Aging Infrastructure

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Hazen

Scope of the Problem

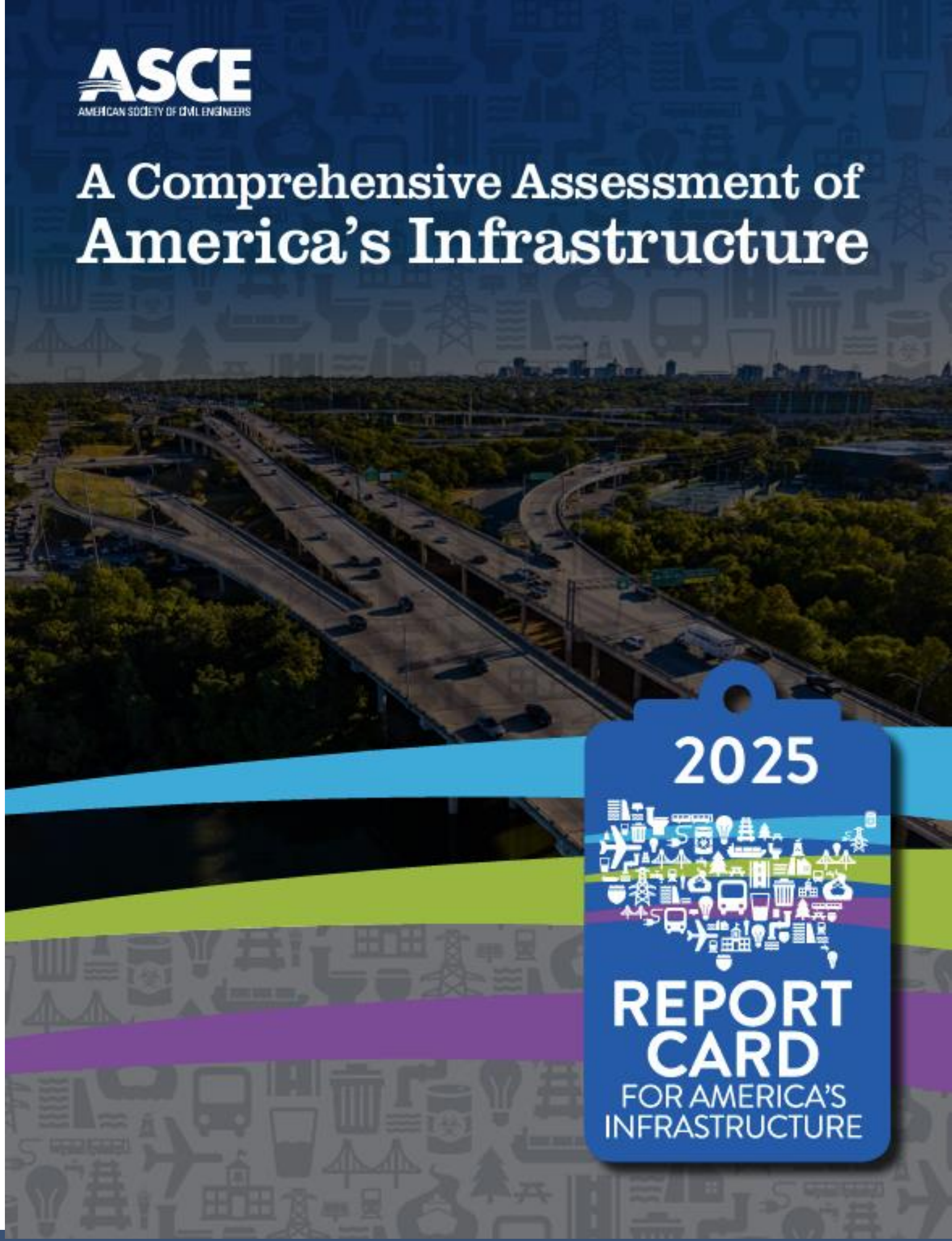
Where do we Stand

The Grades

Every four years, ASCE grades the nation's infrastructure. Water systems continue to lag — weighed down by age, underinvestment, and rising failure rates.

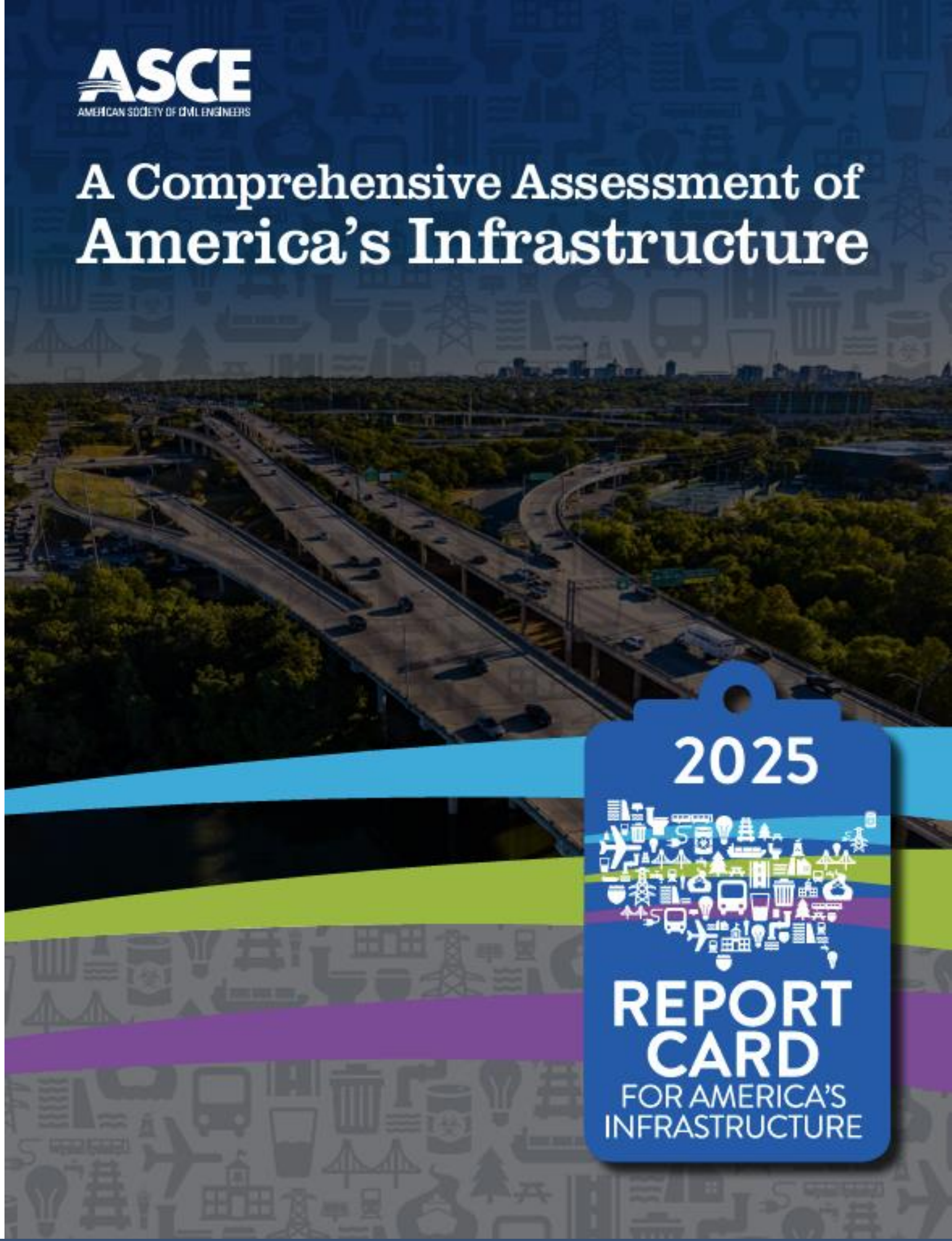
Drinking Water: C-

Wastewater: D+



Making Progress!

- 240k water main breaks per year resulting in 2.6 Billion Dollars in repair and maintenance…. That's down from 300k per year in 2018!
- Sanitary Sewer Overflows have decreased from .7 per 100 miles to .16 per 100 miles from 2015 to 2021. Average bill for a residential wastewater customer has increased from $35-$65 a month 2012-2020
- Collection system failures increased from 2 to 3.3 per 100 miles of pipe
- 30% of water utilities have implemented an asset management plan. Less than 50% are in progress.



A Long Way to Go

Table 1. Top 5 Local Government Wastewater Needs

Top 5 Local Government Wastewater Needs (from EPA's 2022 Clean Watersheds Needs Survey)	Total Need ($ Billions)
City of Charlotte (Charlotte Water)	$4.20
City of Raleigh	$1.05
Fayetteville Public Works Commission	$0.46
Cape Fear Public Utilities	$0.33
Water & Sewer Authority of Cabarrus County	$0.27
Total of the 5 Top Local Government Wastewater Needs	**$6.31**

Source: NCDEQ

Show of Hands:

- Do you have an asset management plan for the assets you are responsible for?
- Are you gaining ground on your asset replacements? Are you falling behind?
- What trend to you see for failures in your system?
- What does Asset Management mean to you?

Myths in aging infrastructure

Myth #1a: My oldest infrastructure is always the worst

Truth: Condition varies by material, quality of installation, service conditions, etc.

Example:

Concrete Sewers and Ductile Iron Sewers

- These materials can fail early due to Corrosion
  - **Pump Station Discharges**
  - **High Wastewater Age**
  - **Industrial Users**
  - **Downstream of Fast Food**

Concrete Sewer Main less than 40 years old

Myth #1b: This pipe went in 20 years ago, I don't need to worry about it

Truth: Condition varies by material, quality of installation, service conditions, etc.

Example:

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- These materials can fail early due to Corrosion
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Ductile Iron Sewer Less than 20 Years Old

Myth #1b: This pipe went in 20 years ago, I don't need to worry about it

Truth: Condition varies by material, quality of installation, service conditions, etc.

How do we put this truth to work?

- **Look at your data gaps:**
  - Fill Age data gaps first. I'd rather know if a main is 90 years old that know what material it is
  - Fill Material data gaps second. Once you know age, material is the next critical piece of information to understand HOW a pipe will fail.

Ductile Iron Sewer Less than 20 Years Old

Myth #1b: This pipe went in 20 years ago, I don't need to worry about it

Truth: Condition varies by material, quality of installation, service conditions, etc.

How do we put this truth to work?

- **Look at your data gaps:**
  - Fill Age data gaps first. I'd rather know if a main is 90 years old tha know what material it is
  - Fill Material data gaps second. Once you know age, material becomes relevant

Ductile Iron Sewer Less than 20 Years Old

Myth #2: All of this pipe material is the same

Truth: Pipe Material standards changed significantly over time. Wall thickness, Joint Type and Coatings all can have a major difference in pipe lifespan

Example: Clay Sewer Mains

1940s

- Research begins into factory-applied joints and materials
- High strength vacuum extrusion of pipe begins

1960s

- Factory-applied joint become standard

1970s

- Extra Strength VCP becomes available
- Clean water act requires leak-free joints

O-Ring VCP Joint

Myth #2: All of this pipe material is the same

Truth: Pipe Material standards changed significantly over time. Wall thickness, Joint Type and Coatings all can have a major difference in pipe lifespan

Example: PVC Water Main Standards

Different Standards

- C900, ASTM D2241

Different Pipe Class

- SDR35, DR14

Different Bedding and Installation!

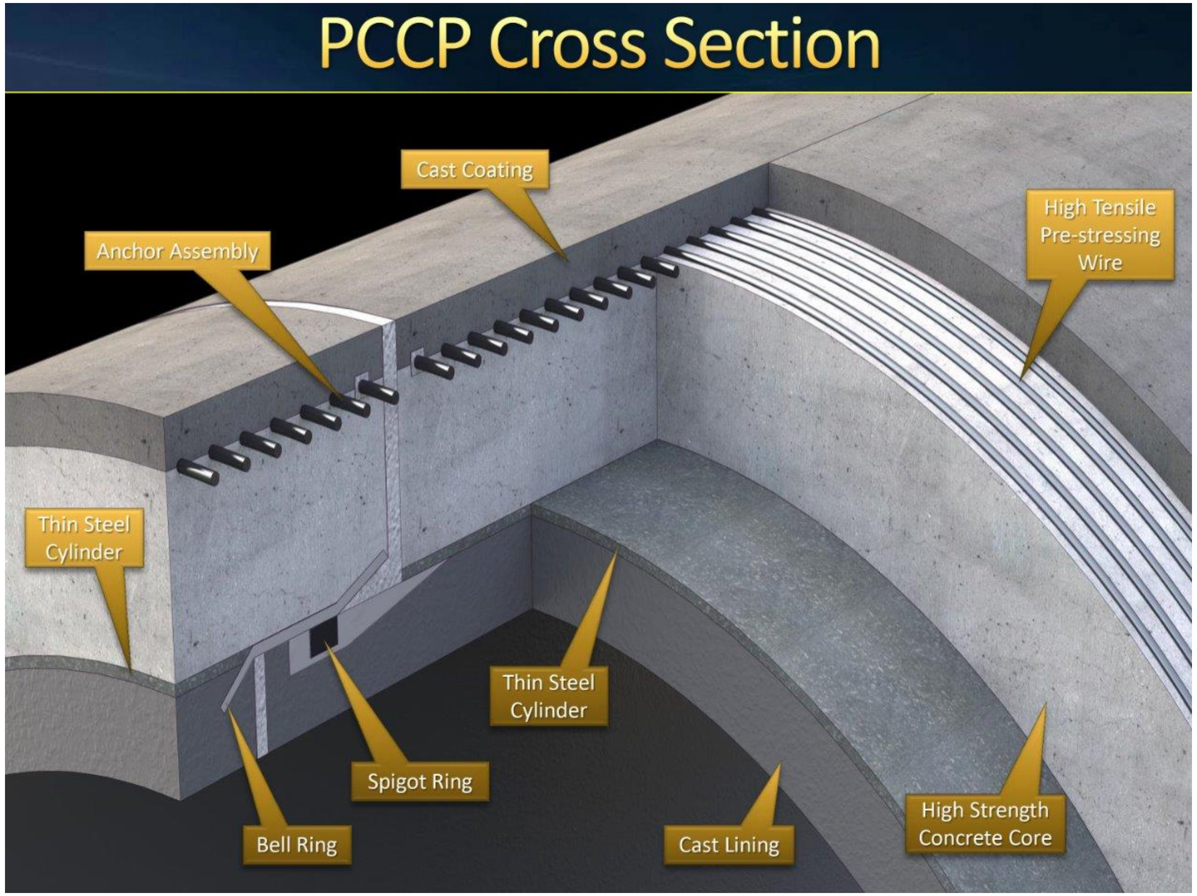
- Overhomed joints, poor bedding

Myth #2: All of this pipe material is the same

Truth: Pipe Material standards changed significantly over time. Wall thickness, Joint Type and Coatings all can have a major difference in pipe lifespan

Example: PCCP

- PCCP installed in the mid-1970s to mid-1980s has history of failures
- Failures caused by change to inferior 8 AWG Type IV prestressing wires
- **8 AWG Type IV wire has "detrimental strain age" from lack of temperature control in drawing process**

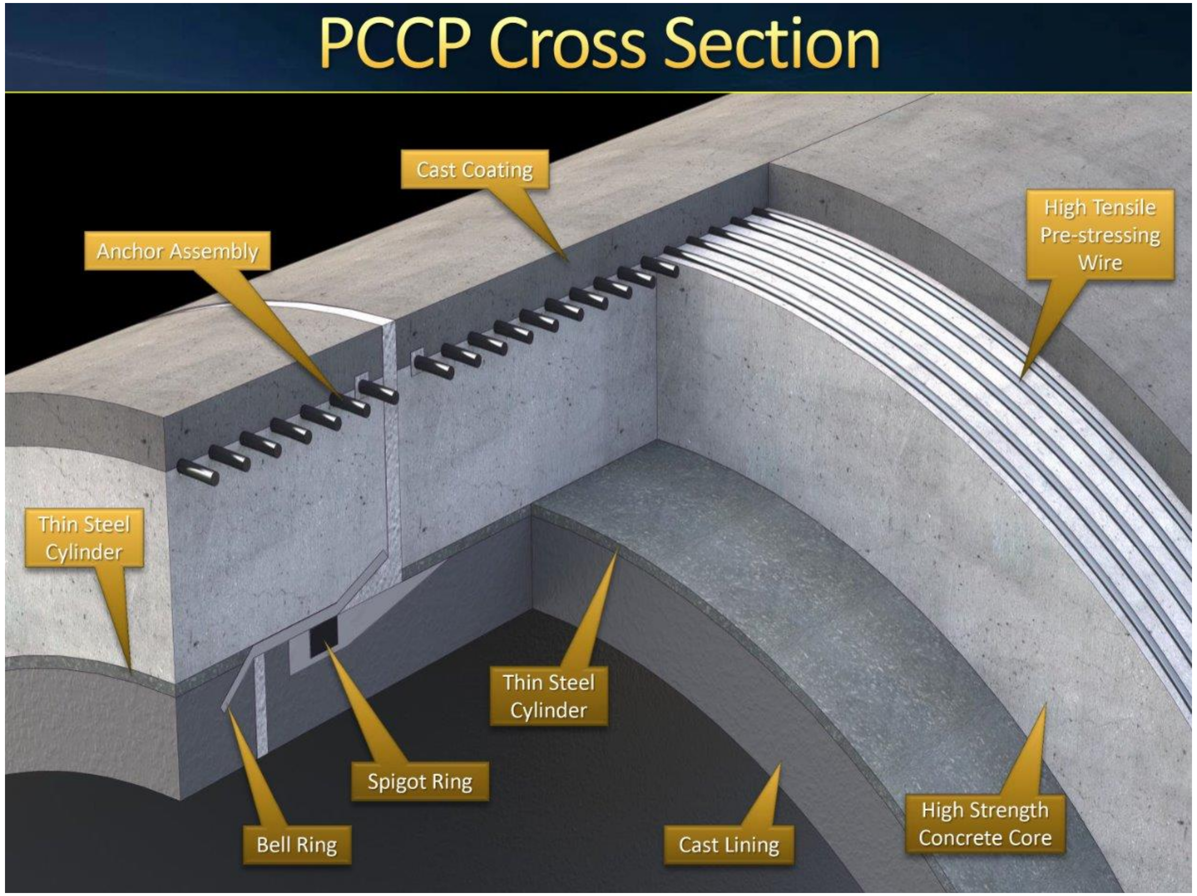


Myth #2: All of this pipe material is the same

Truth: Pipe Material standards changed significantly over time. Wall thickness, Joint Type and Coatings all can have a major difference in pipe lifespan

How do we put this truth to work:

- Avoid sweeping extrapolations “All my clay is failing at the same rate”
- Build better data: Track coatings, wall thickness etc.
- Use Problem Cause Remedy codes to help better understand WHY things are failing.
- Consider Predictive Analytics to better understand what is failing and why



Myth #3: As long as my force main is plastic, I don’t have to worry about corrosion

Truth: Metallic Fittings, Bore Crossings, and ARVs all can be metallic and fail due to corrosion.

Example: ARV Failure

- Fittings and ARVs can be the weak point for internal corrosion on PVC forcemains
- NCDOT often required Ductile Iron in the casing at the road crossings, which were also often high points.

Myth #3: As long as my force main is plastic, I don’t have to worry about corrosion

Truth: Metallic Fittings, Bore Crossings, and ARVs all can be metallic and fail due to corrosion.

How do we put this truth to work?

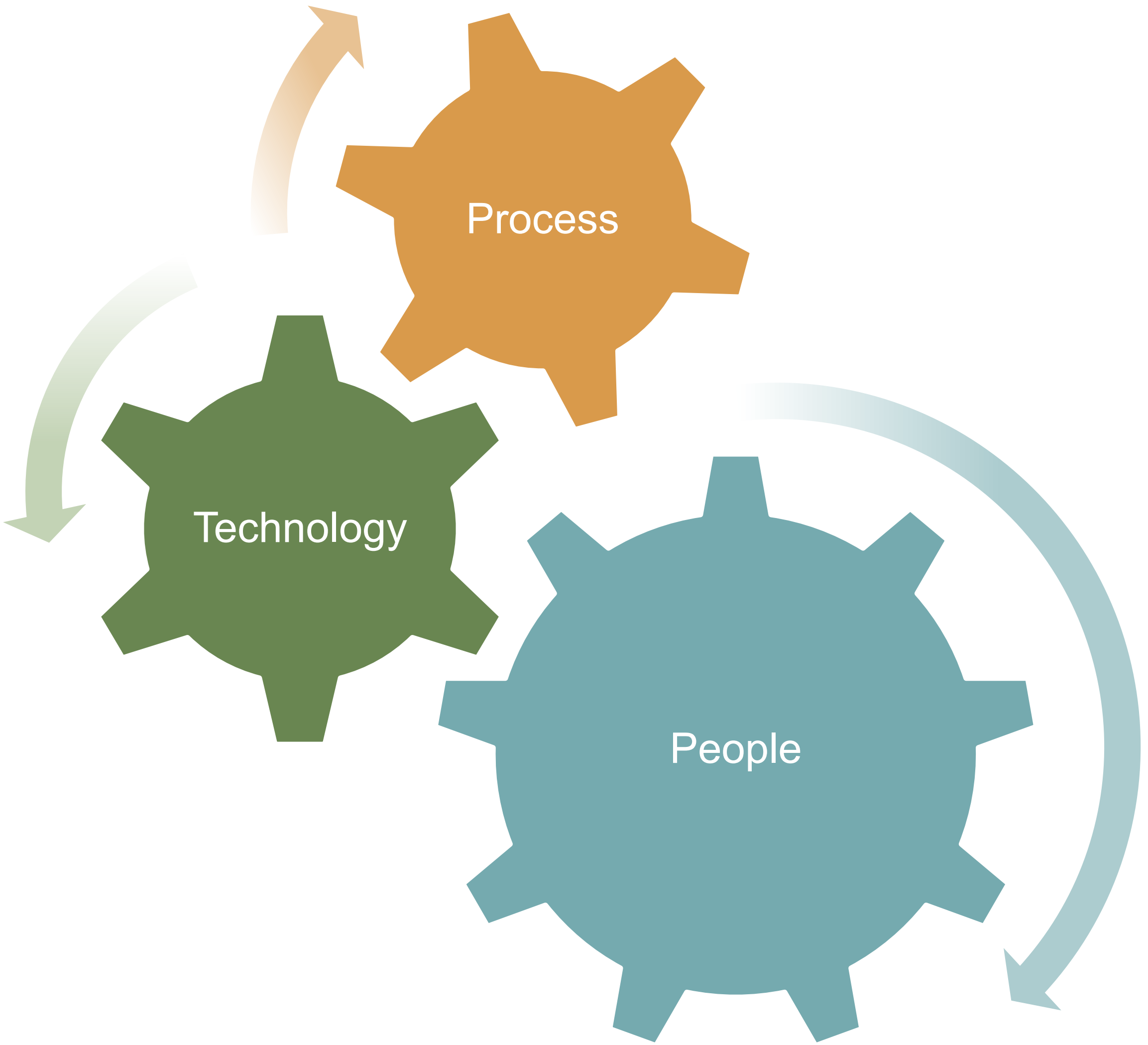
- Consider failure modes at a system level!
- Don’t neglect appurtenances when performing condition assessment

Myth #4: This Software…Hire….Project will solve my aging Infrastructure issues

Truth: Successful asset management is a LONG-TERM investment and requires People, Processes, and Tools working together.

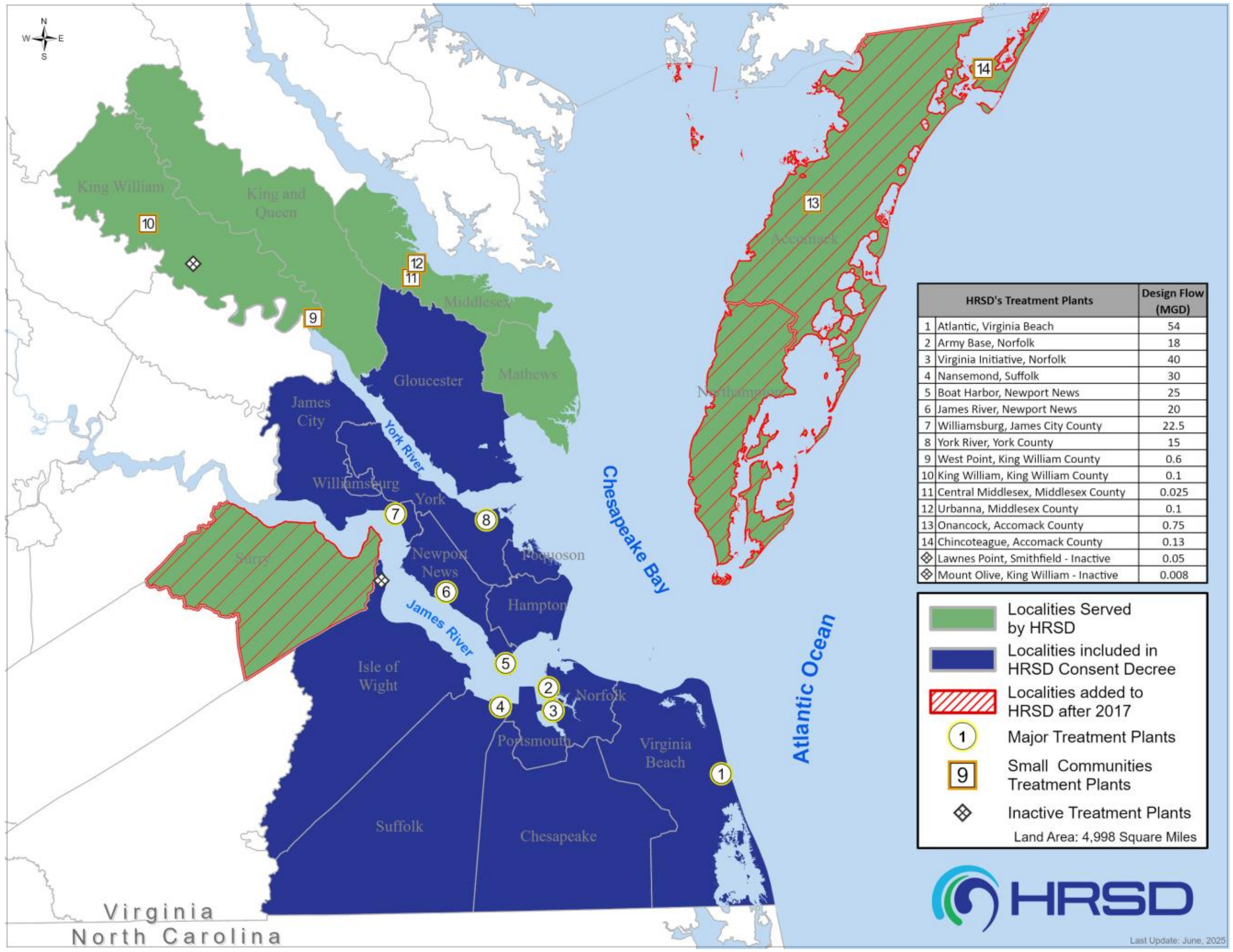
How do we put this truth to work?

- Set and work towards long term goals
- Make sure people, processes, and tools all improve together
- Make Asset Management a part of what you do every day, not a project that is delivered and done.



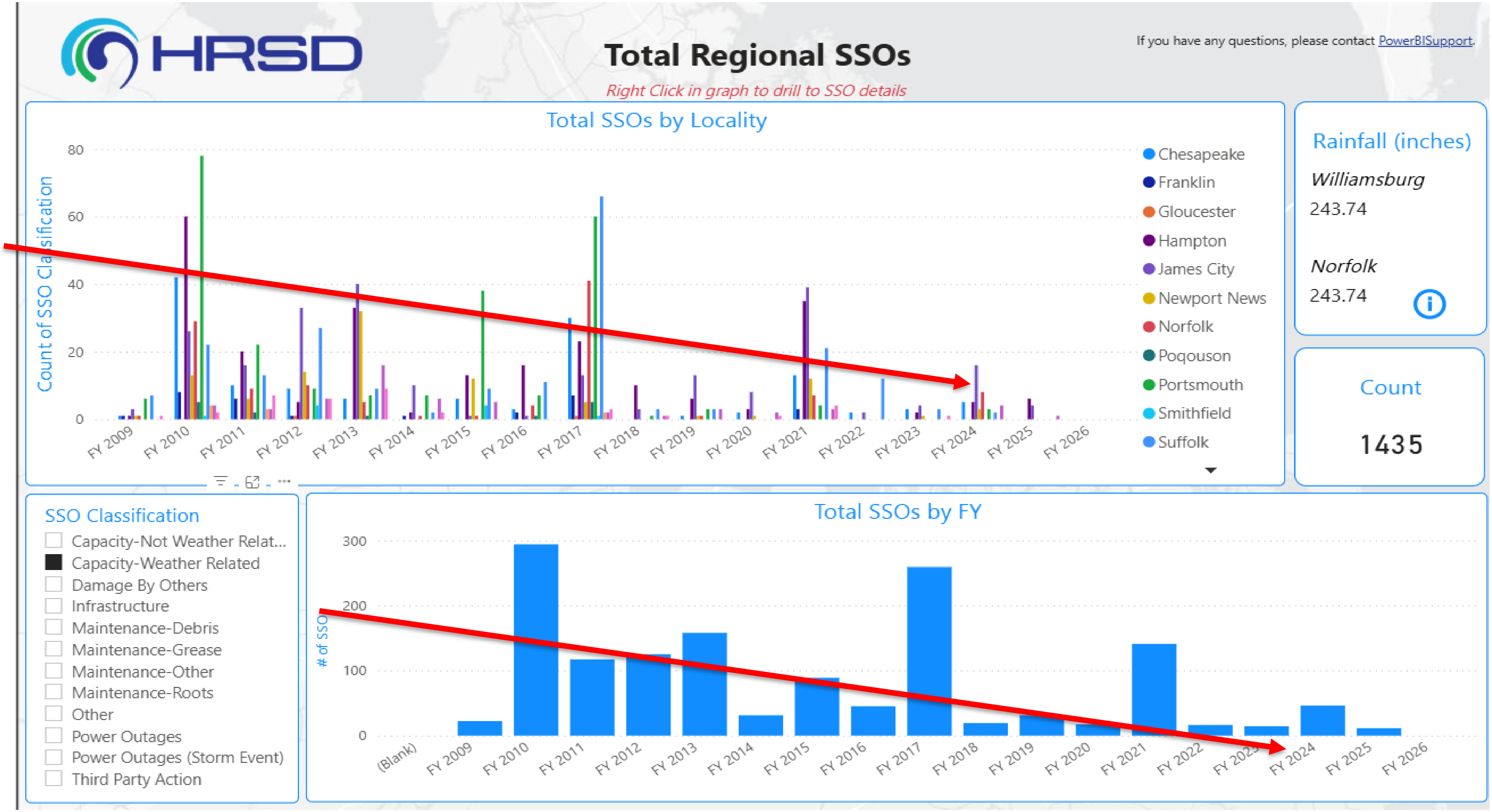
HRSD Example

HRSD: Regulatory / Investment Challenges

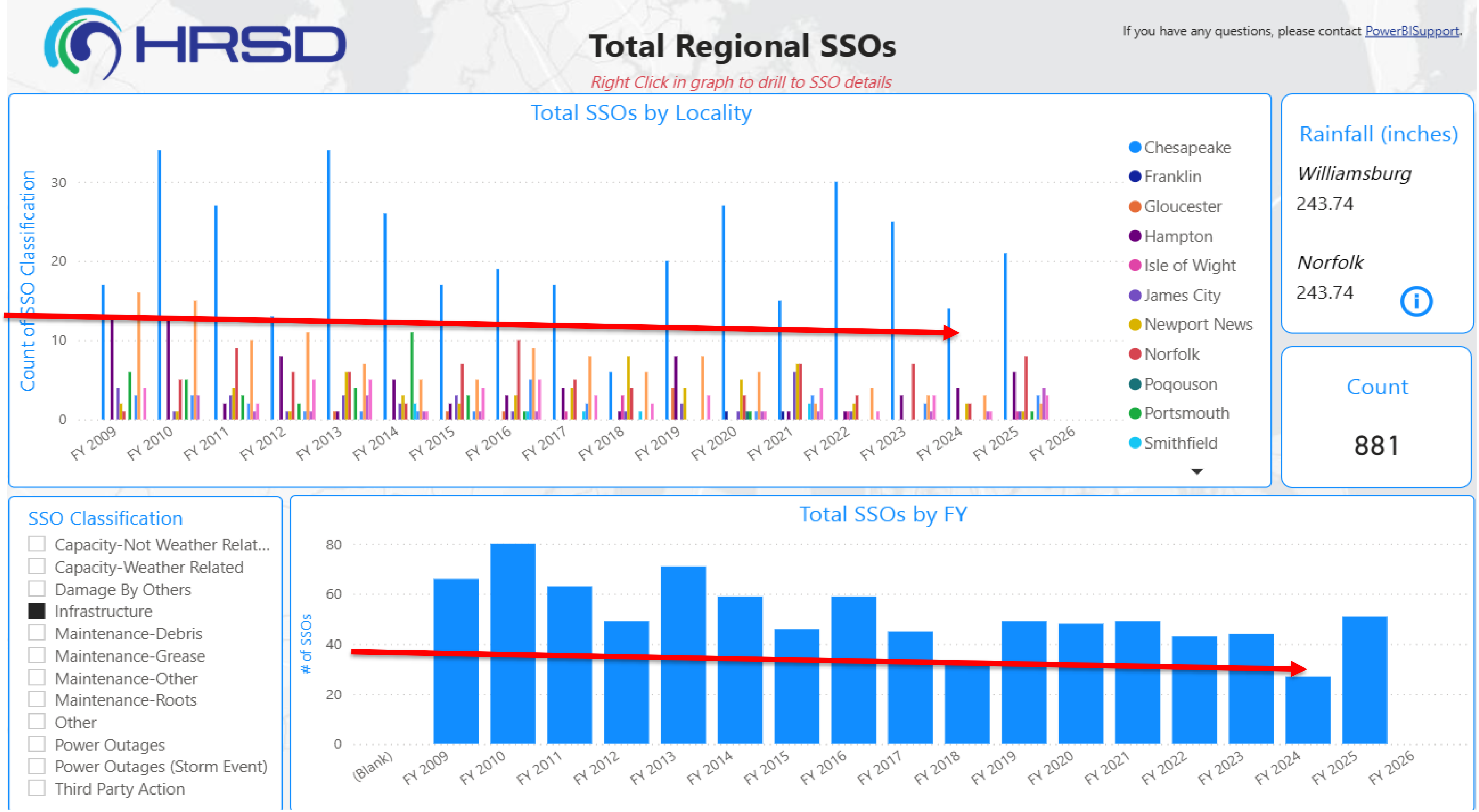


- **VPDES** **(permit compliance)**
- TMDL (total maximum daily load)
- **SSO** **(sanitary sewer overflows)**
- **Coastal Resilience**
- **PFAS**
- **Microplastics**
- **GW replenishment**
- **Economic Development**
- **Aging Infrastructure**

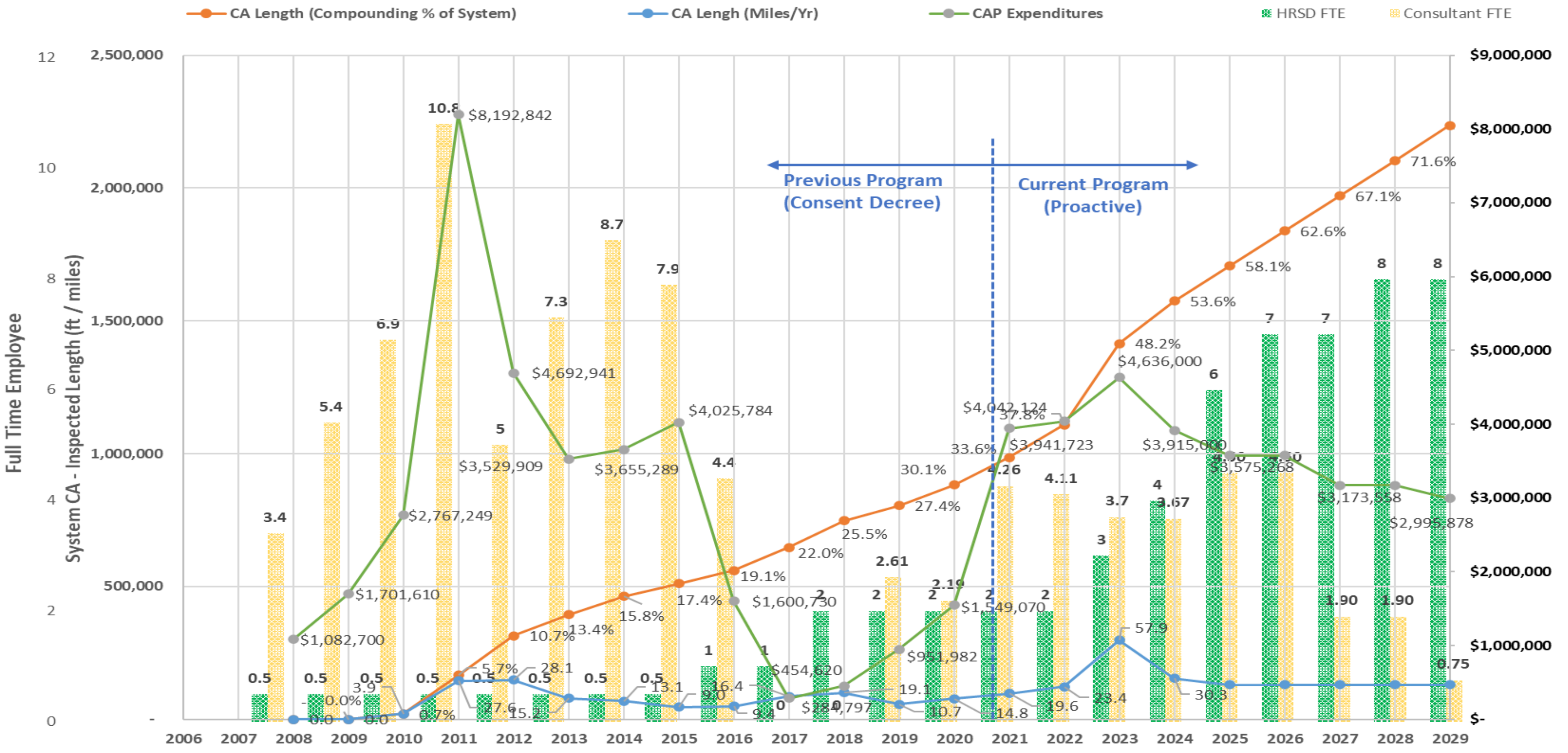
Capacity SSO’s



Infrastructure SSO's

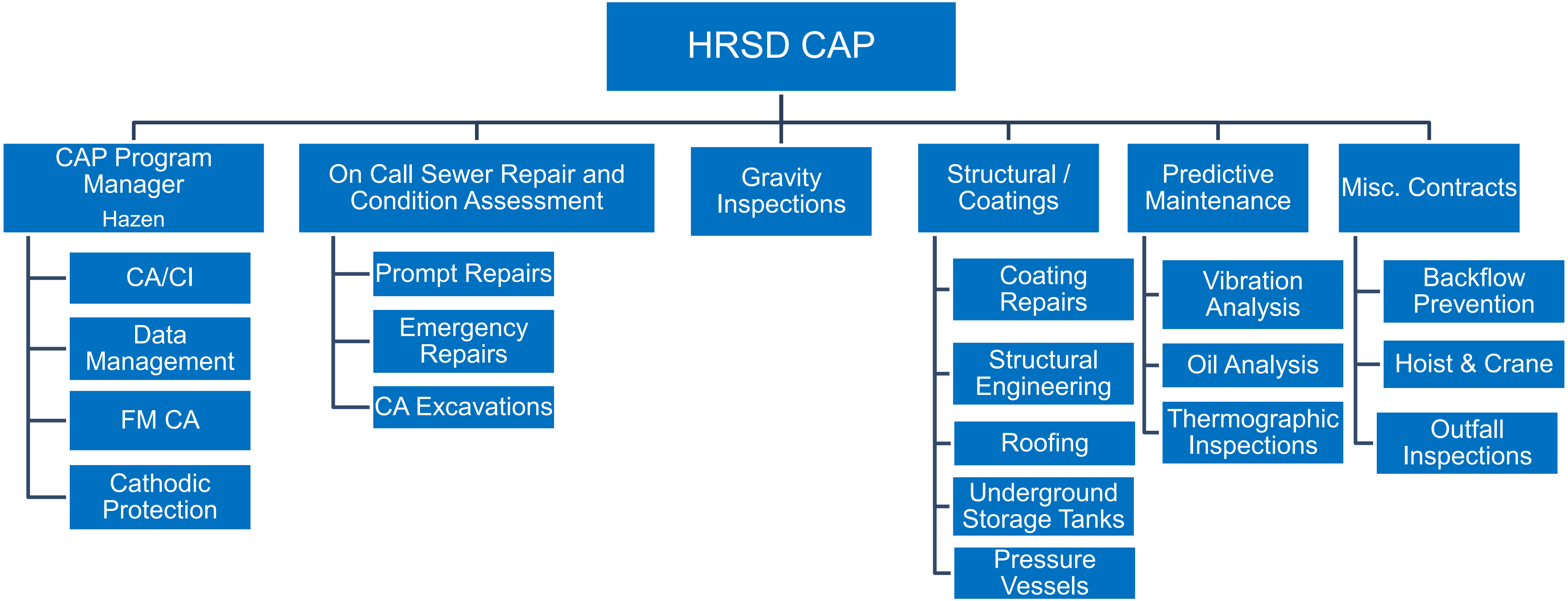


CAP Resources



HRSD Annual Staffing Review

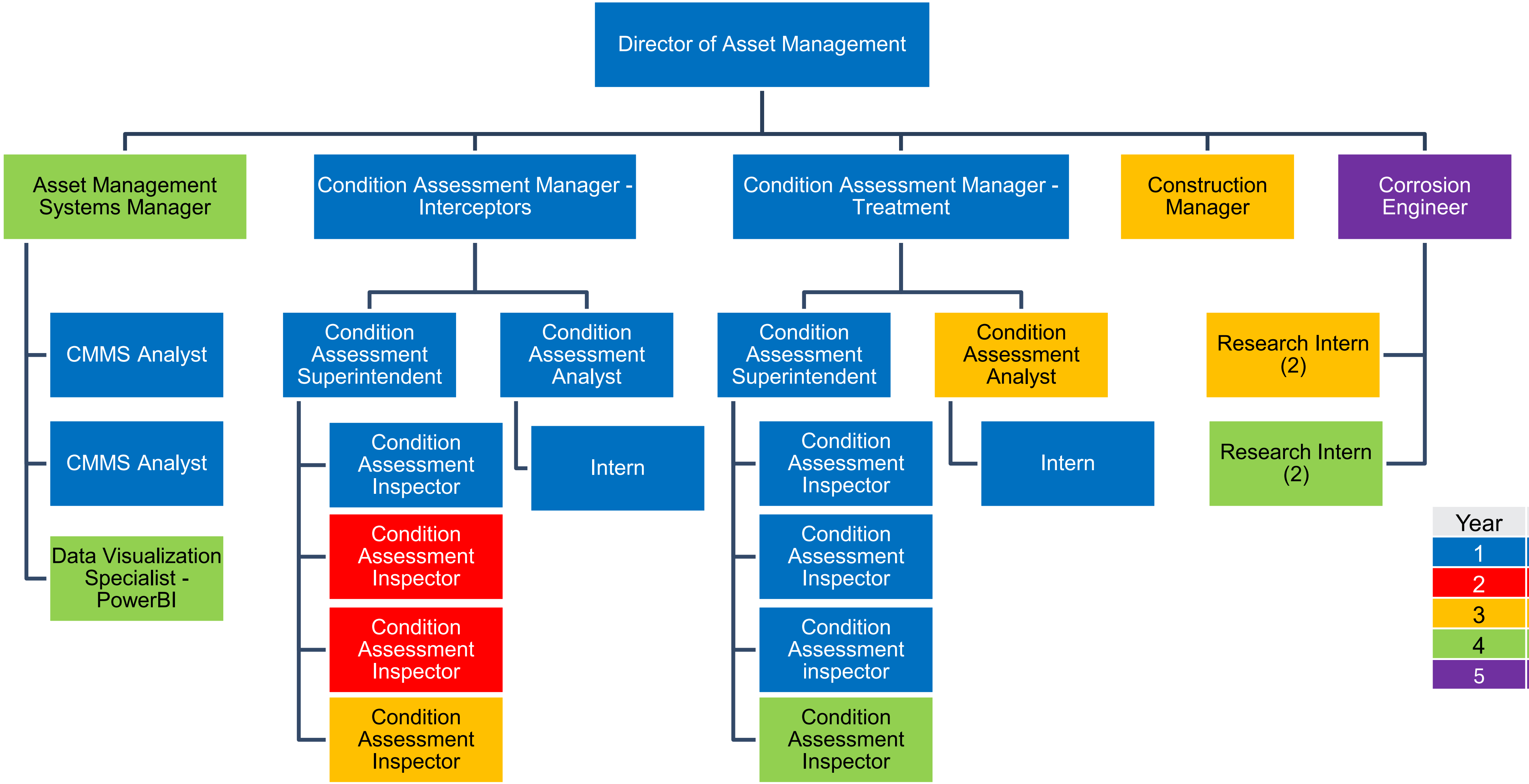
CAP External Resources



Staffing Assessment: New Tasks Beginning Each Year

	Year 1				Year 2				Year 3			
Tasks	**CAP Manager**	**CA Analyst**	**Inspector**	**Total**	**CAP Manager**	**CA Analyst**	**Inspector**	**Total**	**CAP Manager**	**CA Analyst**	**Inspector**	**Total**
Interceptor	**548**	**1226**	**180**	**1954**	**116**	**134**	**1280**	**1530**	**168**	**156**	**180**	**504**
Emergency Response Support				**0**				**0**	48	48	120	**216**
FY 25 Cathodic Protection Evaluation & Minor Repairs				**0**				**0**	80	60	60	**200**
Interceptor Response Committee	16	32		**48**				**0**				**0**
Leak and Gas Pocket Detection Planning	56	100	20	**176**				**0**				**0**
Localized IFM CA Project	308	763	35	**1106**	56	70	1120	**1246**				**0**
Opportunistic CA Support	60	60	120	**240**				**0**				**0**
Reservoir Group IFM CA Project	44	103	5	**152**	8	12	160	**180**				**0**
Risk Model Improvements	48	144		**192**				**0**				**0**
Sewer Repair and CA Contract Management				**0**	52	52		**104**				**0**
Soil Corrosivity Assessment				**0**				**0**	40	48		**88**
Failure Trending Analysis	16	24		**40**				**0**				**0**
Treatment	**404**	**571**	**127**	**1102**	**52**	**122**	**560**	**734**	48	48	120	**216**
Emergency Response Support				**0**				**0**				**0**
Opportunistic CA Support	60	60	120	**240**				**0**				**0**
Risk Model Improvements	48	144		**192**				**0**				**0**
Sewer Repair and CA Contract Management				**0**	52	52		**104**				**0**
TP Piping CA Project	280	343	7	**630**		70	560	**630**				**0**
Failure Trending Analysis	16	24		**40**				**0**	48	48	120	**216**
Grand Total	**952**	**1797**	**307**	**3056**	**168**	**256**	**1840**	**2264**	**216**	**204**	**300**	**720**

Staffing Assessment: Resources Roadmap



Year	FY	FT	PT
1	FY25	12	2
2	FY26	14	2
3	FY27	17	4
4	FY28	20	6
5	FY29	21	6

Where do we start?

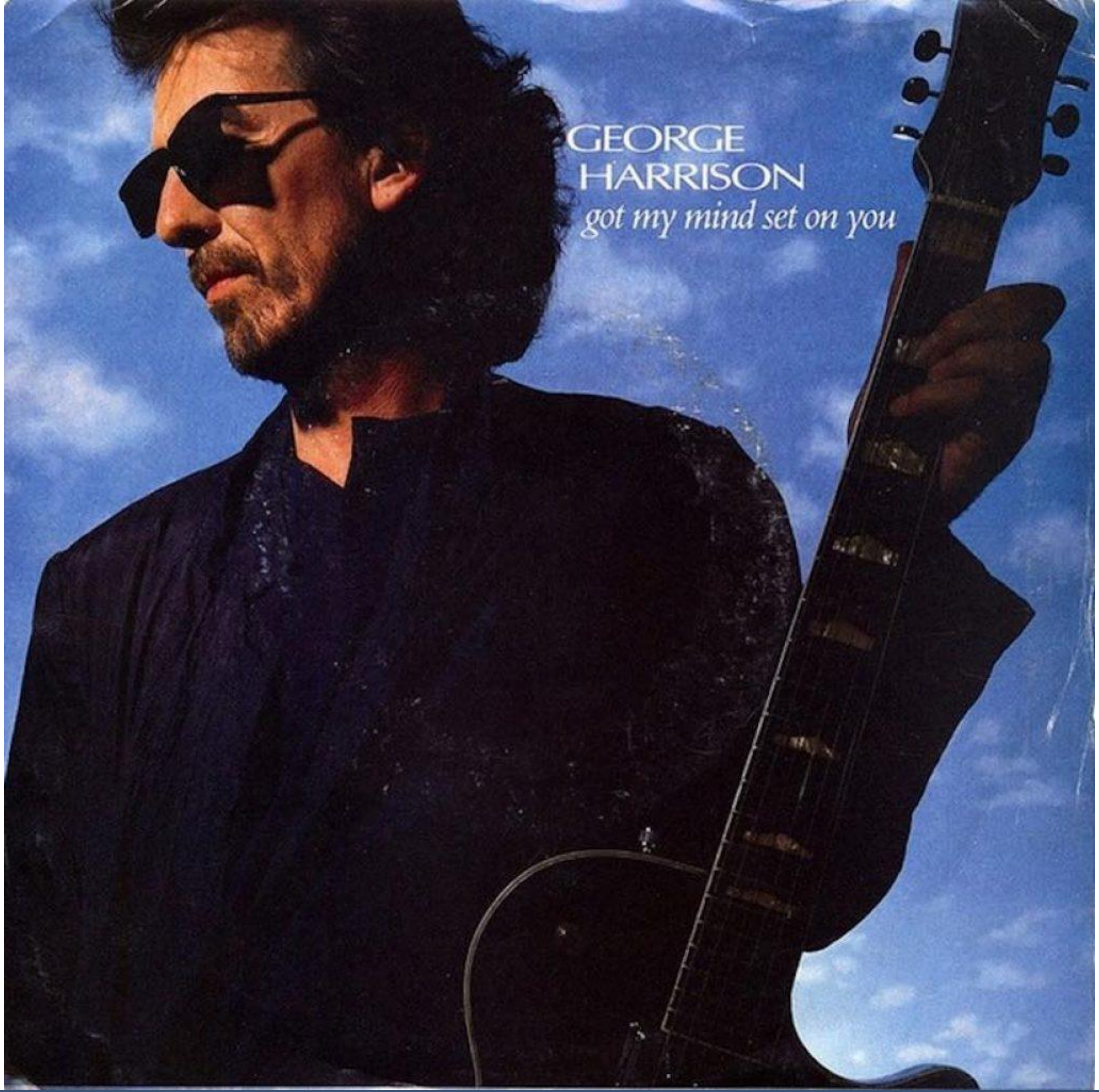
How do we fix it?

"But it's gonna take money
A whole lotta spendin' money
It's gonna take plenty of money
To do it right, child

It's gonna take time
Whole lot of precious time
It's gonna take patience and time
To do it right, child"

Asset Management and Replacement will cost money and take time but…

1) Its less expensive than ignoring the problem
2) The problem isn't going to get better if we wait
3) We don't have to do everything at once. We can improve one step at a time.



Asset Management Maturity Assessment

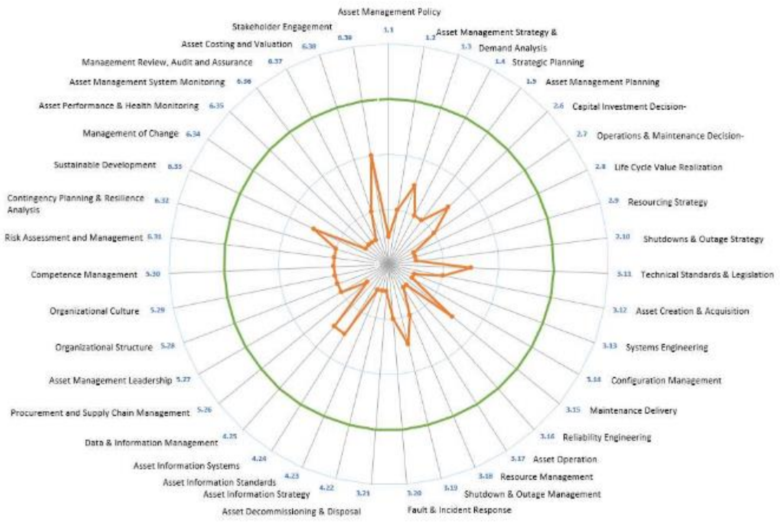
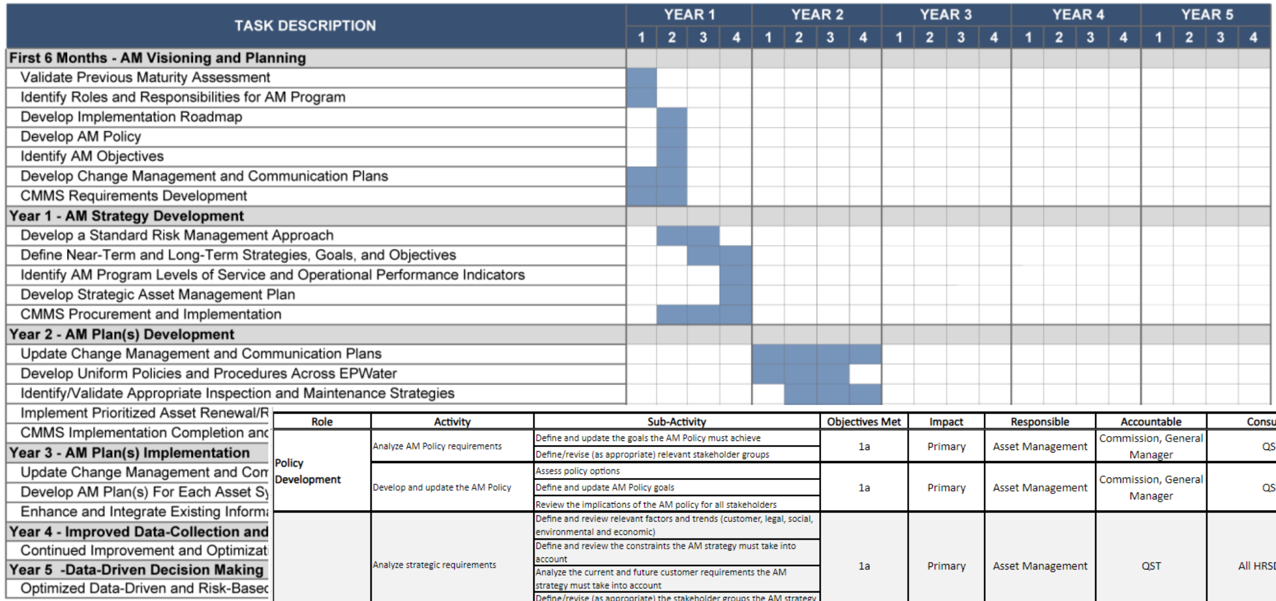


Figure E-4: Institute of Asset Management Maturity Assessment Results

Innocent	Aware	Developing	Competent	Mature	Industry Leader
Maturity Level 0	**Maturity Level 1**	**Maturity Level 2**	**Maturity Level 3**	**Maturity Level 4**	**Maturity Level 5**
The City has not recognized the need for this requirement and/or there is no evidence of commitment to put it in place	The City has identified the need for this requirement and there is evidence of intent to progress it	The City has identified the means of systematically and consistently achieving the requirements, and can demonstrate that these are being progressed with credible and resourced plans in place	The City can demonstrate that it systematically and consistently achieves relevant requirements set out in the IAM Anatomy	The City can demonstrate that it is systematically and consistently optimizing its asset management practice, in line with the City's objectives and operating context	The City can demonstrate that it employs the leading practices and achieves maximum value from the management of its assets, in line with the City's objectives and operating context



Role	Activity	Sub-Activity	Objectives Met	Impact	Responsible	Accountable	Consulted	Informed
Policy Development	Analyze AM Policy requirements	Define and update the goals the AM Policy must achieve Define/revise (as appropriate) relevant stakeholder groups	1a	Primary	Asset Management	Commission, General Manager	QST	All HRSD Staff
	Develop and update the AM Policy	Assess policy options Define and update AM Policy goals Review the implications of the AM policy for all stakeholders	1a	Primary	Asset Management	Commission, General Manager	QST	All HRSD Staff
AM Strategy Development	Analyze strategic requirements	Define and review relevant factors and trends (customer, legal, social, environmental and economic) Define and review the constraints the AM strategy must take into account Analyze the current and future customer requirements the AM strategy must take into account Define/revise (as appropriate) the stakeholder groups the AM strategy must take into account	1a	Primary	Asset Management	QST	All HRSD Staff	QST
	Define, review and update levels of service	Define, review and update levels of service (LOS) and performance measures Implement regular monitoring of LOS and performance measures	1a	Secondary	Asset Management	Commission, General Manager	QST	All HRSD Staff
	Forecast and analyze future requirements and demands	Develop/revise (as appropriate) forecasts of demand and required levels of service	1a, 4a	Primary	Planning and Analysis	Engineering	Water Quality, HRPDC/Localities	QST
	Develop, review and update the AM Strategy	Define, review and update AM Objectives Develop, review and update key strategies for the overall system, asset portfolios and/or asset groups Stakeholder coordination	1a	Primary	Asset Management	QST	All HRSD Staff	Key Stakeholders
	Plan the implementation of the AM Strategy	Define, prioritize, optimize and revise (as appropriate) the AM Strategy Prepare business cases and financial projections Define/revise (as appropriate) how the effectiveness of the AM Strategy will be measured and monitored	1a	Primary	Asset Management, Planning and Analysis, Operations	QST	Key Stakeholders	Key Stakeholders

The AM Implementation Roadmap includes customized, resource-loaded initiatives to advance the AM Program

Practical Asset Management Roadmap Example

Return on Investment Grows Year over Year

FIRST 6 MONTHS: AM Visioning & Planning

- Conduct Maturity Assessment
- Data Gap Analysis
- Identify roles and responsibilities for AM Program
- Develop Implementation Roadmap

YEAR 1: Asset Inventory Refinement

- Define Asset Hierarchy
- Collect Asset Data (as-builts, field data collection)
- Consider opportunistic condition assessment during field work

YEAR 2: COF & LOF

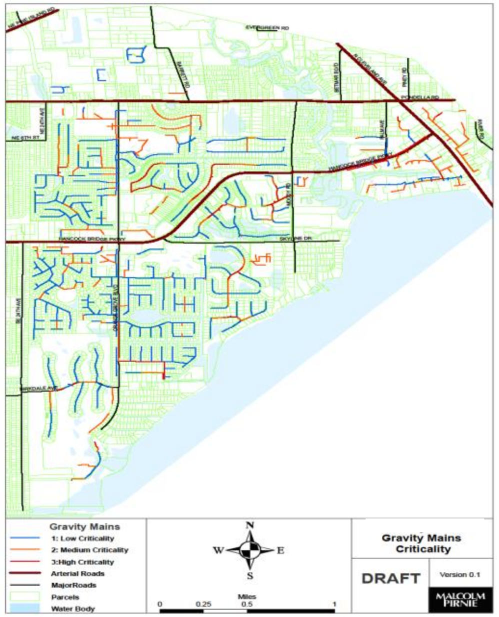
- Develop a Risk Framework
- Score Processes for COF and LOF
- Roll process level scores down to individual assets
- Develop a Condition Assessment Plan

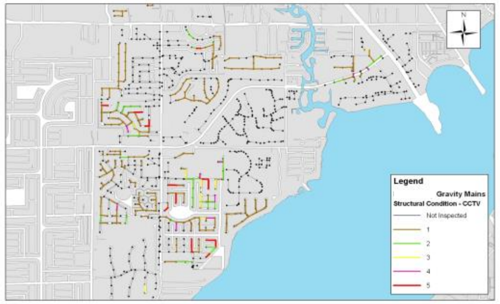
YEAR 3: FMECA, PM Optimization, Condition Assessment

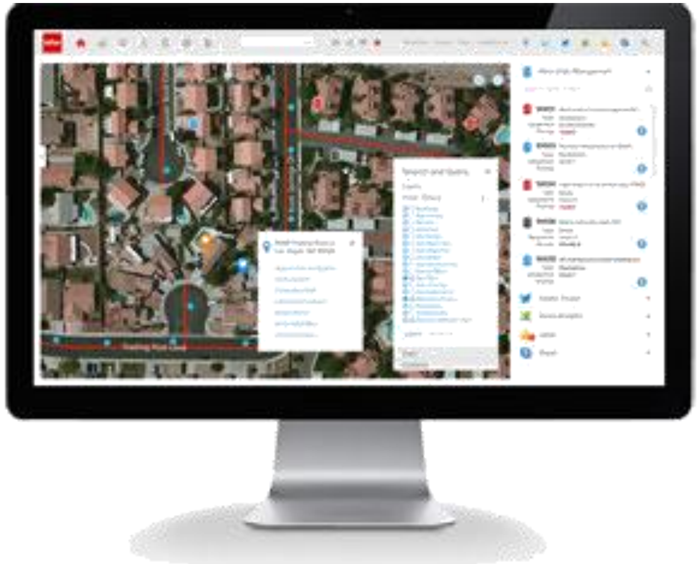
- For most critical assets consider Failure Modes, Effects, and Criticality Analysis
- Optimize and Review Preventative Maintenance
- Continue Condition Assessment
- Review Budgeting Assumptions

Build your Asset Inventory GIS/CMMS

Pipeline Systems	
Attribute	**Purpose**
Length	• Calculate asset value • Indicate complexity of maintenance • Calculate defects per foot of pipe • Necessary for hydraulic modeling
Diameter	• Calculate asset value • Macro understanding of system performance • Necessary for hydraulic modeling
Material	• Calculate asset value • Maintenance and repair methods • Deterioration rates
Depth	• Calculate repair costs
Installation Date	• Calculate asset value • Indicate quality of material and installation • Future planning • C-Factor determination for hydraulic modeling





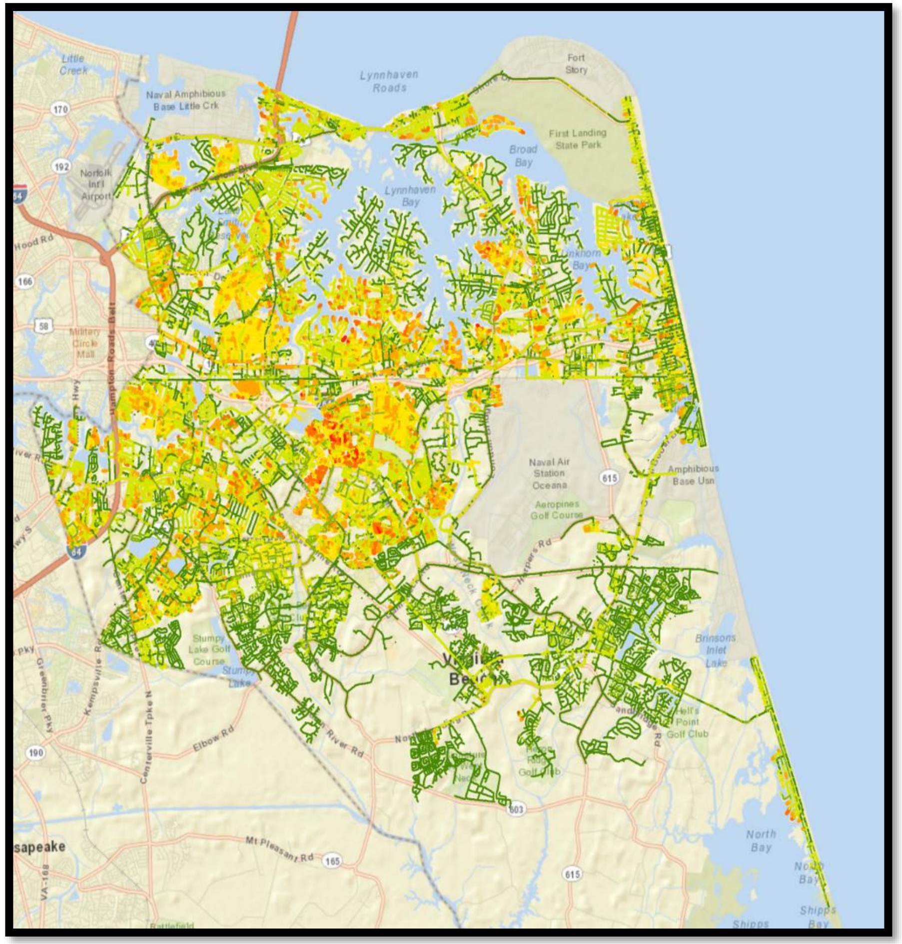


Typical Asset Hierarchy

1. Organization
2. Network
3. Utility Type
4. Facility
5. Process
6. Group
7. Asset
8. Asset-Child

Develop LOF, COF, and Risk scores

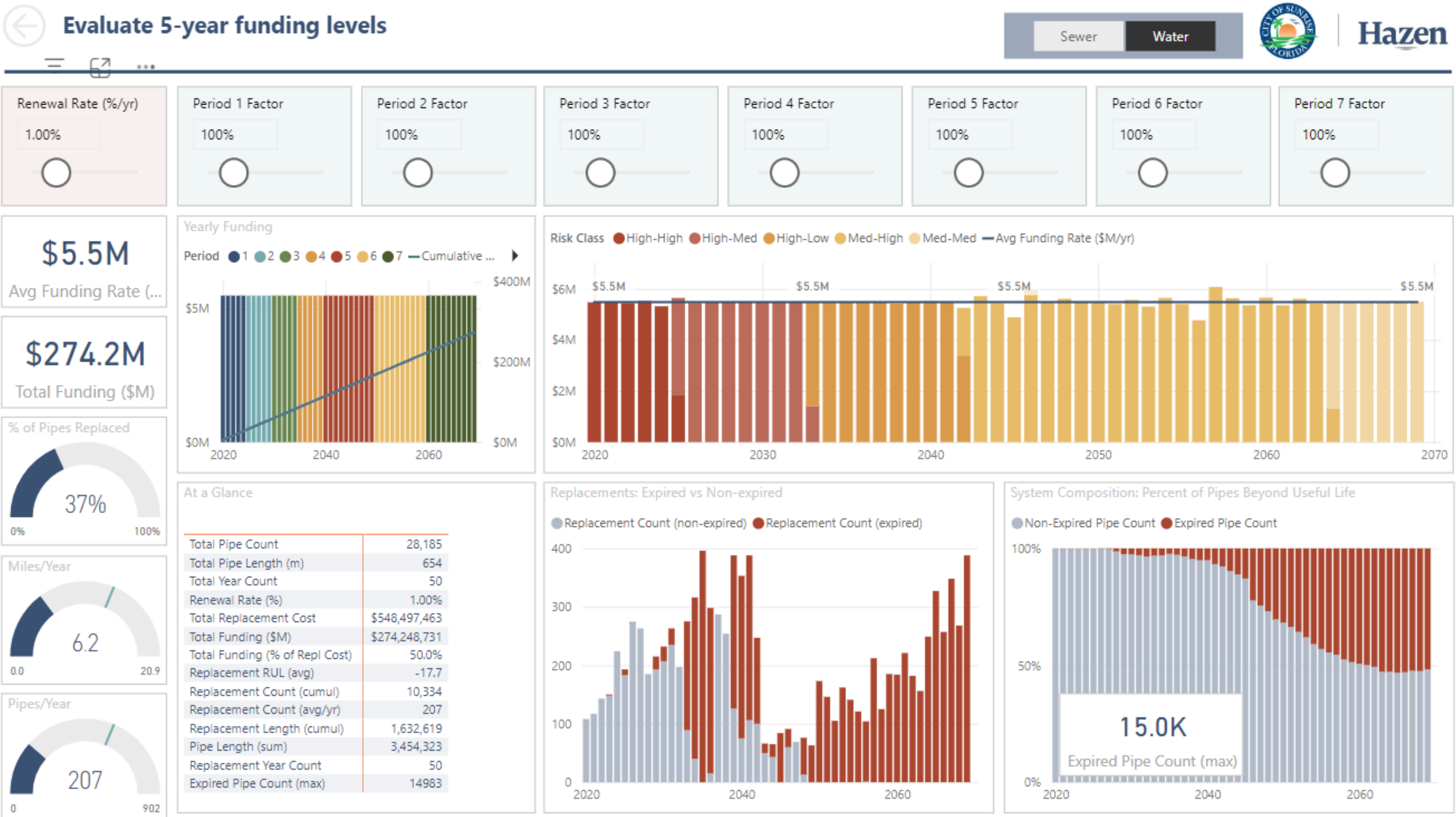
CRITERIA	CATEGORIES		
	Class 3 – High Criticality	Class 2 – Moderate Criticality	Class 1 – Minor Criticality
	Meets any Criteria Below	Meets no Class 3 Criteria and Meets any Criteria Below	Meets no Class 3 or Class 2 Criteria
Pipe Size	Diameter > = 16"	Diameter > = 10"	Meets no Class 3 or 2 Criteria
Traffic	Located on a road categorized as Interstate	Located on a road categorized as Primary	
Educational Services	Serving a college, university, or a high school	Serving a middle school, private school, elementary school, or technical school	
Health Services	Serving a medical facility, hospital, EMS, fire station, dialysis center, or authorized needs	Serving an assisted living center, nursing homes, or adult day care	
Military Services	Serving Military Facilities	-	
Municipality Services	Serving Critical Municipal Facilities (Courthouse, City Hall etc.)	-	
Entertainment Services	Serving Virginia Beach Amphitheater/Sportsplex/ Convention Center	Serving a community youth organization	



Perform Condition Assessment

Condition Assessment Strategy	Criticality
Visual + Performance + Testing	Highest
Visual + Performance	Moderate
Visual	Low
Desktop	Lowest

Financial Forecasting



I’ve Done all that. What comes next?

Failure Mode, Effects, & Criticality Analysis

FMEA & RCM

Increasing Asset (System) Criticality
Increasing Resource Investment

Method	Focus	Application	Advantages
RCM Reliability Centered Maintenance	Function	Highly critical and complex assets	• Promotes reliability of the essential aspects of the asset • Most effective for analyzing complex assets and minimizing maintenance efforts • Process can be used as a template for similar assets
FMEA Failure Mode & Effects Analysis	**Equipment**	**Mid to highly critical assets with moderate complexity**	• **Structured and repeatable approach that is relatively easy to learn** • **Can be performed by a single individual who is familiar with the equipment type** • **Process can be used as a template for similar assets**
MTA Maintenance Task Analysis	Maintenance Tasks	Improving or optimizing existing PM program tasks	• Faster than either RCM or FMEA if just being used to optimize a PM program • Can be used with FMEA to optimize PM program to address all failure modes • Can be performed by a single individual who is familiar with the equipment type
PMO Preventive Maintenance Optimization	**Program**	**Optimizing heavily-loaded PM programs**	• **Provides rapid returns in the form of improved PM tasks and / or reduced PM labor hours** • **Analyzes all PM activities defined in the "program," not just on critical assets** • **Addresses PM scheduling and coordination issues**
DE Defect Elimination	Problem	For resolving evident and high impact problems	• Addresses existing problems • Results are realized in near-term which maintains momentum • Empowers staff to identify and implement solutions which increases acceptance of the process

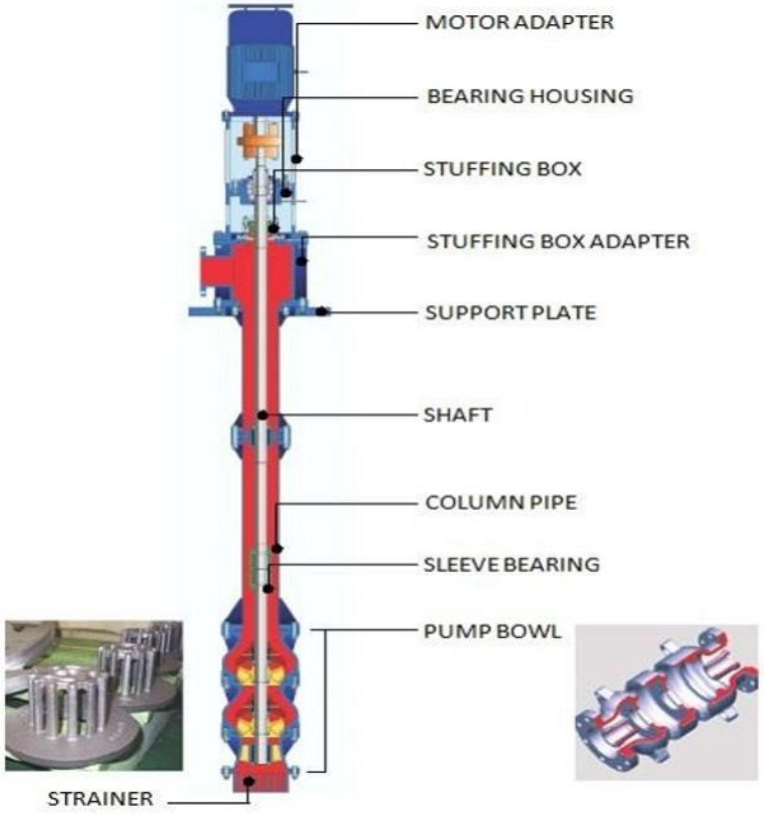
What is a Failure Mode, Effects, & Criticality Analysis?

- FMECA is a method designed to:
  - **Understand and define the intended function of an asset class**
  - **Identify and fully understand the manners in which assets can fail**
  - **Identify potential causes and effects on the asset, system, or end-user**
  - **Identify and carry out proactive actions to address the most serious failure modes**
    - *Proactive maintenance strategies*
    - *Critical spare parts inventory*
    - *Redesign or modifications to assets*

Why is a Failure Mode, Effects, & Criticality Analysis Valuable?

- The Value of FMECA:
  - Minimize asset performance loss or slow degradation
  - Develop maintenance plans focused on mitigating asset failures
  - More effective & efficient use of staff to perform the most value-added activities for critical failure modes
  - Identify and prevent safety hazards
- FMECA at different levels
  - Process area
  - Small sub-systems
  - Individual asset groups

Failure Mode, Effects, & Criticality Analysis (FMECA)



- Determine the general ***Function*** of the asset class
  - **What is the function of the asset?**
    - *Driveshaft- "Provide mechanical transfer of rotational force while maintaining linear and angular stability"*
- Determine the ***Failure Mode***(**s**)
  - **What are the potential causes for the loss of this function?**
    - *Driveshaft- "Driveshaft fractured"*
- Determine the Failure ***Effect(s)***
  - **What is the impact if this function is not prevented or corrected?**
    - *Driveshaft-"No torque output"*
    - *Driveshaft-"No output flow from pump"*
- Determine the Failure ***Cause(s)***
  - **What is the Mechanism of Failure**
    - *Driveshaft-"Insufficient shaft strength, material of construction"*
- Determine Possible ***Detection or Mitigation Strategies***
- Determine **Criticality** of each **Failure Mode** to assign appropriate mitigation strategies

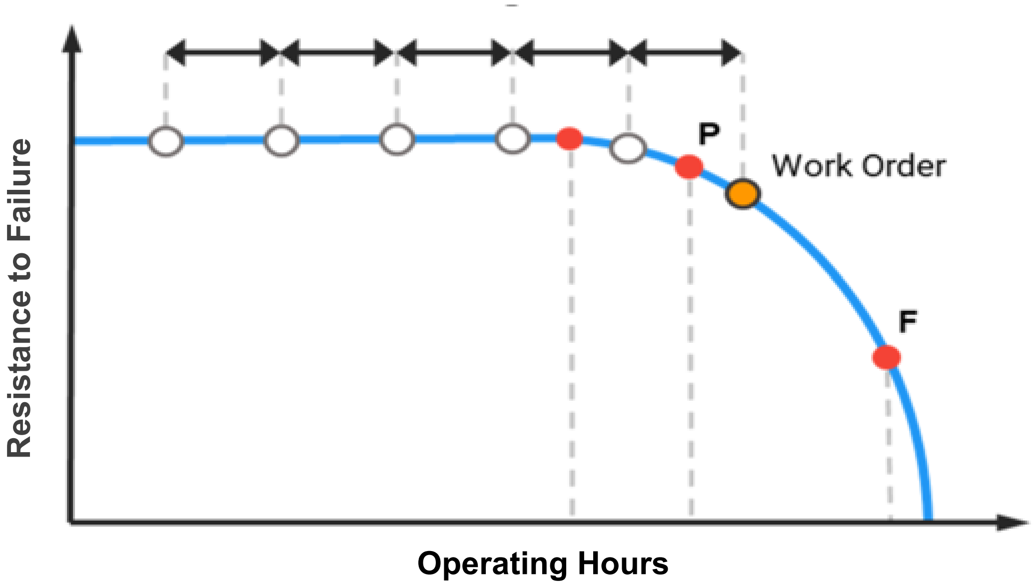
Development of Detection & Mitigation Strategies

Vertical Turbine Pumps

Common Asset Class Failure Problems	Estimated time between 1st indication and functional failure (FDP)	Proactive Activity Type	Activity Frequency minumum (FDP/2)	Estimated Time		
				Mechanic	Electrician	I&C Tech
Safety guarding loose or missing	N/A	Safety	Weekly			
Dirt and Debris Buildup	8-12 weeks	Environmental Conditions	Monthly	0.1		
Fluid leakage	2-4 weeks	Look-Listen-Feel	Weekly	0.1		
Initial bearing damage	2-4 months	Ultrasonic Detection	Monthly	0.25		
Pump flow inconsistancies/ degredations	2-4 months	Power Monitoring and Trending	Monthly		1	
Pump flow inconsistancies/ degredations	2-4 months	Runtime Monitoring	Monthly	0.25		
Vibration in bearings	4-12 weeks	Vibration Analysis	Bi-weekly	0.1		
Oil viscosity failure, contaminants	6-12 months	Lubrication Oil Analysis	Quarterly	0.25		
Over/under lubrication of bearings	6-12 months	Precision Bearing Lubrication	Quarterly	0.25		
Motor coupling failures	1-2 years	Precision Alignment	Annually	2		
Input shaft leakage	1-2 years	Precision Alignment	Annually			
Pump flow inconsistancies/ degredations	1-2 years	Performance Testing	Annually	2	2	
Vibration issues that cannot be resolved	N/A	Motion Amplification Inspection	As needed	4		

Determining Activity Frequency

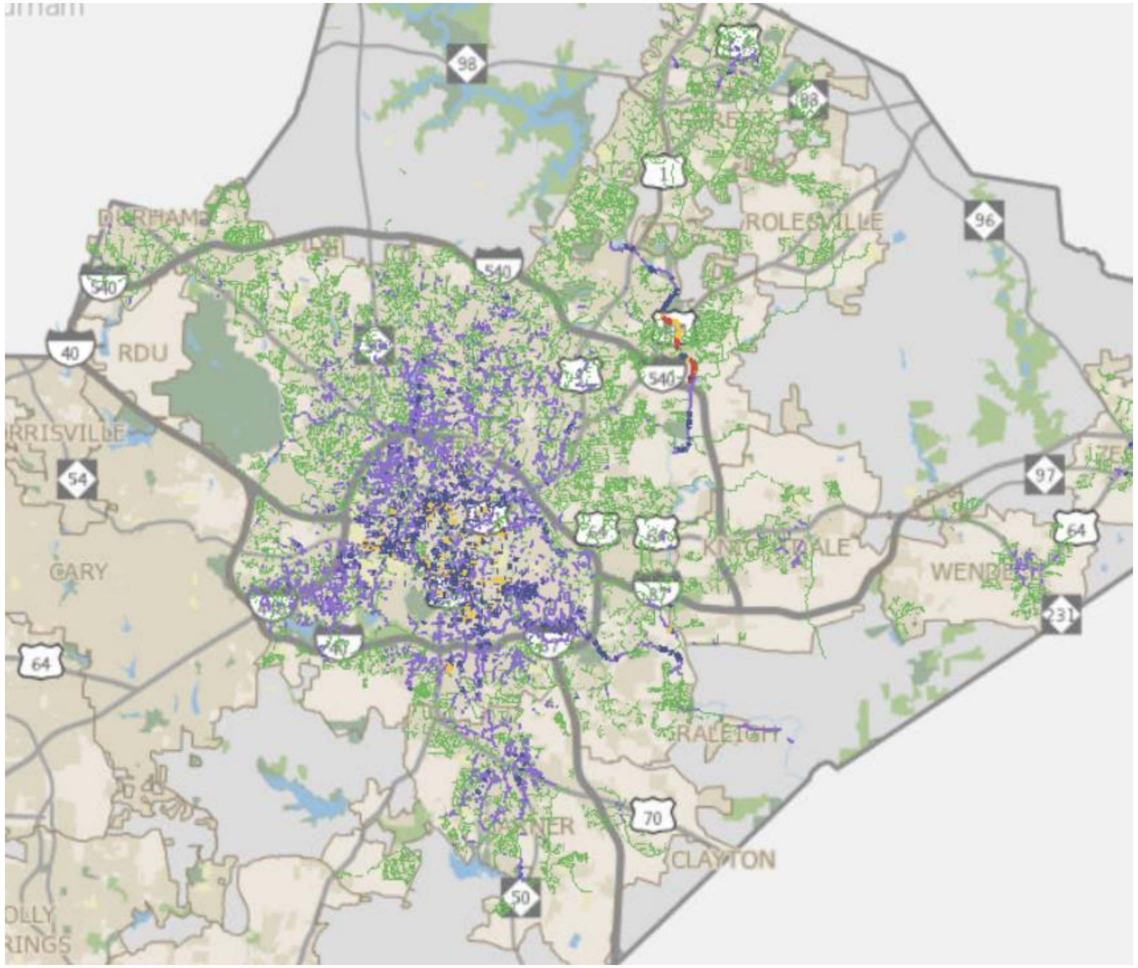
- FDP = P-F (Potential Failure to Functional Failure)
- P-F timeframe dependent on technology available to identify first onset of failure (P)
- Task frequency set to a minimum of (P-F)/2



Predictive Analytics

Raleigh Sewer Main Predictive Analytics

- **How do we prioritize sewer inspections?**
- 1,800 miles uninspected
- Inspection Resources:
  - Internal
  - External Contractors
  - Time
  - $$$



The Solution

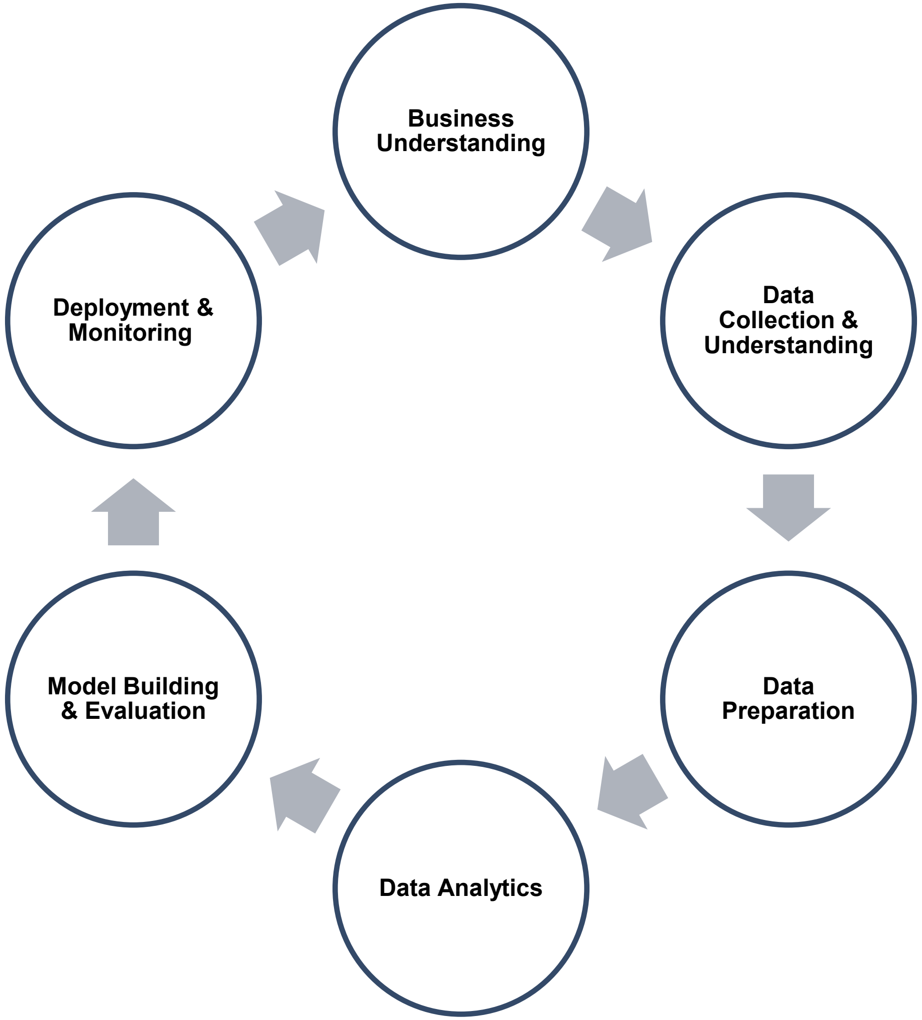
Building a Machine Learning Model To Predict Sewer Main Failure

85% Accurate

2021

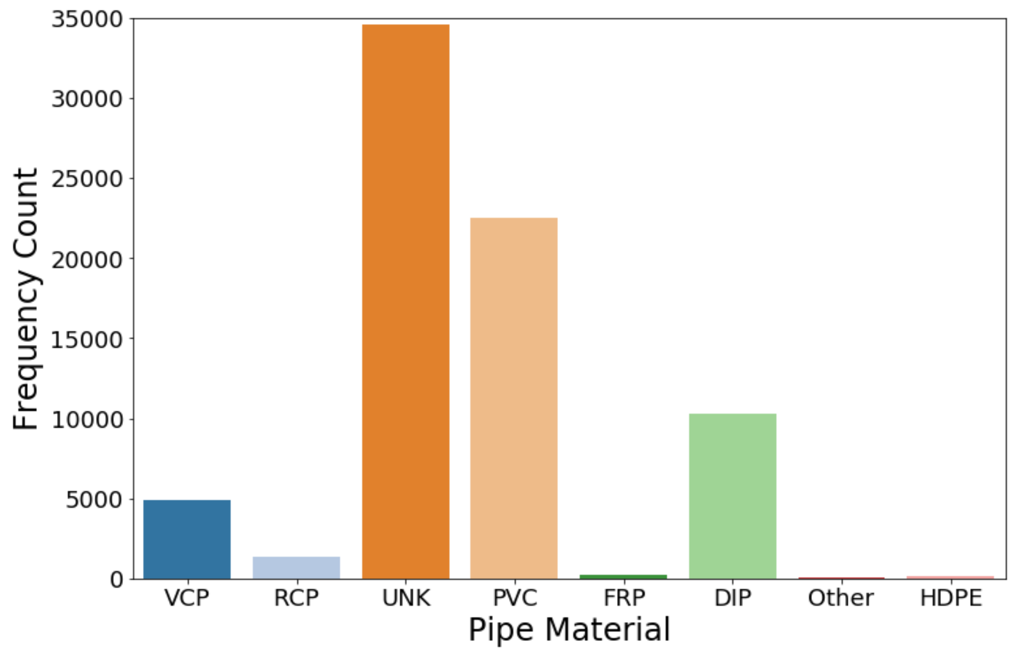
2022

Hazen and Sawyer Workflow for Predictive Modeling

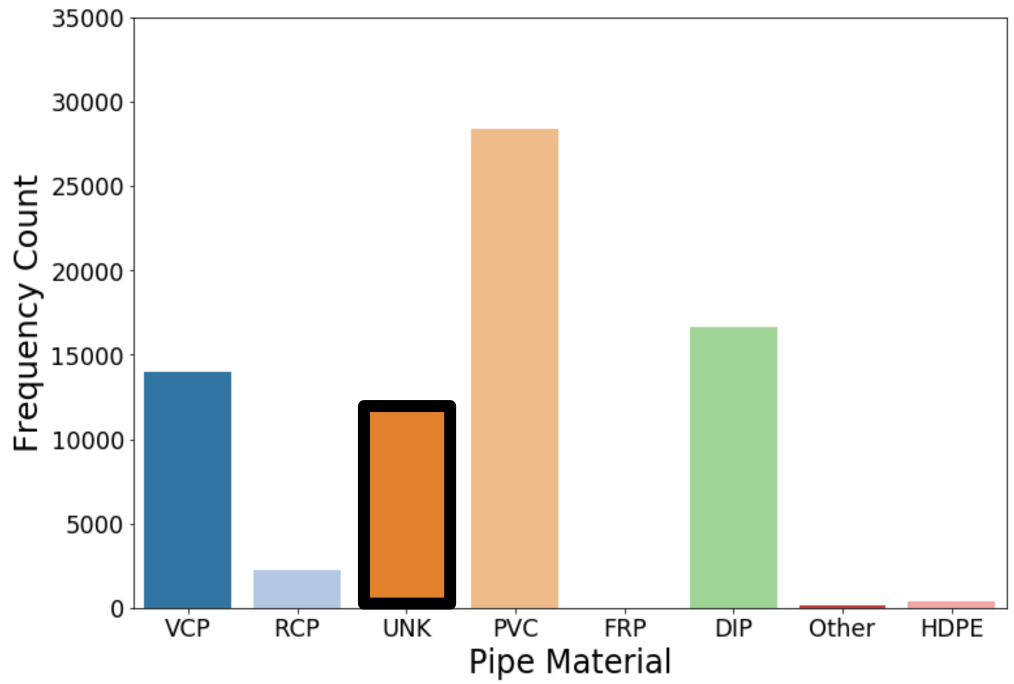


Missing Material Type

Material Type from Original Dataset

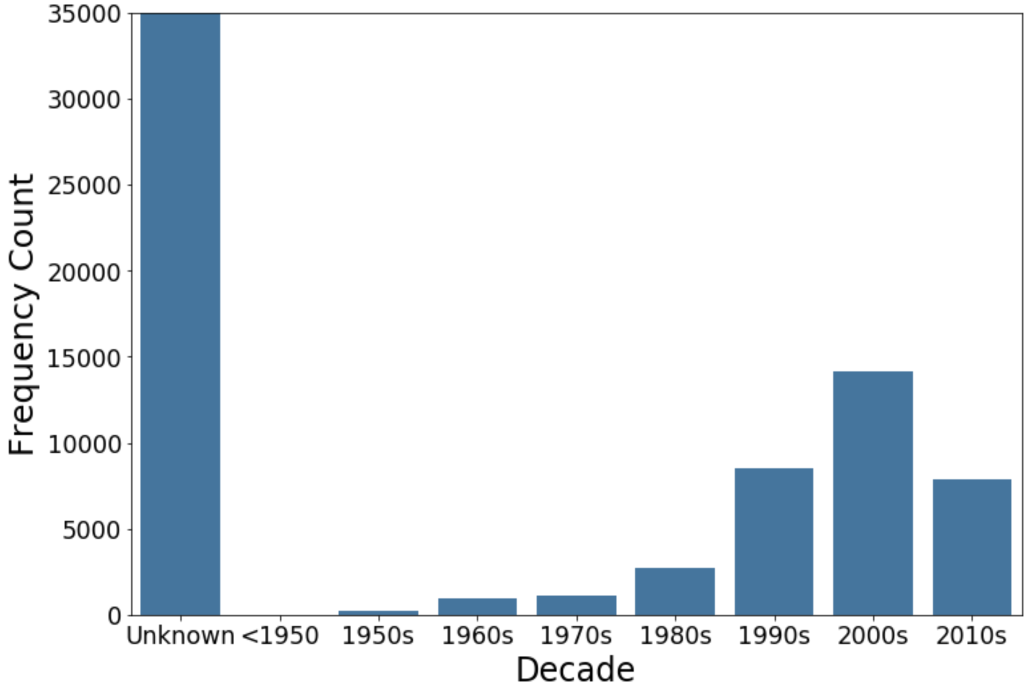


Material Type after Inference

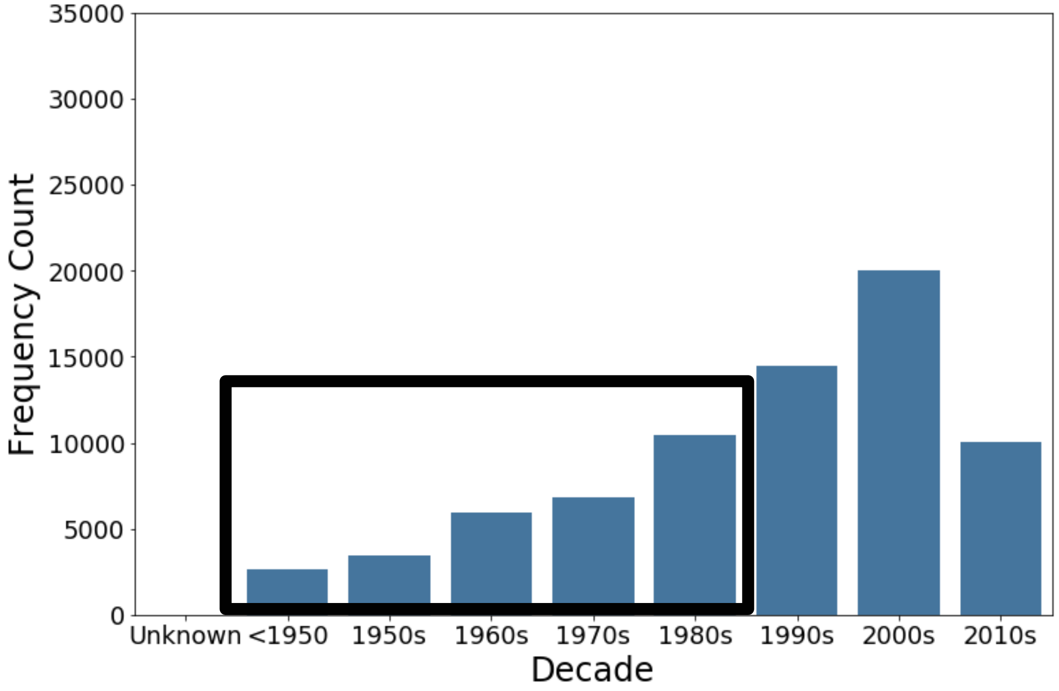


Install Date Results

Install Date Pre-Inference

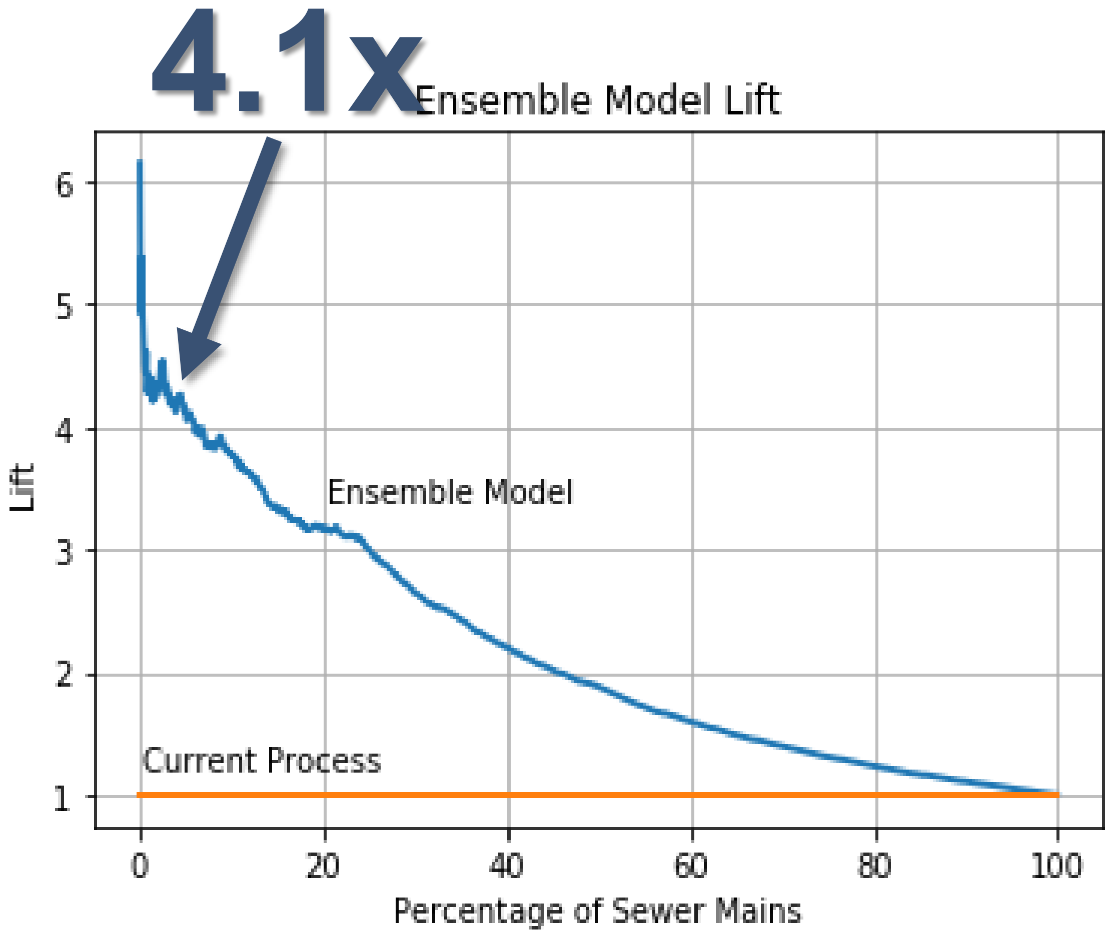


Install Date Post-Inference

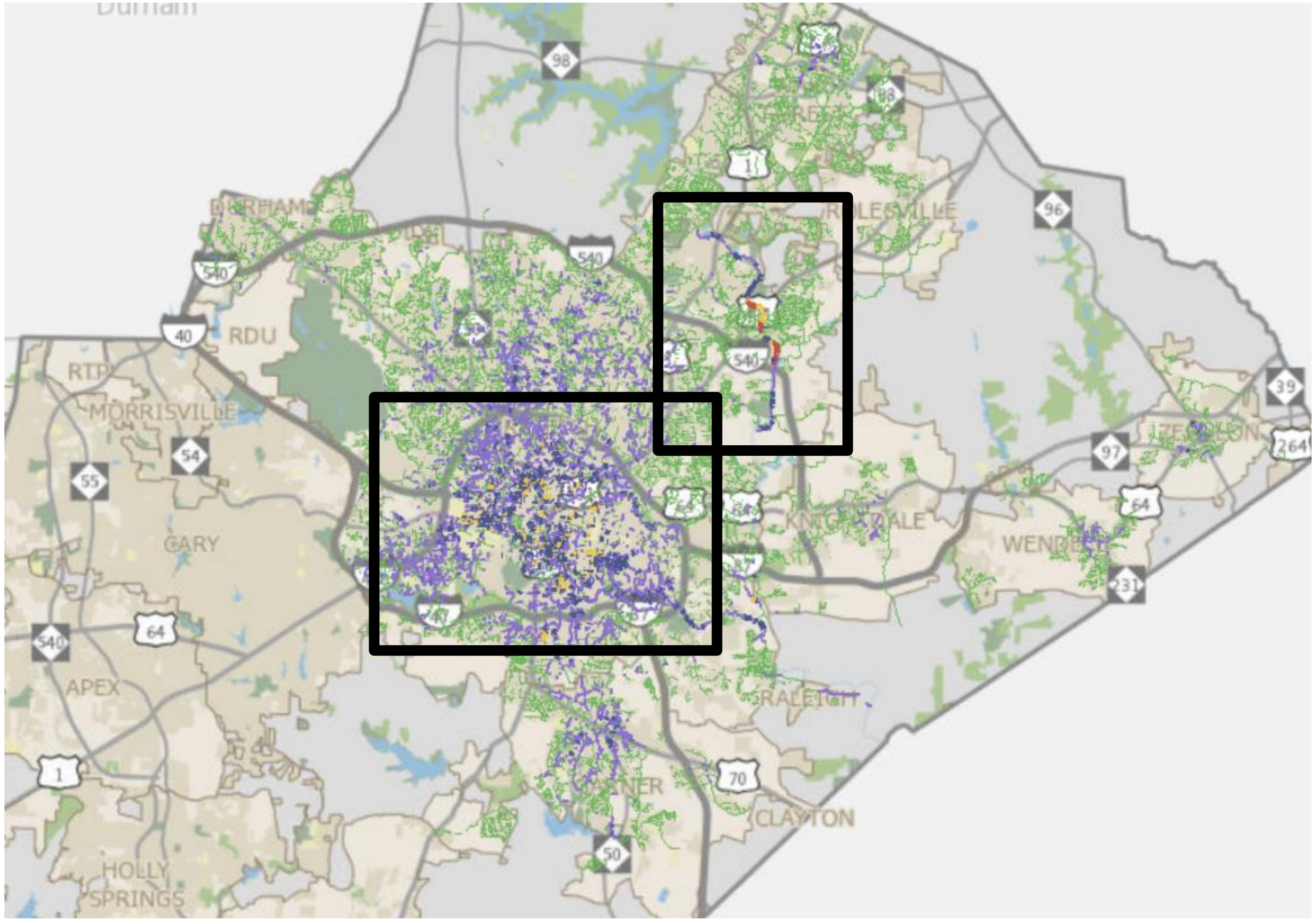


Ensemble Model

- Models created:
  - CatBoost
  - XGBoost
  - Random Forest
  - Neural Net
  - Lasso/Ridge Regression
  - Support Vector Machines
- Results:
  - 86.8% Concordance
  - 4.1x More Failures in Top 5%



Ensemble Model Results

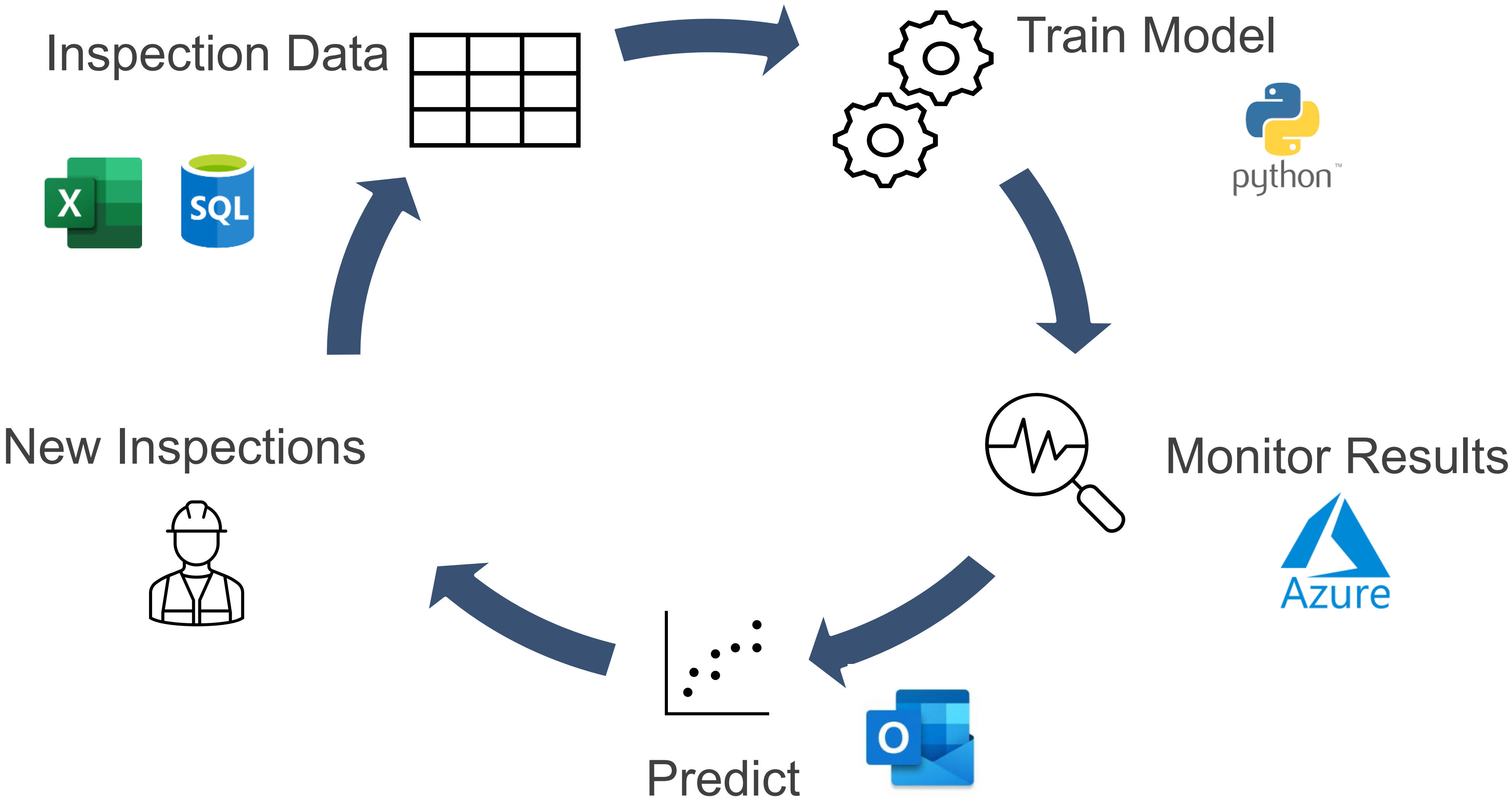


Color	Predicted Probability of Failure
Green	0 - .2
Purple	.2 - .4
Blue	.4 - .6
Yellow	.6 - .8
Red	.8 - 1

Ensemble Model Results

Color	Predicted Probability of Failure
Green	0 - .2
Purple	.2 - .4
Blue	.4 - .6
Yellow	.6 - .8
Red	.8 - 1

Workflow


Inspection Data
SQL
Train Model
python
Monitor Results
Azure
Predict
New Inspections

Pipeline Output: Probabilities

Raleigh Sewer Failure Prediction Model: Output and Performance

R Raleigh-Sewer-ML <Raleigh-Sewer-ML-DoNotReply@bf9110d9-1dc4-4789-9f4a-8a4446020803.us1.azurecomm.net>

Reply | Reply All | Forward | ...

Mon 2/19/2024 6:21 AM

Retention Policy 15 year retention (15 years) Expires 2/15/2039

Model Predictions.csv 3 MB

Model Training Results.csv 3 KB

Dear Recipient,

This email serves as a notification rega ... of predicted probabilities of failure as we

Please review the attached results at y
mturner@hazenandsawyer.com.

Thank you,

Hazen Predict Team

P.S. The message is set to be sent eve

FacilityID	Failure Probability (Percentage)	Length (ft)	Cumulative (ft)	Cumulative Percentile by Length of Uninspected
SGMN161009	0.8441574	516.6	516.6	0.003%
SGMN143583	0.7730277	411.4	928	0.006%
SGMN152466	0.7535881	281.8	1209.8	0.008%
SGMN147660	0.7523762	380.2	1590	0.011%
...	...	...	...	...
SGMN117726	0.5000677	260.4	58633.1	0.395%
SGMN151050	0.5000149	470.1	59103.2	0.398%
SGMN117390	0.4997002	214.1	59317.3	0.399%
...	...	...	...	...
SGMN167118	0.004006248	98.6	7569027.7	50.945%
SGMN166419	0.003989856	114.1	7569141.8	50.946%
SGMN192813	0.003855715	99.2	7569241	50.946%