Resiliency of Drainage & Stormwater Infrastructure

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What is Resiliency?

> Resiliency is the ability to prepare and plan for, absorb, accommodate, recover from, or more successfully adapt to actual or potential **adverse events** as appropriate for the importance of the site.
>
> — The TRB AFF70(2) Resilient and Sustainable Buried Structures Subcommittee

> Capability to mitigate against significant **all-hazards risks and incidents** and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security.
>
> — The American Society of Civil Engineers (ASCE)

Key Points

1. Anticipate
2. Endure
3. Rapidly Recover

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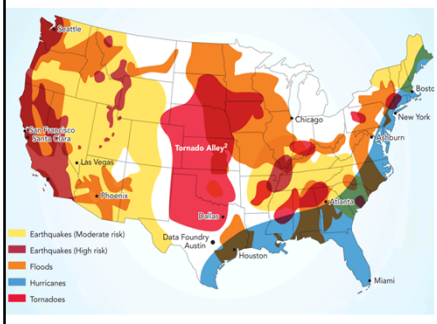
US Natural Disaster Map



Seismic Activity

Underground movement
Differential settlement
Freeze / Thaw

Flooding

High Slope applications
Head pressures
Durability during high flows

Wildfires

Restoration timeline
Design considerations
All materials are affected

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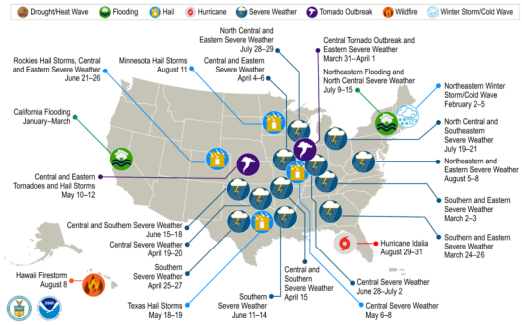
U.S. 2023 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the **23 separate billion-dollar weather and climate disasters that impacted the United States through August 2023.***

Source: https://www.climate.gov/

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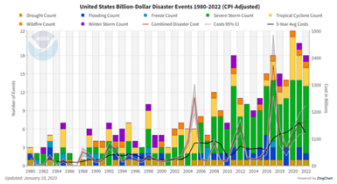
National Oceanic and Atmospheric Administration (NOAA)



The history of billion-dollar disasters in the United States each year from 1980 to 2022, showing event type (colors), frequency (left-hand vertical axis), and cost (right-hand vertical axis.) The number and cost of weather and climate disasters is rising due to a combination of population growth and development along with the influence of human-caused climate change on some type of extreme events that lead to billion-dollar disasters. NOAA NCEI.

Source: https://www.climate.gov/

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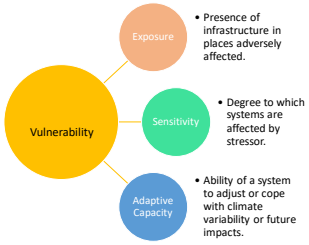
Defining Infrastructure Vulnerabilities



- Presence of infrastructure in places adversely affected.
- Degree to which systems are affected by stressor.
- Ability of a system to adjust or cope with climate variability or future impacts.

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Source: nypost.com

Source: nytimes.com

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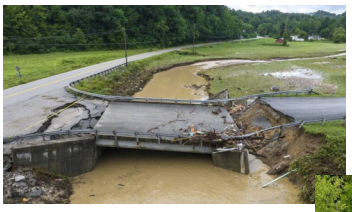

Source: govtech.com

Source: crossvillenewslist.com

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Drainage Infrastructure

*A conveyance [and/or storage] system for excess stormwater that protects transportation and other infrastructure assets from the **destructive forces of water.***

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Water's Impact on Soil

Soil Strength/Consolidation
Changing Moisture Conditions
Differential Settlement
Soil Erosion/Infiltration
Voids and Washouts

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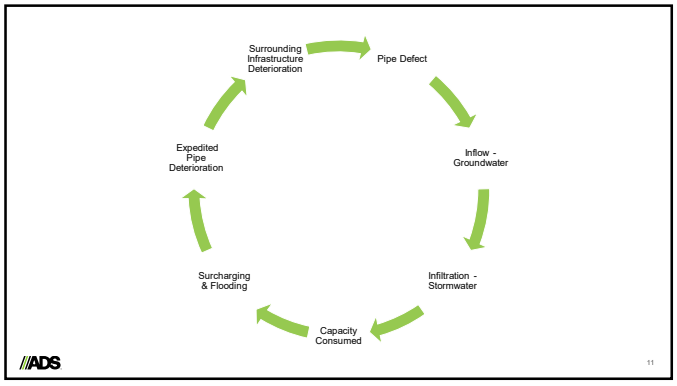

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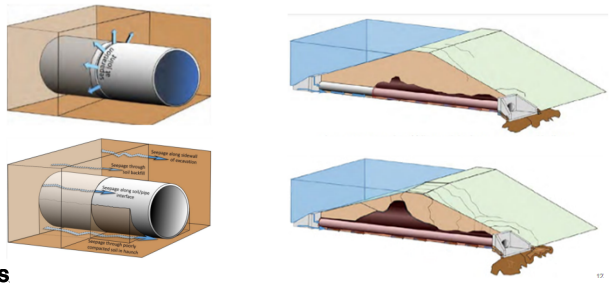
Piping



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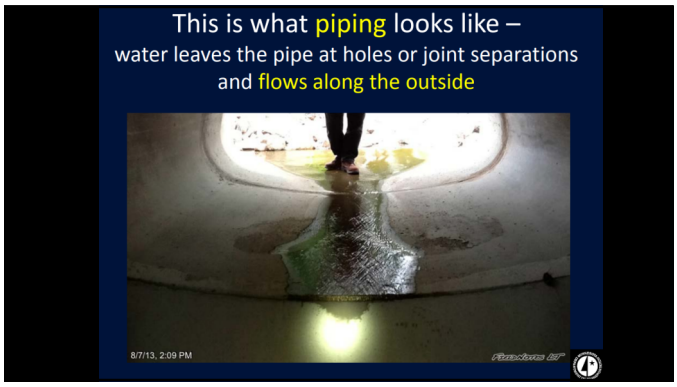
This is what piping looks like –
water leaves the pipe at holes or joint separations
and flows along the outside
8/7/13, 2:09 PM

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Erosion Risk: Joints
Improve Joint Performance
Provide Redundant Safety Measures
Reduce Statistical Chance For Failure
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ASTM C443
ASTM D3212

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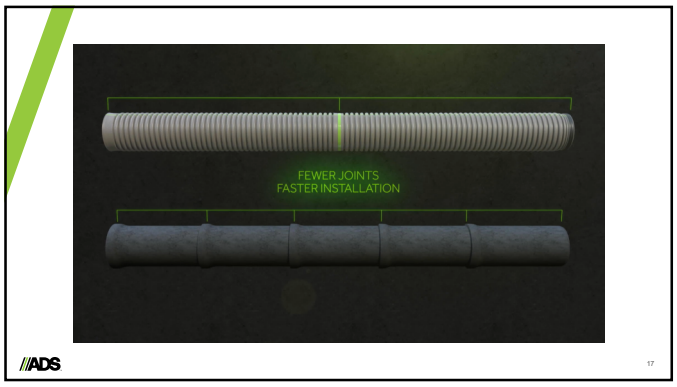
FEWER JOINTS
FASTER INSTALLATION
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Erosion Risk: Entry/Exit Points
Improve End Treatments
Improve Inlets, Catch Basins, Structures
Use Geotextiles for Stabilization
Improve Capacity
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Erosion Risk: Corrosion

Evaluate Soil & Water Conditions
Consider Abrasion Resistance
Specify Inert Materials

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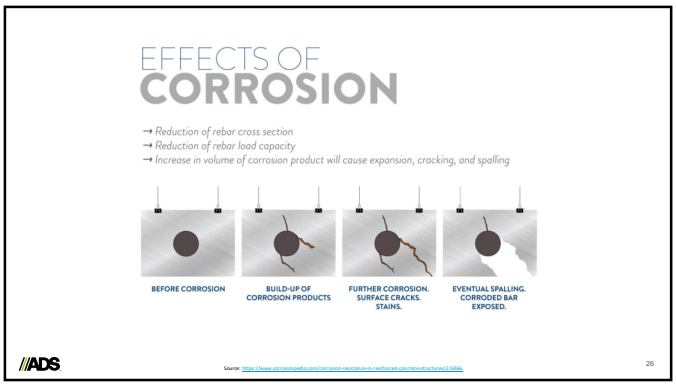
EFFECTS OF
CORROSION
→ Reduction of rebar cross section
→ Reduction of rebar load capacity
→ Increase in volume of corrosion product will cause expansion, cracking, and spalling
BEFORE CORROSION
BUILD-UP OF CORROSION PRODUCTS
FURTHER CORROSION. SURFACE CRACKS. STAINS.
EVENTUAL SPALLING. CORRODED BAR EXPOSED.
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Source: https://www.corrosionpedia.com/corrosion-resistance-in-reinforced-concrete-structures/2/4946
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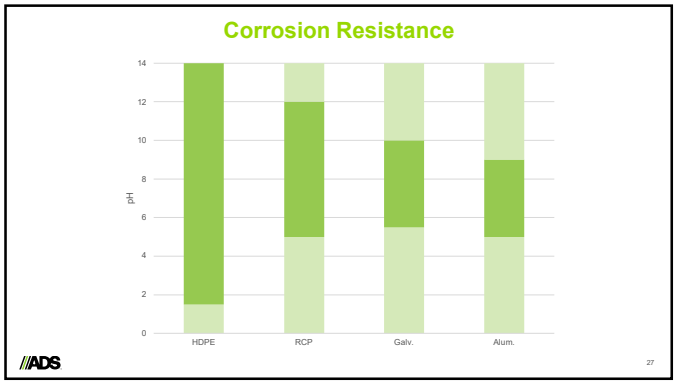
Corrosion Resistance
pH
14
12
10
8
6
4
2
0
HDPE
RCP
Galv.
Alum.
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Hydraulic Risk:
Improve Capacity
Manage Blockages
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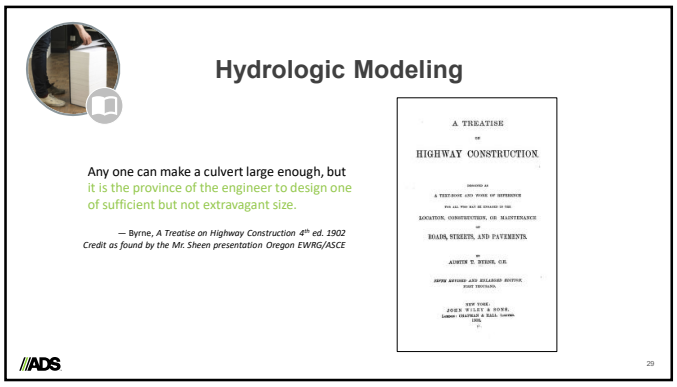
Hydrologic Modeling
Any one can make a culvert large enough, but
it is the province of the engineer to design one
of sufficient but not extravagant size.
— Byrne, A Treatise on Highway Construction 4th ed. 1902
Credit as found by the Mr. Sheen presentation Oregon EWRG/ASCE
A TREATISE
ON
HIGHWAY CONSTRUCTION
ROADS, STREETS, AND PAVEMENTS
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ROAD
FLOODED

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Structural Risk
Design Conservatively (LRFD)
Validate Design (Post-Installation Inspection)
Monitor Performance (Asset Management)
Protect Vulnerabilities in
High Risk Areas Through Design
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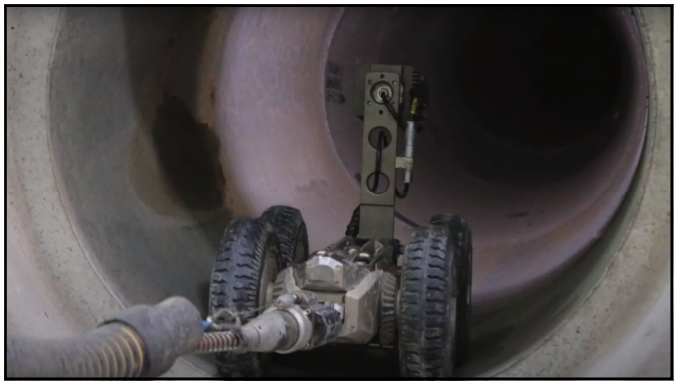

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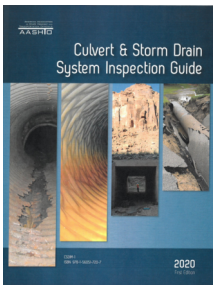
AASHTO Culvert & Storm Drain Inspection Guide

- Voted and Passed By AASHTO Committee on Bridges and Structures
- Update From ***1986***
- 5 Sections:
  - Section 1: Intro
  - Section 2: Design & Performance Characteristics
  - Section 3: Inspection Procedure
  - Section 4: Condition Rating System
  - Section 5: Asset Mgmt
  - Appendices: Details



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Source: AASHTO Used with permission.

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Table 4.2.1-1—Rating Scale and Associated Action

	1 GOOD	2 FAIR	3 POOR	4 SEVERE
CONDITION	Like new, with little or no deterioration, structurally sound and functionally adequate.	Some deterioration, but structurally sound and functionally adequate.	Significant deterioration, functional inadequacy, or both, requiring maintenance or repair.	Very poor conditions that indicate possible imminent failure or failure which could threaten public safety.
ACTION INDICATED	No action is recommended. Note in inspection report only.	No immediate action is recommended, but more frequent inspection may be warranted. Maintenance personnel should be informed.	Team Leader (Inspector) evaluates need for corrective action and makes recommendation in inspection report.	Corrective action is required and urgent. Engineering evaluation is required to specify appropriate repair.

Condition Ratings Table Titles	Table No.
Approach Roadway	4.3.2-1
Embankment	4.4.2-1
Channel Alignment and Protection	4.5.2-1
End Treatments and Appurtenant Structures	4.6.2-1
Concrete Footings and Invert Slab	4.7.2-1
Barrel Alignment	4.8.2-1
Plastic Barrel	4.9.2-1
Concrete Barrel	4.10.2-1
Corrugated Metal Barrel	4.11.2-1
Masonry Barrel	4.12.2-1
Timber Barrel	4.13.2-1
Joints	4.14.1-1
Seams of Corrugated Metal Plate	4.15.1-1
Manholes, Catch Basins, and Buried Junctions	4.17.1-1

Source: AASHTO. Used with permission.

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The tables below should be used when evaluating and rating each characteristic of he culvert & storm drain components. The highest numerical rating assigned to any of these characteristics is the rating of the system component as a whole.

RATING SCALE & ASSOCIATED ACTION	(1) Good	(2) Fair	(3) Poor	(4) Severe
Condition	Like new, with little or no deterioration, structurally sound and functionally adequate	Some deterioration, but structurally sound and functionally adequate	Significant deterioration and/or functional inadequacy, requiring maintenance or repair.	Very poor conditions that indicate possible imminent failure which could threaten public safety.
Action Indicated	No action is recommended. Note in inspection report only.	No immediate action is recommended, but more frequent inspection may be warranted. Maintenance personnel should be informed.	Team Leader (Inspector) evaluates need for corrective action and makes recommendation in inspection report.	Corrective action is required and urgent. Engineering evaluation is required to specify appropriate repair.
PLASTIC PIPE	**(1) Good**	**(2) Fair**	**(3) Poor**	**(4) Severe**
Shape	Barrel maintains round shape with no local wall flattening. Vertical deformation less than 5% of original inside diameter.	Minor wall flattening. Vertical deformation 5%-7.5% of original inside diameter.	Significant wall flattening or increased wall curvature. Vertical deformation 7.5%-10% of original inside diameter. Visual out-of-roundness.	Extreme wall flattening with reversal of curvature (global buckling), and/or kinks. Vertical deformation greater than 10% of original inside diameter. Significant visual out-of-roundness.
Surface Damage	No indication of wear, abrasion, impact damage or UV degradation.	Minor wear, abrasion, less than 10% of wall thickness. Minor staining or UV degradation. Blistering over less than 25% of pipe inner surface (FRP).	Wear, abrasion that exceeds 10% of wall thickness. UV degradation (pipe ends) causing discoloration. Blistering over greater than 25% of pipe inner surface (FRP).	Wear, abrasion that exceeds 25% of wall thickness. UV degradation (pipe ends) resulting in cracked or broken pipe wall.
Local Buckling, Splits, and Cracking	Smooth interior wall. No splits in welded seams nor cracking in wall.	Initiation of local buckling indicated by rippling in wall. Wall cracking or splits, less than a quarter of circumference. No infiltration. No longitudinal cracking.	Advanced and widespread local wall buckling indicated by extensive interior surface rippling. Wall cracking or splits up to half of circumference. Minor water infiltration but no soil infiltration. Longitudinal cracking less than 12 in. in length.	Kinks through the full wall thickness. Pipe wall buckles inward locally. Wall cracking or splits greater than half of the pipe circumference. Longitudinal cracking more than 12in. in length. Cracks with indication of soil infiltration.
CONCRETE PIPE	**(1) Good**	**(2) Fair**	**(3) Poor**	**(4) Severe**
Cracking	No measurable crack width greater than hairline (maximum 0.01 in.).	Longitudinal cracks 0.01 in. to 0.05 in. wide (thickness of dime) with spacing of 3.0 ft or more. Some circumferential cracks with no infiltration. Efflorescence but no rust staining emanating for cracks.	Longitudinal cracks between 0.05 in. and 0.1 in. wide, no exposed rebar with spacing 1.0 – 3.0 ft. Water infiltration through circumferential cracks. Efflorescence and/or rust staining emanating from cracks. No cracks with vertical offset. No increase in cracking from previous inspection.	Longitudinal cracks greater than 0.1 in. wide, exposed rebar, significant water infiltration and/or soil migration. Cracks with vertical offset. Large areas of rust staining emanating from cracks.
Slabbing, Spalling, Delamination, Patches	No spalling or slabbing, as indicated by wall visual appearance. No delamination. Any patched areas are sound.	Localized spalls less than 0.5 in. depth and less than 6 in. in diameter. No exposed rebar. No slabbing. Small delaminations indicated by hollow sounds at patches but patch remains stable.	Spalling and/or delaminations from 0.5 to 0.75 in. in depth and larger than 6 in. in diameter. No exposed rebar. Some rust staining from spalled area, structure stable. Patched areas that are delaminated or deteriorating.	Widespread spalling greater than 0.75 in. in depth or delamination with exposed rebar, structure unstable. Slabbing of concrete.
Deterioration	No scaling, abrasion, or other surface damage.	Light or moderate scaling (less than 0.25 in. exposed aggregate). Abrasion less than 0.25 in. deep over less than 20% of pipe surface. Localized superficial (less than 0.25 in.) impact damage. No rebar exposed. Multiple plugged weep holes.	Moderate to severe scaling (aggregate clearly exposed). Abrasion between 0.25 in. and 0.5 in. deep over more than 30% of pipe surface. Impact damage with exposed rebar.	Extensive surface damage and aggregate pop-out includes exposed and/or corroded rebar. Complete invert deterioration and loss of pipe wall section.
CORRUGATE METAL PIPE	**(1) Good**	**(2) Fair**	**(3) Poor**	**(4) Severe**
Surface Damage	No dents or other localized damage.	Small dents or impact damage to pipe wall or end section with not wall breaches.	Large dents or impact damage to pipe wall or end section with localized wall breaches, no more than one corrugation over circumferential length of 6 in.	Dents or damage that warrant engineering evaluation. Through-wallholes greater than one corrugation over a length more than 6 in. allowing unimpeded soil infiltration.
Corrosion	Isolated areas of freckled rust.	Freckled rust, corrosion of pipe wall material. No loss of section, no through-wall penetration from corrosion.	Corrosion of pipe material and widespread section loss less than 10% of wall thickness. Localized deep pitting. Several holes less than 1 in. diameter. Penetration possible with hammer pick strike.	Widespread through-wall penetration. Invert missing in localized sections. Though-wall penetrations present. Holes greater than 1 in. diameter or many smaller holes grouped closely.
Abrasion	No damage due to abrasion.	Small or local abrasion of wall or coating with no breaches in the coating exposing structural wall or signs of corrosion.	Widespread abrasion of protective coating with breaches exposing the pipe wall material and allowing through wall penetration during inspection probing with a pick.	Abrasion has worn large holes through the metal pipe greater than one corrugation in length for more than 6 in. around the circumference.
Shape (Closed Shape)	Smooth curvature in barrel, deformation less than 5% of inside diameter.	Top half smooth. Minor bulges or flattening of bottom. Deformation 5%-10% of original inside diameter.	Significant distortions or flattening. Lower third may be kinked. Deformation 10%-15% of original inside diameter. Visible out-of-roundness.	Extreme distortion throughout pipe, local areas of reverse curvature and kinks. Deformation greater than 15% of original inside diameter. Significant out-of-roundness.
Shape (Open Shape)	Smooth curvature, rise and span measurements within tolerance.	Refer to shape inspection requirements for specific structure types.	Refer to shape inspection requirements for specific structure types.	Refer to shape inspection requirements for specific structure types.

PPI Plastics Pipe Institute

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Rapid Recovery

Leverage sourcing efficiencies
Maximize spending efficiency
Minimize installation time
Utilize adaptable repair methods

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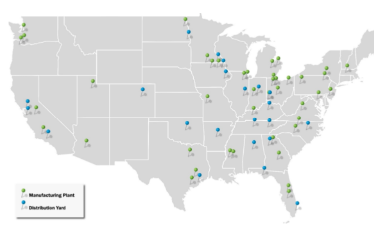
Material Logistics



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Economics of Open [Qualified] Competition

Referring to the Texas Drainage Cost Study:
One mile of 24" pipe showed average of $156,077 savings

Total installed cost $156,077 – Cost of Post Install Inspection $58,080 =

$97,997

Research suggests that municipalities which bid two or more technically qualified materials save up to 50% in total installed costs versus municipalities that specify and bid only one material.

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Source: pdworld.com

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Your Opportunity

1. *Consider infrastructure exposure to adverse events, severity of risk*
2. *Resilient infrastructure endures erosion, corrosion, hydraulic, structural risks*
3. *Leverage logistic efficiencies of rapid recovery*

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Thank You
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