Webcast

The Remaining Economic Life Analysis (RELAY) Tool

01/19/2021

Housekeeping Items

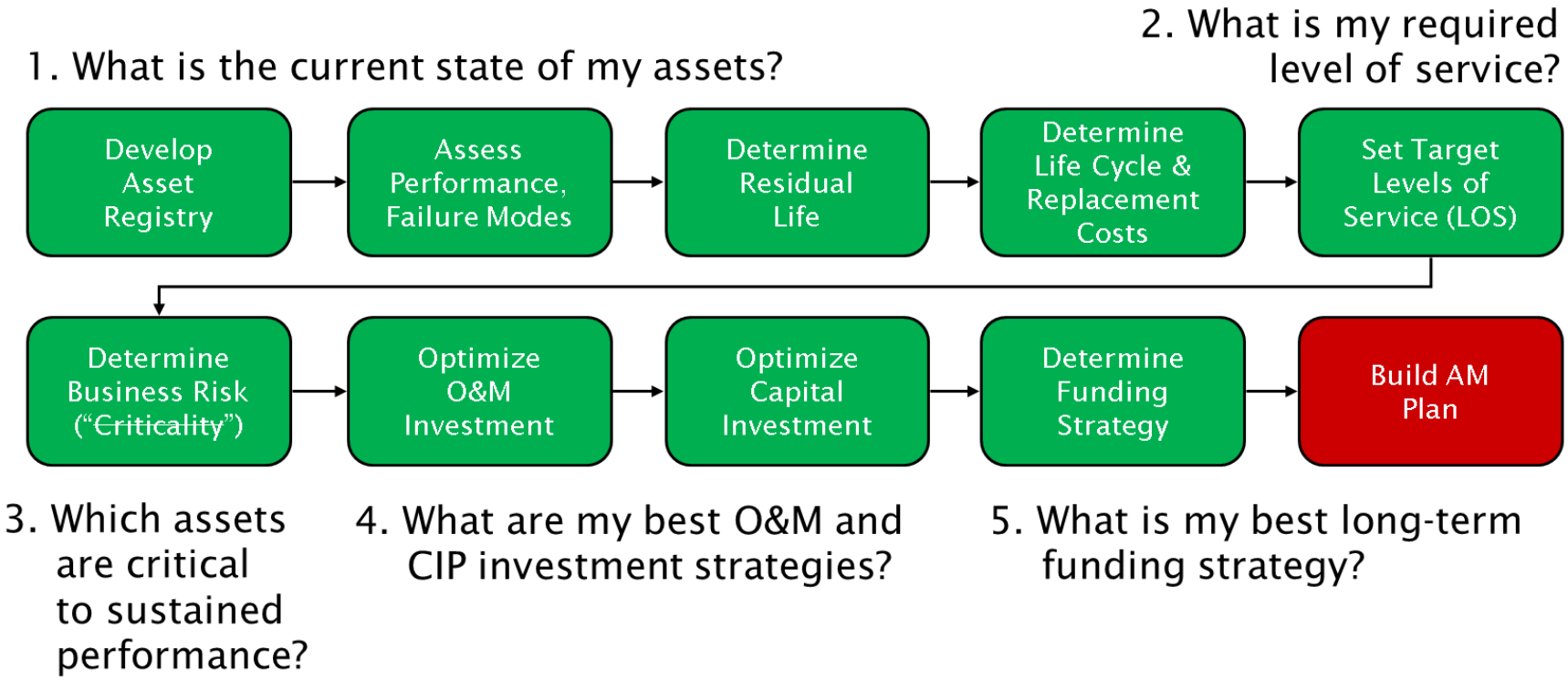
- Submit questions through the question box at any time. We will do a Q&A at the end of the webcast.
- Slides and a recording of the webcast will be available at www.waterrf.org.
- You will receive a certificate of completion at the end of the webcast.
- Survey at the end of the webcast.

Agenda

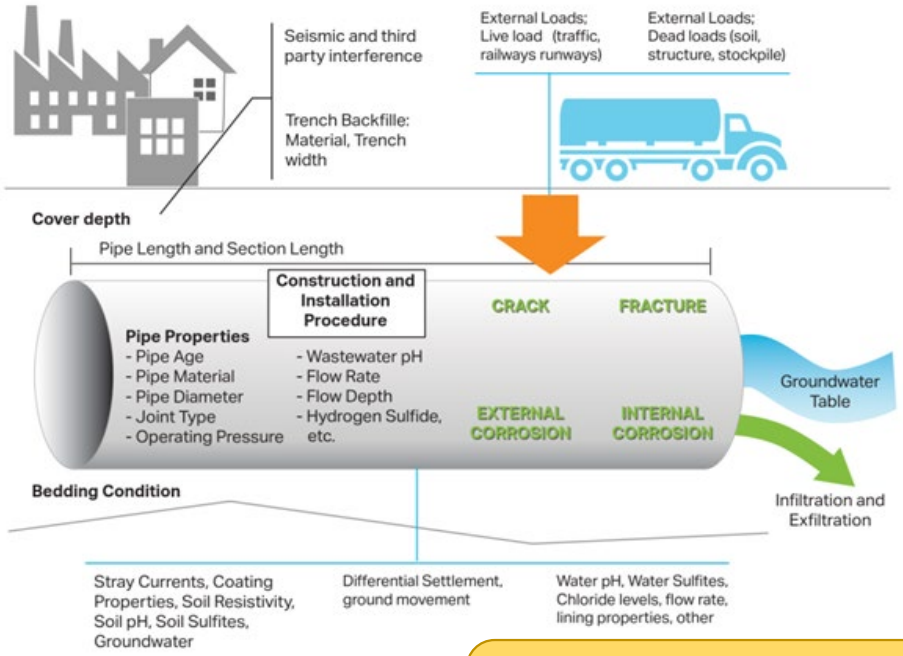
- Introduction and Background
- Research Goals and Objectives
- Data Standards
- Performance Indices
- Performance Prediction
- Piloting with Utilities
- PIPEiD – National Database

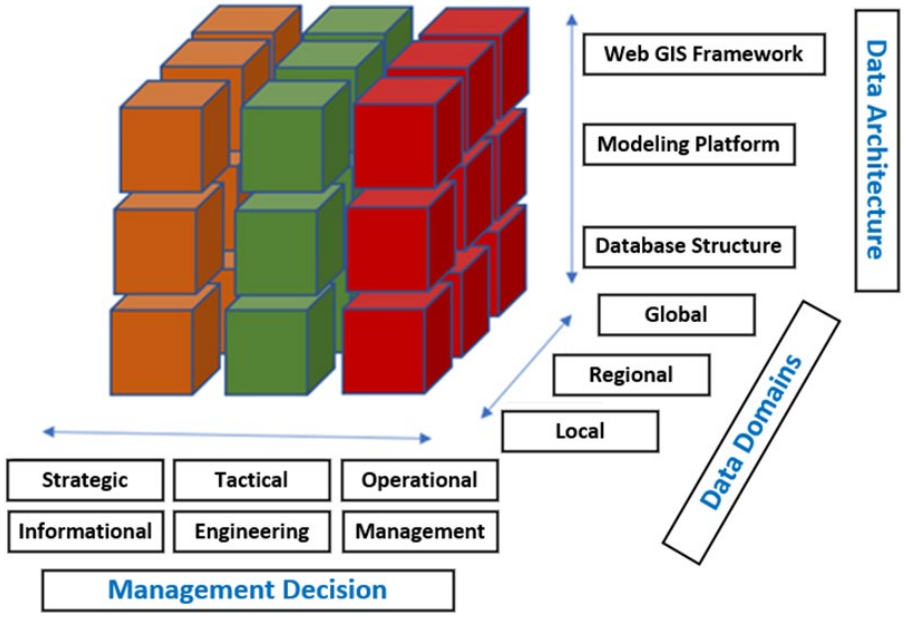
Infrastructure Asset Management

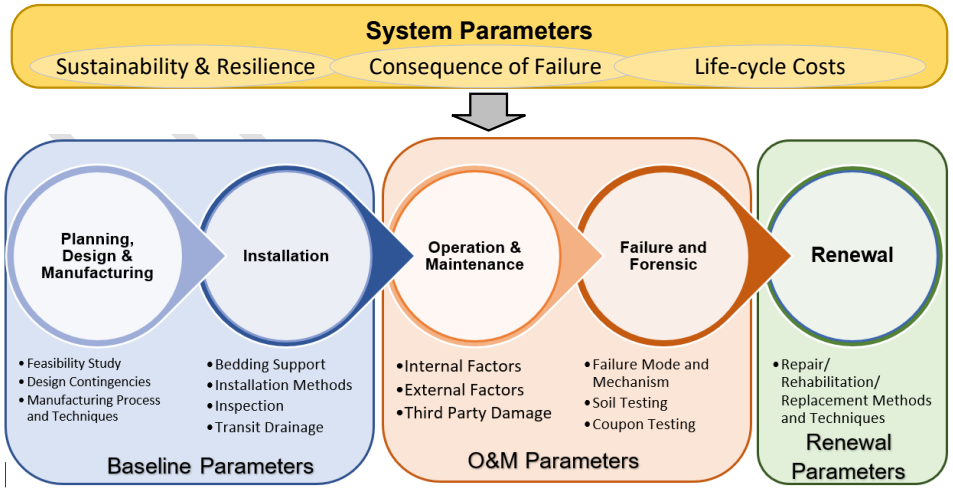
- There are numerous frameworks for the infrastructure asset management practice.
  - ISO 55000
  - EPA 10 Step Process



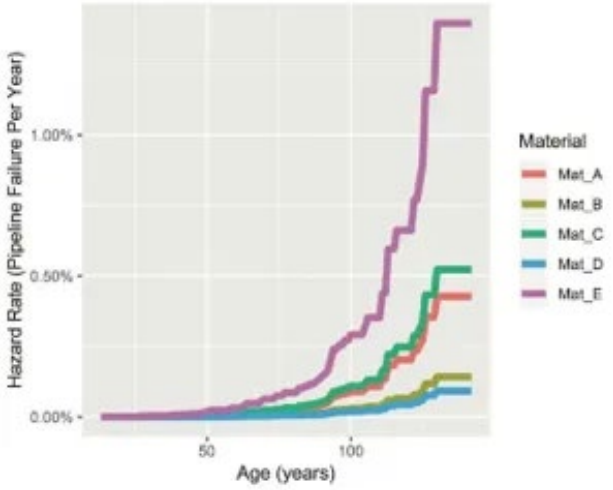
Models and Tools for Decision Support



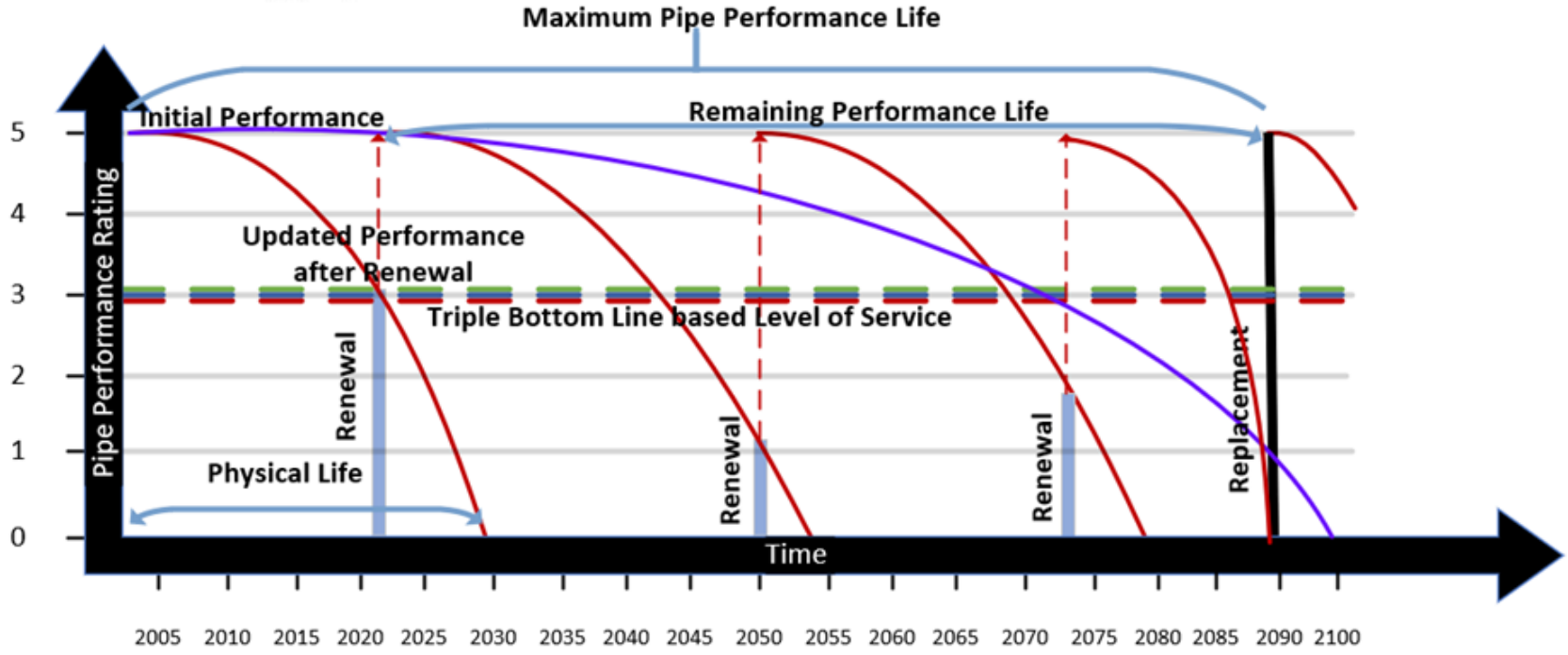




Failure Prediction & Deterioration Model

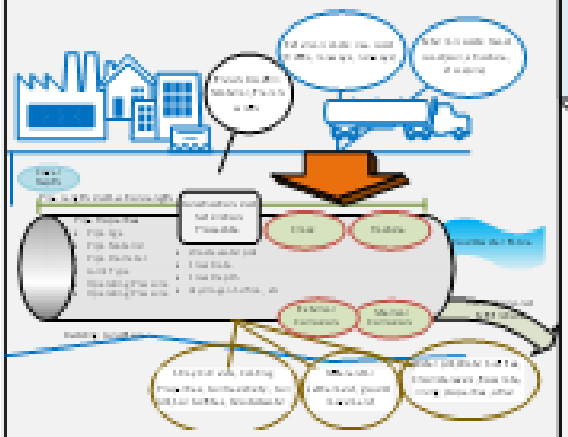


Grade	Representation	Definition
1	Excellent	Very low probability of failure; Excellent expected service life; Almost no deterioration or corrosion;
2	Good	Low probability of failure; Satisfactory expected service life; A little deterioration or corrosion;
3	Fair	Acceptable probability of failure; Acceptable expected service life; Acceptable deterioration or corrosion;
4	Poor	Hard-to-accept probability of failure; Short expected service life; Obvious deterioration or corrosion;
5	Very Poor	Unacceptable probability of failure; Unacceptable expected service life; Unacceptable deterioration or corrosion; The pipe can no longer provide service (need to be replaced)



Research Goals

Phase I – Data Standards



Essential and preferable parameters affecting the gravity and force main wastewater pipes on environmental, structural, functional, operational, and financial factors.

Phase II – Performance Index

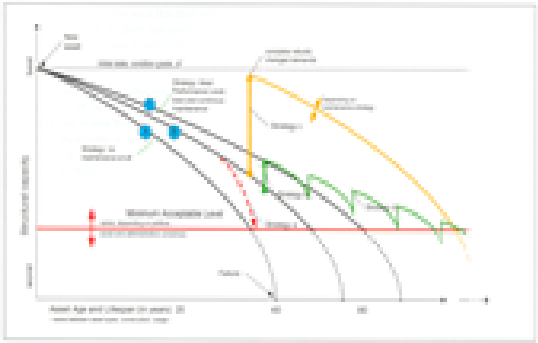
Internal Environment | External Environment | Pipe

Performance Modules (Gravity)	Performance Modules (Force Main)
Integrity	Integrity
Internal Corr.	Internal Corr.
External Corr.	External Corr.
Surface Wear	Surface Wear
Joint	Joint
Lining	Lining
Blockage	Blockage
I and I	Capacity
Root Int.	
Capacity	

Performance Scores	Explanation
1	Excellent
2	Very Good
3	Good
4	Satisfactory
5	Fair
6	Unsatisfactory
7	Poor
8	V. Poor
9	Failing
10	Failed

Index to determine the performance combining inspections and various environmental, structural, and functional parameters. Can only determine performance at inspection time.

Phase III – Performance Prediction



State Dependent Models

Time Dependent Models

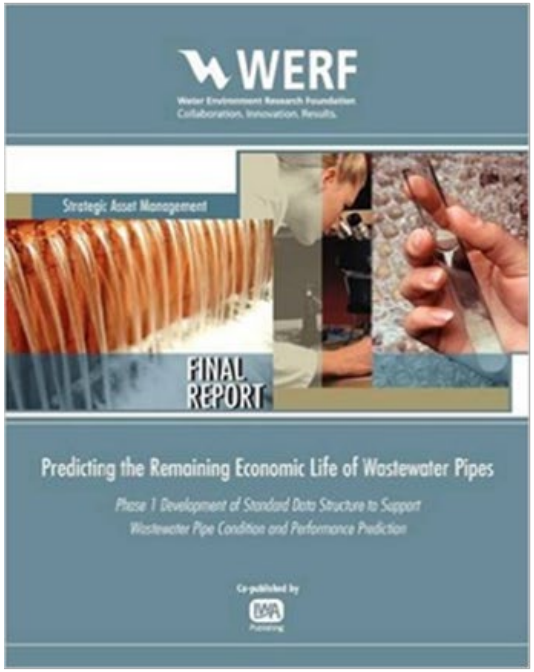
Robust Performance Prediction

Performance prediction models for remaining life analysis with time dependent and state dependent models.

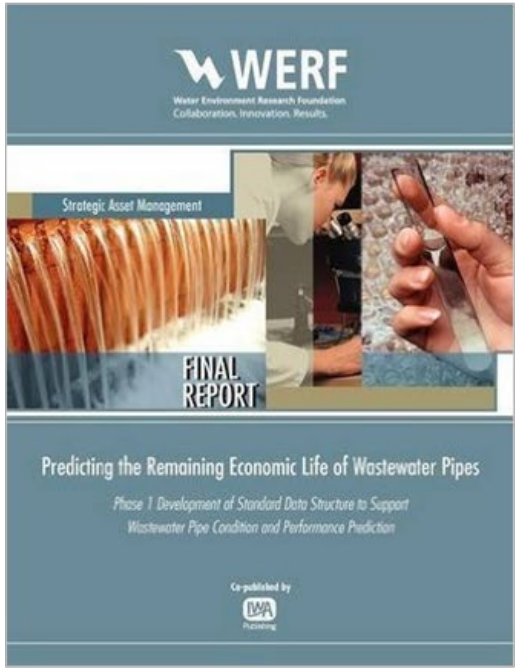
Research Project

- Development of Protocols and Methods for Predicting the Remaining Economic Life of Wastewater Pipe Infrastructure Assets, WE&RF Project Number U4R14

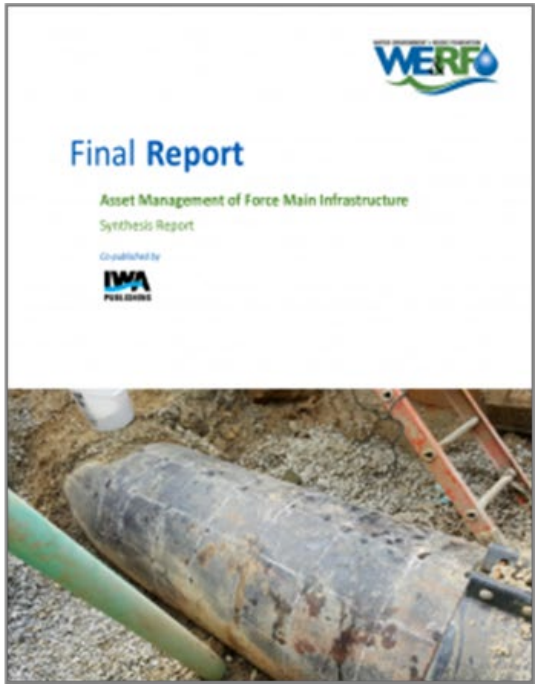
Phase 1: Data Standard



Phase 2: Performance Index



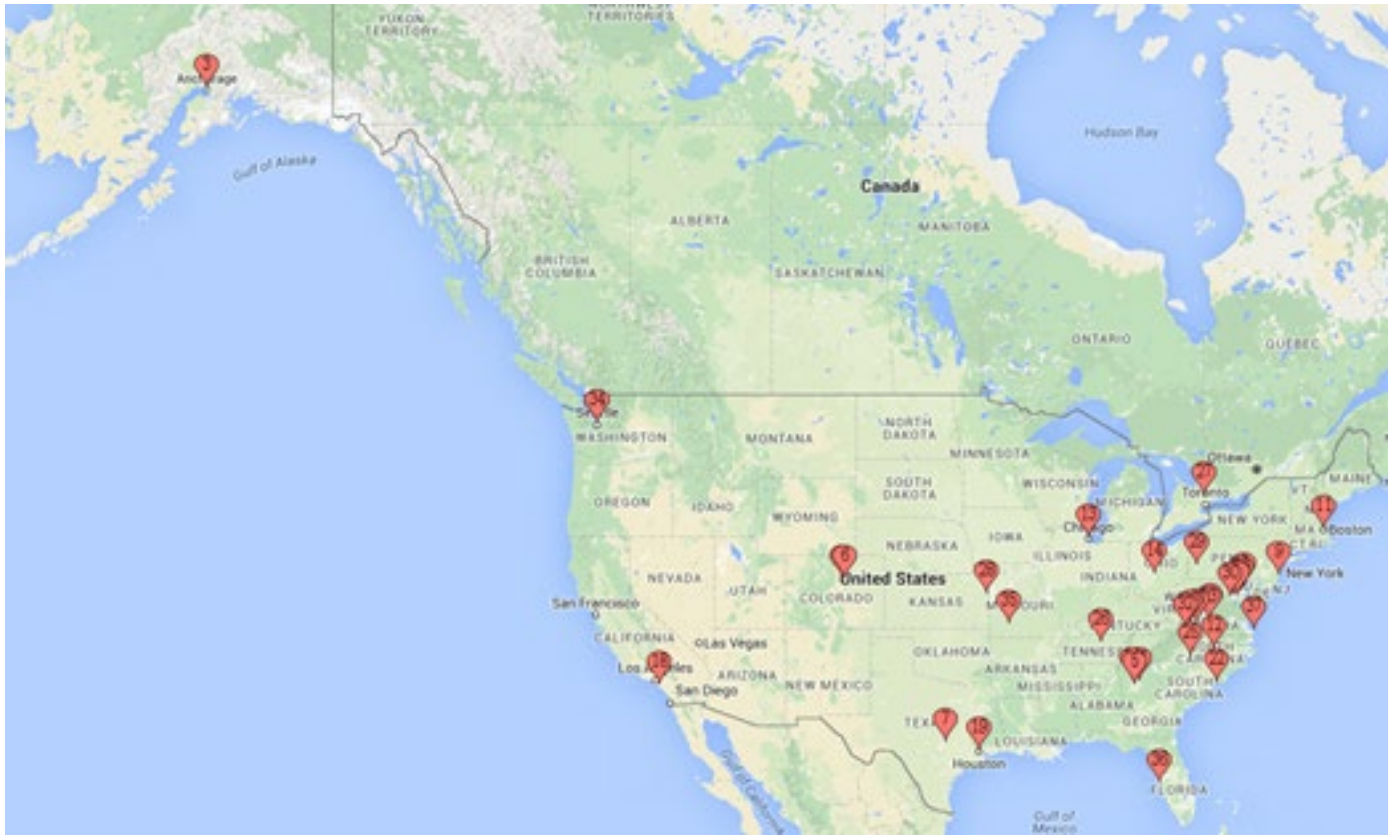
Force Main Asset Management



Research Objective

- Models and tools from practice - too simplistic and limited
- Practitioners do not understand the modeling techniques
- Practitioners do not trust the models in literature
- Application of models and tools at the wrong level

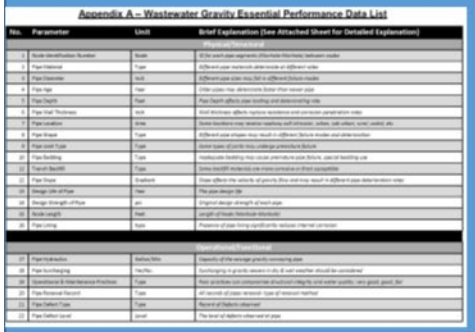
Participation and Outreach



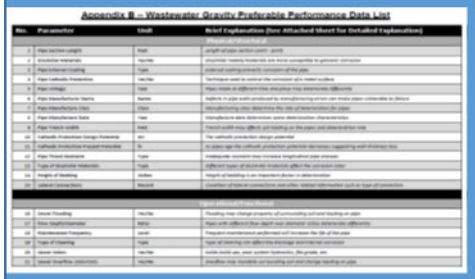
Phase 1. Data Standard

Gravity Pipe Data Standard (Updated)

- Updated from earlier Phase II work
- Contains essential and preferable parameters (total of 118 parameters)


Appendix A – Wastewater Gravity Essential Performance Data List

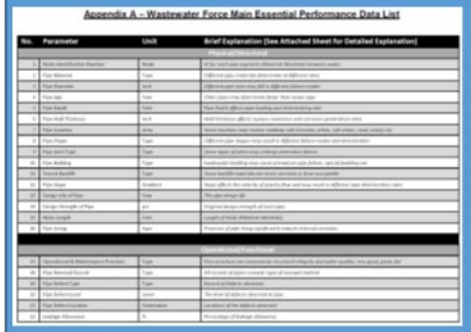
45 Essential parameters


Appendix B – Wastewater Gravity Preferable Performance Data List

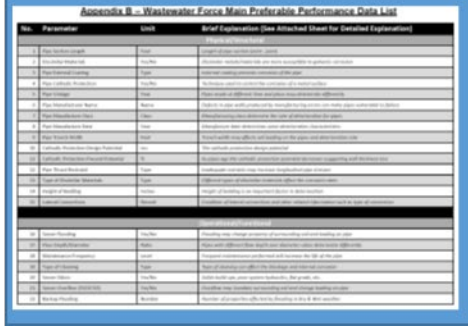
73 Preferable parameters

Force Main Pipe Data Standard (New)

- Developed new for this research
- Contains 92 parameters


Appendix A – Wastewater Force Main Essential Performance Data List

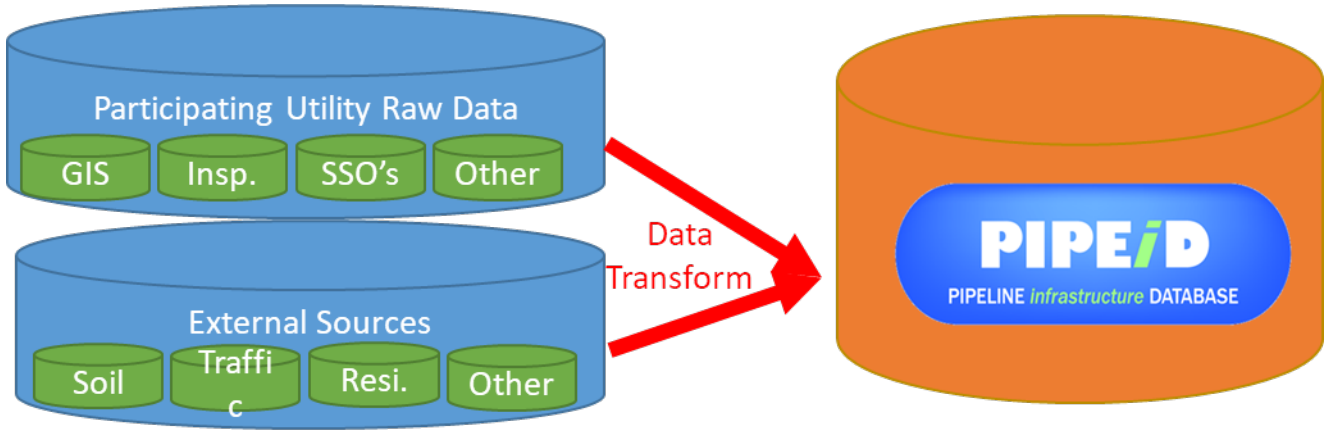
46 Essential parameters


Appendix B – Wastewater Force Main Preferable Performance Data List

46 Preferable parameters

Phase 1. Data Mining and Conflation

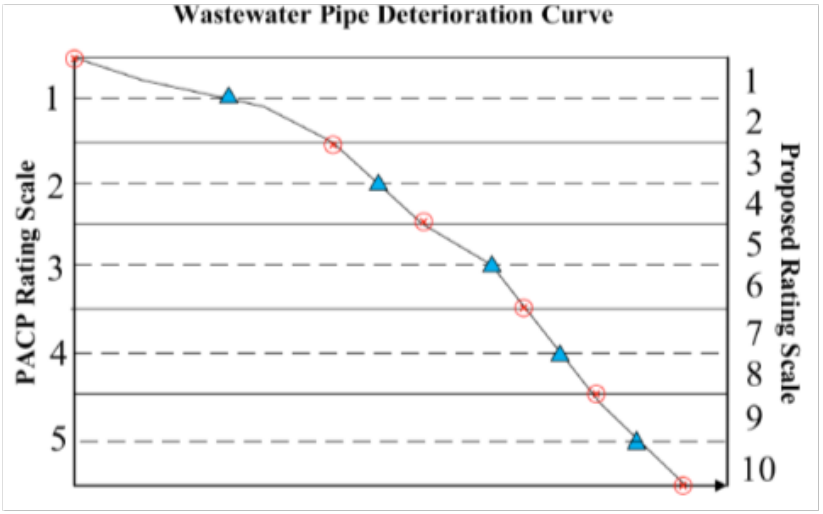
- Developed with feedback from participating utilities and SWIM Data committee members (formed by various service providers and organizations)
- Data has been collected and conflated in this data standard for future research steps.



Phase 2– Extending Grading Scale

5 Point Scale	
1	Excellent
2	Good
3	Fair
4	Poor
5	Failed

10 Point Scale	
1	Excellent
2	Very Good
3	Good
4	Satisfactory
5	Fair
6	Bad
7	Poor
8	Very Poor
9	Failure
10	Failed



Phase 2. Performance Index

- Defect Index VS. Performance Index

Defect type	Code	Weight
Roots		
fine roots, restricting flow <10%	RL	2
10% to 25% diameter loss	RM	8
> 25% diameter loss	RS	10
Debris		
< 10% flow restriction	DEL	5
10% - 25% diameter loss	DEM	8
> 25% diameter loss	DES	10
Encrustation		
< 10% flow restriction	EL	2
10% - 25% diameter loss	EM	8
> 25% diameter loss	ES	10
Protruding service connection		
< 10% flow restriction	PL	2
10% - 25% diameter loss	PM	8
> 25% diameter loss	PS	10
Infiltration		
Seeping, dripping	IL	2
Running, trickling	IM	5
Gushing, spurting	IS	10

WRC Defect Index

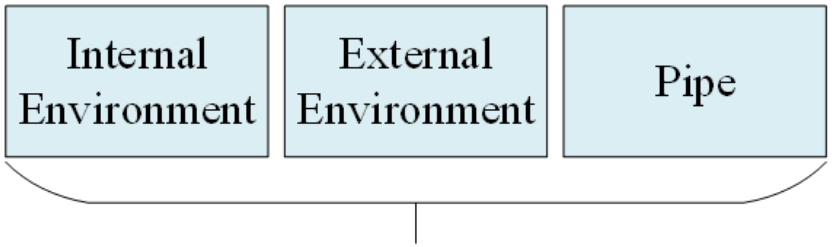
V.S.

Purpose of Analysis	Criteria	Weighting	Normalized Weighting	Relative Importance Factor
Performance Index	Inspection Evaluation (Structural Condition)			
	Good	0	0.00	5
	Moderate	1	0.50	
	Poor	2	1.00	
	Pipe Material			
	Cast Iron	1	0.33	4
	Ductile Iron	1.5	0.50	
	PCCP	3	1.00	
	Pipe Age – Installation Date			
	1980 to Present	1	0.20	
	1960 to 1979	3	0.60	3
	1935 to 1959	3.5	0.70	
	< 1935	5	1.00	
	Depth			
	Existing Depth < Theoretical Max. Allowable	0	0.00	2
	Existing Depth > Theoretical Max. Allowable	1	1.00	
	Operating Conditions			
	Flow Conditions			
	Operating Internal Pressure < Theoretical Allowable Operating Pressure	0	0.00	1
	Operating Internal Pressure > Theoretical Allowable Operating Pressure	1	1.00	

Baltimore County Force Main Performance Index

Phase 2. Performance Index

- Phase 2 performance index evaluate the pipe condition by using not only CCTV data, but also structural, environmental, operational, and other data.
- Uses performance parameters (Phase I) and defect index to establish the performance of the wastewater pipes.
- Separate gravity and force main performance models.
- Only gives the current performance, no future prediction



Performance Modules (Gravity)	Performance Modules (Force Main)
Integrity	Integrity
Internal Corr.	Internal Corr.
External Corr.	External Corr.
Surface Wear	Surface Wear
Joint	Joint
Lining	Lining
Blockage	Blockage
I and I	Capacity
Root Int.	
Capacity	

Performance Scores	Explanation
1	Excellent
2	Very Good
3	Good
4	Satisfactory
5	Fair
6	Unsatisfactory
7	Poor
8	V. Poor
9	Failing
10	Failed

Phase 2. Performance Index

Integrity Module	•Evaluates the structural integrity of the pipes.
Internal Corrosion Module	•Evaluates the extend of corrosion inside the pipe wall prone to internal factors such as H2S buildup.
External Corrosion Module	•Evaluates the extend of corrosion at the external surface of the pipe walls prone to outside influences.
Surface Wear Module	•Evaluates the extend of wall erosion, spalling, tuberculation and other defect which might cause interruptions of flow.
Joint Performance Module	•Evaluates the performance of joints
Lining Performance Module	•Evaluates the performance of lining (if present)
Blockage Module	•Evaluates reduction of pipe effective diameter due to sediment, fats and grease, or mineral buildup.
Capacity Module	•Evaluates the flow and the overall capacity of the gravity pipes.

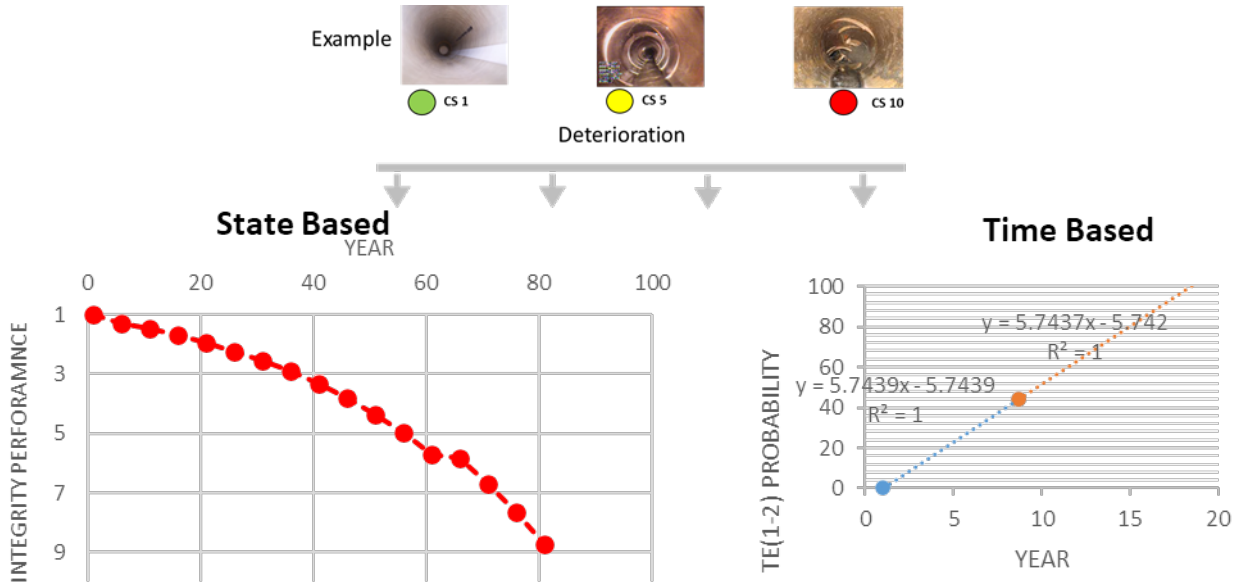
Phase 3. Performance Prediction Model

State Based

Probability of condition changes of an infrastructure facility over a unit time.

Time based

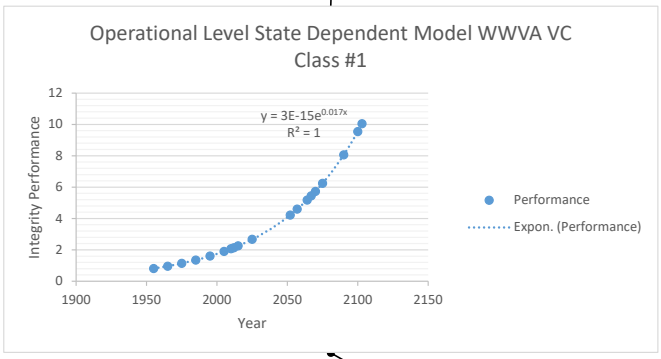
Probability distribution of time spent to have a unit change of the asset condition



Phase 3. Performance Prediction Model

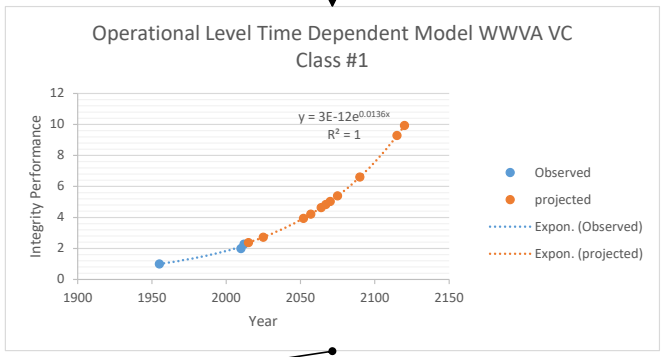
Step 8.b Integration of Operational Level Models

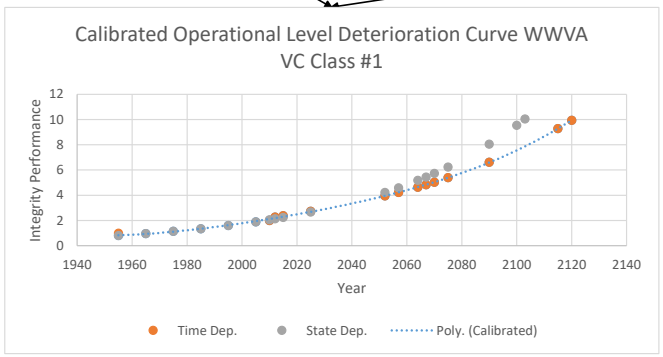
Operational Level State Dependent Model



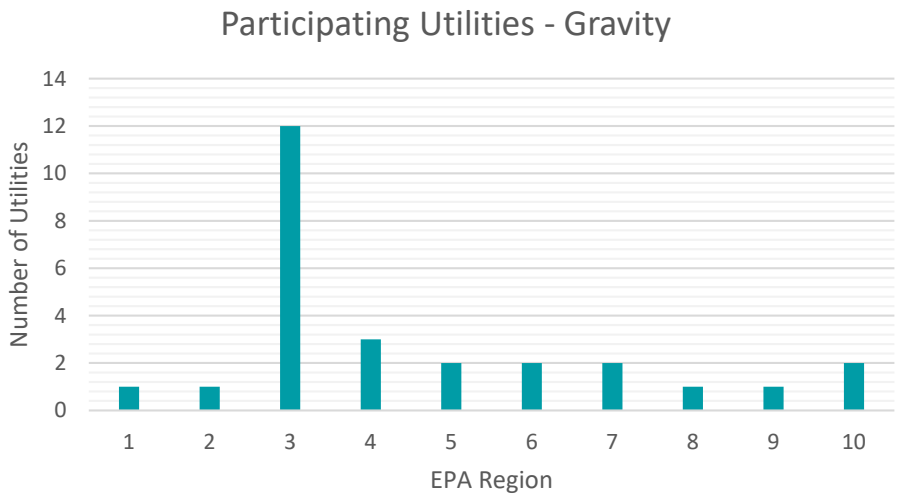
us_node_id	ds_node_id	Install Date	Length	material	pacp_overall_index_rating	Integrity Index	date_completed	joined_pipe_type	Age at Inspection
01A-3657.0	01A-3652.0	1/2/1960	152.0445	VCP	1.14	2.28	6/14/2012	COLLECTOR	52.4865
01A-3657.0	01A-3652.0	1/2/1960	152.0445	VCP	1	2	10/5/2010	COLLECTOR	50.79355

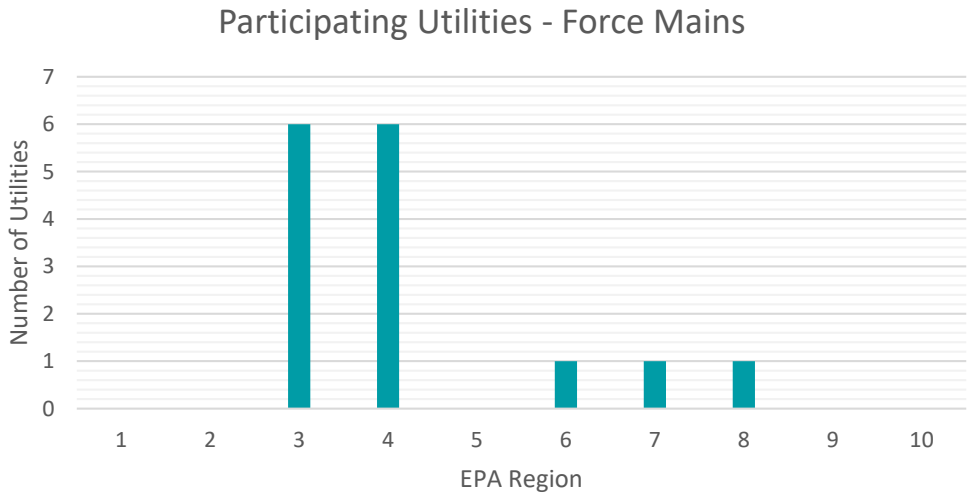
Operational Level Time Dependent Model





Data Validation - Population





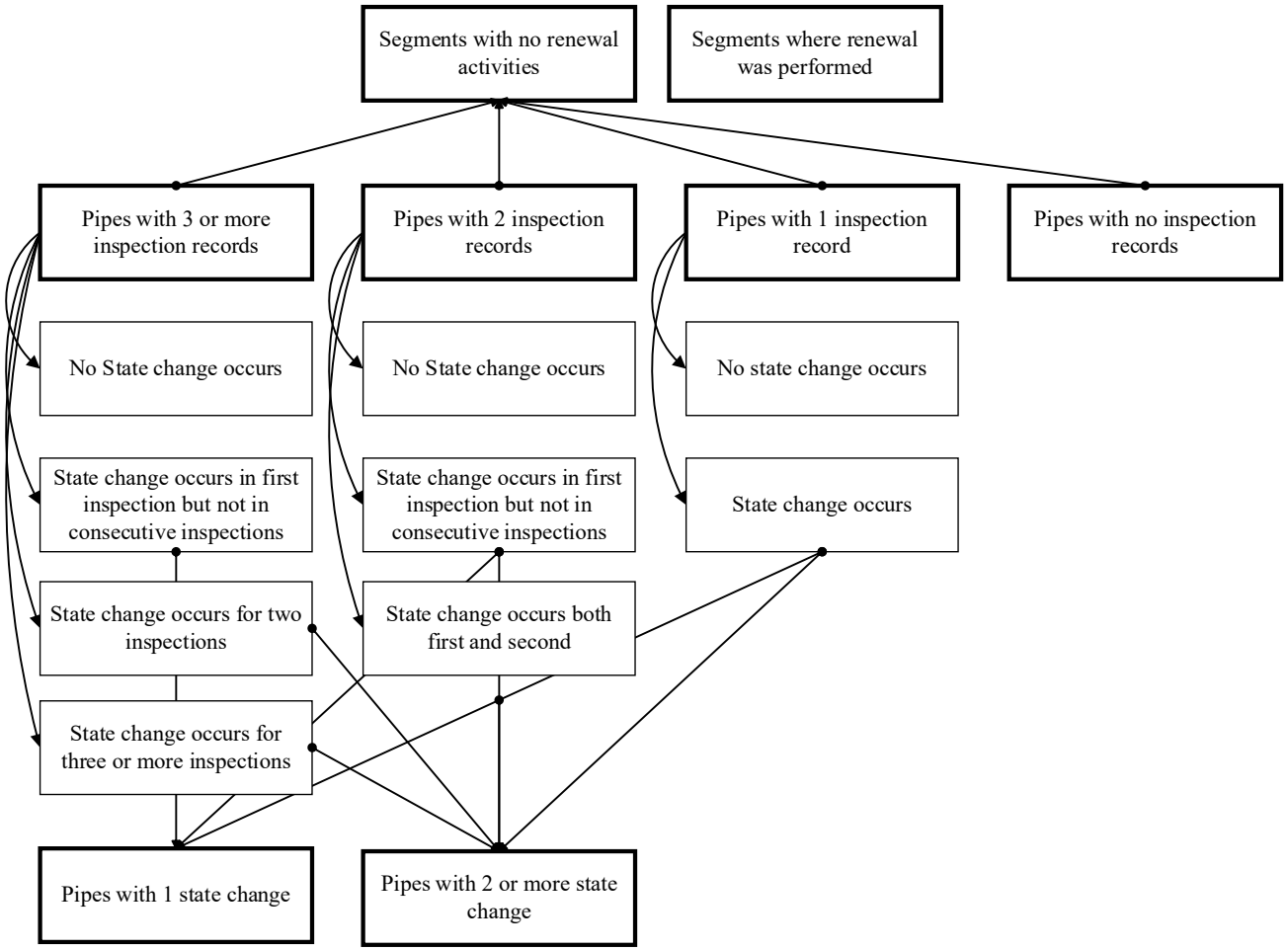
19

Data Validation– Stratification

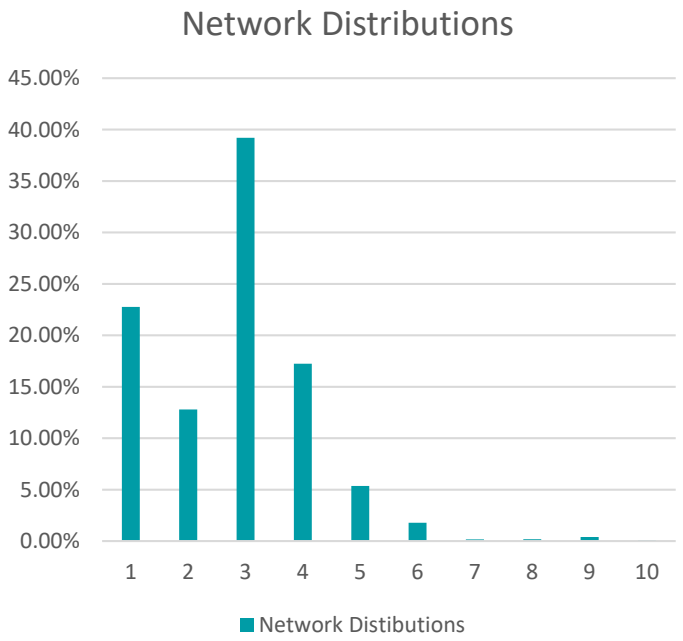
Material	Era 1	Era 2	Era 3	Era 4	Era 5	Era 6
Corrugated Metal	1896 to 1900	1901 to 1920	1921 to 1947	1947 to 1956	1957 to 1976	1976 to present
HDPE	pre 1950	1951 to 1960	1961 to 1980	1981 to 1990	1990 to 2002	2002 to present
PCCP	1942 to 1955	1955 to 1963	1963 to 1970	1971 to 1980	1981 to 1991	1991 to present
PE	pre 1950	1951 to 1960	1961 to 1980	1981 to 1990	1990 to 2002	2002 to present
Steel	1896 to 1900	1901 to 1920	1921 to 1947	1947 to 1956	1957 to 1976	1976 to present
Vitrified Clay	Pre 1915	1915 to 1955	1955 to 1975	1975 to 1983	1983 to present	

Data Validation– Record Selection Process

- Time dependent vs. State Dependent data
- Identified a records selection process to separate the time and state dependent data



Piloting Results – Network Level



Number	Parameter	Value	Unit
1	PIPEiD	SF-031-4972	ID
2	Break <5 Years	No	Yes/No
3	Cathodic Protection	No	Yes/No
4	External Coating	NO	Yes/No
5	Flow Velocity	Unknown	Ft/Sec
6	Foreign Anode Distance	33	Ft.
7	Ground Cover	Gravel	Type
8	H2S	Unknown	ppm
9	Live Load	High	Type
10	Node Length	356.32	Feet
11	Operating Pressure	Unknown	PSI
12	Pipe Age	36	Years
13	Pipe Break	No	Yes/No
14	Pipe Depth	10	Feet
15	Pipe Diameter	8	Inch
16	Pipe Joint Type	Unknown	Type
17	Pipe Lining	No	Yes/No
18	Pipe Location	Railroad	Type
19	Pipe Material	Ductile Iron	Type
20	Pipe Renewal	No	Yes/No
21	Pipe Shape	Circular	Type
22	Pipe Slope	Unknown	%
23	Proximity to Trees	30	Feet
24	Stray Currents	Yes	Yes/No
25	Tidal Influences	No	Yes/No
26	Wall Thickness	Unknown	%
27	Gas Pockets	Unknown	Number
28	Factor of Safety Left	Unknown	Factor

Index Output = 9 (Failing)

Module = External Corrosion

Reason = Presence of Railroad and Possible stray current

Piloting Results – Asset Level

Number	Parameter	Source
1	Line Number	GIS
2	id	GIS
3	PIPEiD	GIS
4	Pipe Material	GIS
5	Pipe Diameter	GIS
6	Pipe Age	GIS
7	Pipe Location	GIS
8	Pipe Joint Type	GIS
9	Pipe Slope	GIS
10	Node Length	GIS
11	Pipe Lining	GIS
12	Failure Type	Failure Data
13	Cathodic Protection	GIS
14	Soil Corrosivity	USGS
15	Pipe Break Rate	Failure Data
16	Pipe Break <5 Years	Failure Data
17	Operating Pressure	Sahara Inspections
18	Flow Velocity	Sahara Inspections
19	Treatment Plant	GIS
20	Number of Gas Pockets	Sahara Inspections
21	Length of Gas Pockets	Sahara Inspections
22	Remaining factor of Safety	BEM

- Evaluated all available 17031 segments from participating utility
- Field measurements on;
  - Pressure
  - Flow (gallons/min)
  - Remaining factor of safety
  - Number of gas pockets
  - Length of gas pockets
- Extracted soil Corrosivity from USGS database.

Piloting Results – Asset Level

Regions of Interest

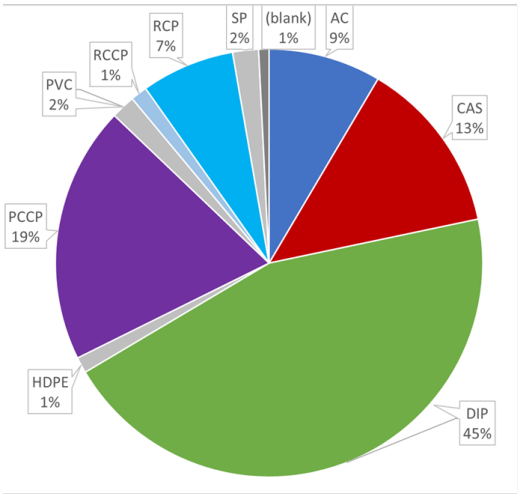
Cast Iron Pipes

High age: >70

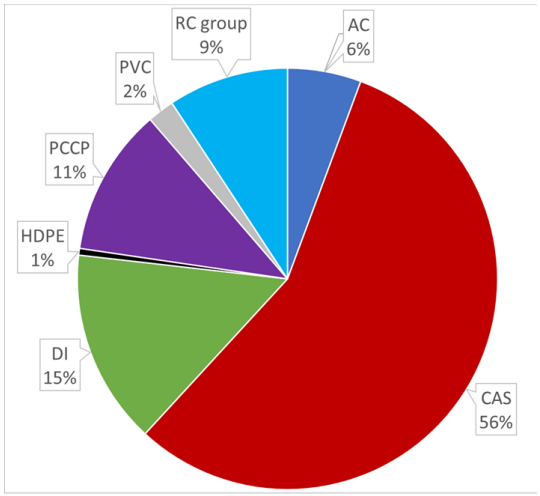
Unlined

Prone to Tidal Influence

Corrosive Soil



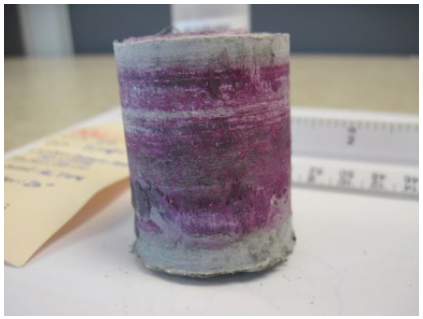
SYSTEM MATERIALS
(Current Composition, 2.6M ft)

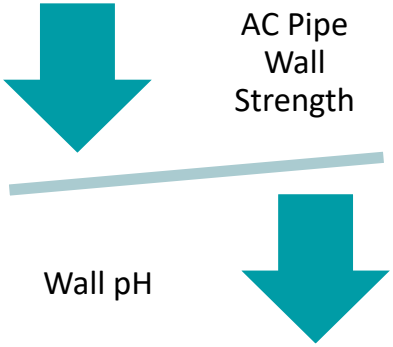


FAILURE EVENTS
(25-yr Period, 194 failures)

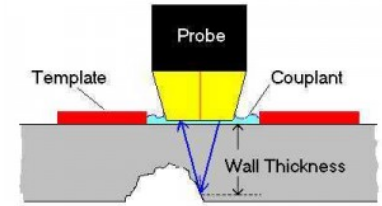
Piloting Results – Asset Level

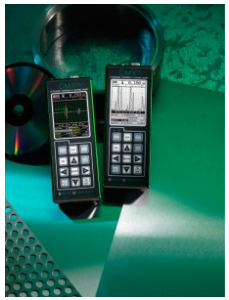
Site Number	Pipe Material	Pipe Vintage	Pipe Diameter (Inches)
1	Asbestos Cement	1968	14
2	Asbestos Cement	1968	16
3	Asbestos Cement	1968	20
4	Ductile Iron	2002	30
5	Cast Iron	1949	16





Phenolphthalein Testing for AC





Dakota CMX DL + Wall thickness Testing for DI

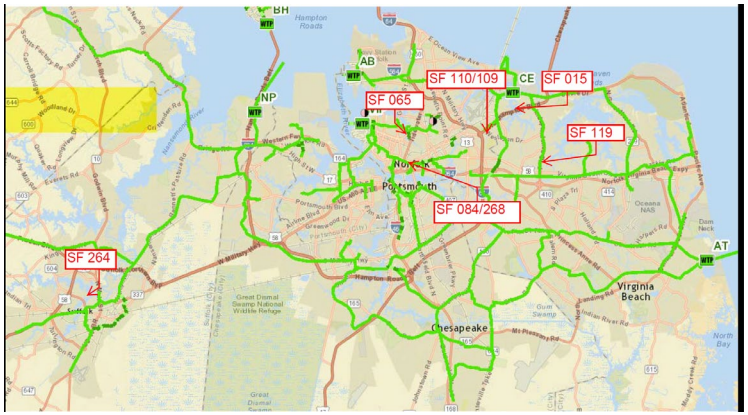
25

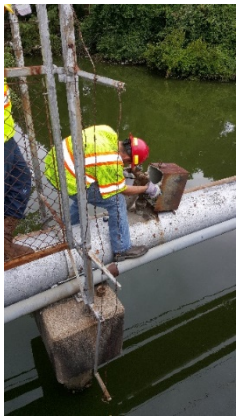
Piloting Results – Asset Level

- In Situ Tests and Water, Soil samples were conducted to measure;

No	Parameter	Test
1	Cathodic Protection	Field Observation
2	FOG	Field Observation
3	Ground Cover	Field Observation
4	Ground Water Table	Field Observation
5	H2S	H2S Monitor
6	Height of Bedding	As Build Records
7	Pipe Age	As Build Records
8	Pipe Depth	As Build Records
9	Pipe Diameter	As Build Records
10	Pipe Location	As Build Records
11	Pipe Material	As Build Records
12	Pipe Shape	As Build Records

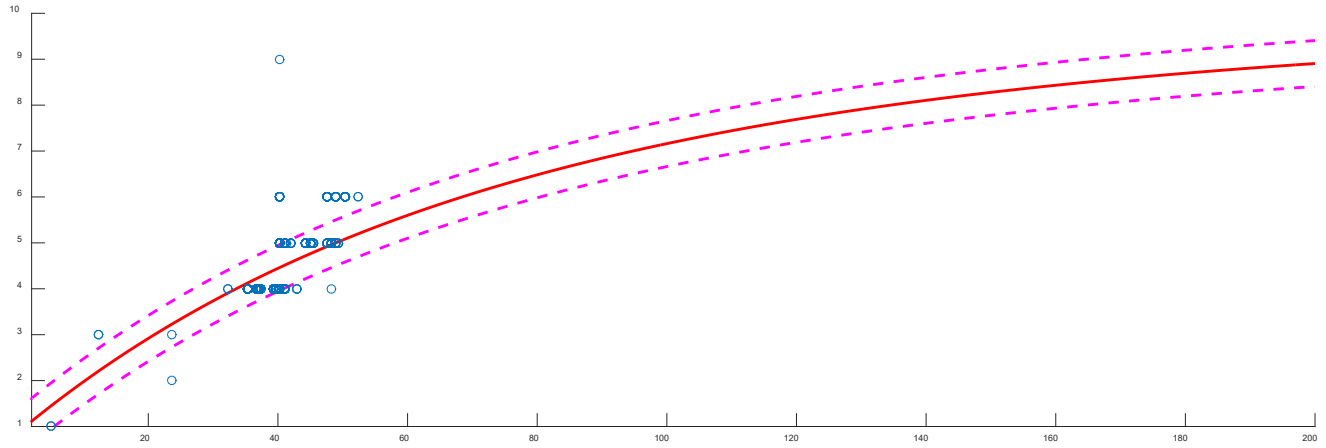
No	Parameter	Test
13	Soil Moisture	Piezometer
14	Soil pH	Piezometer
15	Soil Resistivity	Earth Ground Resistance Tester
16	Soil Type	Field Observation
17	Stray Currents	Earth Ground Resistance Tester
18	Thrust Restraint	As Build Records
19	Tidal Influences	As Build Records
20	Wastewater pH	Litmus paper
21	Turbidity	Turbidity Tube
22	Wastewater Temp	Thermometer
23	Wall Thickness (AC)	Phenolphthalein
24	Wall Thickness (Metallic)	Ultrasound





26

Piloting Results – Asset Level



Total Number of Segments = 736
True Positives = 537
True Negatives = 199

Accuracy = % 72.69

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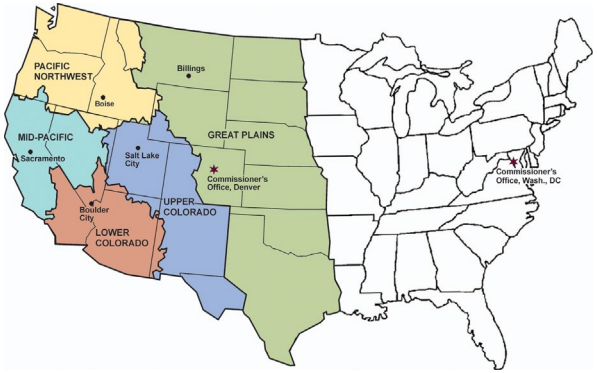
PIPELINE *infrastructure* DATABASE

U.S. DEPARTMENT OF THE INTERIOR

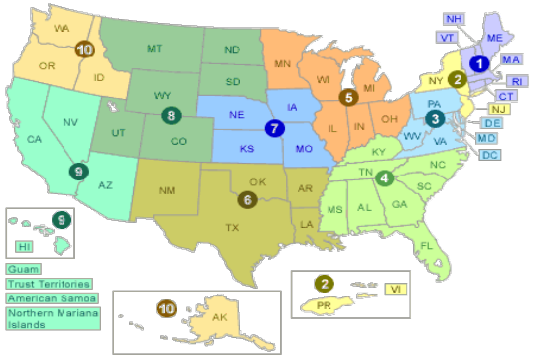
BUREAU OF RECLAMATION

RECLAMATION

Managing Water in the West



100 Federal Facilities



500 Water Utilities

Under the United States Congressional Direction

Federal Register - OMB Control Number: 1006-0031

COLLECTION AND COMPILATION OF WATER PIPELINE FIELD PERFORMANCE DATA

- **The purpose of this project is to collect high quality field performance data on pipeline reliability for water pipelines of different materials, including cast iron, ductile iron, pre-tensioned concrete, reinforced concrete, steel, pvc, hdpe, others.**
- **This project will also develop a database capable of efficiently storing the collected data and supporting data analytics and analysis of the performance of water pipeline infrastructure systems across the county.**

This Project will lay the Foundation of a National Database of Water Utility Infrastructure.

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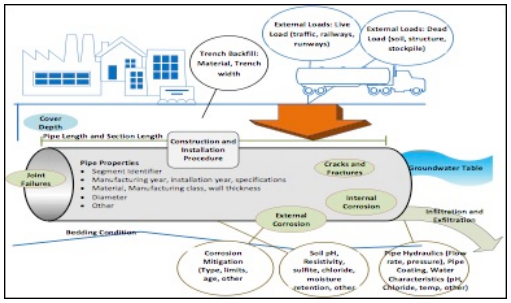
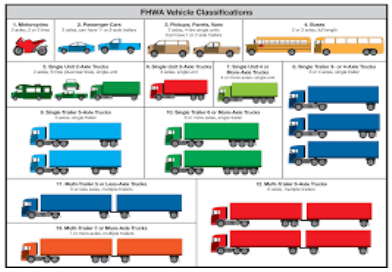
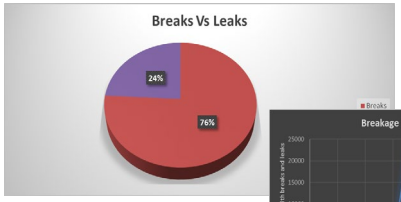
Benefits for Participating Water Utilities

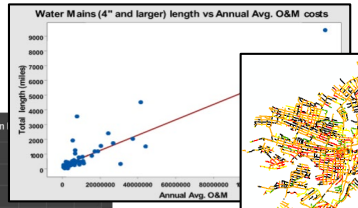
- **Standardized Data**
  - Comprehensive Standardized Data
  - ***External Data Service***
    - Utility data will be combined with external data sources like EPA, USGS, SSURGO, NLCD, etc.

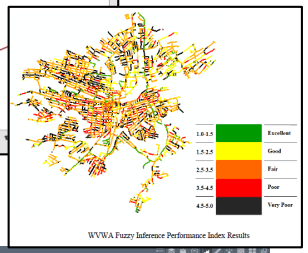




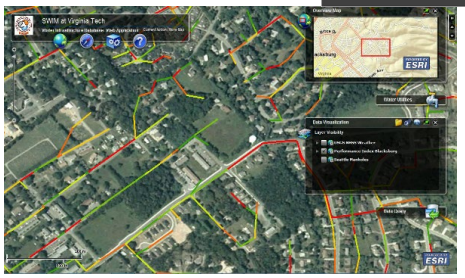
- **Data Analytics**
  - Strategical – General Information
  - Tactical – Pipe Performance Analysis
  - Operational – Advanced Models/Tools

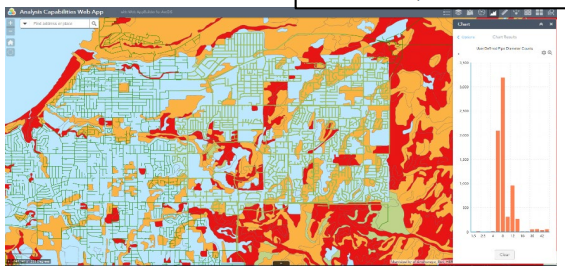






- **Decision Support**
  - Preliminary Analysis of the Standardized Utility Data
  - Visualization of GIS Web-applications for decision support





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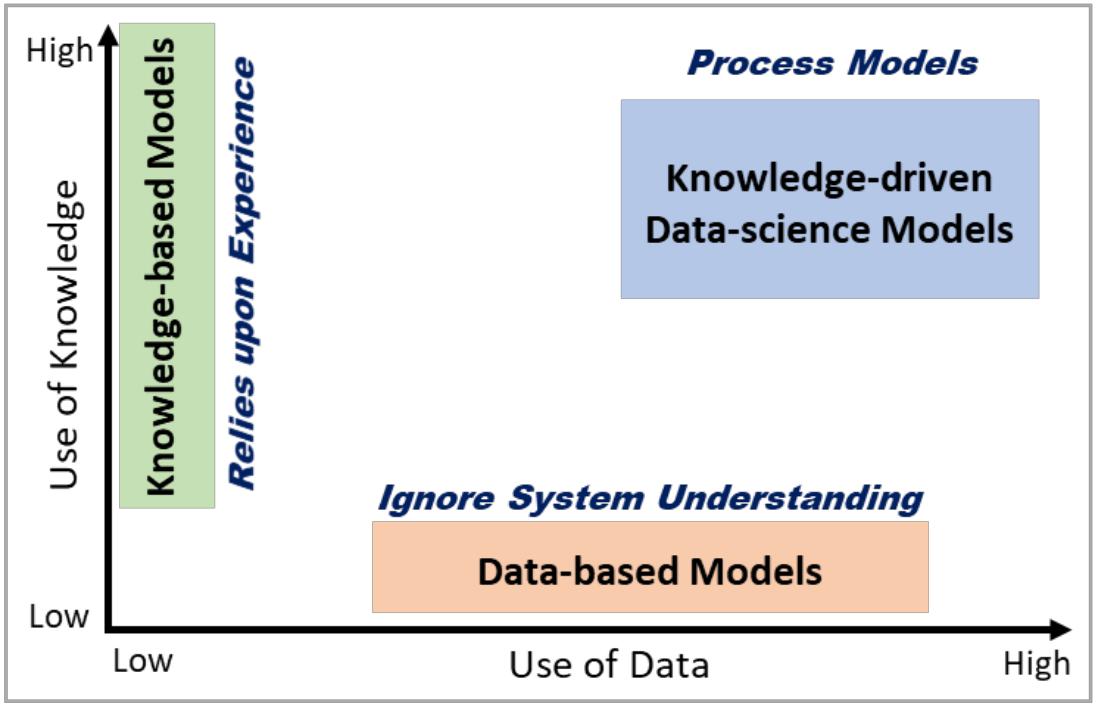
PIPELINE infrastructure DATABASE

MODELING APPROACH & DATABASE PLATFORM



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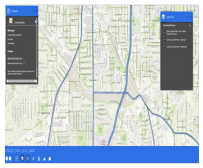
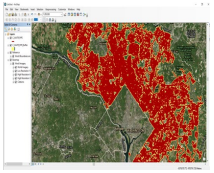
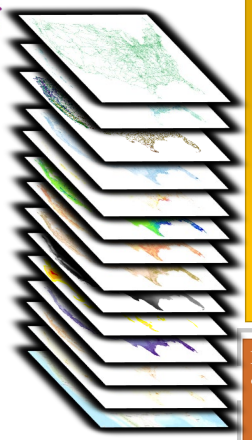
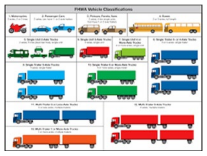
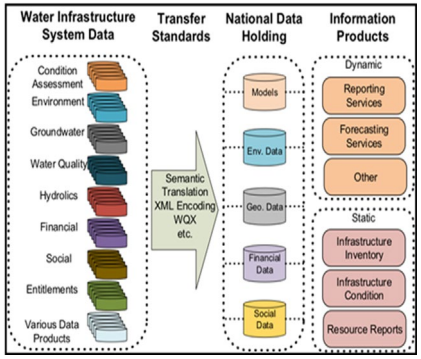
Data Source











PIPEiD DATABASE ARCHITECTURE

Local – For specific Water Utility

Regional – For specific Ecological Cohorts

Global – For entire USA

Ecological Cohorts
- Climatic conditions (arid, coastal, arctic, mountainous)
- Natural event conditions (earthquakes, hurricane, cyclone, floods)
- Operational conditions (soil temperature, groundwater, traffic loading, railway tracks and others)

Performance Analysis Framework

- Metallic: CI, ST, DI, GI, WI
- Plastic: PVC, PE
- Cementitious: PCCP, RCP, BWP, AC

Diameter: <16", 16"-36", >36"

- Design and Installation
  - Lining/Coating
  - Bedding specifications
  - Joint characteristics
- Corrosion
  - Internal: Water Corrosivity; Corrosion Protection (Lining); Friction Factor
  - External: Soil Corrosivity; Stray Current; Corrosion Protection (Coating/ Wrapping/ Cathodic Protection); Soil Moisture; Groundwater Corrosivity
- Loading
  - Internal: Hydraulic Pressure; Frequency of Pressure Surge Events; Proximity to valves and pump stations; Water Temperature
  - External: Traffic Loading (Roads, Railways); Frost Loading; Frost Action; Improper bedding; Soil Temperature Regime
- Failure and Defect Analysis: Mean Age at First Failure; Successive Failures; Failure Mode; Failure Root Cause; Failure Rate
- Unpredictable Events: Frequency of earthquakes (Proximity to fault lines); Coastal Area (Saltwater Intrusion); Third party damage

Target Deliverables

Descriptive Analysis
- Characteristics: Material, Lining, Coating, Cathodic Protection distribution
- Trend Analysis: Installation and Failure Trends
- Performance Analysis: Influence of performance parameters

Statistical Analysis
- Descriptive Analysis: Distribution, Correlation, Clustering
- Failure Analysis: Survival curves and Useful Life Prediction
- Performance analysis: Performance Index and Performance Curves

Risk Analysis: Risk Matrix developed using LoF, CoF and Criticality

Economic Analysis: Future spending, Lifecycle Costs and Optimum Replacement times and methods

SPATIAL ANALYSIS

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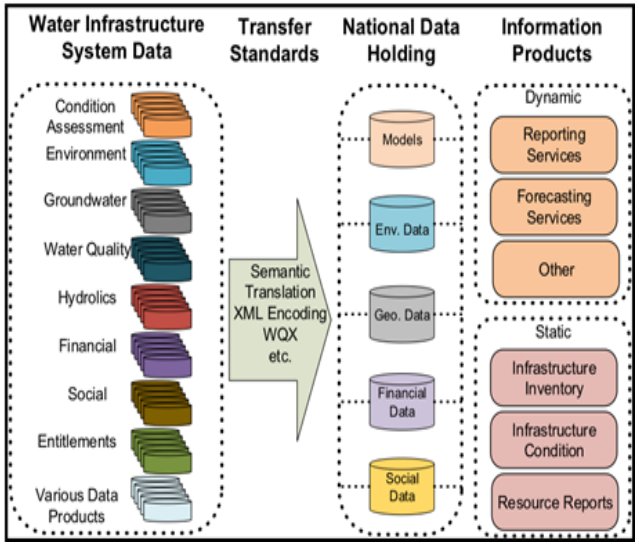
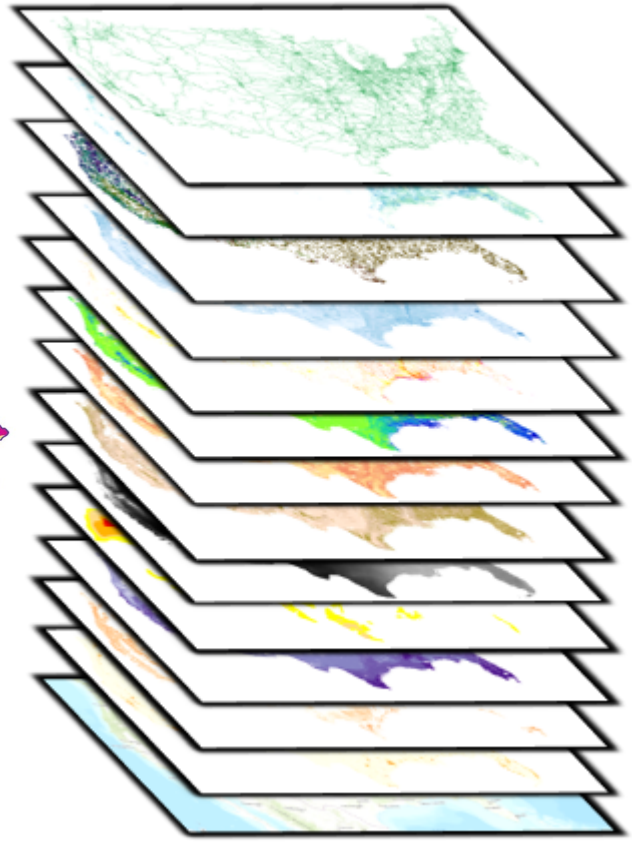
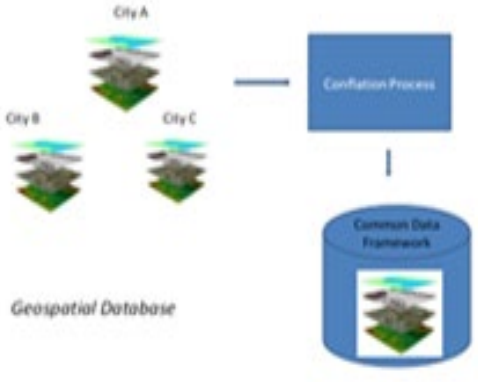
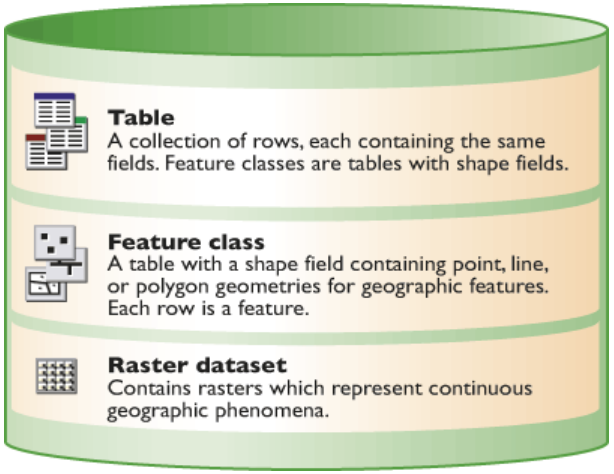
PIPELINE *infrastructure* DATABASE

Data Storage & Mapping









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Water Utilities Engagement and Services

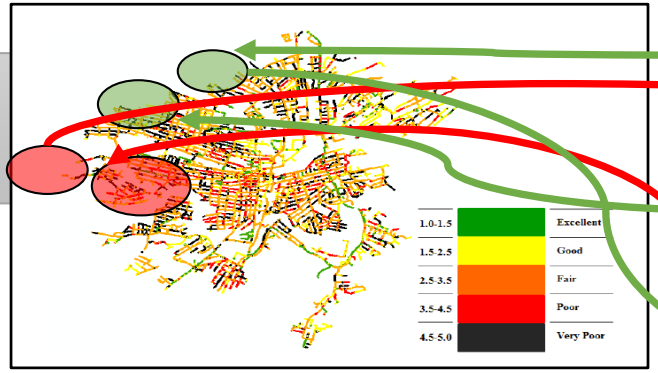
Data Collection, Compilation and Database Management

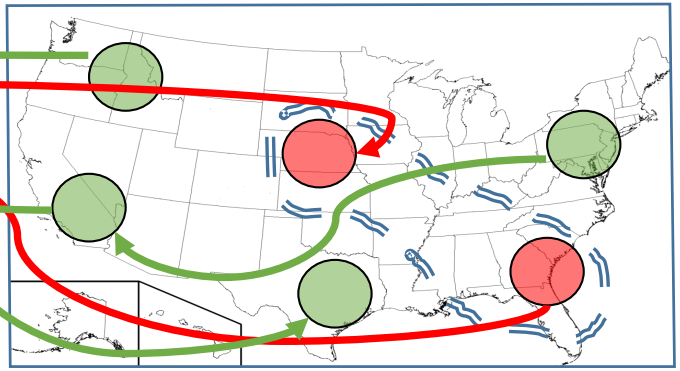
Statistical Qualitative and Quantitative Analysis for Hypothesis Testing

Information and Knowledge to Support Advanced Water Pipeline Asset Management

Cross Scale Interaction → Cohort Analysis → Global Trend Emerges

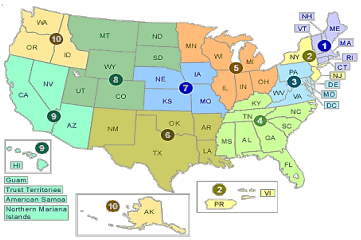
LOCAL ANALYSIS





REGIONAL ANALYSIS

Identify the high-level trends across the country and around the world



GLOBAL ANALYSIS

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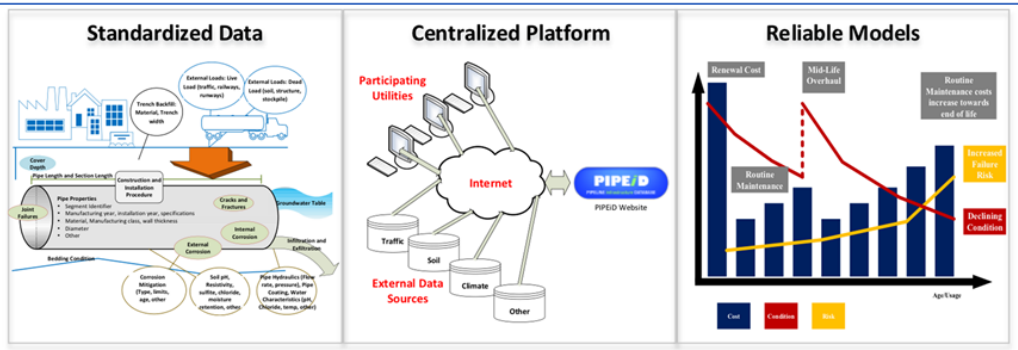
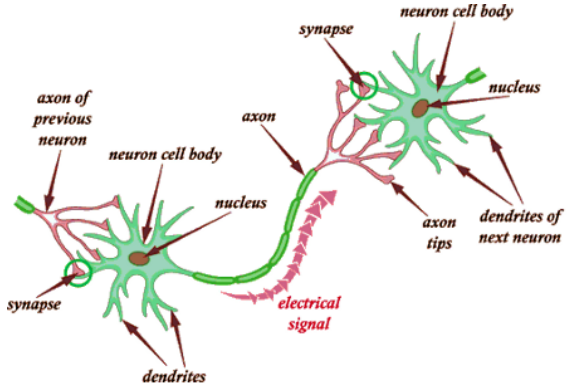
Artificial Intelligence Application for Water Pipelines

Data-Centric **aspect would focus on substantial datasets of water pipeline**

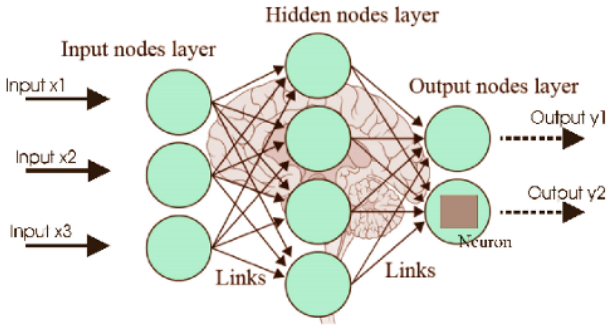


Better Data + Better PLATFORM + Better PROCESSES = Better WATER INFRASTRUCTURE ASSET MANAGEMENT"

Model-Centric **aspect would focus on annotation and sharing of robust models**



Neuron in our brain.



Neural Network develop using A.I.

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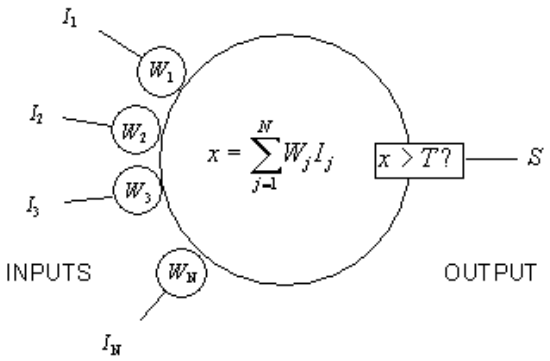
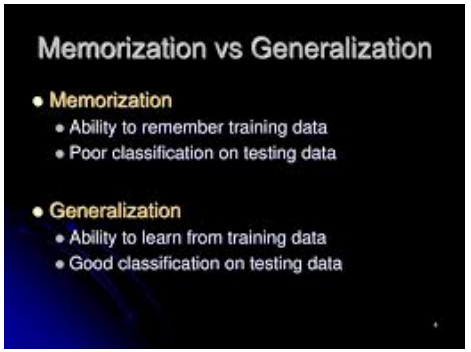
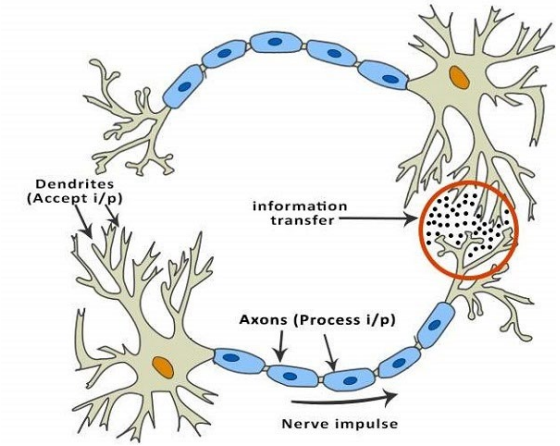
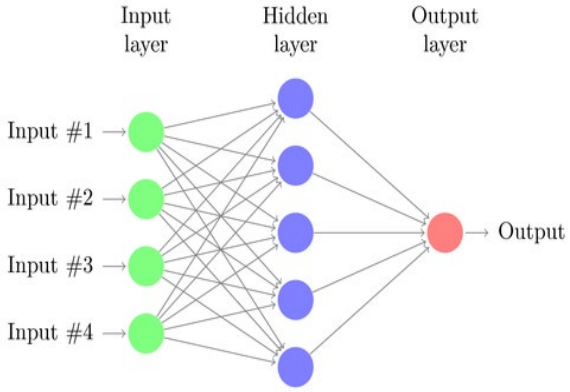
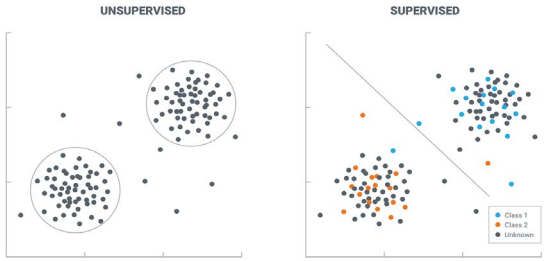
‘Artificial Neural Network’

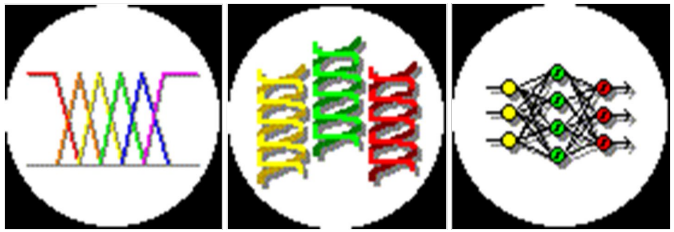












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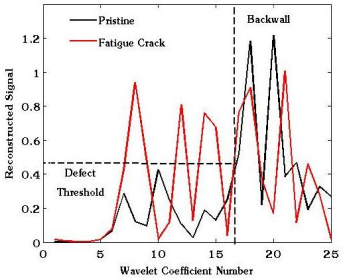
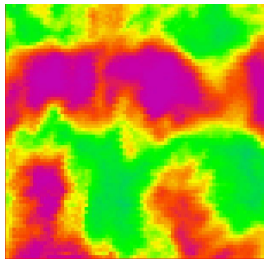
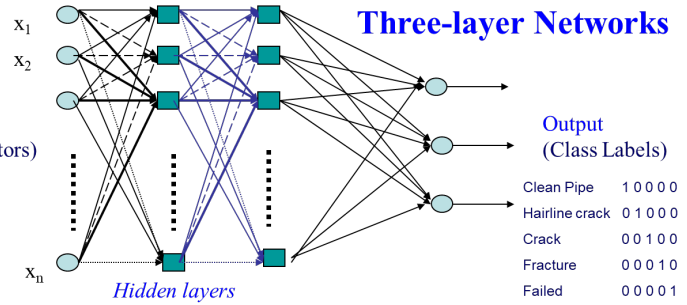
PIPELINE PERFORMANCE ANALYSIS

Operational Level Analysis

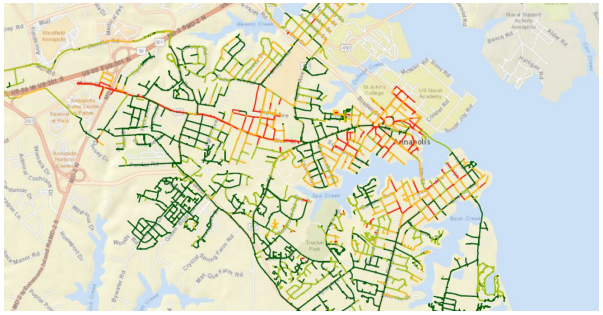


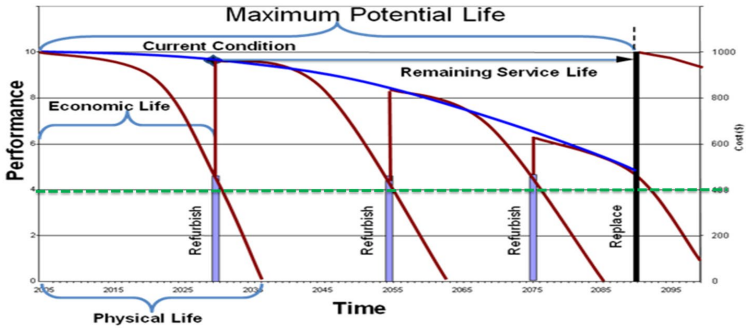


Input
(Feature Vectors)

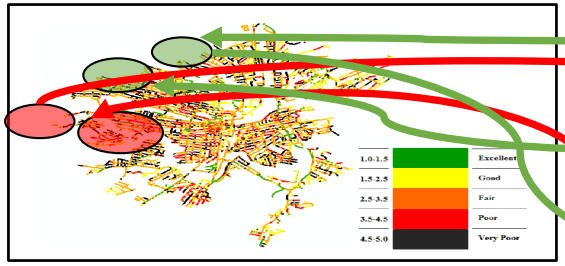


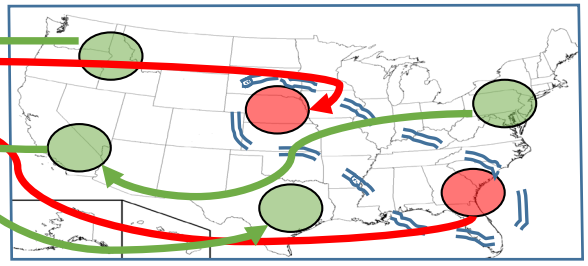
Tactical Level Analysis





Strategic Level Analysis





Questions?

Thank You

Comments or questions, please contact:

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Walter Graf: wgraf@waterrf.org

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