# REPAIR OR REPLACE?

The Price of Aging Infrastructure

Jason Spinnato, PE
Geoff Scheid, EIT

# OVERVIEW

- **US Infrastructure Needs vs. Spending**
- Concrete Structures in W/WW Treatment
- Types of Deterioration
- Types of Repair & Protection
- Case Studies

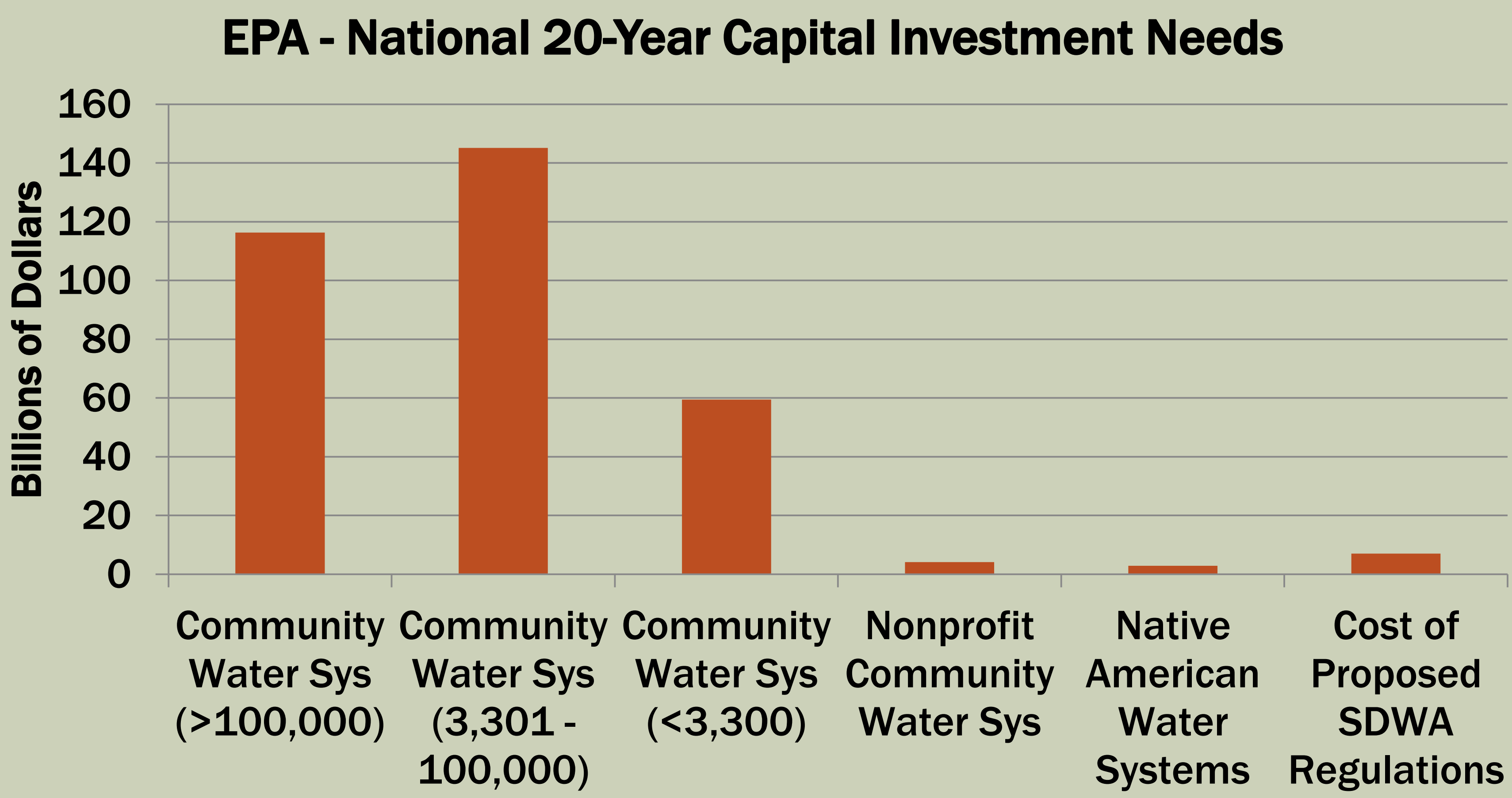
# US WATER INFRASTRUCTURE

- 170,000 Public Water Systems
- Serving 264,000,000 People
- Failures lead to disruption in:
  - Transportation infrastructure
  - Communication infrastructure
  - Emergency response
- 1,000,000 miles of Water Mains
  - Condition mostly unknown
  - 240,000 Water main breaks each year
  - Worst in older cities
- Safe Drinking Water Act of 1996
  - Stricter regulatory requirements
  - Increased operating costs + shrinking budgets =>
  - Deferred maintenance

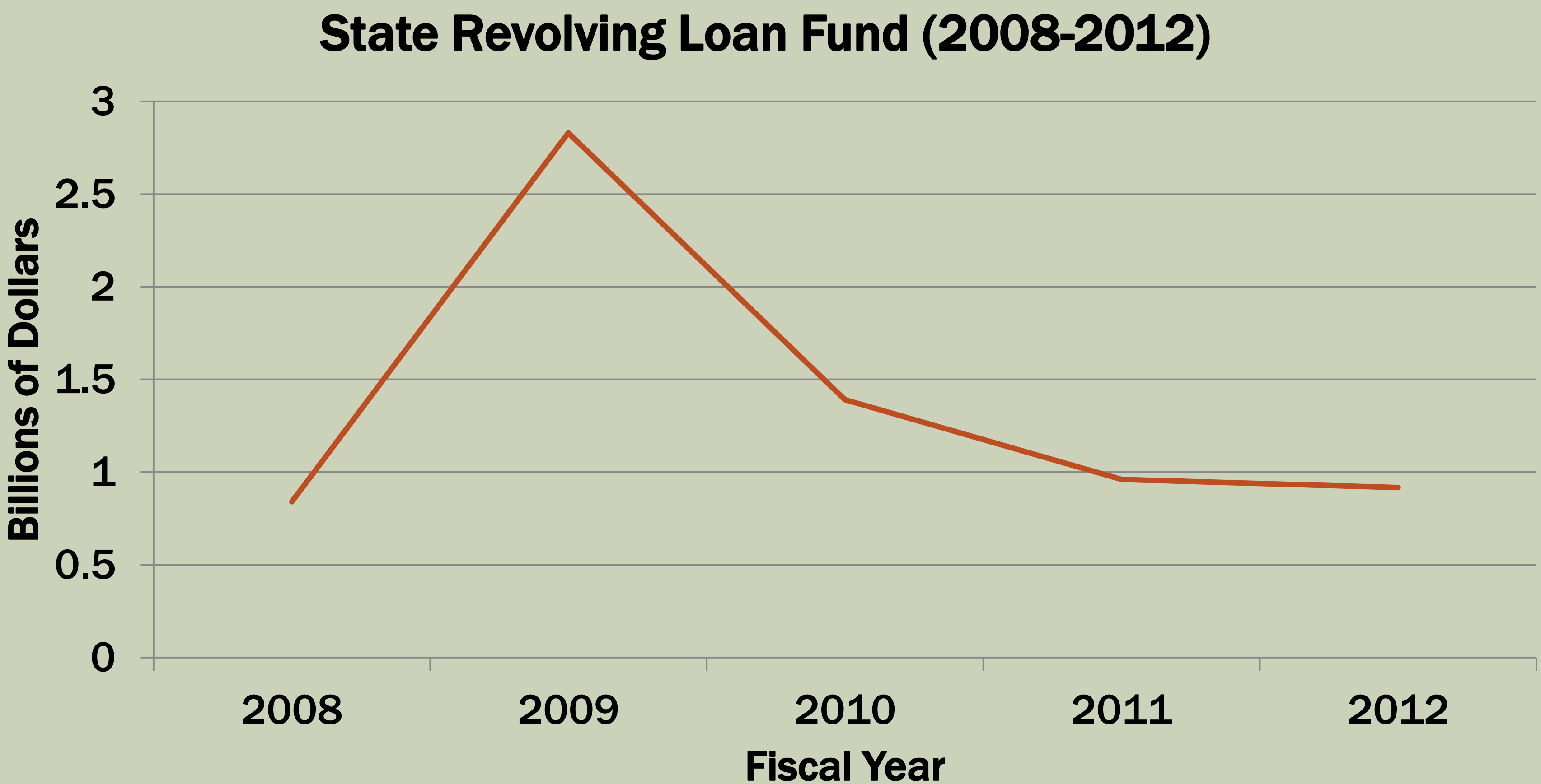
# US WATER INFRASTRUCTURE

- 20-year Capital Investment Needs (EPA)
  - $334,800,000,000
  - Does not include additional capacity for growth
  - 53,000 Community water systems
  - 21,400 Nonprofit water systems
- Federal Appropriations
  - Average $1,380,000,000 annually
  - 8% of EPA estimate over 20 years
  - Trending toward state & local funding
  - Water rates to rise

# US WATER INFRASTRUCTURE



# US WATER INFRASTRUCTURE



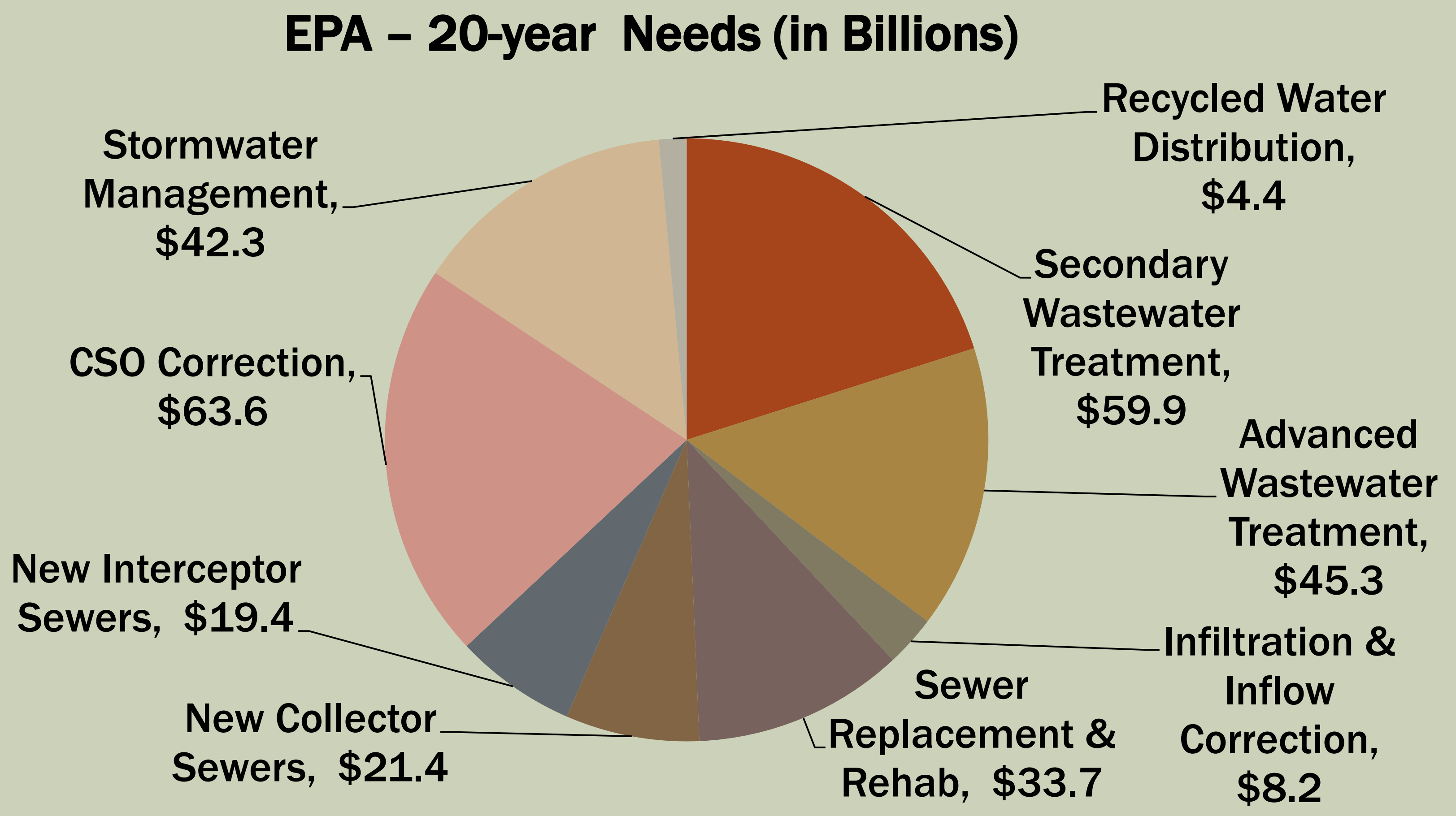
# US WASTEWATER INFRASTRUCTURE

- 750,000 Miles of public sewer mains
- 14,780 Wastewater treatment facilities
- 19,739 Wastewater pipe systems
- 900 Billion gallons of sewage discharged annually
  - Aging sewer mains
  - Inadequate capacity
  - Discharged to rivers & streams

# US WASTEWATER INFRASTRUCTURE

- 20-year Capital Investment Needs (EPA)
  - $298,000,000,000
  - $105 Billion (35%) for wastewater treatment
- Federal Appropriations
  - Average $2,100,000,000 annually
  - 14% of EPA estimate over 20 years
- Looking Ahead
  - Water reuse (From poo-to-you!)

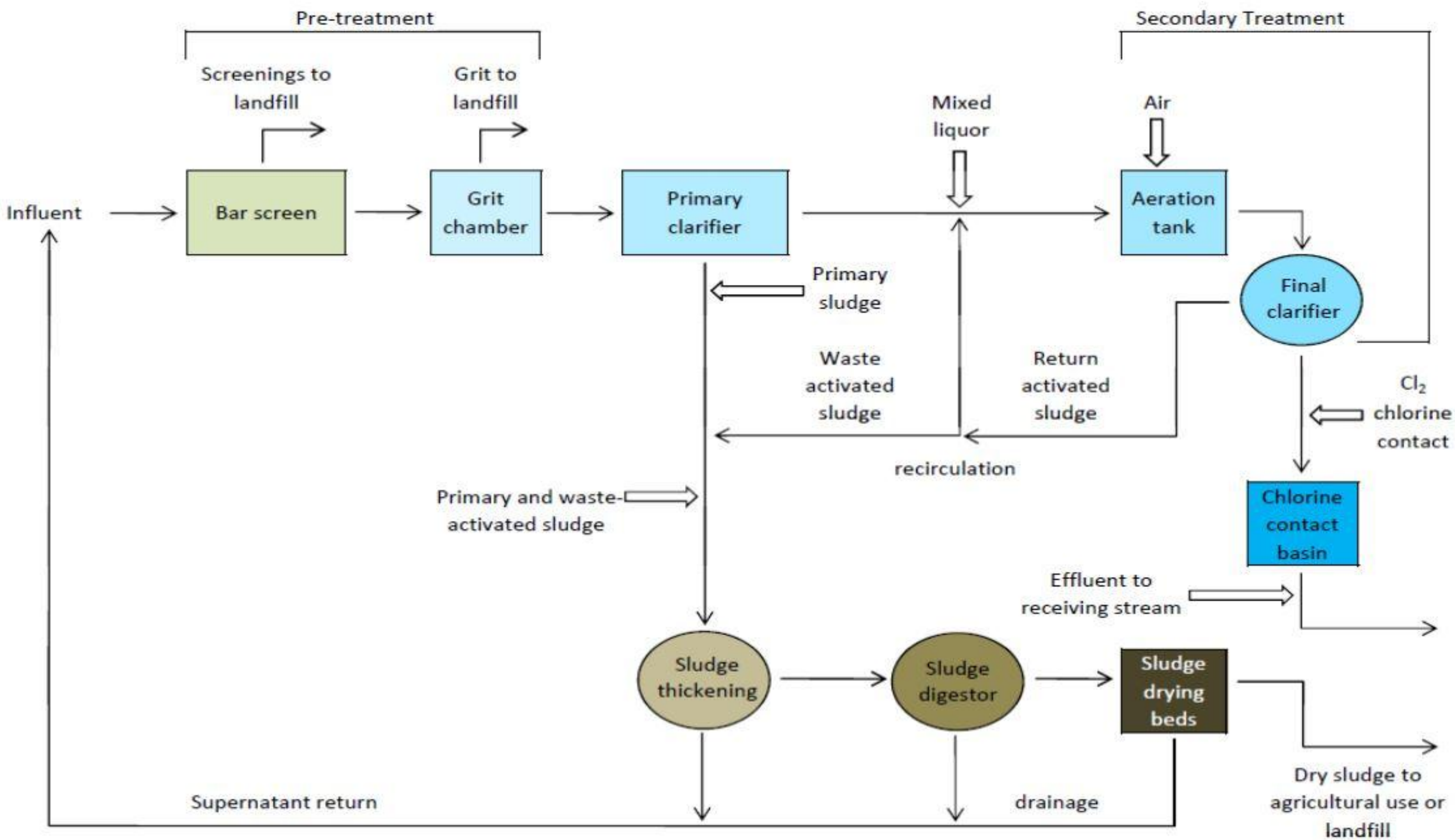
# US WASTEWATER INFRASTRUCTURE



# OVERVIEW

- US Infrastructure Needs vs. Spending
- **Concrete Structures in W/WW Treatment**
- Types of Deterioration
- Types of Repair & Protection
- Case Studies

# WASTEWATER TREATMENT PROCESS



# CONCRETE STRUCTURES IN W/WW

- Concrete Basins
  - Primary/Secondary Clarifiers
  - Aeration Basins
  - Equalization Basins
- Founded below grade
- Open top

# CONCRETE STRUCTURES IN W/WW

- Concrete Buildings
  - Junction Boxes
  - Pump Stations
  - Headworks
- Above or below grade
- Typically enclosed

# CONCRETE STRUCTURES IN W/WW

- Concrete Tanks
  - Clear well Tanks
  - Sludge Thickeners
- Typically below grade
- Typically enclosed

# OVERVIEW

- US Infrastructure Needs vs. Spending
- Concrete Structures in W/WW Treatment
- **Types of Deterioration**
- Types of Repair & Protection
- Case Studies

# TYPES OF DETERIORATION

## CHEMICAL ATTACK

- Causes
  - $H_2S$
  - Chlorine
- Effects
  - Concrete deterioration
  - Rebar corrosion

# TYPES OF DETERIORATION
## JOINT MATERIAL

- Causes
  - Groundwater
  - Joint material degradation
- Effects
  - Leaking in/out

# TYPES OF DETERIORATION
## CRACKING

- Causes
  - Shrinkage
  - Excessive stress in concrete
    - Soil movements
    - Loading/Unloading
- Effects
  - Process fluids leaking out
    - Contamination of groundwater
  - Groundwater leaking in
    - Contamination of process fluids

# TYPES OF DETERIORATION

## CARBONATION

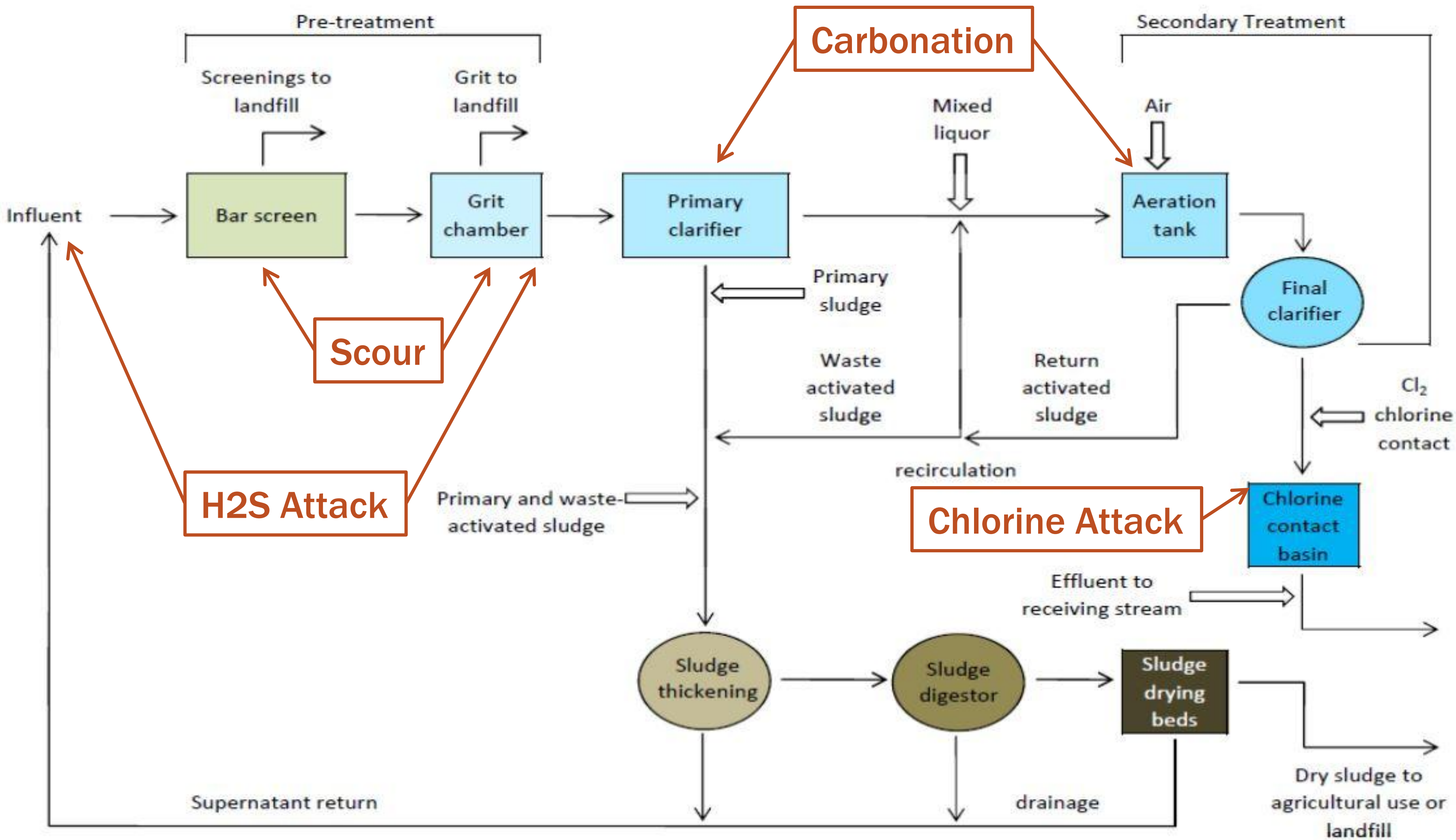
- Causes
  - High relative humidity
  - Carbon Dioxide reacts with alkali to lower pH
- Effects
  - Spalling
  - Rebar corrosion

# TYPES OF DETERIORATION

## SCOUR (EROSION)

- Causes
  - Nonlinear flow velocities (turbulence)
  - Abrasive wear
    - Process “solids” & grit
    - Process equipment
- Effects
  - Loss of concrete cover
  - Exposure and corrosion of rebar

# WASTEWATER TREATMENT PROCESS



# OVERVIEW

- US Infrastructure Needs vs. Spending
- Concrete Structures in W/WW Treatment
- Types of Deterioration
- **Types of Repair & Protection**
- Case Studies

# TYPES OF REPAIR

- Repair Mortars
  - Applications
    - Hand-applied
    - Spray-applied
    - Form-and-pour/pump
  - Uses
    - Spalled areas
    - Matrix loss
    - Chemical Protection
  - Typical Cost
    - ~$250-$300 per $ft^3$

# TYPES OF REPAIR

- Crack Injection
  - Types
    - Epoxy
    - Polyurethane
  - Uses
    - Restore structural integrity
    - Water-tightness
    - Limit reinforcing corrosion
  - Typical Cost
    - ~$30-$35 per ft.

# TYPES OF REPAIR

- Expansion Joint Systems
  - Applications
    - Within-the-joint
    - Surface-applied
  - Uses
    - Water-tightness
  - Typical Cost
    - ~$50 per ft. for a 1-inch joint

# TYPES OF PROTECTION

- PVC Liners
  - Applications
    - Adhesive-applied
  - Uses
    - Water-tightness
    - Chemical Protection
    - Acidic Protection
  - Typical Cost
    - ~$30-$50 per ft$^2$

# TYPES OF PROTECTION

- Epoxy & Composite Coatings
  - Applications
    - Trowel-applied
    - Spray-applied
  - Uses
    - Chemical Protection
    - Acidic Protection
  - Typical Cost
    - ~\$10-\$15 per $ft^2$

# OVERVIEW

- US Infrastructure Needs vs. Spending
- Concrete Structures in W/WW Treatment
- Types of Deterioration
- Types of Repair & Protection
- **Case Studies**

# CASE STUDIES

- **$H_2S$ Attack**
- Coating Failure
- Chlorine Attack
- Carbonation
- Rehabilitation

# $H_2S$ ATTACK

- Background
  - Wastewater Treatment Plant – 100 Million Gal/Day
  - Critical Flow Structure
  - Sub-grade
  - Closed-top
  - Constructed in 1974

# $H_2S$ ATTACK

- Observations
  - Severe deterioration (max 5”)
  - Severely corroded reinforcing
  - Corroded embedded metals
  - No coating or liner system
  - Spalling & delamination
  - Varying degrees of deterioration

# $H_2S$ ATTACK

- Causes
  - Severe $H_2S$ exposure
  - High velocity flows
  - Turbulent flow releases liquid $H_2S$ to sulfuric acid gas
  - No protection system

# $H_2S$ ATTACK

- Recommendations
  - Sandblast or hydro blast back to sound concrete
  - Replace corroded reinforcing
  - Spray-applied repair mortar
  - Replace embedded metals
  - Install liner protection system
- Influent Box (worst case)
  - Sluice gate failure blocked critical influent to plant
  - Beyond repair; entirely new construction around existing
  - Compromised structural integrity

# $H_2S$ ATTACK

- Owner Considerations
  - Cost of repairs vs. expected performance & service life
  - Critical structures to be kept in service or bypassed
  - Cost of inaction
    - Further deterioration
    - Imminent failure of key structure
    - Life/Safety concerns

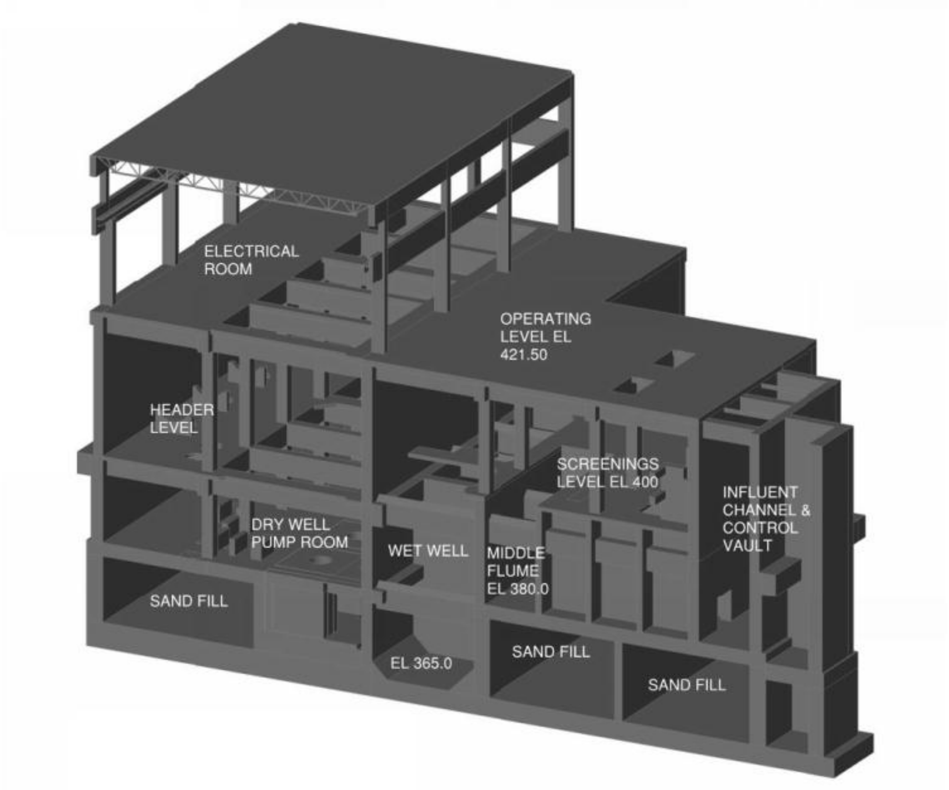
# $H_2S$ ATTACK

# CASE STUDIES

- $H_2S$ Attack
- **Coating Failure**
- Chlorine Attack
- Carbonation
- Rehabilitation

# COATING FAILURE

- Background
  - Headworks Structure
  - Constructed in late 1970's
  - Modifications and coatings installed 2002
  - Coatings began failing shortly after installation



# COATING FAILURE

- Observations
  - Failure of repair from 2002
  - Extensive coating failure
  - Delamination
  - Pin holing & Holidays

# COATING FAILURE

# COATING FAILURE

- Recommendations
  - Near future (1-2 years) replacement of failed coatings for highest risk areas. Estimated cost ~$270,000
  - Replacement of failed coatings within 3-5 years for areas with lower $H_2S$ concentrations. Risk to pumps due to coating failure a concern. Estimated cost ~ $1.9 million
  - Delay in repairs may lead to further structure deterioration and more costly repairs in the future.
- Owner Considerations
  - Repair failed coatings or delay?
  - Risk of equipment damage?
  - Liability for failures?

# CASE STUDIES

- $H_2S$ Attack
- Coating Failure
- **Chlorine Attack**
- Carbonation
- Rehabilitation

# CHLORINE ATTACK

- Background
  - Wastewater Treatment Plant
  - Chlorine Contact Basin Mixer Chamber
  - Confined Space
  - Sub-grade Vault
  - No protective coatings

# CHLORINE ATTACK

- Observations
  - Significantly deteriorated concrete
  - Full sections of exposed reinforcing
  - Reinforcing corroded to ½ original section
  - Visible scaling and general deterioration
  - No protective coating or liner

# CHLORINE ATTACK

- Causes
  - Chlorine Attack
    - Severe exposure with no protective coating
  - Scour
    - Mixing with grit and solids causing erosion

# CHLORINE ATTACK

- Recommendations
  - Estimated repair costs = $70,000 - $80,000
  - Level of deterioration did not warrant consideration for replacement
  - Complete section replacement of significantly deteriorated section
  - Protective coating application (quartz-reinforced composite)

# CASE STUDIES

- $H_2S$ Attack
- Coating Failure
- Chlorine Attack
- **Carbonation**
- Rehabilitation

# CARBONATION

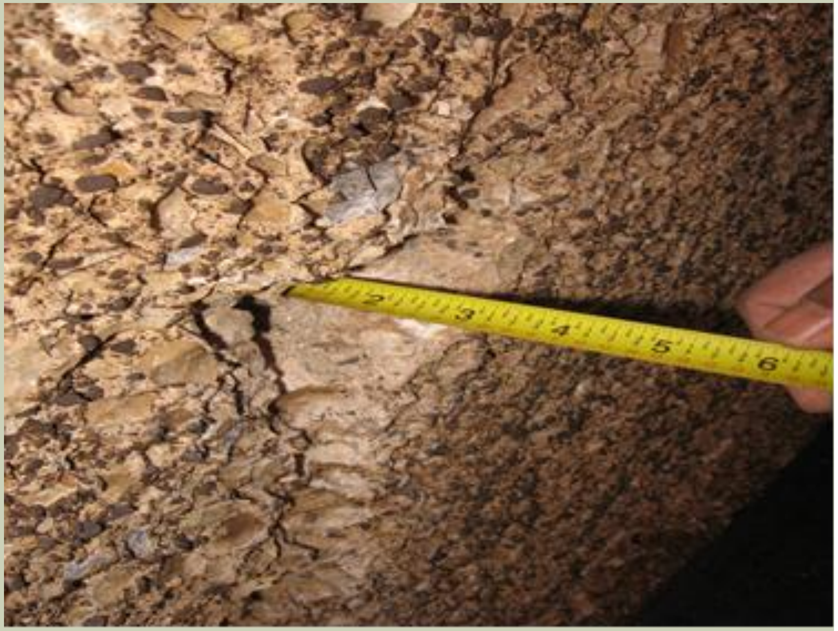
- Background
  - Water Treatment Plant
  - Two sub-grade basins
  - First constructed 1955
  - Second constructed 1972
  - Process fluids highly acidic

# CARBONATION

- Observations
  - Walls show severe matrix loss
  - Minimal reinforcement exposure
  - Base slab in good condition
  - Significant cracking/leaking
  - Embedded metals corroded
  - Highly acidic raw water influent

# CARBONATION

- Causes
  - Petrographic testing performed on core samples
  - Approx. 1” of cover remaining
  - Matrix loss of approximately ½”
  - Carbonation due to highly acidic process fluids



# CARBONATION

## Recommendations

- Option 1
  - Composite Overlay
  - Trowel-applied
  - Epoxy-based
  - Quartz-reinforced
  - ¼” Thickness
  - \$35 - \$40 per $ft^2$ at ¼ inch thickness
- Option 2
  - Liner System
  - 100% Solid
  - Epoxy-based
  - \$18 per $ft^2$ at 80 mil thickness
- Option 3
  - Repair Mortar
  - Spray-applied
  - Fiber-reinforced
  - ½” – ¾” Thickness
  - \$24 per $ft^2$ at 1 inch thickness (\$325/$ft^3$)

## Owner Considerations

- Pros & Cons of each system
- Expected service life vs. quality of protection
- Cost of future repairs for each system

# CASE STUDIES

- $H_2S$ Attack
- Coating Failure
- Chlorine Attack
- Carbonation
- **Rehabilitation**

# REHABILITATION

- Background
  - Rehab to add 30 years of service life
  - Replacement Considered
  - Constructed in 1950's
  - Modified in 2006
  - 6 Primary Clarifier Basins
  - Service Tunnels
  - Effluent Channel
  - Influent Channel

# REHABILITATION

## Observations

- Primary Clarifiers
  - Isolated matrix loss and spalling near embedded metals
  - Significant deterioration or failure of expansion joint material
  - Embedded metals severely corroded
  - Operational capability limited
- Service Tunnels
  - Expansion joint material completely failed
  - Spalling at soffit of top slab w/ corroded reinforcing
- Influent/Effluent Channels
  - Minor $H_2S$ deterioration (¼” or less)
  - Embedded metals corroded
  - Expansion joint material failed

# REHABILITATION

# REHABILITATION

# REHABILITATION

- Testing
  - Petrographic testing on core samples
  - 3 cores from PC walls
  - 3 cores from PC floors
  - Carbonation up to 3/8” deep
  - Minor $H_2S$ deterioration
  - No evidence of ASR

# REHABILITATION

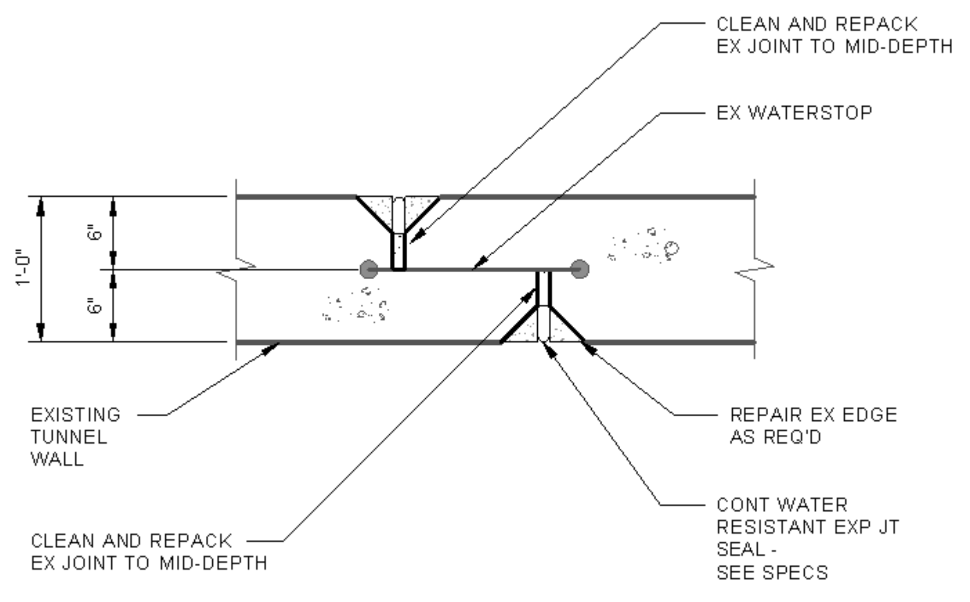
## Rehab vs. Replace

- Cost of Rehab
  - Projected Cost ~ $14 Million
- Advantages –
  - Cheaper option now
  - 30 year design life
  - More redundancy with six basins
  - Able to maintain operations
- Disadvantages –
  - Extensive rehabilitation required
  - Eventual replacement required
  - Systems more difficult to maintain

- Cost of Replacement
  - Projected Cost ~ $21.0 Million
- Advantages –
  - New structures with 30 year design life
  - Systems with current technology
  - Circular clarifiers provide greater efficiency
- Disadvantages –
  - Higher capital construction cost
  - Less redundancy with two clarifiers vs. six

# REHABILITATION

- Recommendations
  - Replacement of clarifiers too costly
  - Install rock anchors in new basin slab (to address buoyancy)
  - Repair mortar at spalled areas
  - Remove abandoned embeds
  - Liner/coating not needed
  - Expansion Joint repair
  - Replace deficient walkways
  - Replace railings



# CONCLUSION

- The Cost of Inaction
  - Enormous investments needed to maintain current systems and provide capacity for population growth
  - Difficult decisions for owners with limited capital funds and needs for repair. Limiting rehab often leads to more expensive repairs in the future.
  - A properly identified and executed rehab can provide Owners with a viable option to replacement offering legitimate balance between life cycle cost and available capital funds.

# QUESTIONS?

Jason Spinnato, PE
Geoff Scheid, EIT