Corrosion in your distribution system… the silent pipe killer

NEWFOUNDLAND DESIGN ASSOCIATES LIMITED
CONSULTING ENGINEERS

Clean and Safe
Drinking Water Workshop
Gander, NL 2004

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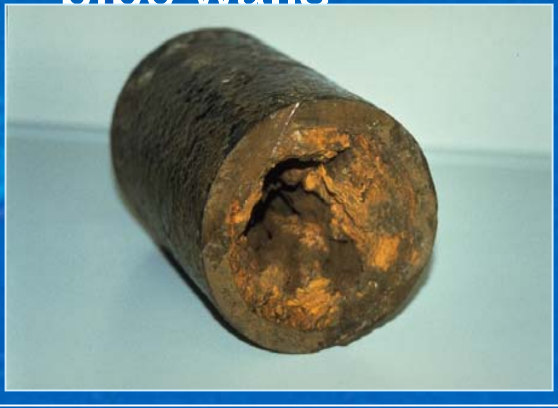
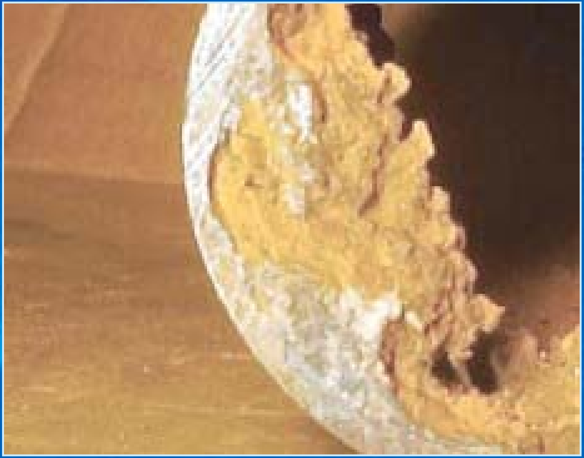
Overview of Presentation

- What is corrosion?
- Why do we care?
- How to determine if your water is corrosive
- How to control corrosion
- Example where corrosion control measures are being implemented

What is Corrosion?

- Gnawing away or attack on a material, usually by some chemical or electrochemical means
  - Thinning of pipe walls or,
  - Formation of a precipitate on pipe walls





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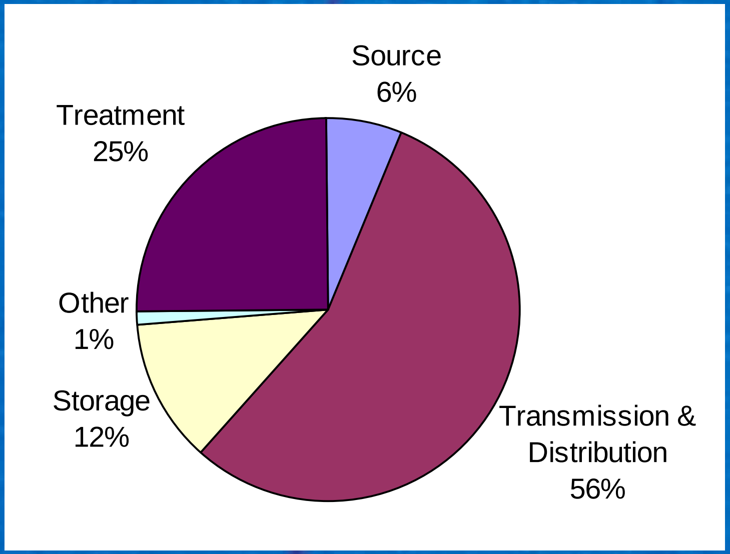
Why Should We Care?

- Corrosion leads to two different kinds of problems
  - Pipe killer - failure of pipe
  - Water quality changes (aesthetic and health)
- Economics - investment in buried infrastructure (pipes, valves, etc)
  - Greater than the cost of the treatment plant



Source: EPA's 1999 Drinking Water Infrastructure Needs Survey

Failure of Pipes

- Impact on carrying capacity of a pipe
  - Thinning of pipe
    - Pipe leakage
    - Catastrophic pipe failure
  - Formation of a precipitate
    - Loss of hydraulic capacity
- Economic impact
  - Early replacement of piping, plumbing and water heaters
  - Increased pumping costs

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Water Quality Changes

- Potential to remove metals (copper, lead and iron) from pipes in distribution system
  - Health concerns - toxic properties of metals such as lead
  - Regulatory compliance
- Staining of laundry and plumbing fixtures
  - Aesthetic objectives
  - Red/brown from iron, blue/green from copper
- Creates areas for microorganisms to live

Factors Impacting Corrosion

- Dissolved oxygen
- pH - acidic or caustic nature of water
- Alkalinity - capacity of water to neutralize an acid, expressed as mg/L of $CaCO_3$
- Calcium concentration
- Suspended solids and organic matter
- Free chlorine residual
- Temperature

How to Measure Water's Potential for Corrosion

- Many methods can be used
- Visual signs
  - Dirty water, staining, corroded pipe, pipe failures
- Measurement and observation in distribution system
  - Compare copper, iron or lead levels at the plant with first flush concentration at consumer taps
  - True indication of what is happening in distribution system
    - Associated analytical costs

How to Measure Water's Potential for Corrosion

- Calculation using a corrosiveness index
  - Based on pH, alkalinity and calcium
    - Aggressive Index
    - Ryznar Index
    - CCPP (Calcium Carbonate Precipitation Potential)
    - Langelier Saturation Index (LSI)
  - Computer programs simplify the calculations
  - Rough guide - there is no perfect index
- Corrosion chemistry is very complex!

Corrosiveness Index

- Langelier Saturation Index (LSI) - most commonly used
  - Estimates the theoretical tendency of a water to form a protective coating of calcium carbonate ($CaCO_3$) on a pipe wall
    - Under-saturated water is corrosive (negative LSI)
      - Most raw surface waters in Newfoundland
    - Over-saturated water will deposit calcium carbonate (positive LSI)

LSI

- LSI can be interpreted as the pH change required to bring the water to equilibrium
- Indicator (not an absolute measurement) of the potential for corrosion or deposits
- Recommended LSI range +0.5 to -0.5

LSI Calculation

- $LSI = pH - pH_s$
  - pH = measured water pH
  - pH_s = pH at which a water is saturated with $CaCO_3$

    = (9.3 + A+ B) - (C + D)

    - A = (Log_{10} [Total Dissolved Solids in mg/L] - 1) /10
    - B = -13.12 x Log_{10} (Temperature in ºC + 273) + 34.55
    - C = Log_{10} [Calcium hardness in mg/L as $CaCO_3$] - 0.4
    - D = Log_{10} [Alkalinity in mg/L as $CaCO_3$]

LSI Calculation

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    - $D = \text{Log}_{10}$ [Alkalinity in mg/L as $CaCO_3$]
- AWWA website - LSI calculator/program
- Sample calculation provided at end of handout

Factors Affecting LSI

- LSI will increase in value if
  - Calcium hardness is increased
  - pH is increased
  - Alkalinity is increased
  - Temperature is increased
- A change in pH has greatest impact on LSI

Mitigating Corrosion

- Use only pipe and materials that can withstand corrosive water
  - PVC, stainless steel, lined steel
  - Replace existing pipes/plumbing material/solder
    - Expensive!
- Adjusting the water chemistry to make the water non-corrosive
  - Change pH and alkalinity of water
- Add a chemical to line the pipe
  - Corrosion inhibitor

Adjusting the Water Chemistry

- Alter the water quality such that chemical reactions between the water supply and pipe material favour the formation of a protective layer on the interior of the pipe walls

Adjusting the Water Chemistry

- Adjust the pH and alkalinity of the water to make it non-aggressive and stable
  - Increase pH (ideally > 8.5)
  - Increase alkalinity to 30 to 40 mg/L as $CaCO_3$
    - Maintain a constant water quality in the distribution system

Adjusting the Water Chemistry

- Various chemicals can be used
  - Increase alkalinity and pH differently
  - Chemical form varies
    - Application method varies
- Poorly buffered waters (low alkalinity and pH) may require a combination of chemicals

Chemical	Use	Composition	Alkalinity Change per mg/L of Chemical
Caustic Soda $NaOH$	Raise pH	• 93% purity liquid • Storage at <50% purity to prevent freezing	1.55 mg/L $CaCO_3$
Lime $Ca(OH)_2$	Raise pH	• 95-98% purity • Dry storage with slurry feed	1.21 mg/L $CaCO_3$
Sodium Bicarbonate $NaHCO_3$	Little increase in pH	• 98% purity • Dry storage with solution feed	0.60 mg/L $CaCO_3$
Soda Ash Na_2CO_3	Moderate increase in pH	• 95% purity • Dry storage with solution feed	0.90 mg/L $CaCO_3$

From AWWA Lead and Copper Rule Guidance Manual, Volume 2: Corrosion Control Treatment

Batching System

Liquid Chemical

Adjusting the Water Chemistry

- LSI can be used to estimate the impact of water chemistry adjustment on corrosion control
- Example
  - Raw water characteristics
    - pH = 6.2
    - Alkalinity = 3 mg/L as $CaCO_3$
    - Calcium hardness = 5 mg/L as $CaCO_3$
    - Temperature = 4^{o}C
    - LSI = -4.5
    - Water is corrosive - tendency to remove metals from pipes

Adjusting the Water Chemistry

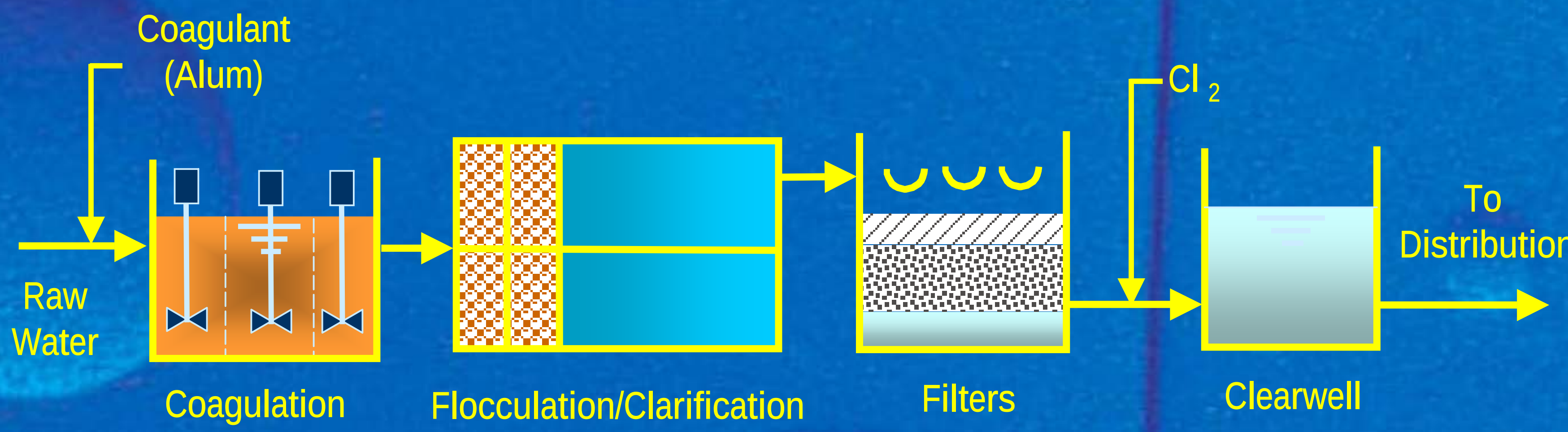
- Example (continued)
  - Add 12 mg/L of soda ash to water
  - Treated water characteristics
    - pH = 8.5
    - Alkalinity = 14 mg/L as $CaCO_3$
    - Calcium hardness = 5 mg/L as $CaCO_3$
    - LSI = -1.3
    - Treated water is less corrosive than raw water (LSI = -4.5)

Adjusting the Water Chemistry

- Selection of chemical depends on various factors
  - Cost of chemical and associated equipment
  - Impact on water quality
    - Lime addition can increase aluminum concentration
    - Sodium based chemicals will increase sodium concentration of water
    - Addition of a batched chemical (lime, soda ash, etc.) may increase turbidity of water
  - O&M and safety
  - Type of treatment provided at facility

Example - Conventional Treatment Process Train

- Coloured water
- High organic content



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Items to Consider

- Do you have sufficient alkalinity for coagulation?
  - Coagulant consumes alkalinity
    - 1 mg/L of alum consumes ~ 0.5 mg/L as $CaCO_3$
    - 1 mg/L of polyaluminum chloride (SternPAC) consumes ~ 0.18 mg/L as $CaCO_3$
  - Recommended to have > 20 mg/L as $CaCO_3$ prior to coagulation for complete coagulation reaction
    - Minimize aluminum residuals
    - Optimize organics, turbidity and colour removal

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Items to Consider

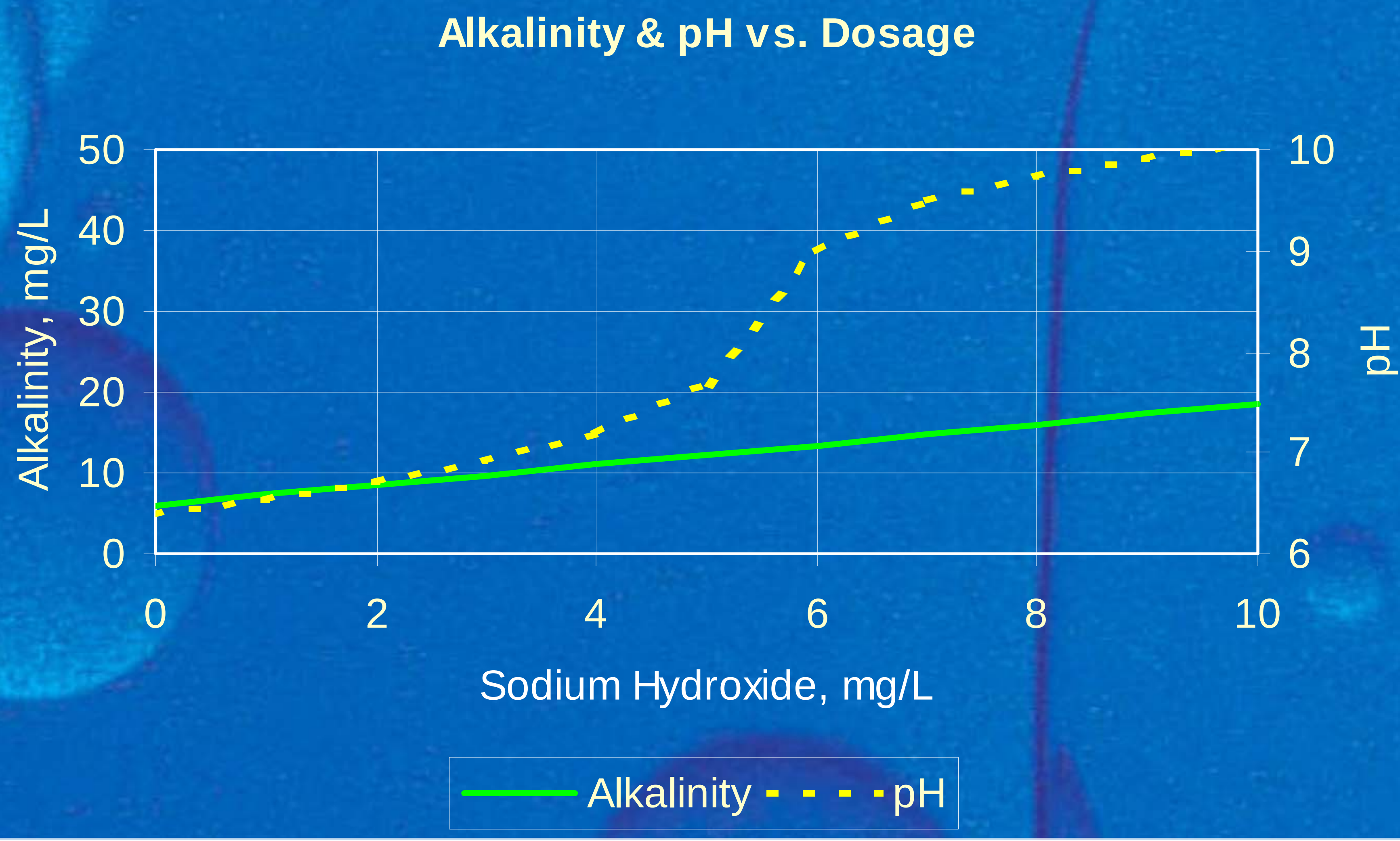
- Is the pH optimal for coagulation?
  - Alkalinity adjustment chemicals typically increases pH
  - pH reduction will most likely be required
    - Minimize aluminum residuals
    - Optimize organics, turbidity and colour removal
  - pH adjustment chemical
    - Sulphuric acid
    - Carbon dioxide (CO_2)
      - Does not consume alkalinity

Items to Consider

- Is your water non-corrosive following filtration?
  - Low pH required for good coagulation and effective disinfection
  - Higher pH is required to make water less corrosive
  - Preference to use caustic soda (NaOH)
    - Does not impact turbidity to the water
  - If insufficient alkalinity prior to NaOH adjustment, pH will drastically increase
    - Important to have > 20 mg/L of alkalinity as $CaCO_3$ after coagulation
  - Recommended treated water alkalinity = 30 to 40 mg/L to maintain water quality stable in distribution system

Low Alkalinity Example

(alkalinity = 6 mg/L as $CaCO_3$, pH = 6.4)



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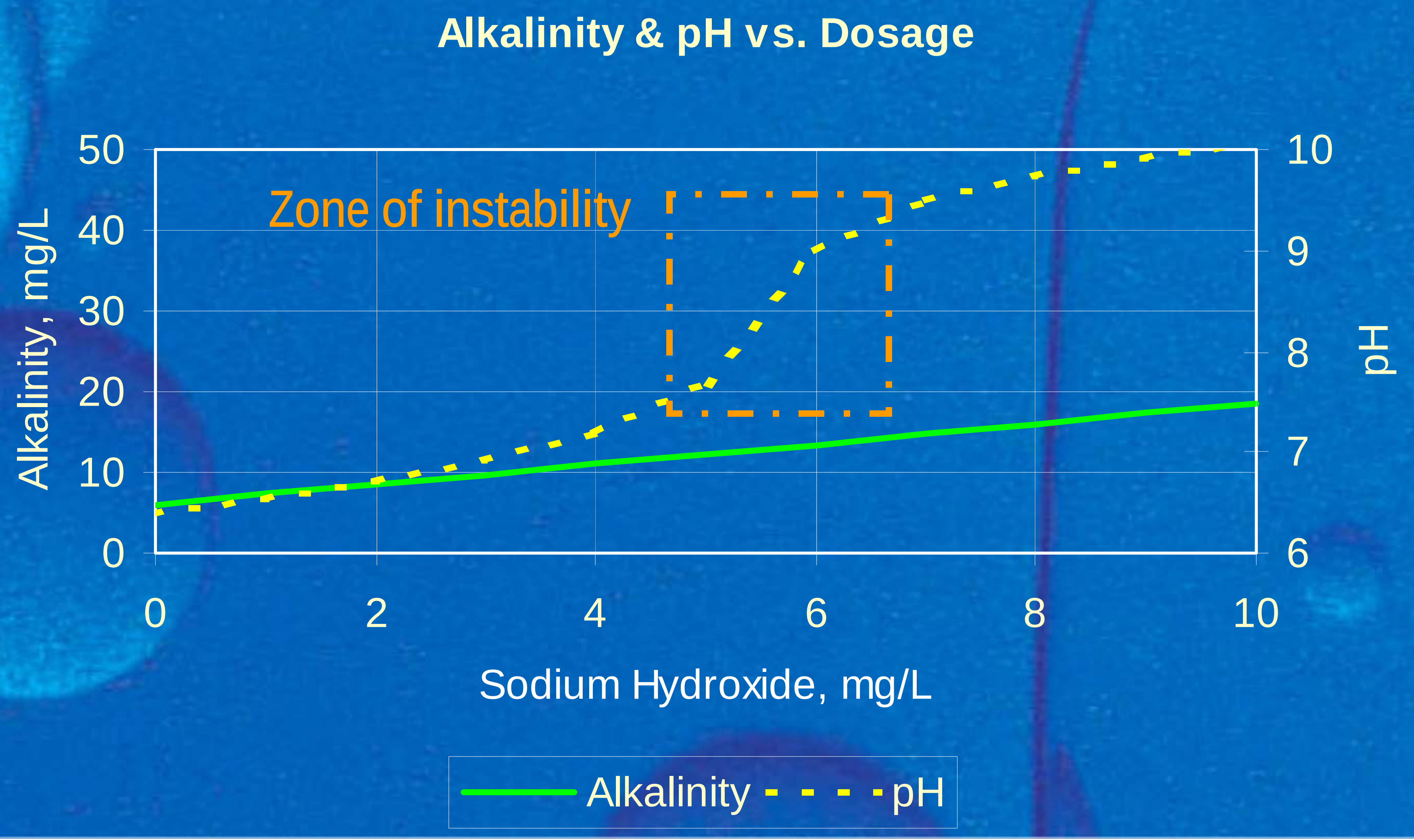

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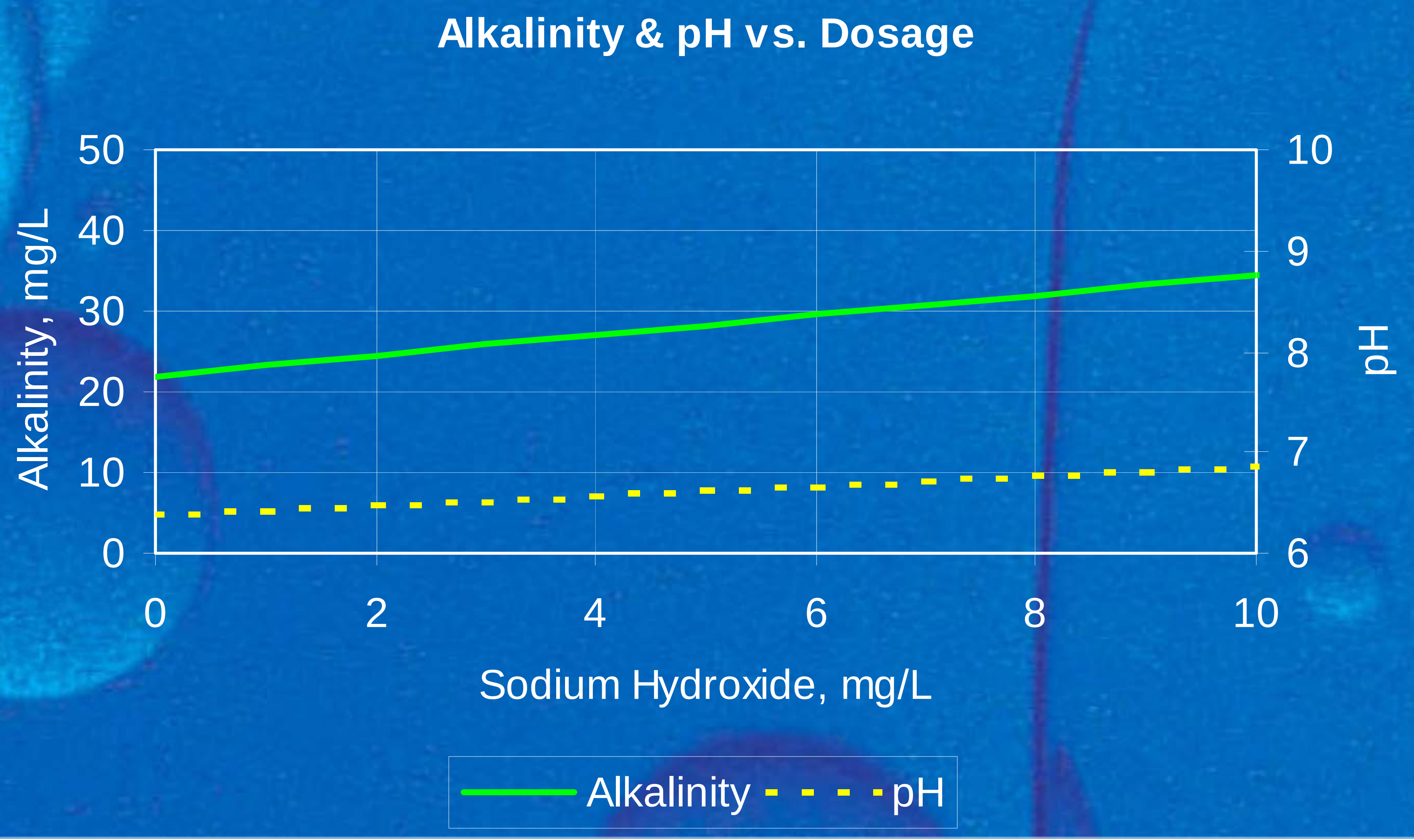
High Alkalinity Example

(alkalinity = 22 mg/L as $CaCO_3$, pH = 6.4)



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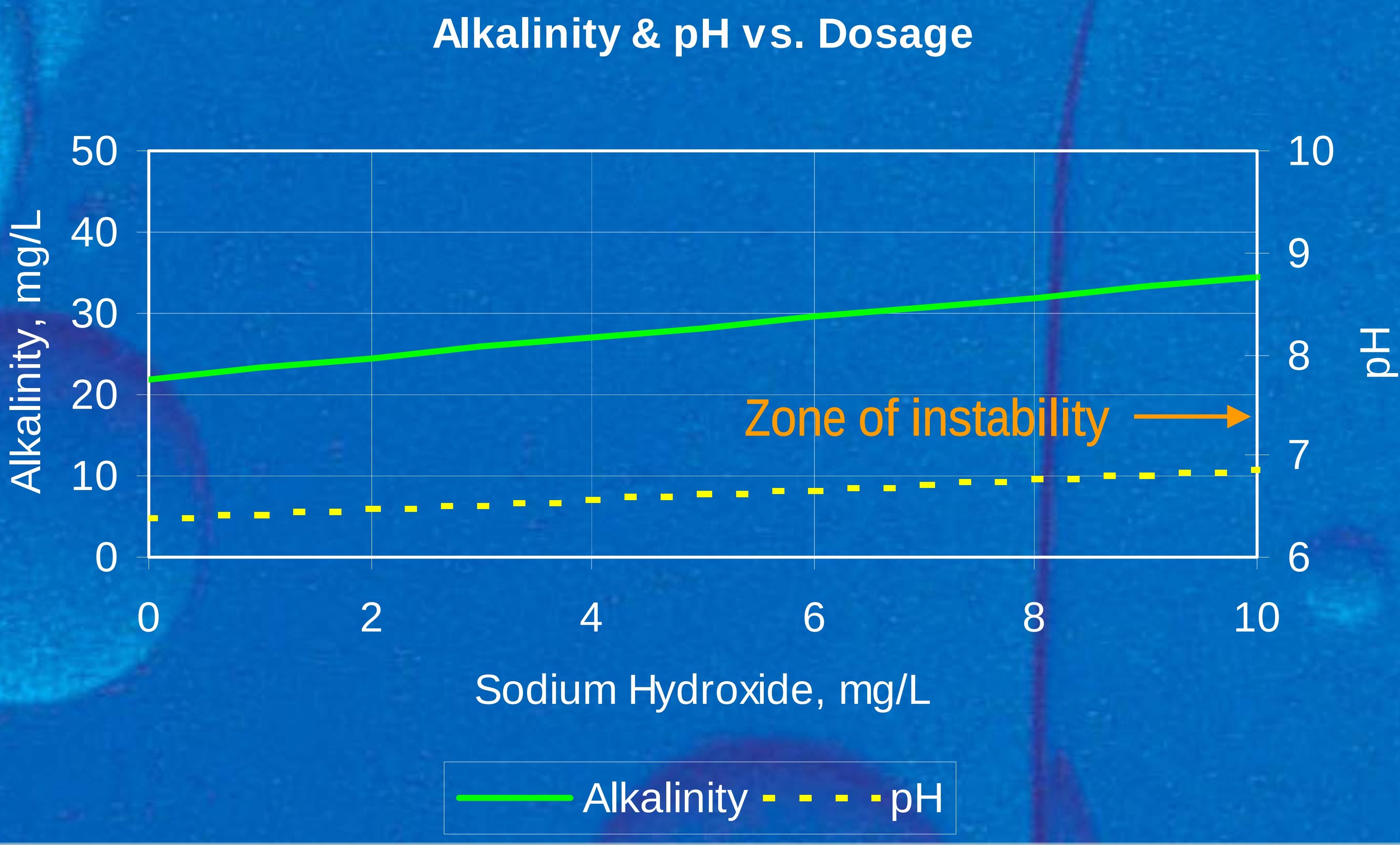

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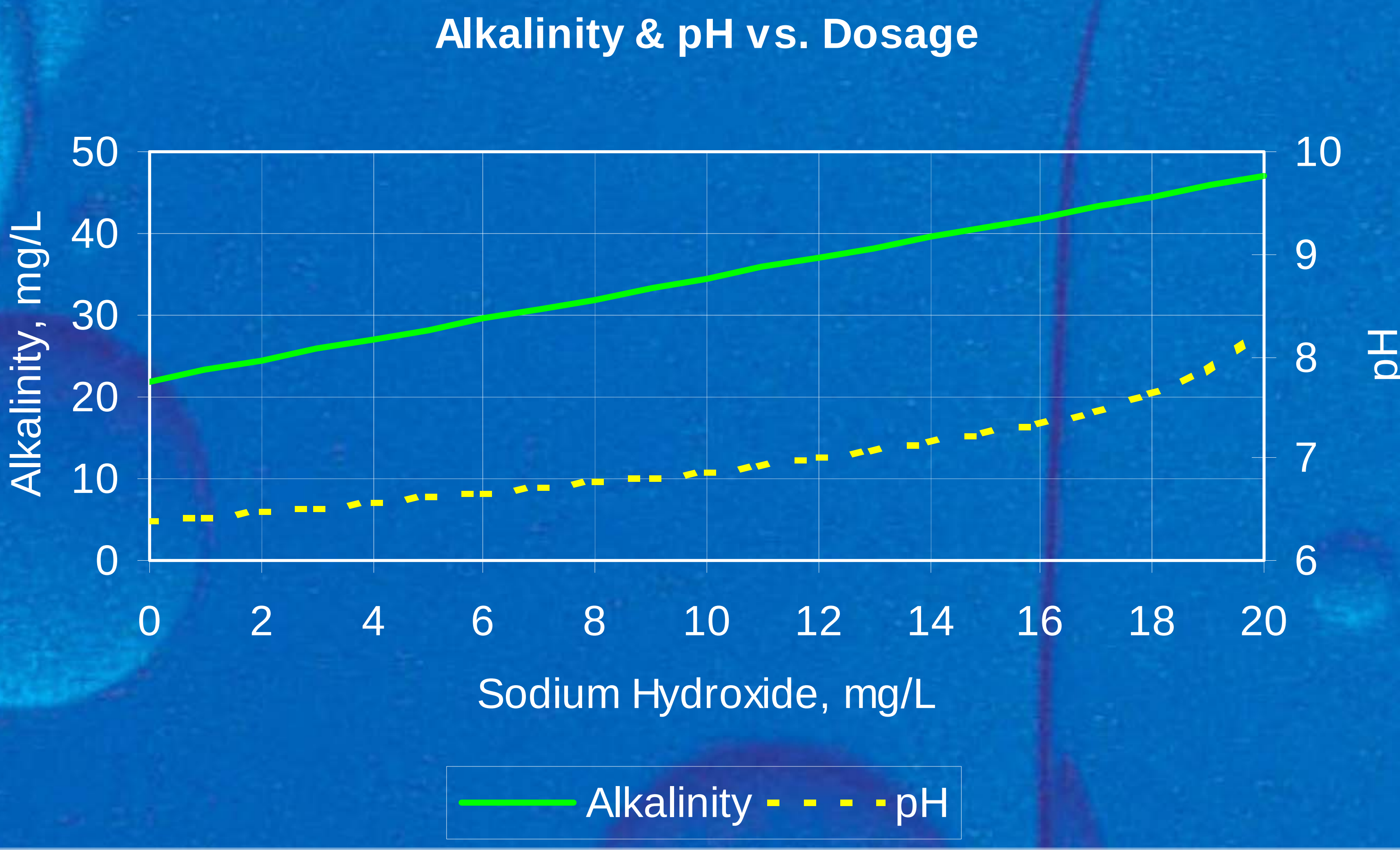

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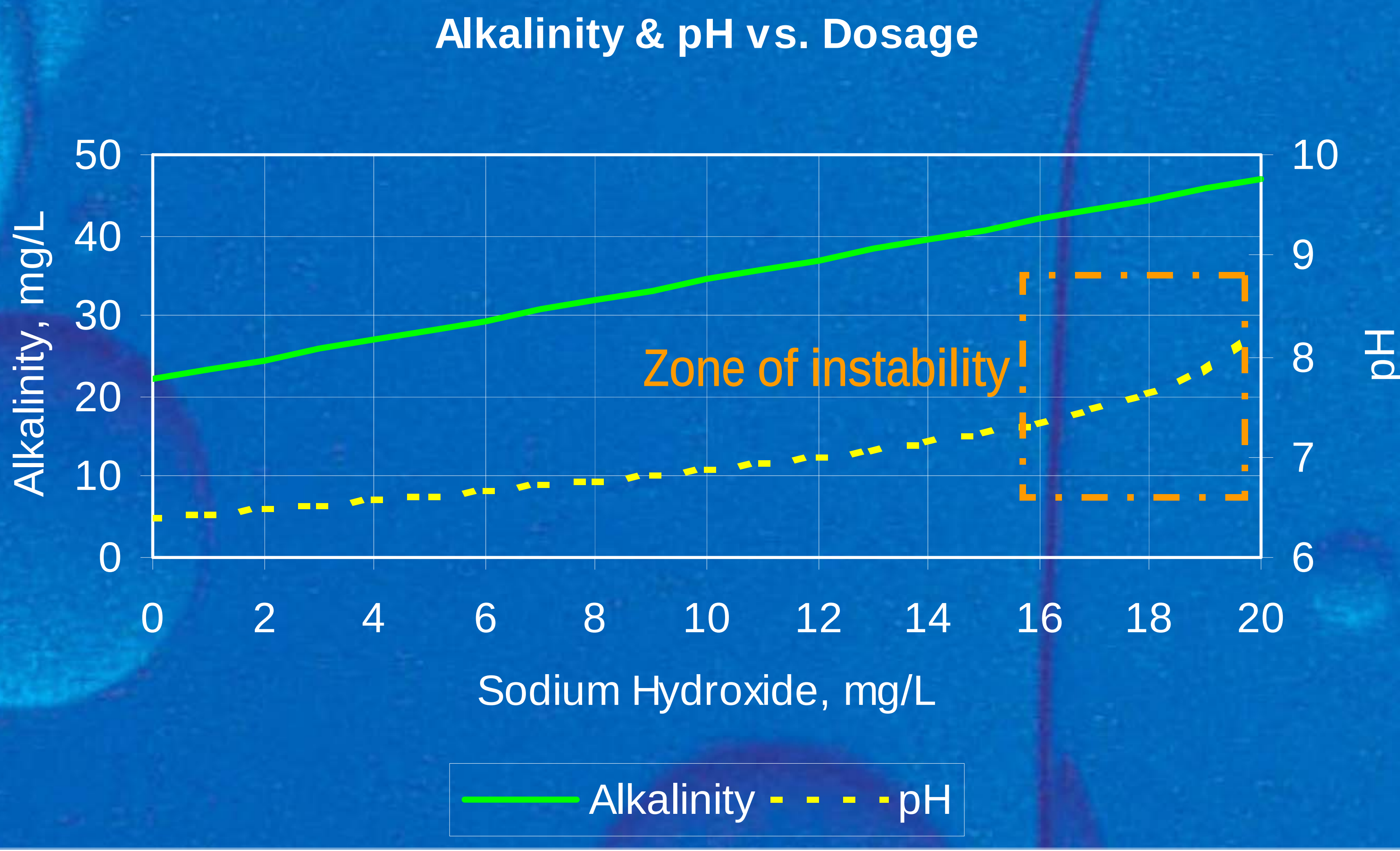

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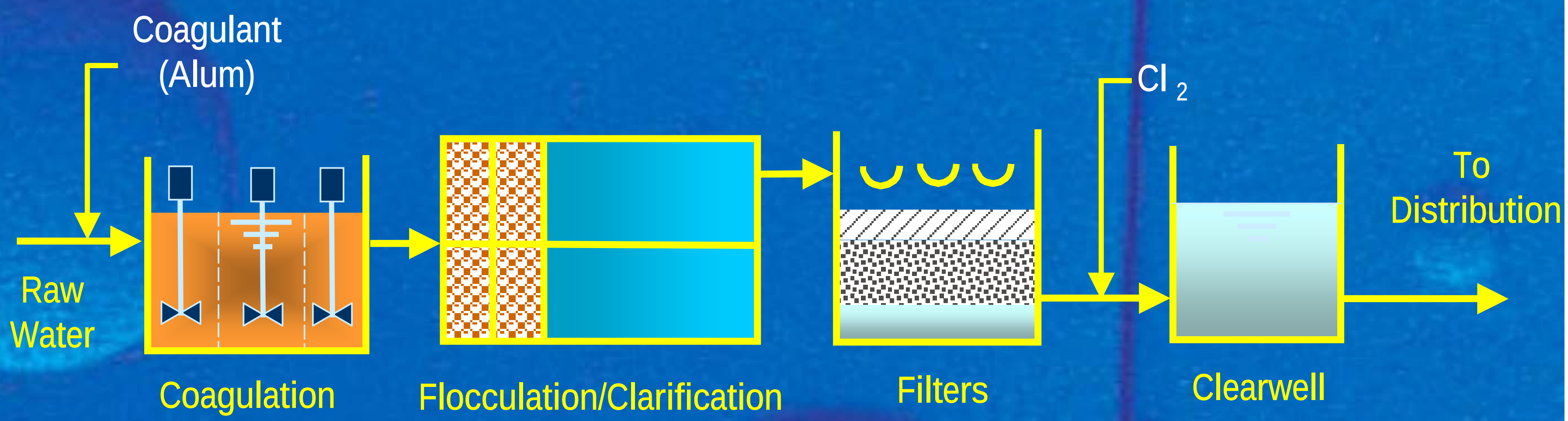
Example - Conventional Treatment Process Train

- Coloured water
- High organic content



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Example - Classic Conventional Treatment Process Train

- Coloured water
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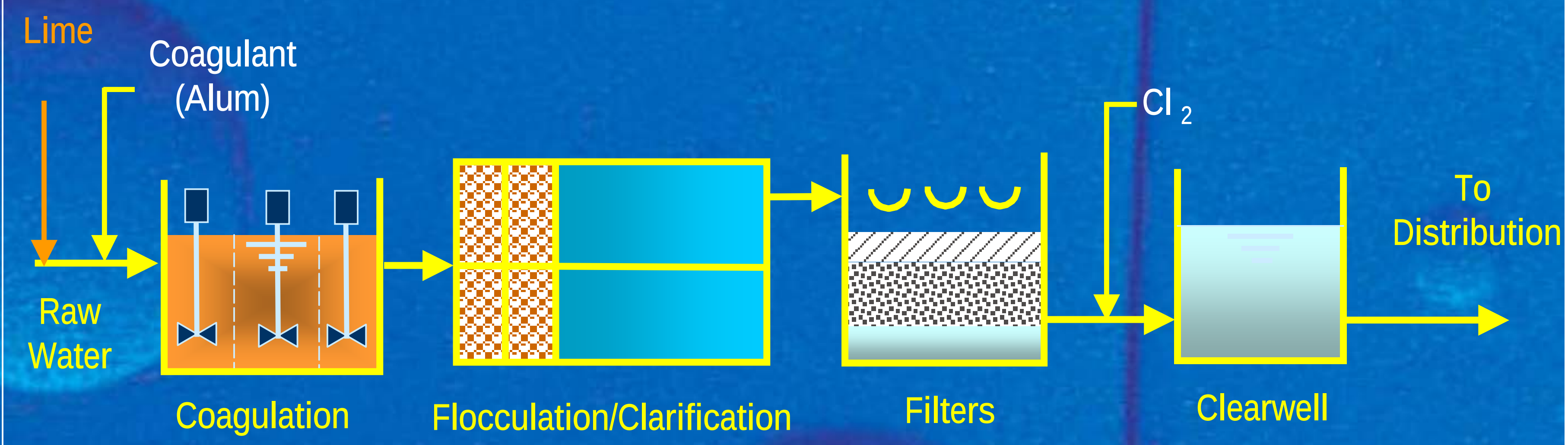
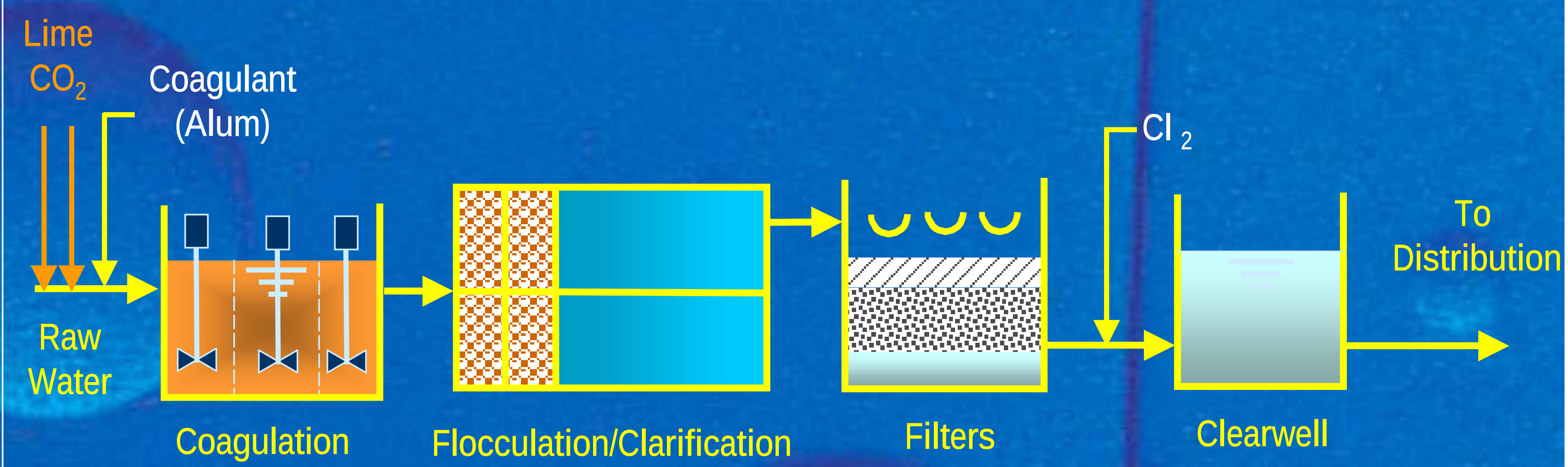


Corrosion Inhibitor

- Sodium silicates, polyphosphates and orthophosphates
  - Proprietary chemicals
  - ANSI/NSF 60 approval or equivalency
- Cover potentially corrosive sites by passivating the metal surfaces in contact with water or by forming a protective film or scale
  - Long time to form film
  - Long time to assess effectiveness

Example - Classic Conventional Treatment Process Train

- Coloured water
- High organic content



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Example - Classic Conventional Treatment Process Train

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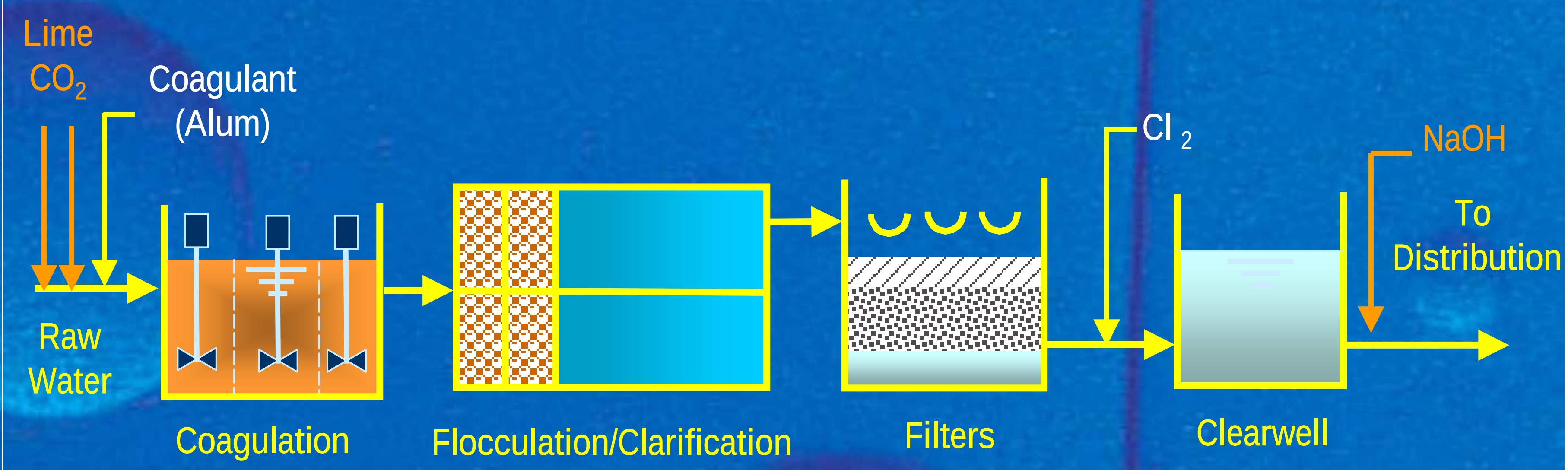
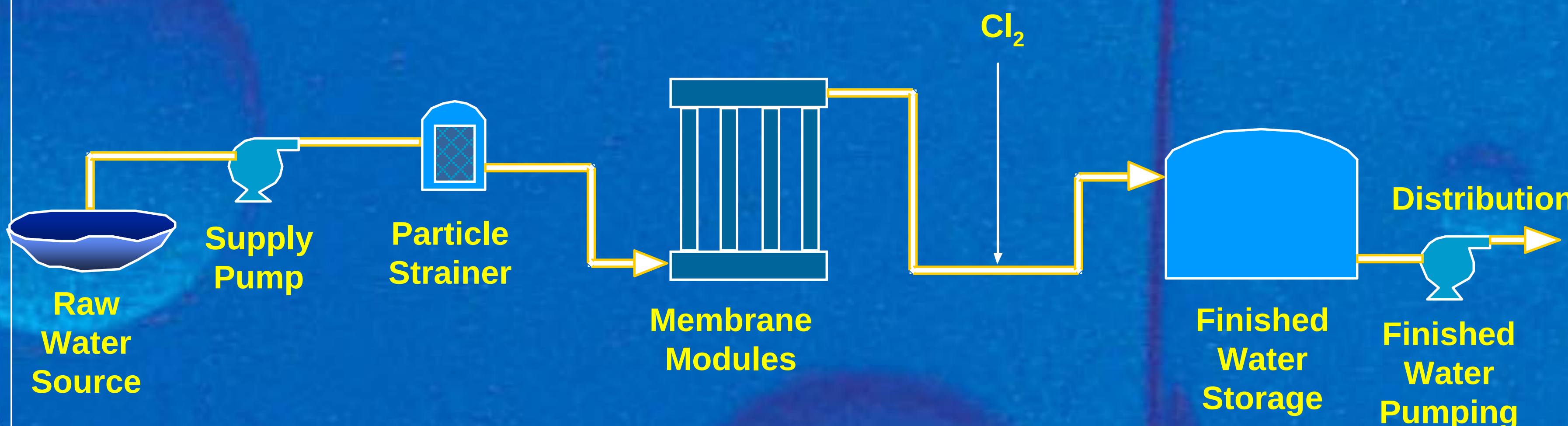


Example - Membrane Filtration Plant

- Low turbidity water
- Low colour
- Low organics



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Items to Consider

- Location of water chemistry adjustment
  - Turbidity impact of chemical
  - Membrane supplier preferences
- May not require pH adjustment with carbon dioxide
  - Depends on selection of alkalinity adjustment chemical
  - Depends on raw water alkalinity

Corrosion Inhibitor

- Dosage determine by trial
  - Assistance from chemical supplier
  - Site specific (source water, material and condition of pipes)
  - Want to maintain slight phosphate or silica residual
  - Water sampling - metals, phosphate or silica

Corrosion Inhibitor

- Addition of corrosion inhibitor does not change LSI
  - Performance is difficult to assess without obtaining samples in distribution system
- May require pH correction to effectively work
- May require a constant pH
  - Issue for poorly buffered water

Corrosion Inhibitor

- Selection of inhibitor is dependent on target metal
- May cause microbial growth in distribution system
  - Addition of nutrients
- Phosphate based corrosion inhibitors may result in additional wastewater treatment

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Do I Need to Implement Corrosion Control Measures?

- Determine corrosivity of water
  - LSI < -1
- Recommended to perform a full-scale corrosion monitoring study in distribution system
  - Exceed MAC for lead, iron, copper?
  - Pipe material

Selection of Corrosion Control Approach

- Approach is site specific
  - Performance
  - Chemical availability
  - Chemicals currently used on site
  - Operability (ease of use, reliability, maintenance, staffing, training)
  - Current treatment process
  - Cost (capital, chemical and O&M)

Chemical	Dosage (mg/L)	Chemical Cost* $/1000 m^3	O&M Cost** $/1000 m^3
Caustic Soda NaOH	2 to 30	0.70 – 10.50	0.15 – 0.73
Lime $Ca(OH)_2$	2 to 30	0.45 – 6.75	0.38 – 1.39
Soda Ash Na_2CO_3	10 to 30	4.70 – 14.10	0.38 – 1.39
Carbon Dioxide (CO_2)	5 to 20	2.80 – 14.00	N/A
Blended Orthophosphate	0.3 to 1.3	6.00 – 25.00	0.15 – 0.73
Sodium Silicate	4 to 10	10.00 – 25.00	0.15 – 0.73

* For 10,000 m^3/d, Northern Ontario

** From Lead Control Strategies, AWWARF, 1990 – adjusted to CAN$ and 2004 prices

Selection of Corrosion Control Approach

- Approach is site specific (continued)
  - Implementation (ease, time, public opinion)
  - Secondary impacts (disinfection efficiency and maintenance of a residual in distribution system, THM levels, wastewater processing capabilities)

Conclusions

- You should care about corrosion
  - Silent pipe killer - extend the life of distribution system
  - Maintain water quality - health and aesthetic
- Various tools can be used to measure the corrosivity of your water
- Various methods can be implemented to control corrosion - site specific
- Corrosion control costs $ but you will save much more $$$ in the long run

Local Example of Corrosion Control Implementation

- Town of Bonnavista
- Surface water supply from Long Pond
- Industrial water supply built in 1967
- Designed for additional capacity for the Town
- System started in 1970
- Water quality satisfactory with exception of
    - pH = 6.1
    - Colour = 30 TCU

Local Example of Corrosion Control Implementation

- Water is pumped from supply main to 2 distribution reservoirs
- Pumping is controlled to avoid conflict with peak industrial demand, i.e. generally 6 p.m. to 6 a.m.
- In early 1980's, leaks appeared as a result of corrosion in copper pipes
- Initially, recommendation to monitor the occurrences of corrosion

Local Example of Corrosion Control Implementation

- In early 1990's, start of complaints of staining of plumbing fixtures, discoloration of laundry and frequent leaks in copper service lines
- In 1993, water analyses were carried out
  - Source water was unchanged
  - Tap water indicated
    - pH levels were 4.7 to 5.7
    - Iron levels were 0.47 to 1.2 mg/L
    - Copper levels were 4.7 to 6.7 mg/L

Local Example of Corrosion Control Implementation

- In 1996, year long source sampling program
  - pH = 5.78 to 6.51
  - Colour = 10 to 40 TCU
  - LSI = -4.3 to -5.1
- Recommendations
  - Add hydrated lime to increase pH and alkalinity and decrease corrosiveness

Local Example of Corrosion Control Implementation

- Design carried out in 1997
- Tenders called in 1998
- System installed and operational in late 1998
- System operated for 2 years using hydrated lime
- Due to operational problems, Town switched to soda ash in late 2000
- Operating range for system
  - pH 6.8 to 7.0

Local Example of Corrosion Control Implementation

- Operating cost of system = $12,000/year
- Operating and maintenance expenditures works department
  - 1994 to 1998 - $295,220/year
  - 1999 to 2003 - $248,120/year
  - Net saving - $47,100/year
- Water main leaks due to corrosion
  - 1994 to 1998 - 83 leaks/year
  - 1999 to 2003 - 17 leaks/year

Questions and Answers

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LSI Sample Calculation

- Given - Water Plant A
  - Temperature = 18°C
  - pH = 8.0
  - TDS = 64 mg/L
  - Calcium = 42 mg/L as $CaCO_3$
  - Alkalinity = 47 mg/L as $CaCO_3$

LSI Sample Calculation

- Given - Water Plant A
  - Temperature = 18^{o}C
  - pH = 8.0
  - TDS = 64 mg/L
  - Calcium = 42 mg/L as $CaCO_3$
  - Alkalinity = 47 mg/L as $CaCO_3$
- Solution
  - LSI = pH - pH_s
  - pH_s = (9.3 + A + B) - (C + D)

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LSI Sample Calculation

- Solution (continued)
  - A = (Log$_{10}$ [TDS in mg/L] - 1) /10

    = (Log$_{10}$ [64] - 1) /10

    = 0.08

LSI Sample Calculation

- Solution (continued)
  - $A = (\text{Log}_{10}\ [\text{TDS in mg/L}] - 1)\ /10$

    $= (\text{Log}_{10}\ [64] - 1)\ /10$

    $= 0.08$
  - $B = -13.12 \times \text{Log}_{10}\ (\text{Temp. in } {}^{o}\text{C} + 273) + 34.55$

    $= -13.12 \times \text{Log}_{10}\ (18 + 273) + 34.55$

    $= \underline{2.22}$

LSI Sample Calculation

- Solution (continued)
  - $C = Log_{10}$ [Ca^{2+} in mg/L as $CaCO_3$] - 0.4

    = Log_{10} [42] - 0.4

    = <u>1.22</u>

LSI Sample Calculation

- Solution (continued)
  - $C = \text{Log}_{10}$ [Ca^{2+} in mg/L as $CaCO_3$] - 0.4

    $= \text{Log}_{10}$ [42] - 0.4

    = 1.22
  - $D = \text{Log}_{10}$ [Alkalinity in mg/L as $CaCO_3$]

    $= \text{Log}_{10}$ [47]

    = 1.67

LSI Sample Calculation

- Solution (continued)
  - $C = Log_{10}$ [Ca^{2+} in mg/L as $CaCO_3$] - 0.4
    $= Log_{10}$ [42] - 0.4
    = 1.22
  - $D = Log_{10}$ [Alkalinity in mg/L as $CaCO_3$]
    $= Log_{10}$ [47]
    = 1.67
  - $pH_s = (9.3 + A + B) - (C + D)$

LSI Sample Calculation

- Solution (continued)
  - $pH_s = (9.3 + A + B) - (C + D)$

    $= (9.3 + 0.08 + 2.22) - (1.22 + 1.67)$

    $= \underline{8.71}$

LSI Sample Calculation

- Solution (continued)
  - $pH_s = (9.3 + A + B) - (C + D)$

    $= (9.3 + 0.08 + 2.22) - (1.22 + 1.67)$

    $= 8.71$
  - $LSI = pH - pH_s$

    $= 8.0 - 8.71$

    $= \underline{-0.71}$

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LSI Sample Calculation

- Solution (continued)
  - $pH_s = (9.3 + A + B) - (C + D)$

    $= (9.3 + 0.08 + 2.22) - (1.22 + 1.67)$

    $= 8.71$
  - $LSI = pH - pH_s$

    $= 8.0 - 8.71$

    $= \underline{-0.71}$
  - Water is still slightly corrosive
    - pH will not easily fluctuate once in distribution system (good alkalinity level in water)
    - a slight tendency to remove metals from pipes

LSI Calculation

- If calcium hardness is not known, assume calcium hardness = total hardness
- If total dissolved solids (TDS) is unknown but conductivity is known, estimate TDS with table shown on next page
  - Conductivity is easily measured using a lab pH analyzer

Conductivity vs TDS

Conductivity (µmho/cm)	TDS (mg/L as $CaCO_3$)
1	0.42
10.6	4.2
21.2	8.5
42.4	17.0
63.7	25.5
84.8	34.0
106.0	42.5
127.3	51.0
148.5	59.5