mg/L as C per mg/L as NaHCO <sub>3</sub>	Good alkalinity adjustment chemical but expensive. <sup>2</sup>
Carbon Dioxide, CO <sub>2</sub>	Lowers pH. Converts hydroxide to bicarbonate and carbonate species.	Pressurized gas storage, Fed either through eduction or directly. <sup>2</sup>	None <sup>2</sup>	0.27 mg/L as C per mg/L as CO <sub>2</sub>	Can be used to enhance NaOH or lime feed systems. <sup>2</sup>
Caustic Potash, KOH (potassium hydroxide)	Raises pH. Converts excess carbon dioxide to carbonate alkalinity species.	KOH is available as a 45% solution. <sup>5</sup> Has a low freezing point and may be stored at higher concentrations.	0.89 mg/L as CaCO <sub>3</sub> alkalinity per mg/L as KOH <sup>3, 4</sup>	None	pH control is difficult when applied to poorly buffered water. <sup>5</sup> Is a hazardous chemical, requires safe handling and containment areas.
Caustic Soda, NaOH (sodium hydroxide) <sup>6</sup>	Raises pH. Converts excess carbon dioxide to carbonate alkalinity species.	93% purity liquid bulk, but generally shipped and stored at < 50% purity to prevent freezing. <sup>2</sup>	1.25 mg/L as CaCO <sub>3</sub> alkalinity per mg/L as NaOH <sup>3, 4</sup>	None	pH control is difficult when applied to poorly buffered water. <sup>2</sup> Is a hazardous chemical, requires safe handling and containment areas.
Hydrated Lime, Ca(OH) <sub>2</sub> (calcium hydroxide) <sup>7</sup>	Raises pH. Increases alkalinity and calcium content (i.e., hardness).	95 to 98% purity as Ca(OH) <sub>2</sub> . 74% active ingredient as CaO. Dry storage with slurry feed. <sup>2</sup>	1.35 mg/L as CaCO <sub>3</sub> alkalinity per mg/L as Ca(OH) <sub>2</sub> <sup>3, 4</sup>	None	pH control is difficult when applied to poorly buffered water. Slurry feed can cause excess turbidity. O&M is intensive. <sup>2</sup>
Potash, K <sub>2</sub> CO <sub>3</sub> (potassium carbonate)	Increases alkalinity with moderate increase in pH.	Dry storage with solution feed. <sup>5</sup>	0.72 mg/L as CaCO <sub>3</sub> alkalinity per mg/L K <sub>2</sub> CO <sub>3</sub> <sup>3, 4</sup>	0.09 mg/L as C per mg/L as K <sub>2</sub> CO <sub>3</sub>	More expensive than soda ash but more soluble and easier to handle. <sup>5</sup>



Chemical	Use	Composition	Alkalinity Change	DIC Change <sup>1</sup>	Notes
Soda Ash, Na <sub>2</sub> CO <sub>3</sub> (sodium carbonate)	Increases alkalinity with moderate increase in pH.	95% purity. Dry storage with solution feed. <sup>2</sup>	0.94 mg/L as CaCO <sub>3</sub> alkalinity per mg/L as Na <sub>2</sub> CO <sub>3</sub> <sup>3, 4</sup>	0.11 mg/L as C per mg/L as Na <sub>2</sub> CO <sub>3</sub>	More pH increase compared with NaHCO <sub>3</sub> , but less costly. <sup>2</sup> Has increased buffer capacity over hydroxides.
Sodium Silicates, Na <sub>2</sub> SiO <sub>3</sub>	Moderate increases in alkalinity and pH.	Available in liquid form mainly in 1:3.2 or 1:2 ratios of Na <sub>2</sub> O:SiO <sub>2</sub> . <sup>5</sup>	Depends on formulation	None	More expensive than other options but easier to handle than lime and other solid feed options. Has additional benefits in sequestering or passivating metals. <sup>8</sup>

Notes and adapted sources:

<sup>1</sup> Calculated by the formula DIC Change = 12 x (moles carbon/mole compound) / molecular weight of compound.

<sup>2</sup> USEPA, 1992a

<sup>3</sup> Wachinski, 2016

<sup>4</sup> Simon, 1991

<sup>5</sup> USEPA, 2003

<sup>6</sup> Caustic potash (KOH), or potassium hydroxide, is an alternative that does not add sodium to water.

<sup>7</sup> Lime is available as hydrated or slaked lime (Ca(OH)<sub>2</sub>) and quicklime (CaO).

<sup>8</sup> Schock, 1996



# Orthophosphates

- Phosphate based inhibitors can include orthophosphates, polyphosphates, or an ortho/poly blend.
- Only orthophosphate inhibitors react with the pipe wall to form a metallic phosphate scale Only dissolved (not precipitated) Orthophosphate reacts with pipe wall to inhibit corrosion.
- Start-up concentration of 2-4 mg/L as PO<sub>4</sub> for 3-12 months.
- Maintenance concentration 0.5-2 mg/L as PO<sub>4</sub>.



# Polyphosphates

- Polyphosphates are used to keep dissolved iron or manganese in solution by sequestering
- Polyphosphates must be added **BEFORE** Chlorine
- Polyphosphates are not meant to be used to prevent Lead or Copper release
- Over time, Polyphosphates break down into Orthophosphates

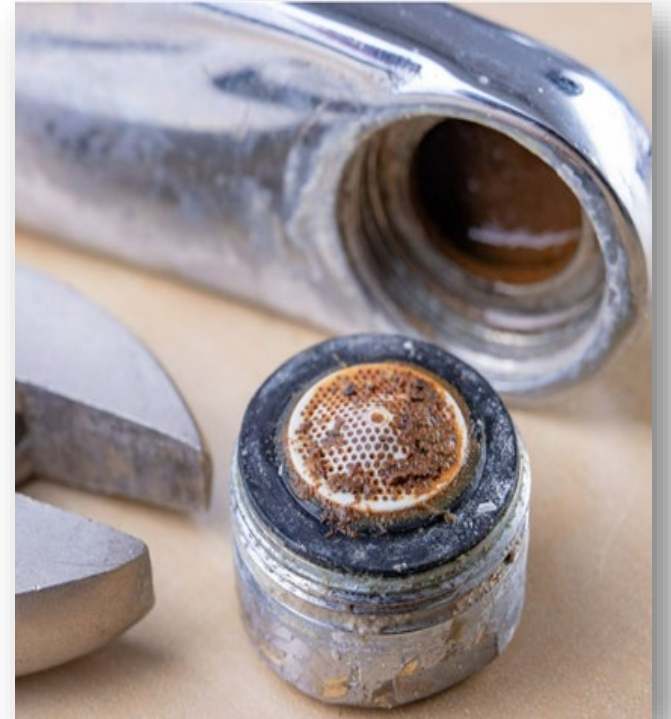




# Lead and Copper Sampling

## Where and How were Samples Collected?

- EPA mandates that sampling instructions NOT direct customers to remove or clean aerators prior to or during sample collection for lead and copper.
- Residential Sampling  
Collect samples from COLD water tap in kitchen or bathroom
- Non-Residential sampling  
Collect samples from INDOOR taps





# **Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems**



**Appendix B – Estimated Dissolved Inorganic Carbon (mg/L as C) based on Alkalinity and pH (with water temperature of 25 degrees C and TDS of 200)<sup>1, 2, 3</sup>**

Total Alkalinity	pH																				
	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																				
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	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	2	2	2	2	2	2	2	2	2	2	2	2	1	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	2	2	2	2	1	1	
14	6	5	4	4	4	4	4	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	3	3	3	2	2	1	0
18	8	7	6	5	5	5	5	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	4	4	4	4	3	3	2	1
22	10	8	7	6	6	6	6	5	5	5	5	5	5	5	5	4	4	4	3	2	1
24	11	9	8	7	7	6	6	6	6	6	6	6	5	5	5	5	4	4	3	2	2
26	11	10	8	8	7	7	7	6	6	6	6	6	6	6	6	5	5	4	4	3	2
28	12	10	9	8	8	7	7	7	7	7	7	7	6	6	6	6	5	5	4	3	2
30	13	11	10	9	8	8	8	7	7	7	7	7	7	7	6	6	6	5	4	3	2
35	15	13	11	10	9	9	9	9	9	8	8	8	8	8	8	7	7	6	5	4	3
40	18	15	13	12	11	10	10	10	10	10	10	9	9	9	9	8	8	7	6	5	4
45	20	16	14	13	12	12	11	11	11	11	11	11	10	10	10	9	9	8	7	6	5
50	22	18	16	14	14	13	13	12	12	12	12	12	12	11	11	10	10	9	8	7	5
55	24	20	18	16	15	14	14	14	13	13	13	13	13	12	12	11	11	10	9	8	6
60	26	22	19	17	16	16	15	15	15	14	14	14	14	14	13	12	12	11	10	8	7
65	29	24	21	19	18	17	16	16	16	16	15	15	15	15	14	14	13	12	10	9	8



Total Alkalinity	pH																				
	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
70	31	26	22	20	19	18	18	17	17	17	17	16	16	16	15	15	14	13	11	10	8
75	33	27	24	22	20	19	19	19	18	18	18	18	17	17	16	16	15	14	12	11	9
80	35	29	26	23	22	21	20	20	19	19	19	19	19	18	18	17	16	14	13	12	10
85	37	31	27	25	23	22	21	21	21	20	20	20	20	19	19	18	17	15	14	12	11
90	40	33	29	26	24	23	23	22	22	22	21	21	21	20	20	19	18	16	15	13	11
95	42	35	30	28	26	25	24	23	23	23	23	22	22	22	21	20	19	17	16	14	12
100	44	37	32	29	27	26	25	25	24	24	24	24	23	23	22	21	20	18	17	15	13
125	55	46	40	36	34	32	31	31	30	30	30	29	29	28	27	26	25	23	21	19	17
150	66	55	48	43	41	39	38	37	37	36	36	35	35	34	33	32	30	28	25	23	20
175	77	64	56	51	47	45	44	43	43	42	42	41	41	40	39	37	35	32	30	27	24
200	88	73	64	58	54	52	50	49	49	48	48	47	46	45	44	42	40	37	34	31	28
225	99	82	72	65	61	58	57	56	55	54	54	53	52	51	50	48	45	42	38	35	32
250	110	91	80	72	68	65	63	62	61	60	60	59	58	57	55	53	50	47	43	39	36
275	121	100	88	80	75	71	69	68	67	66	66	65	64	63	61	58	55	51	47	43	39
300	132	110	96	87	81	78	76	74	73	72	72	71	70	68	66	64	60	56	52	47	43
325	143	119	104	94	88	84	82	80	79	78	77	77	75	74	72	69	65	61	56	51	47
350	154	128	112	101	95	91	88	86	85	84	83	82	81	80	77	74	70	65	60	55	51
375	165	137	120	109	102	97	94	93	91	90	89	88	87	85	83	79	75	70	65	59	54
400	176	146	128	116	108	104	101	99	97	96	95	94	93	91	88	85	80	75	69	63	58

Notes:

<sup>1</sup> This table is meant to help primacy agencies and water systems identify potential carbonate precipitation constraints when evaluating CCT alternatives in Section 3.2. DIC values may be up to 20% higher at temperatures as low as 10 degrees C, and may vary slightly at higher and lower TDS.

<sup>2</sup> Shaded cells indicate chemically impossible conditions. May indicate analytical quality or total dissolved solids (TDS) assumption error.

<sup>3</sup> See USEPA (2003) for information on the formula used to calculate the DIC values provided above. Equilibrium constants are referenced from Butler and Cogley (1998); Plummer and Busenberg (1982); Schock (1980); and USEPA (2003).





**Exhibit 3.3: Identifying the Appropriate Flowchart for Preliminary CCT Selection**

Is iron or manganese present in finished water? <sup>1</sup>	What is the contaminant to be addressed?	What is the finished water pH?	Use This Flowchart <sup>2</sup>
No	Lead only, or Both Lead and Copper	< 7.2	<b>1a</b>
		7.2 - 7.8	<b>1b</b>
		>7.8 - 9.5	<b>1c</b>
		>9.5	<b>1d</b>
	Copper only	< 7.2	<b>2a</b>
		7.2 - 7.8	<b>2b</b>
>7.8		<b>2c</b>	
Yes	Lead and/or Copper	< 7.2	<b>3a</b>
		≥ 7.2	<b>3b</b>

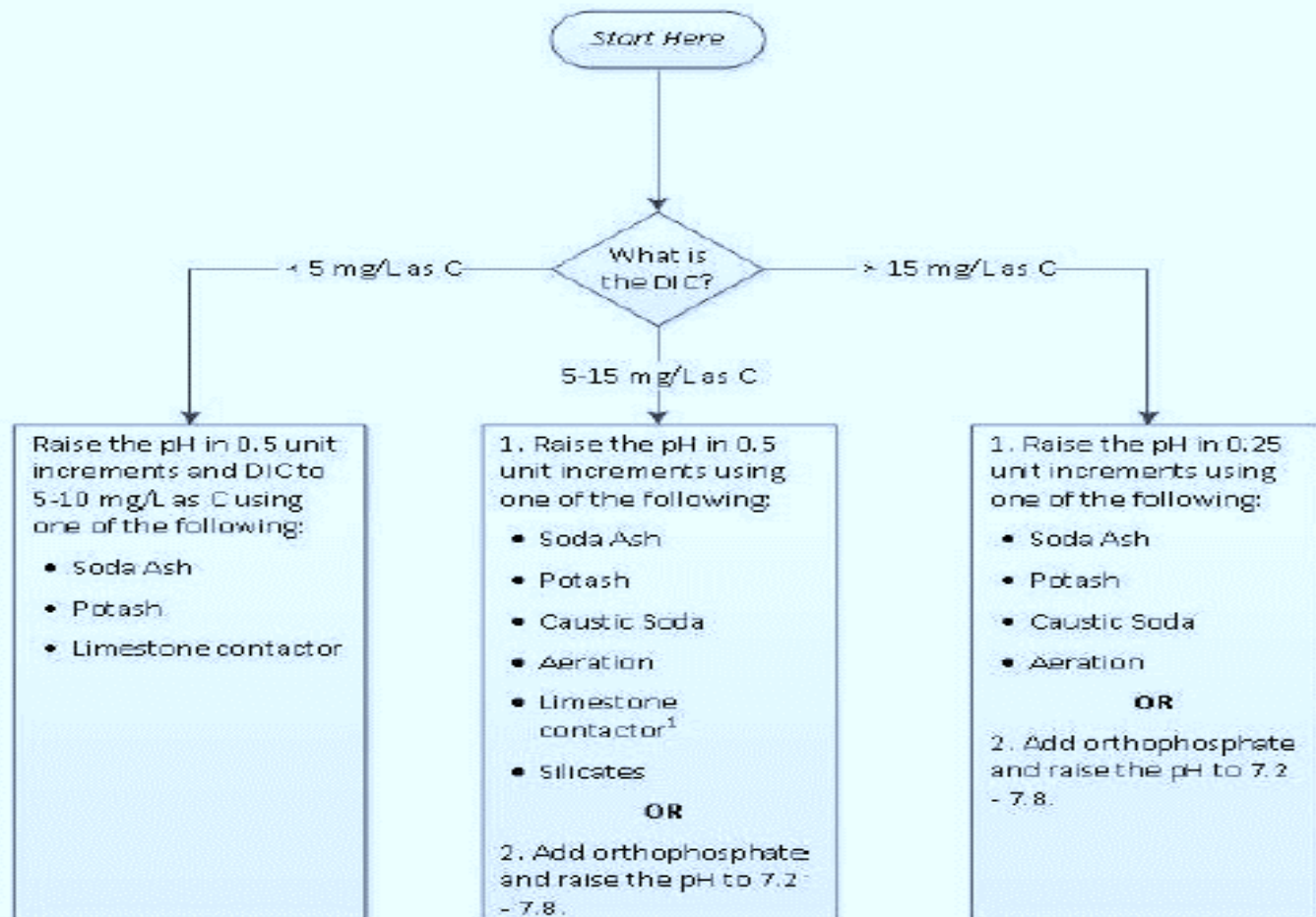
Notes:

<sup>1</sup> Flowcharts 3a and 3b present several treatment options for lead and copper that also reduce iron and manganese. Systems can also consider removing iron and manganese first, then using flowcharts 1a through 2c to control for lead and/or copper.

<sup>2</sup> As discussed in Section 3.1.1, the term "limestone contactor" generically identifies filtration processes where calcite-containing materials are used to add pH, alkalinity, and DIC to water.



### Flowchart 1a: Selecting Treatment for Lead only or Lead and Copper with pH < 7.2

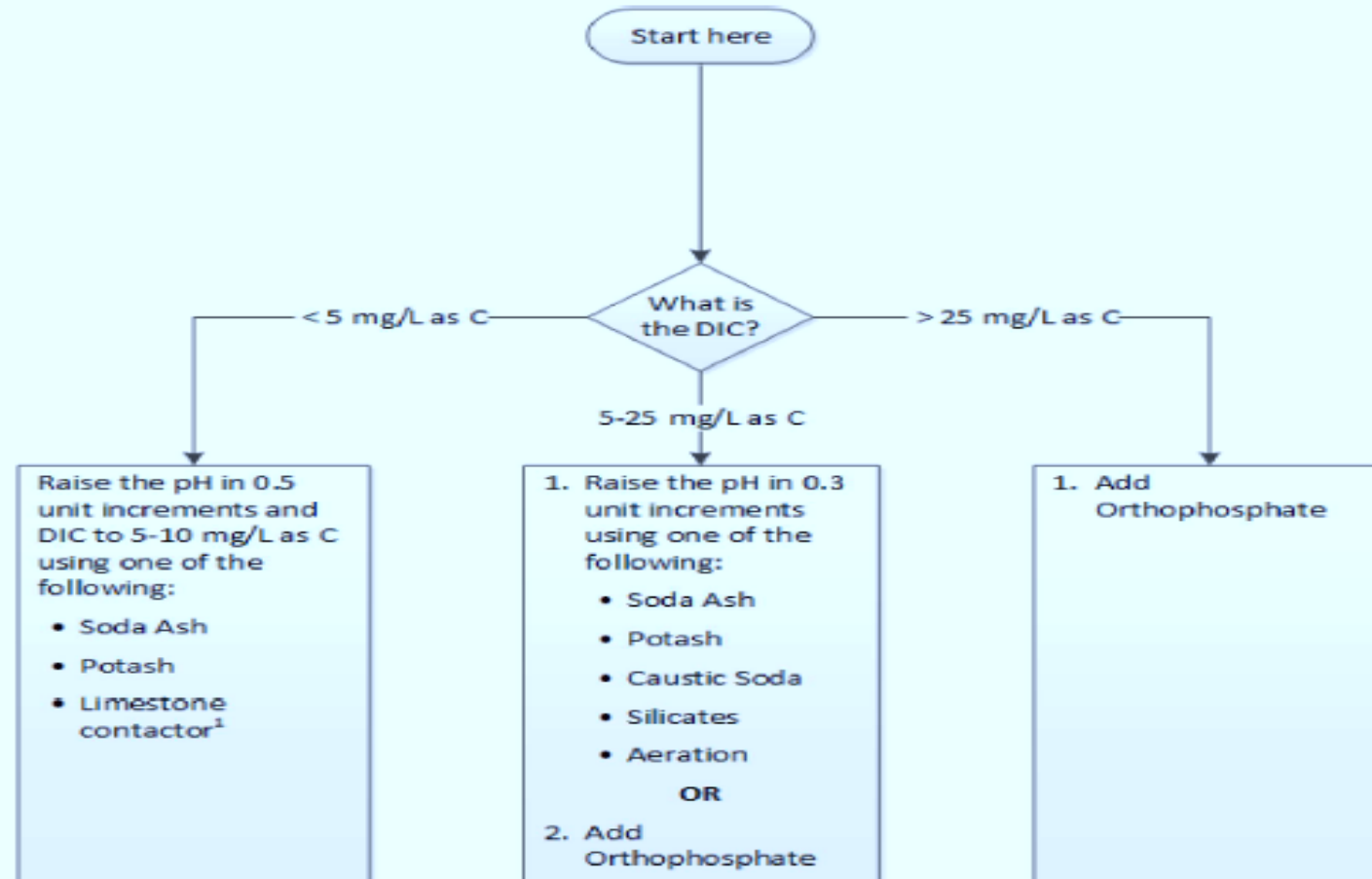


**KEY:**  
AL = Action Level  
Caustic soda = sodium hydroxide (NaOH)  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon  
Potash = potassium carbonate (K<sub>2</sub>CO<sub>3</sub>)  
Soda ash = sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>)

**Footnotes:**  
1. Limestone contactors may not be appropriate when DIC > 10 mg/L as C.



**Flowchart 1b: Selecting Treatment for Lead only or Lead and Copper with pH from 7.2 to 7.8**

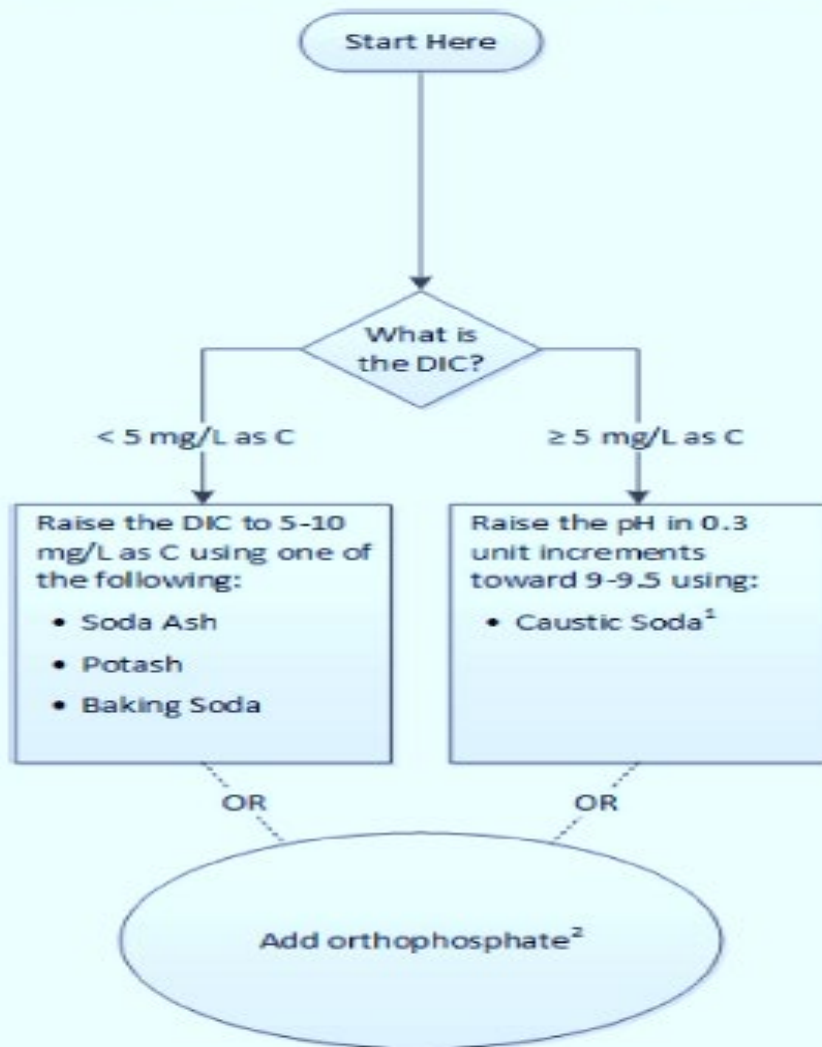


**KEY:**  
AL = Action Level  
Caustic soda = sodium hydroxide (NaOH)  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon  
Potash = potassium carbonate (K<sub>2</sub>CO<sub>3</sub>)  
Soda ash = sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>)

**Footnotes:**  
1. Carbon dioxide feed before the limestone contactor may be necessary.



### Flowchart 1c: Selecting Treatment for Lead only or Lead and Copper with pH > 7.8 to 9.5



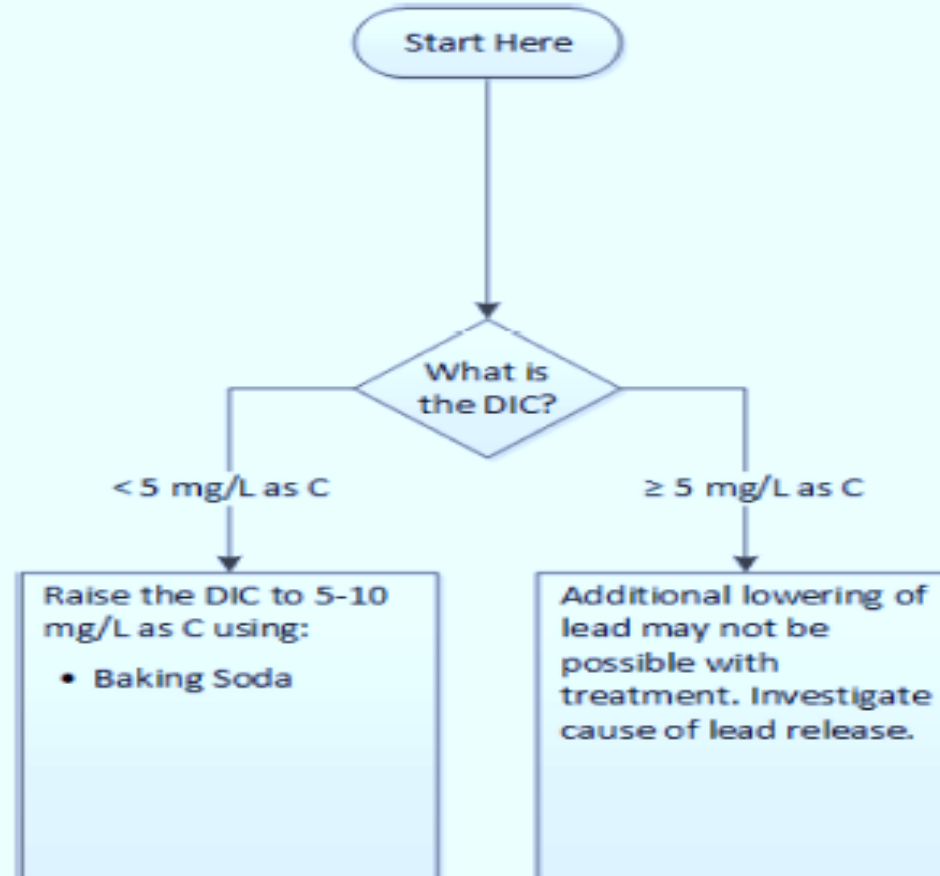
**KEY:**  
AL = Action Level  
Baking soda = sodium bicarbonate (NaHCO<sub>3</sub>)  
Caustic soda = sodium hydroxide (NaOH)  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon  
Potash = potassium carbonate (K<sub>2</sub>CO<sub>3</sub>)  
Soda ash = sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>)

**Footnotes:**  
1. Systems with copper plumbing may experience copper pitting problems when operating at pH 9 – 9.5 and DIC of 5 – 15. Orthophosphate may be a better option for these systems.  
2. Optimal pH range for orthophosphate is 7.2 - 7.8 but phosphate may be effective at higher pH depending on dose. Orthophosphate effectiveness is lowest in the pH range of 8 – 8.5. Systems should also avoid this range because of inadequate buffering in the distribution system.





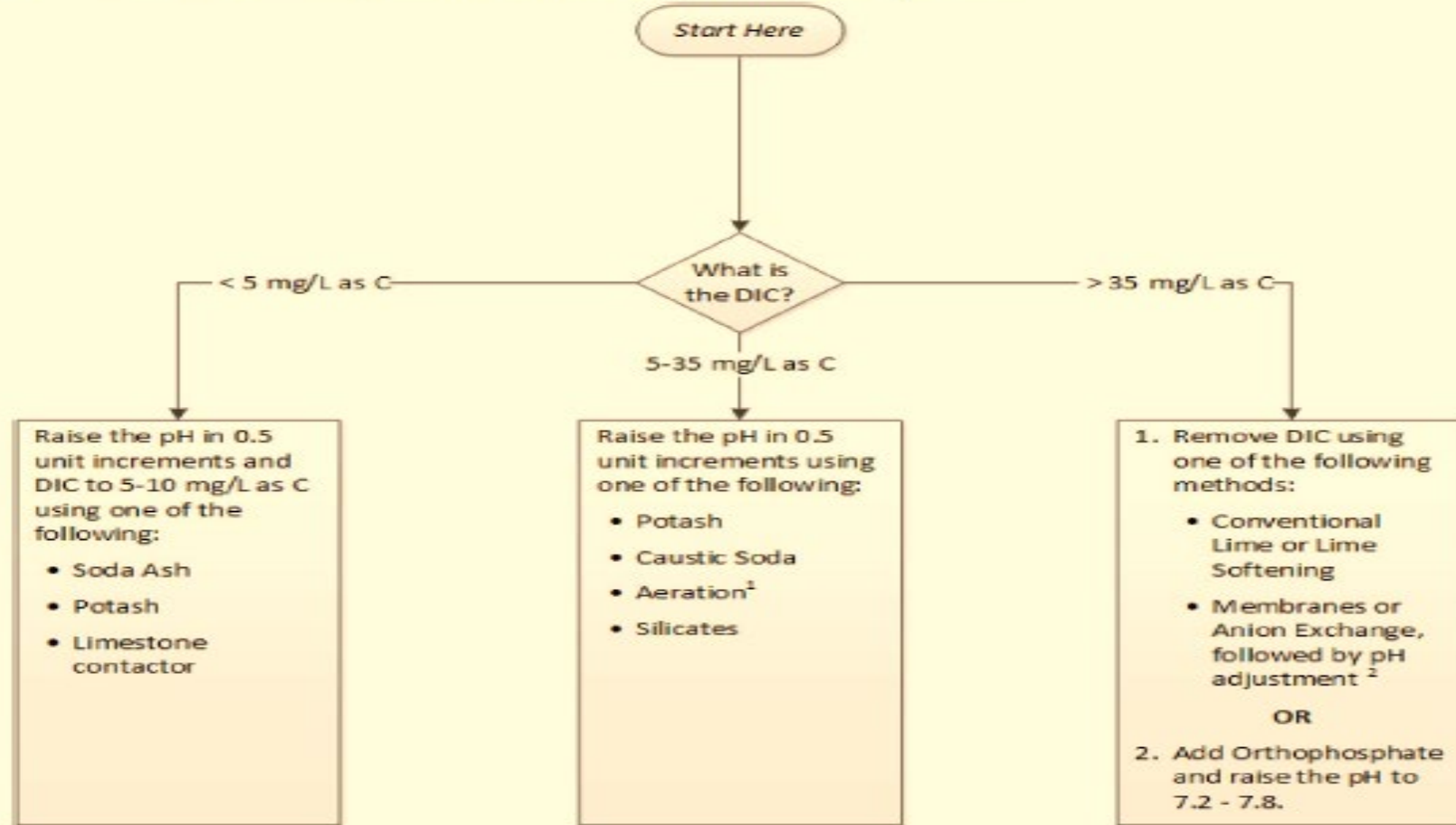
### Flowchart 1d: Selecting Treatment for Lead only or Lead and Copper with pH > 9.5



KEY:  
AL = Action Level  
Baking soda = sodium bicarbonate (NaHCO<sub>3</sub>)  
DIC = Dissolved Inorganic Carbon



### Flowchart 2a: Selecting Treatment for Copper Only with pH < 7.2

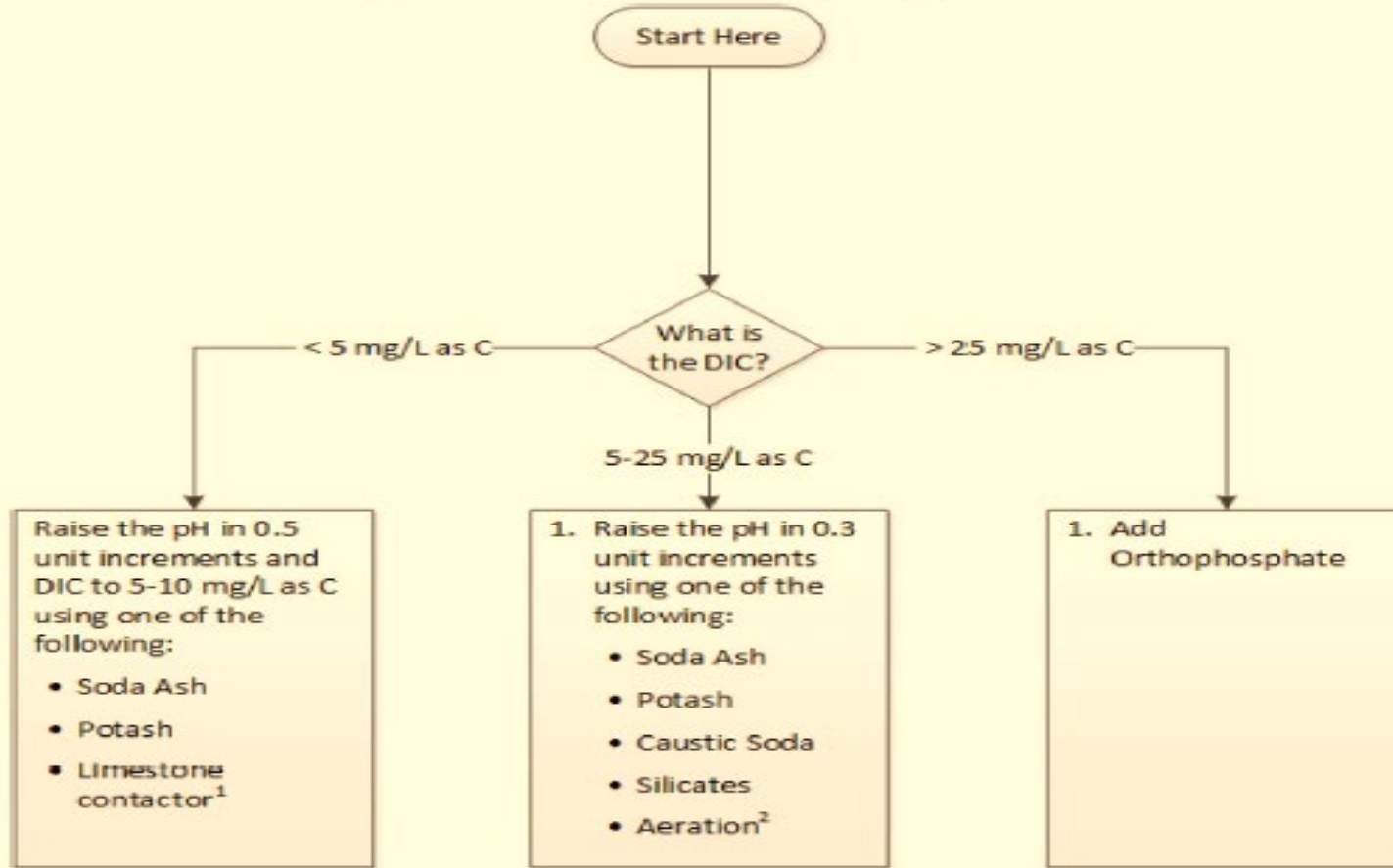


**KEY:**  
AL = Action Level  
Caustic soda = sodium hydroxide (NaOH)  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon  
Potash = potassium carbonate (K<sub>2</sub>CO<sub>3</sub>)  
Soda ash = sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>)

**Footnotes:**  
1. May be most appropriate at higher end of DIC range  
2. To achieve optimal levels, consider treating less than 100 percent of the water (i.e., split stream).



### Flowchart 2b: Selecting Treatment for Copper Only with pH from 7.2 to 7.8

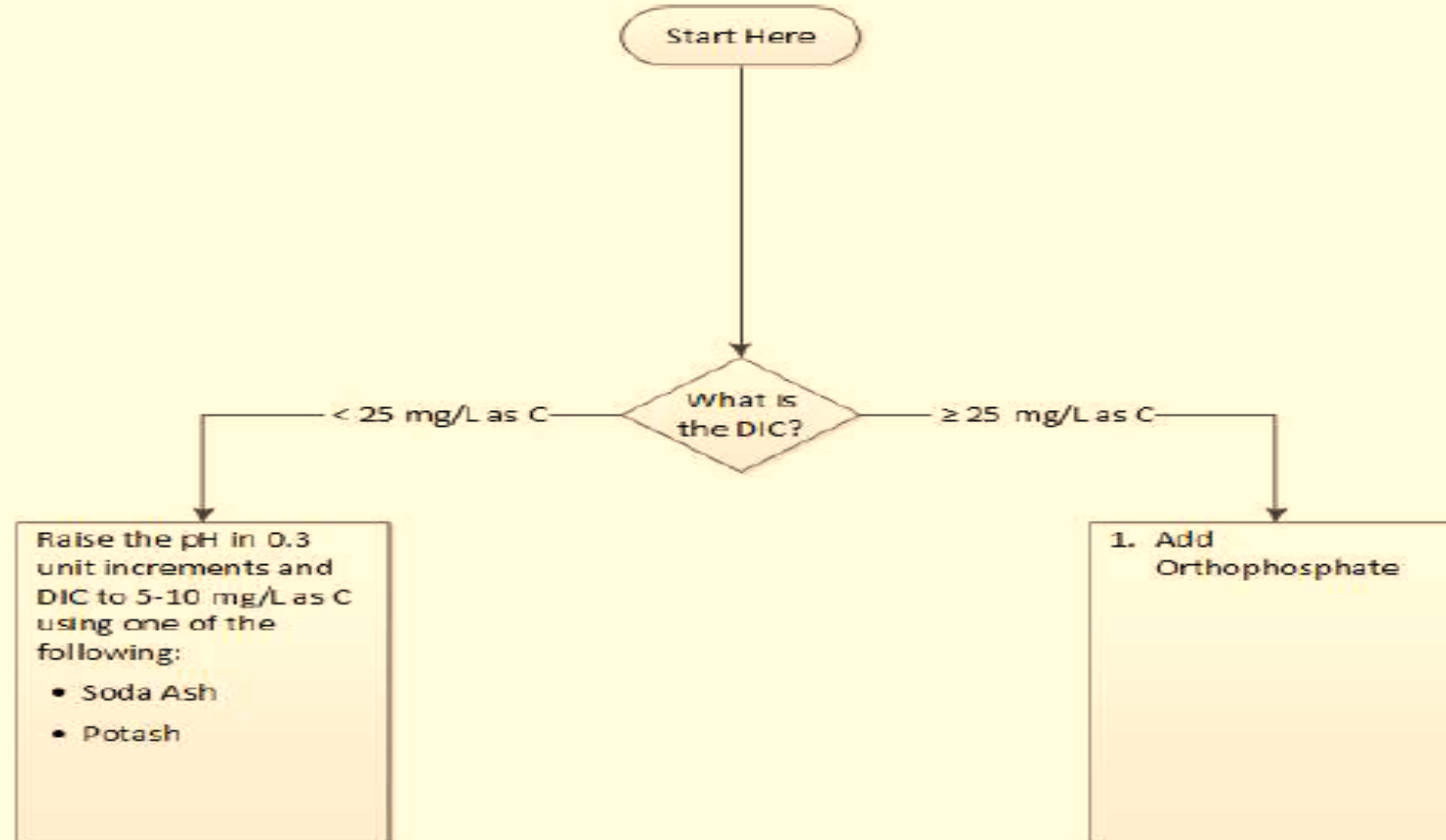


**KEY:**  
AL = Action Level  
Caustic soda = sodium hydroxide (NaOH)  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon  
Potash = potassium carbonate (K<sub>2</sub>CO<sub>3</sub>)  
Soda ash = sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>)

**Footnotes:**  
1. Carbon dioxide feed before the limestone contactor may be necessary.  
2. May be most appropriate at higher end of DIC range



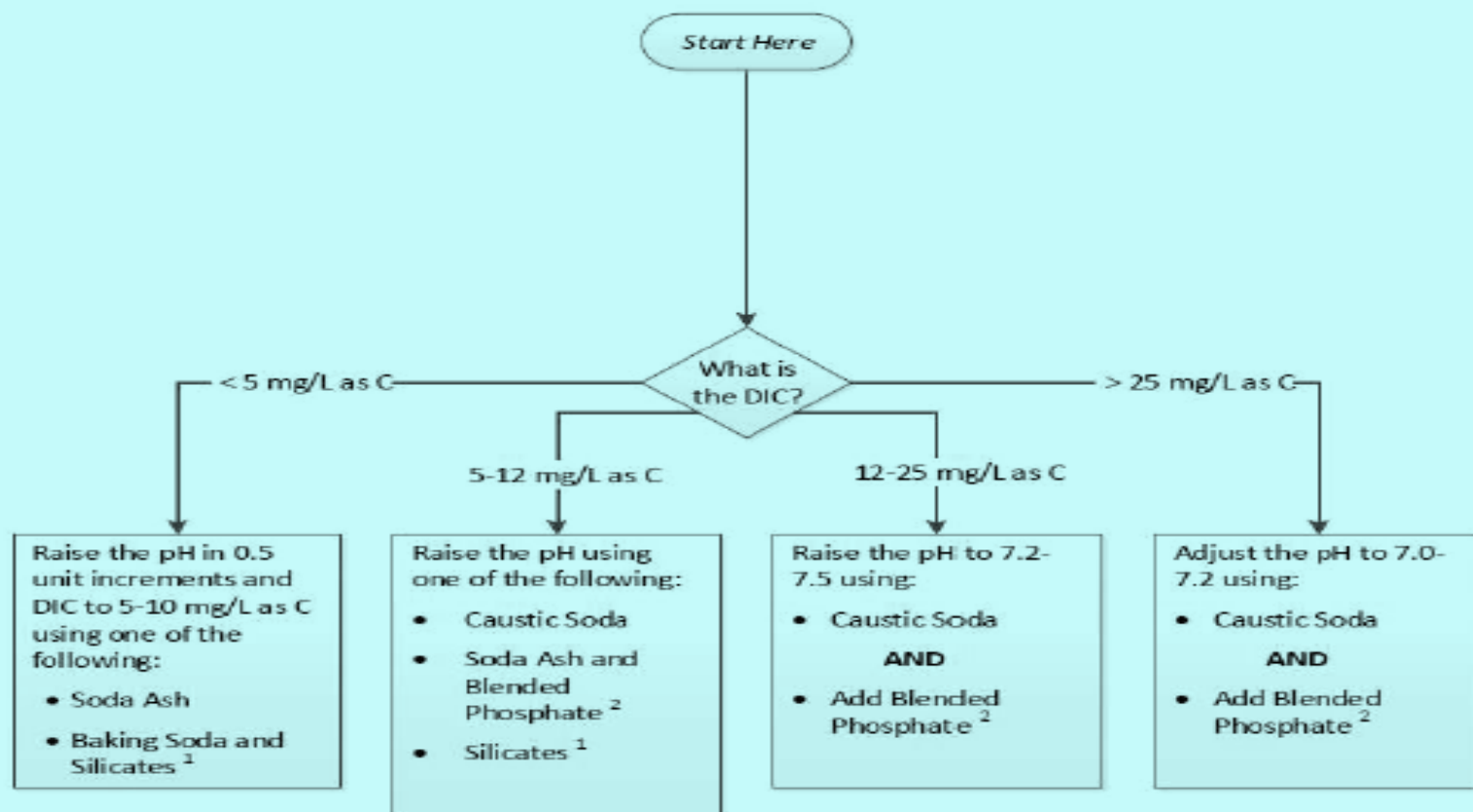
### Flowchart 2c: Selecting Treatment for Copper Only with pH > 7.8



KEY:  
AL = Action Level  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon  
Potash = potassium carbonate ( $K_2CO_3$ )  
Soda ash = sodium carbonate ( $Na_2CO_3$ )



### Flowchart 3a: Selecting Treatment for Lead and/or Copper with Iron and Manganese in Finished Water and pH < 7.2



**KEY:**  
AL = Action Level  
Baking soda = sodium bicarbonate (NaHCO<sub>3</sub>)  
Caustic soda = sodium hydroxide (NaOH)  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon  
Soda ash = sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>)

**Footnotes:**  
1. Silicates are most effective when combined iron and manganese concentrations are less than 1.0 mg/L.  
2. The effectiveness of blended phosphate varies based on the formulation. Additional evaluation and/or monitoring is recommended. See Section 3.3.2 for additional discussion.





### Flowchart 3b: Selecting Treatment for Lead and/or Copper with Iron and Manganese in Finished Water and pH $\geq 7.2$



**KEY:**  
AL = Action Level  
Baking soda = sodium bicarbonate ( $\text{NaHCO}_3$ )  
DIC = Dissolved Inorganic Carbon  
mg/L as C = milligrams per liter as carbon

**Footnotes:**

1. Silicates are most effective when combined iron and manganese concentrations are less than 1.0 mg/L.
2. The effectiveness of blended phosphate varies based on the formulation. Additional evaluation and/or monitoring is recommended. See Section 3.3.2 for additional discussion. Blended phosphates are less effective for controlling copper at DIC greater than 25 mg/L as C.



# Langelier Saturation Index

- **The LSI is a corrosion index used to determine a water's potential to be:**

aggressive/corrosive=negative LSI

**OR**

scale forming=positive LSI



- **The LSI is based on a water's calcium carbonate saturation point.**

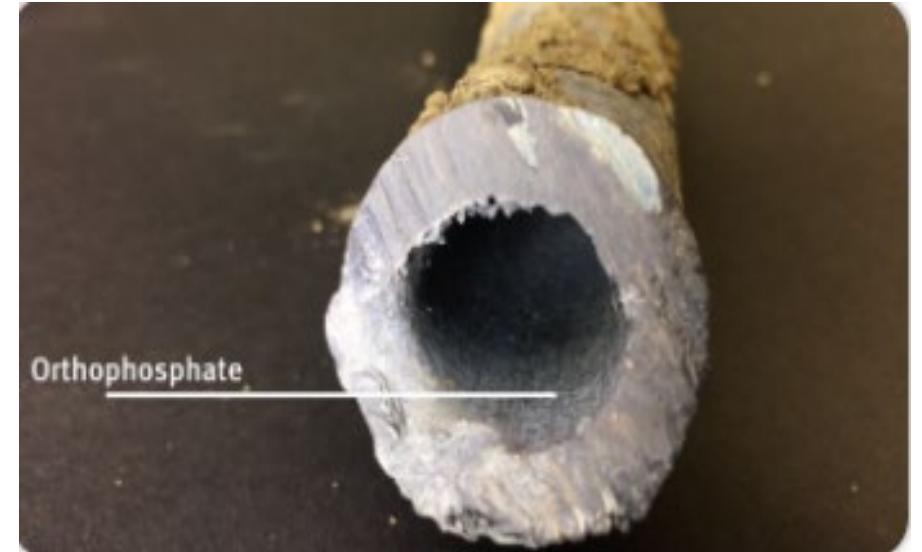
A water that is saturated with calcium has the potential to precipitate calcium/magnesium carbonates.

A water that is not saturated with calcium has the potential to dissolve calcium/magnesium carbonates.



# Unintended Consequences

- Orthophosphates- Nutrient loading to WWTP or surface water discharge
- Zinc Orthophosphate- Zinc in WWTP residuals  
Surface water discharge  
Inhibition of Nitrification/Denitrification at WWTP
- Overfeeding polyphosphates/blended phosphates  
Can start to sequester Lead and Copper
- Aluminum  
Aluminum Phosphate precipitates  
Reduced Head loss and pipe diameters  
Aluminum Phosphate Scale prone to sloughing when disturbed





# Unintended Consequences

- Other Treatment processes that could be Impacted by raising pH
  - Increase in TTHMs
  - Increase in Disinfectant Contact Time Needed
- Calcium Carbonate Precipitation
  - High Hardness (calcium), raising pH or DIC

If raw water is high in Calcium  
May need to remove with Ion Exchange,  
Membranes, Lime Softening





# Summary

- Two Main Forms of Corrosion Control
  - Carbonate Passivation
  - Corrosion Inhibitor Passivation
- Goal of Passivation
  - Creating an insoluble adherent barrier (metal complexes) between the water and the pipe wall
- Understand your water's chemistry and operate within optimal ranges
- Use Multiple tools to correct unstable water
  - Make changes in small increments then measure effectiveness
  - Perform pilot studies and/or site-specific investigations







# QUIZ

- 1.) Most lead action level exceedances originate from naturally occurring lead in the ground water? True/False
- 2.) If the pH of Bleach is 13 and the pH of an Ammonia solution is 11, bleach is \_\_\_\_\_ times more alkaline than Ammonia?
- 3.) At what pH range is a waters buffering capacity the lowest?
- 4.) Why do regulators care most about corrosion?
- 5.) Water with an Alkalinity of 200 mg/L CaCO<sub>3</sub> and a pH of 9 is likely to be: scale forming, or stable, or corrosive
- 6.) Water with an Alkalinity of 50 mg/L CaCO<sub>3</sub> and a pH of 6.5 is likely to be: scale forming, or stable, or corrosive
- 7.) Polyphosphates are excellent corrosion inhibitors True/False
- 8.) Hardness is primarily composed of Calcium and Magnesium, or Chloride and Sulfate, or Iron and Manganese
- 9.) TDS is closely related to: Alkalinity, or pH, or conductivity
- 10.) Copper corrosion is easy to spot on exposed pipe due to its characteristic \_\_\_\_\_ color?
- 11) Alkalinity and Hardness are both expressed as mg/L of CaCO<sub>3</sub>?
- 12.) Galvanized Iron pipe is coated with \_\_\_\_\_ to prevent corrosion?
- 13.) The optimal pH range for Orthophosphates to work best is \_\_\_\_\_?
- 14.) Name one way to increase your pH without adding chemicals.
- 15.) Polyphosphates should be added before or after chlorination?
- 16.) Why is Calcium precipitation rarely used as a means of corrosion control?
- 17.) Gas chlorine raises/lowers the pH? Sodium Hypochlorite raises/lowers the pH?
- 18.) What does pH stand for?
- 19.) Water with a Hardness of 16 mg/L CaCO<sub>3</sub> would be considered soft.
- 20.) Immediately prior to collecting Lead & Copper samples for compliance it is important to clean the faucet aerator screens.



# Lessons Learned







# THANK YOU

**Patty Baron**

**Environmental Specialist III**

Florida Department of Environmental Protection

Contact Information:

Phone (239) 344-5615

Email: [Patty.Baron@FloridaDEP.gov](mailto:Patty.Baron@FloridaDEP.gov)



Closing slide

