Distribution System Considerations for Treatment

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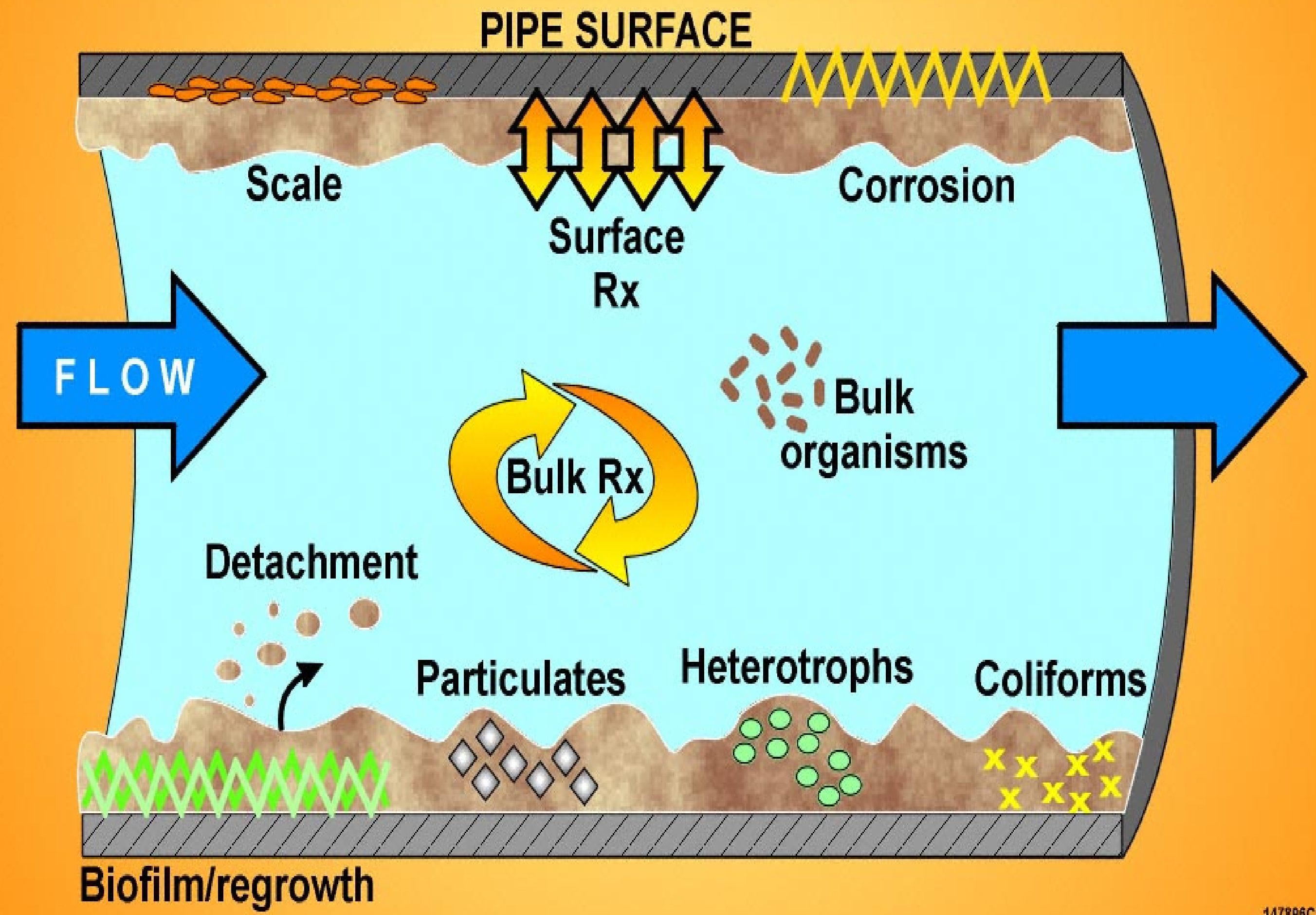
The Distribution System as Reactor



Examples of Distribution System Piping

Most often, treatment changes are applied to "old" pipes

Unlined iron

Asbestos-Cement

General Nature of Pipe Surfaces

- Metallic
  - Oxides, hydroxides, hydroxycarbonates, carbonates, hydroxysulfates, etc. from corrosion
  - Similar compounds from deposition or post-precipitation (particularly Fe, Mn, Al), may include silicates
  - Phosphates from corrosion control
  - All may be mixed with NOM

General Nature of Pipe Surfaces

- Cement (A-C, CML, Concrete)
  - Metallic oxides, hydroxides, hydroxycarbonates, carbonates, hydroxysulfates, silicates,etc. from deposition or post-precipitation
  - Aluminosilicates, hydroxides, hydroxycarbonates from "corrosion"
  - May be mixed with NOM

General Nature of Pipe Surfaces

- Plastics
  - Metallic oxides, hydroxides, hydroxycarbonates, carbonates, hydroxysulfates, silicates,etc. from deposition or post-precipitation
  - May be mixed with NOM

How Might Pipes Be Reactors?

- Sorption, desorption of constituents
- Dissolution, precipitation, coprecipitation
  - Corrosion/solubilization
  - Post-deposition
  - Instability of water quality
    - Anions
    - Oxidants
    - pH
    - NOM

How Might Pipes Be Reactors?

- Substrate for microbial activity
  - Transformation of sorbed material
    - Redox reactions
    - DBP's
    - Nitrification
  - Microbially-specific parameters
    - HPC
    - Pathogens?
- Lime (Ca, OH^-) and Al leaching from cements

Holistic View of Treatment Changes and Possible Adverse Impacts

Some Thoughts on Vulnerability to Unintended or Unwanted Side-Effects

Imbalancing Processes

- Softening processes
- "Tight" membrane processes
- Optimum or enhanced coagulation
- Polyphosphate sequestration
- Major changes to pH, Ca, Alkalinity

Softening Processes

- Over-softening
- "Enhanced softening" & Mg removal
- Ion-exchange
- Membrane softening

"Tight" Membrane Processes

- Reverse Osmosis (RO)
- Nanofiltration (NF)
- Electrodialysis reversal (EDR)

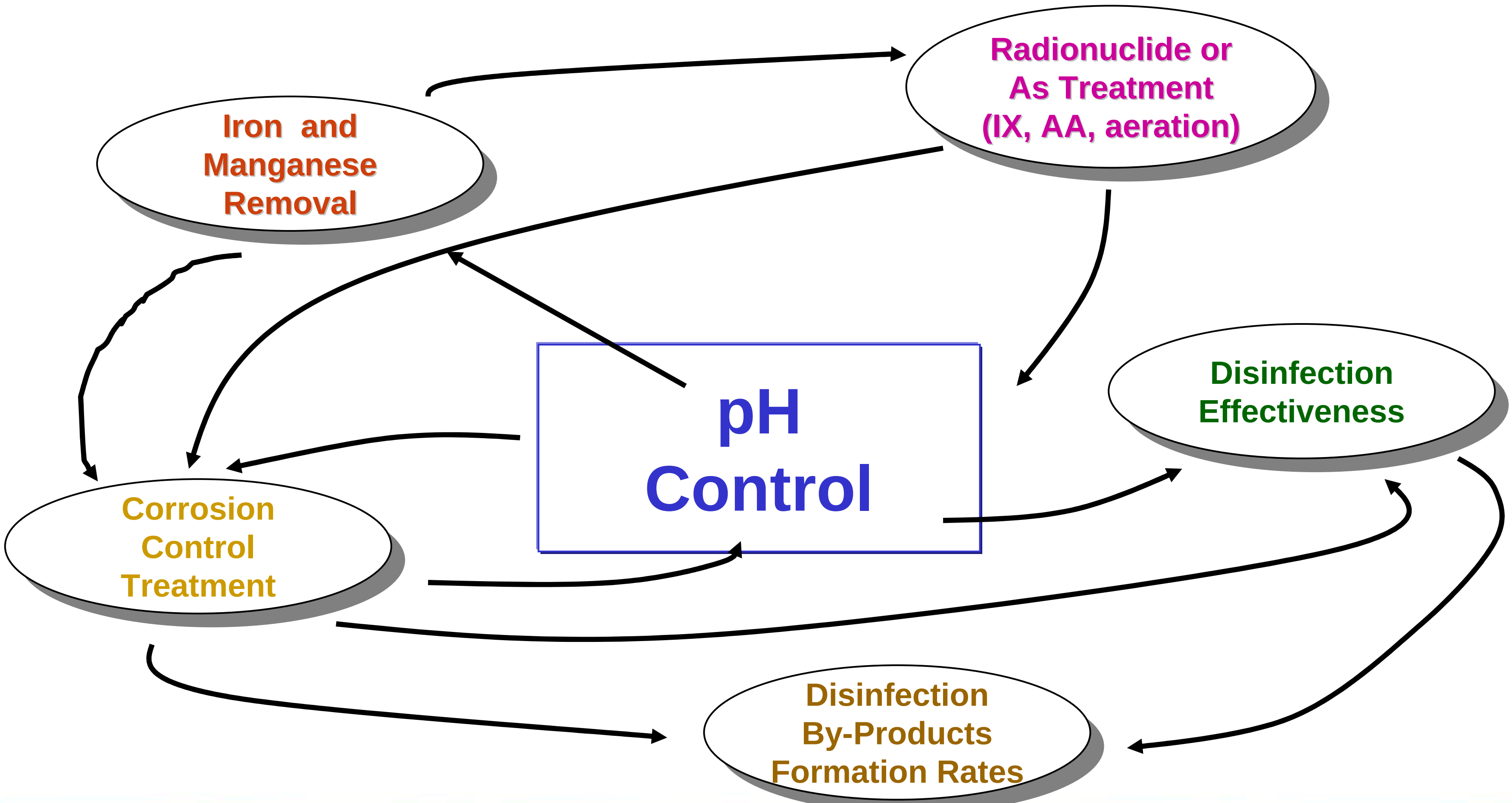
Optimum or Enhanced Coagulation

- Lowers pH
- Increases sulfate or chloride

Polyphosphate Sequestration

- Reduces effectiveness of existing Ca, HCO_3^-
- Attacks calcareous cement minerals
- Prevents Ca-supported passivation (when hardness plays beneficial role)

pH Interactions with Treatment Processes



Potential Treatment Change Impacts by Reg

LCR Chemistry Considerations

- pH in distribution system
- DIC
- (Ortho)phosphate addition
- ORP

ESWTR Interactions

- Coagulant increase = alkalinity decrease
- Acid addition to depress pH
- Role of residual aluminum

Groundwater Rule

- Change in oxidation state affects metals in solution
  - Iron
  - Manganese
  - Copper
  - Arsenic
- Disturb existing distribution system
  - Fremont, Nebraska started chlorination
  - Release of iron, copper and arsenic
  - Particular problem in high alkalinity, near neutral pH waters of Midwest

Arsenic Removal Interactions

- Nanofiltration and RO - may require pH depression and remove hardness, DIC
- Anion exchange - pH adjustment, supplement DIC to replace loss
- Activated alumina - may require pH adjustment before and/or after
- Iron Media - may require oxidizing conditions either for disinfection or enhanced removal
- Ferric coagulation - requires oxidizing conditions

Radon

- Aeration is BAT
  - Removes carbon dioxide
  - Raises pH
  - Changes redox conditions

Radionuclides: Radium

- Cation exchange - removes calcium, can depress pH
- Alumina - can change pH or needs lowered pH
- Nanofiltration - pH adjustment, can remove hardness, DIC
- RO - Needs pH adjustment, removes hardness, DIC

Radionuclide - uranium and Inorganics - nitrate and nitrite

- Anion Exchange
  - May require pH adjustment and stabilization
  - Supplement alkalinity to increase DIC lost via carbonate and bicarbonate removal

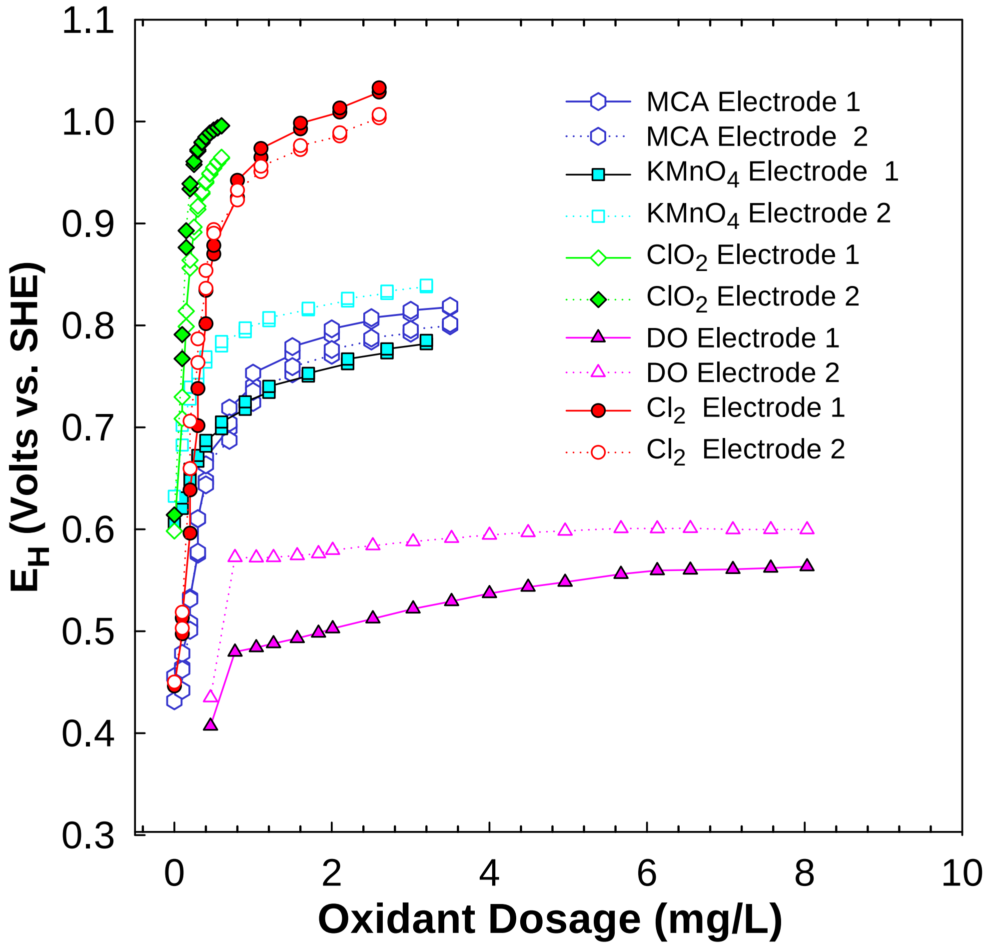
Treatment Changes Related to Oxidant/Disinfectant Changes

Treatment Influences on ORP in Drinking Water

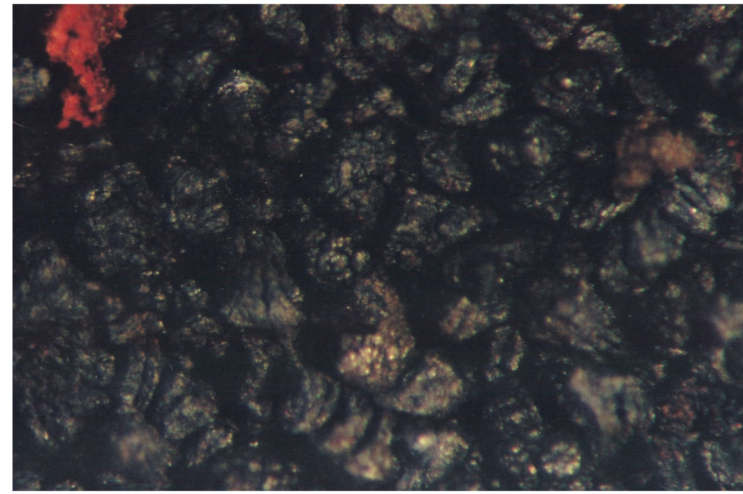
- Disinfection
- Pre-oxidation (O_3, H_2O_2, ClO_2, $KMnO_4$)
- Oxidative metal removal (eg. As, Fe, Mn)
- Ammonia removal
- Aeration (corrosion control, VOC, Rn, H_sS removal)
- Taste and odor control

Redox Potential of Common Oxidants

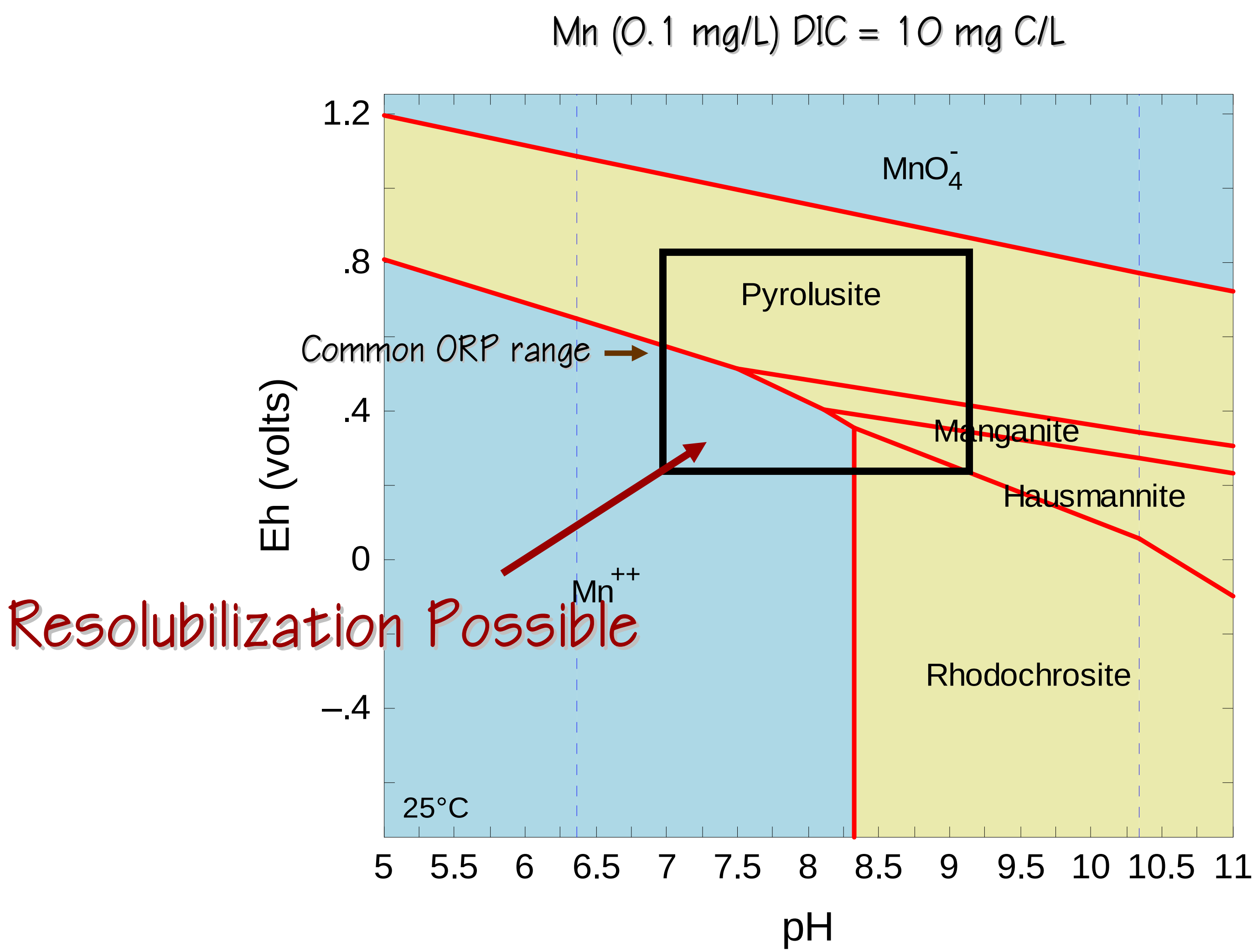
(pH 7, 10 mg C/L, 25°C)



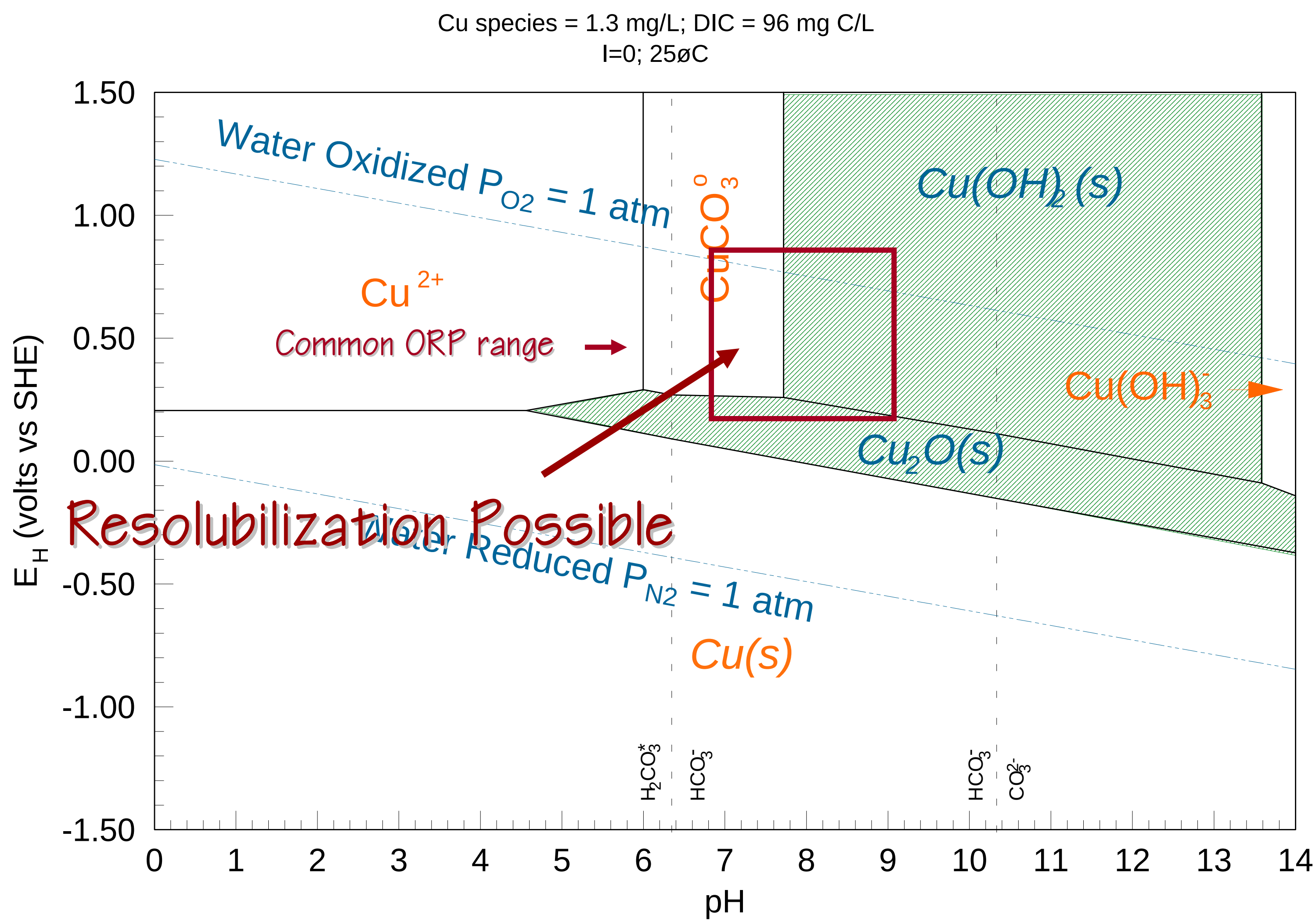
Mn Deposit from Northeastern US DS



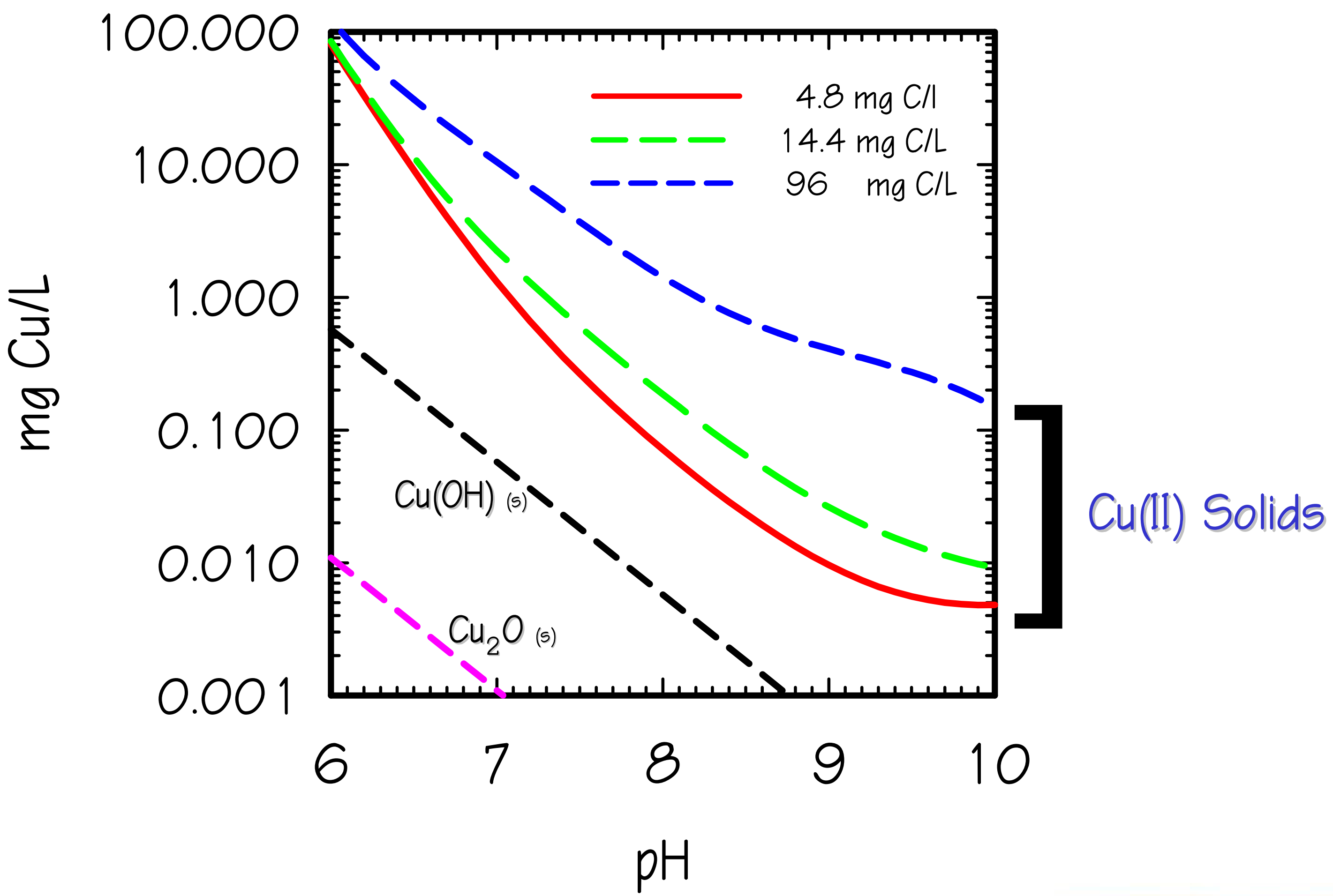
pH & ORP Impact on Manganese



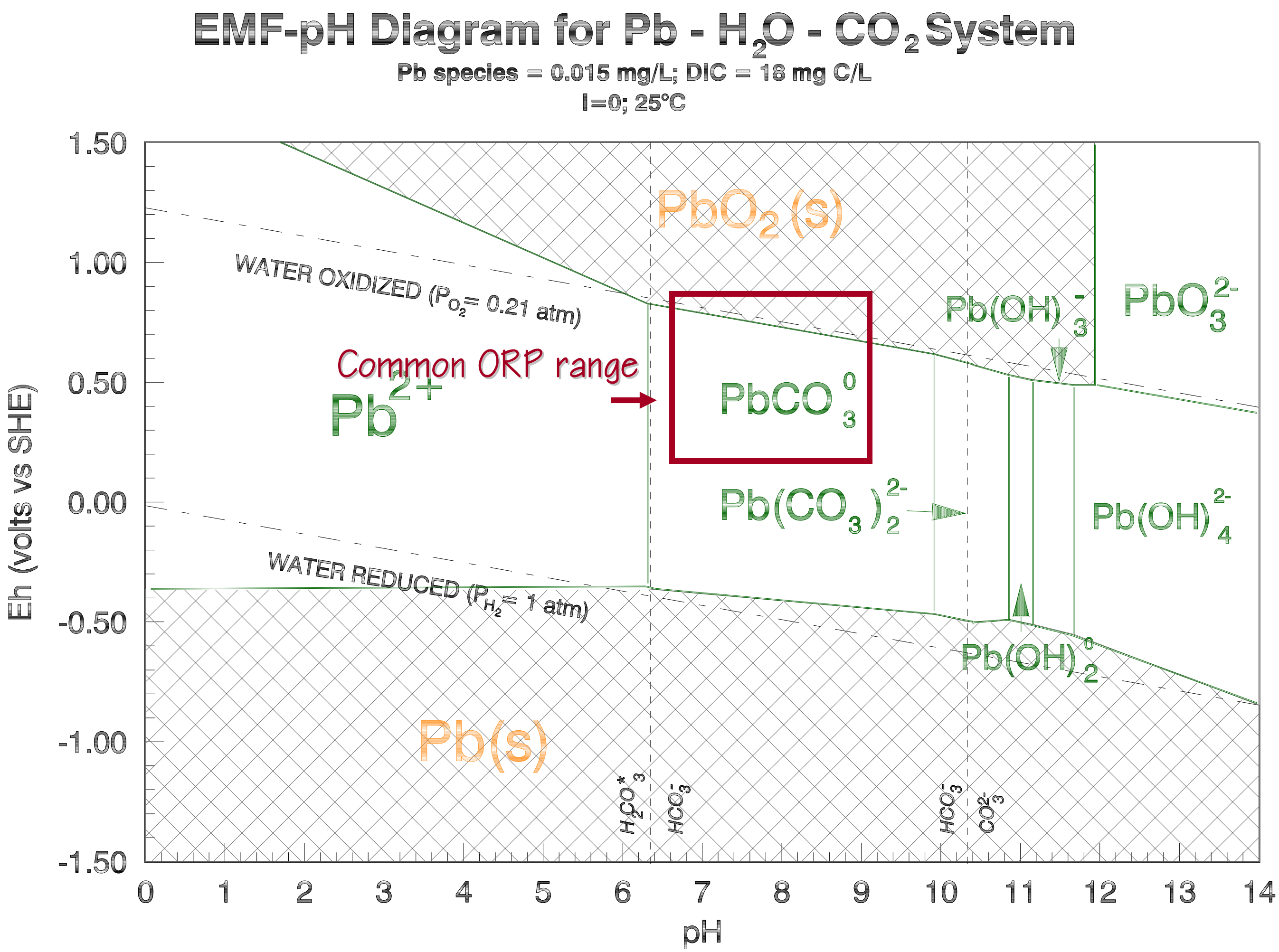
ORP-pH Effects in High DIC Water



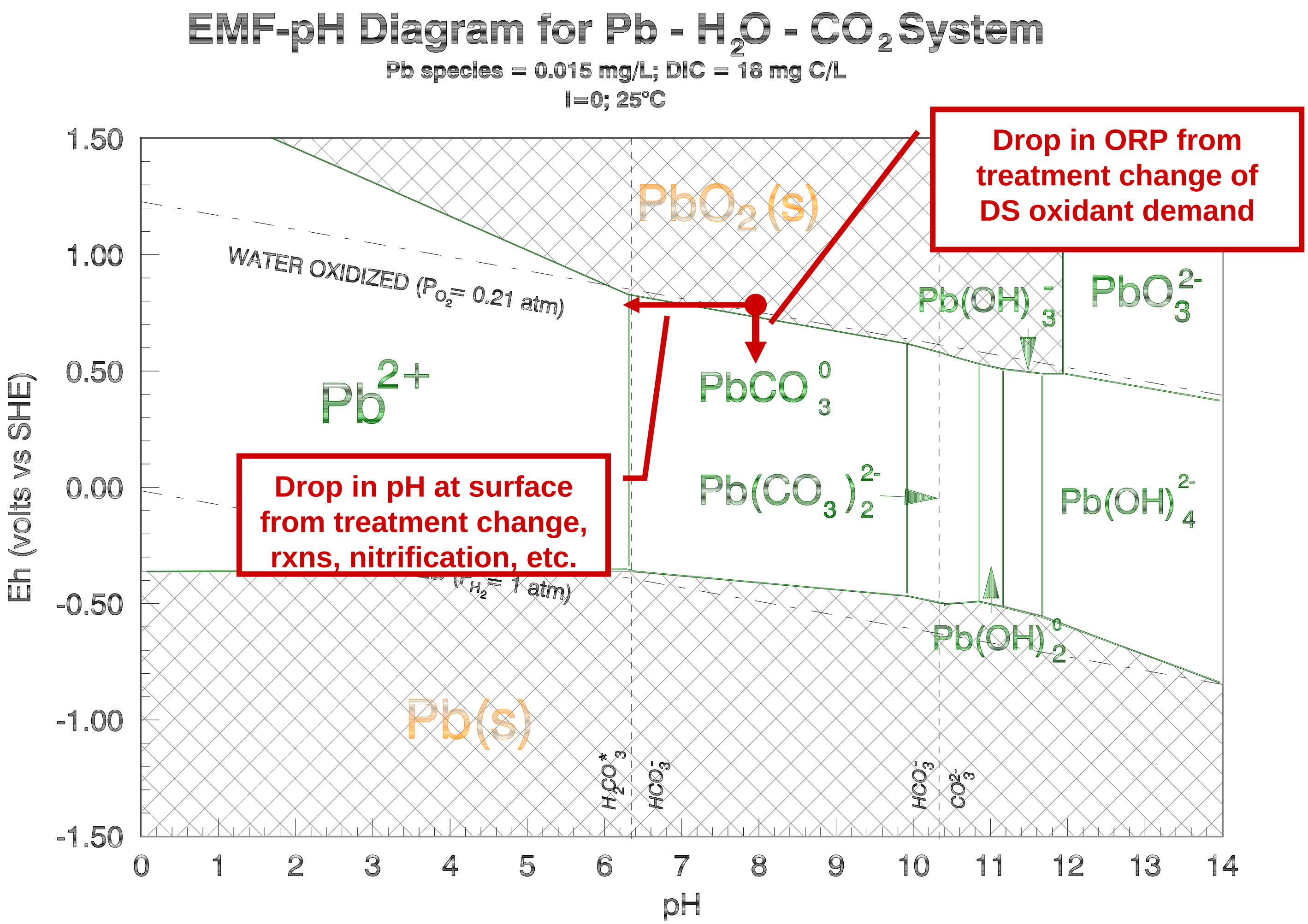
Introducing Disinfection or Oxidation: May Induce New Copper Corrosion Issue



Pb(II)-Pb(IV) Relationships

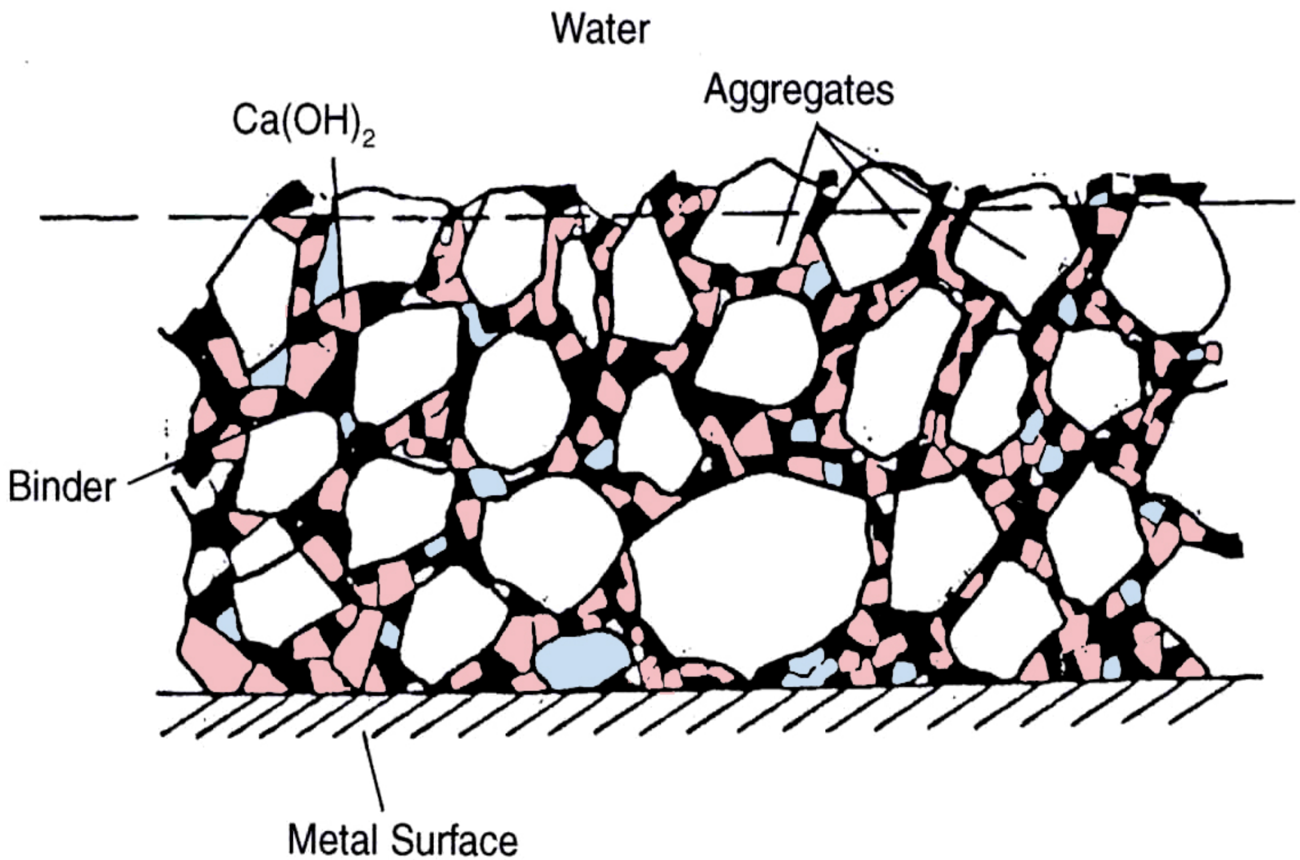


Ways to Destabilize PbO_2



Beware! Cements Are Not Inert!!

Schematic Anatomy of Cement Lining



Manifestations of Cement Deterioration

- Increased pH
  - Decreased performance of lead or copper control with phosphate dosing
  - Turbid water from various precipitates
  - Taste problems
  - Higher THM's
  - In extreme cases (pH >> 10), higher lead

Manifestations of Cement Deterioration

- Increased aluminum
  - possible future CCL issue
  - challenge to industry or hospital treatment
- Increased calcium
- Increased trace metals

Remedies for Cement Deterioration

- Materials-based
  - Alternate cement mixes
    - Carefully check for data from similar water
    - Compare vendors and processes
    - Some experience in UK with modified mortar
    - Do NOT use CML in low-flow or dead end areas
  - Epoxy material relining
  - Various plastic lining processes

How Does Zinc Protect Cement?

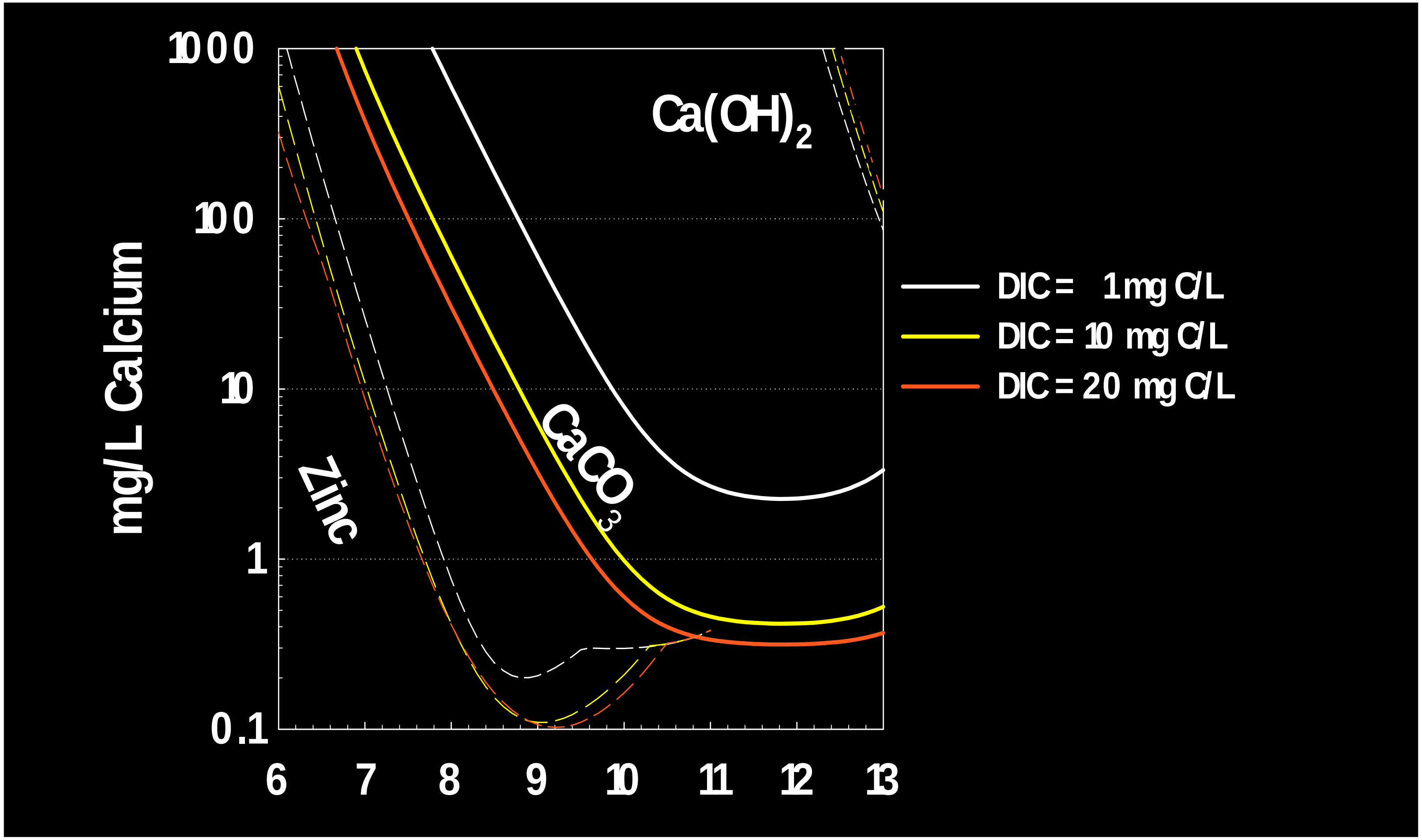
2- Step Hypothesis (hemimorphite example):

$$5Zn^{2+} + 2CO_3^{2-} + 6H_2O \rightleftharpoons Zn_5(CO_3)_2(OH)_6 + 6H^+$$

$$4\{Zn_5(CO_3)_2(OH)_6\} + 10\{Si(OH)_4\} \rightleftharpoons$$

$$5\{Zn_4Si_2O_7(OH)_2 \bullet H_2O\} + 8CO_3^{2-} + 16H^+ + 14H_2O$$

Solubility of Protective Initial Zinc Solids Compared to Calcium Solids



Avoiding or Mitigating Possible Adverse Impacts

Solutions for Imbalances

- Careful process control
- Post-treatment
  - Recarbonation (softening)
  - Limestone/dolomite contactors
  - Chemical adjustments
    - pH
    - Corrosion inhibitors
    - Others (eg. lime, soda ash, etc.)
  - Aeration
- Blending (when feasible)

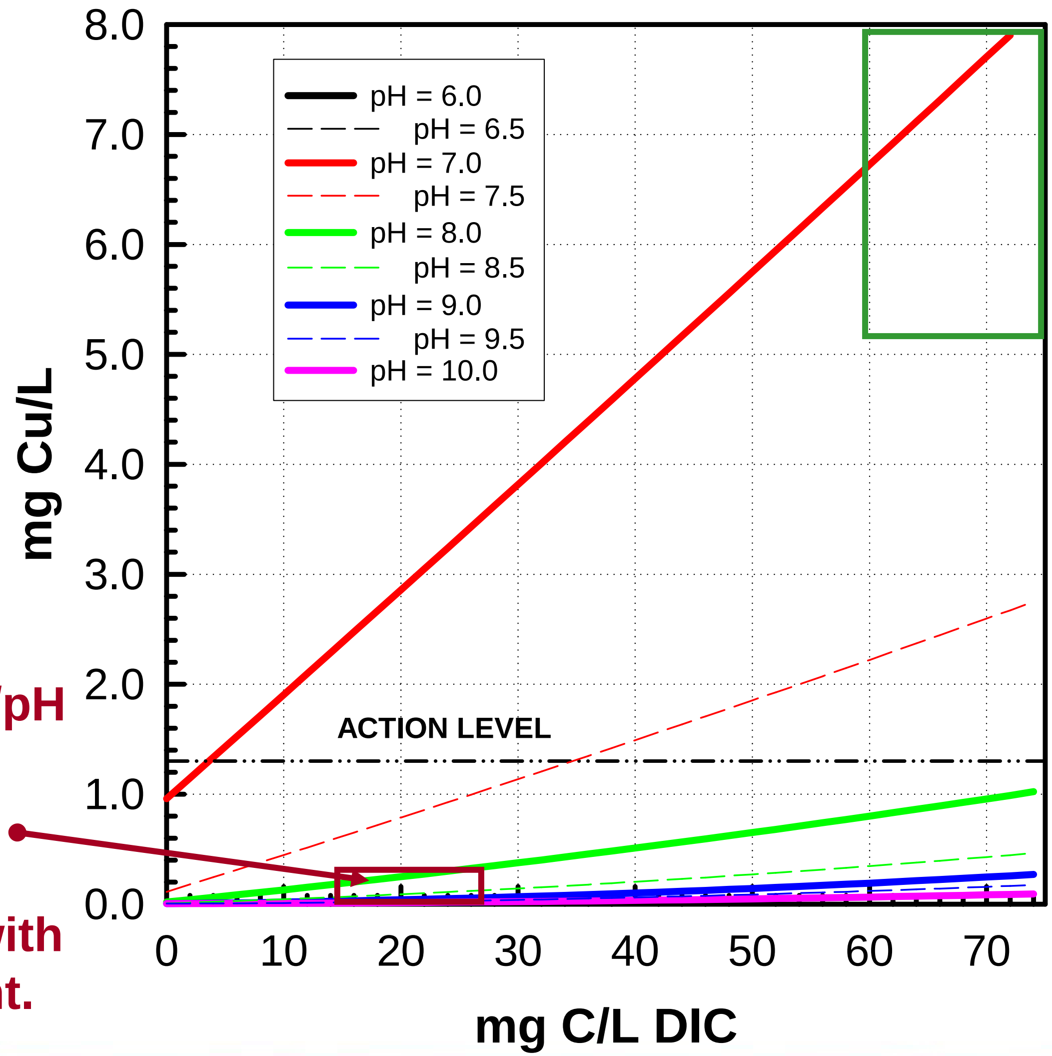
Minimize Water Quality Changes

- Well-buffered water
  - Reduces general corrosion
  - Reduces tuberculation of iron
  - Deters nitrification
  - Holds quality with storage
  - Facilitates action of phosphates
- Balance of hardness, DIC, pH--Why?
  - Unlined iron
  - Cement linings
  - Asbestos-cement

Special Softening Issues

- Copper corrosion impacts
- Polyphosphate over-dosing in lime-softened systems

All Softening Processes Are Not Equal



Common DIC/pH zone for hard ground waters (extending off chart).

NOTE: IX softening leaves DIC/pH unchanged.

Common DIC/pH zone for lime softening. Similar for membranes with post-treatment.

Effect of polyphosphate on phosphate dose response (Colin Hayes, Swansea Univ.)

Median Pb emissions (µg/l) after 30 min contact with new Pb pipe at 25^{o}C

o-PO4 dose	Zero poly-P	0.2 mg/l poly-P	1.6 mg/l poly-P
0	142	143	281
1	3	19	54
2	3	12	51
3	3	10	44
4	3	9	32

Be careful not to overdose polyphosphate, or hydrocerussite protective coatings will be damaged.

Watch for Study Extrapolation Problems

Lab to Field

- "New" surface vs. "old" surface
  - Reaction with existing scale
  - No cathodic reaction on "old" surface
  - Corrosion rate vs. metal release tendency
- Stagnation time
- Differences in materials
- "Aging" rates could be months to years

Some Constructive Pro-actions

- Know the locations of materials in DS and how water flow relates to them
- Consideration of potential changes in water treatment should trigger
  - Studies of impact on existing scales
  - Enhanced monitoring during implementation

Constructive Pro-actions

- Examples of significant changes
  - Anything that changes pH
  - Corrosion inhibitor formulations
  - Coagulation/coagulant changes
  - Disinfection/disinfectant changes
  - Membrane filtration
  - Mixing/blending

More Constructive Pro-actions

- Know what inorganics/radionuclides are in source water, even if below MCL
  - Monitor periodically in DS
  - Trigger more DS monitoring when
    - Hydraulic disturbances (fires, main breaks, flushing)
    - Drought conditions or storms change water quality
    - Unusual microbial data noted
    - Consumers complain of discolored water or unusual tastes

Final Suggestion for LCR Conflicts: Optimal Corrosion and DBP Control

- Removal of precursor material solves problems
  - Reduces DBP formation and potential formation
  - Reduces nutrient material, starving biofilms
  - Reduces disinfectant demand and decay
- Coupling with iron corrosion control is important
  - Reduces demand, hence dosage, hence DBPs
  - Reduces microbe habitat, less disinfectant needed

Questions?

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