WATER INFRASTRCUTURE SYSTEM MANAGEMENT

Performance, Resiliency, and Sustainability

"Water Systems plays a critical role in protecting public health, promoting economic prosperity, and ensuring quality of life across the United States & around the World"

Dr. Sunil Sinha, Professor and Director

Civil and Environmental Engineering

Sustainable Water Infrastructure Management

Virginia Tech

VIRGINIA TECH

WATERiD WATER infrastructure DATABASE

PIPEiD PIPELINE infrastructure DATABASE

SWIMeD SWIM education Program

NSF-ERC-SOW

SWIM Sustainable Water Infrastructure Management

What Do I Do Outside of Work?

Recipient of National Science Foundation (NSF) CAREER AWARD for Research and Education in the Areas of Sustainable Water Infrastructure Management Systems

Chair, ASCE Infrastructure Asset Management Division
Vice Chair, NIST Community Resilience Panel, US DOE
Panel Member, National Infrastructure Advisory Council, US DHS

The Public Broadcasting Service (PBS) documentary

Liquid Assets The Story of Our Water Infrastructure

2008 Engineering Journalism Award

History Channel documentary: "The Crumbling of America"

Appeared as Water Infrastructure Expert

npr news

PBS NEWS HOUR

Given many interviews related to Water!!

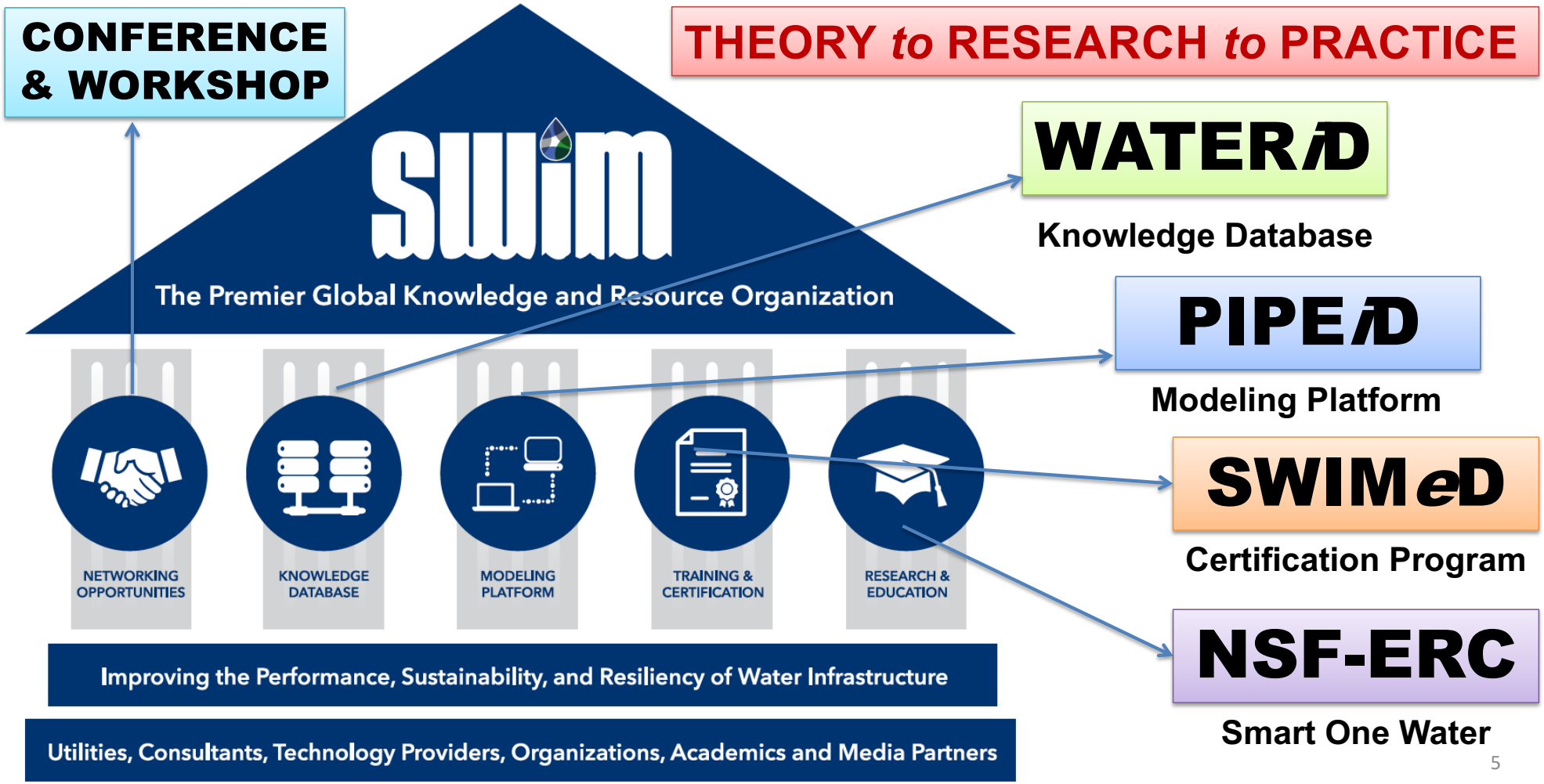
- **Over 450 publications in technical referred journals, technical conference proceedings, and technical reports**
- **Currently supervising 1 Post-doc, 5 Ph.D. & 5 MS students**
- **Graduated 67 MS, 21 Ph.D. students, and 5 Post-doctoral**

Sustainable Water Infrastructure Management

VISION – To become the premier global knowledge and resource organization for planning, engineering, constructing and operating sustainable and resilient water infrastructure systems

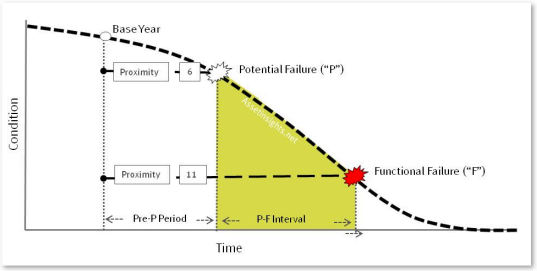
MISSION – To bring together the global water industry to improve the performance, sustainability, and resiliency of existing and future water infrastructure systems

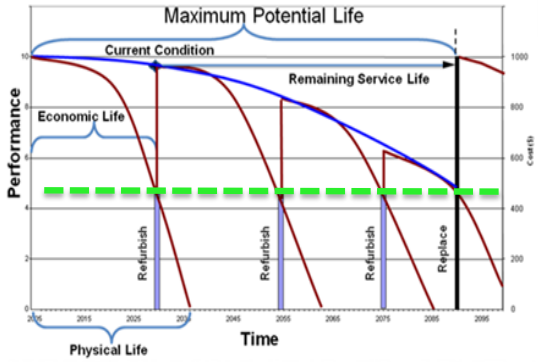
SWIM CORE ACTIVITIES

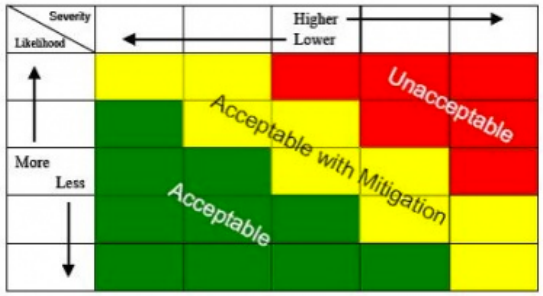


Resilience Management

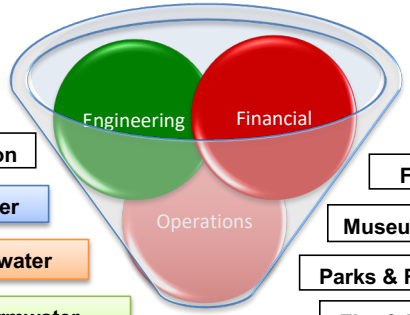
Performance Management







Urban Infrastructure



- Transportation
- Drinking Water
- Wastewater
- Stormwater
- Facilities
- Museums/Cultural
- Parks & Recreation
- Fire & Rescue

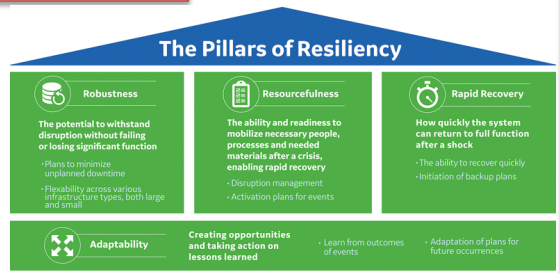
Water Infrastructure Management

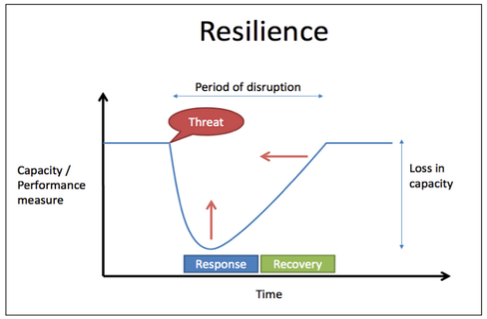
Performance | Resilience | Sustainability

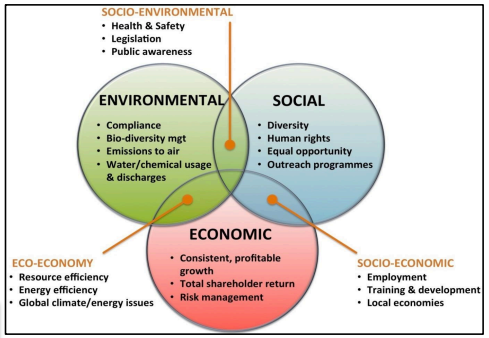
Data & Modeling Platform

- Asset Management
- Condition Assessment
- Renewal Engineering
- Life-cycle Cost Analysis
- Risk Management
- Utility Benchmarks

Community Services



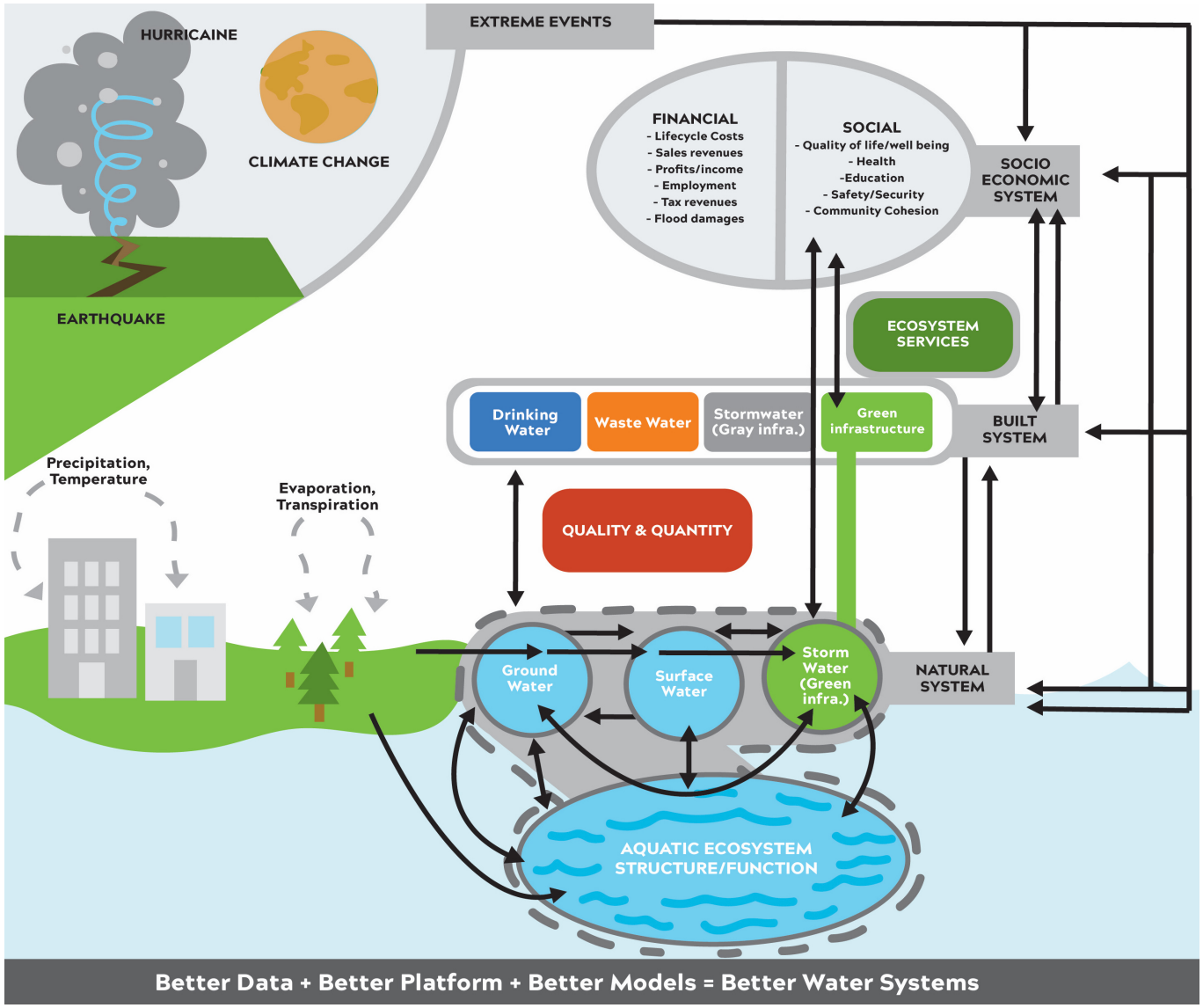




Sustainability Management

THREE DIMENSIONAL WATER INFRASTRUCTURE SYSTEMS

(NATURAL, BUILT, AND SOCIO-ECONOMIC)



KNOWLEDGE DATABASE

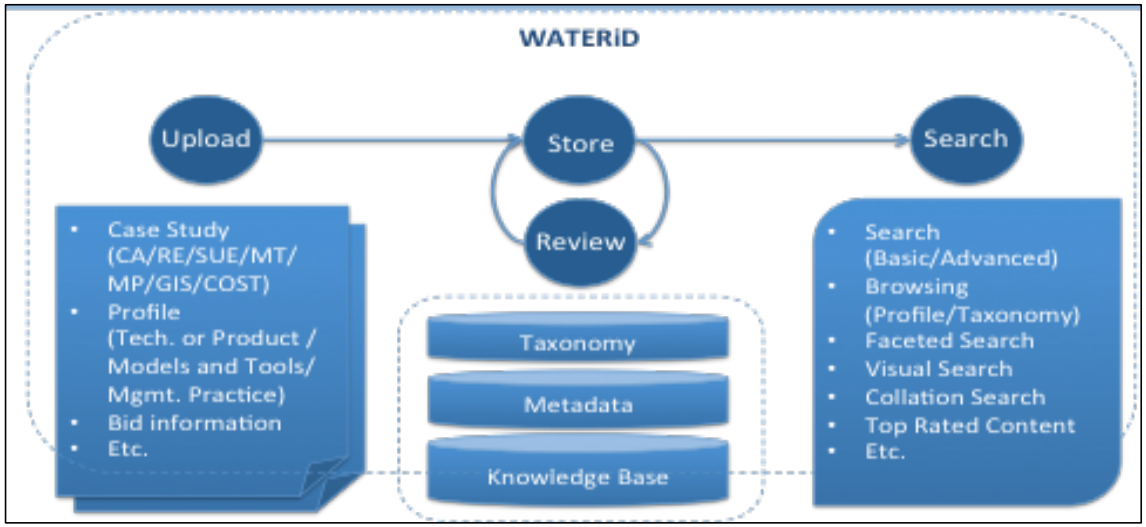
www.waterid.org

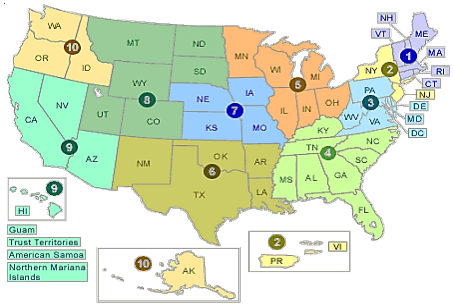
The United Sates Environmental Protection Agency (U.S. EPA) through the Aging Water Infrastructure (AWI) research program efforts and the Water Research Foundation (WRF), have teamed up to fund the national WATER Infrastructure DATABASE (WATERiD).

"*Having a comprehensive knowledge base for condition assessment and renewal technologies that can assist drinking water and wastewater entities to more effectively put comprehensive asset management into practice, and meet their Clean Water Act and Safe Drinking Water Act requirements, fits well with the Environmental Protection Agency's (EPA) long-standing research investment into managing our nation's water infrastructure systems*."

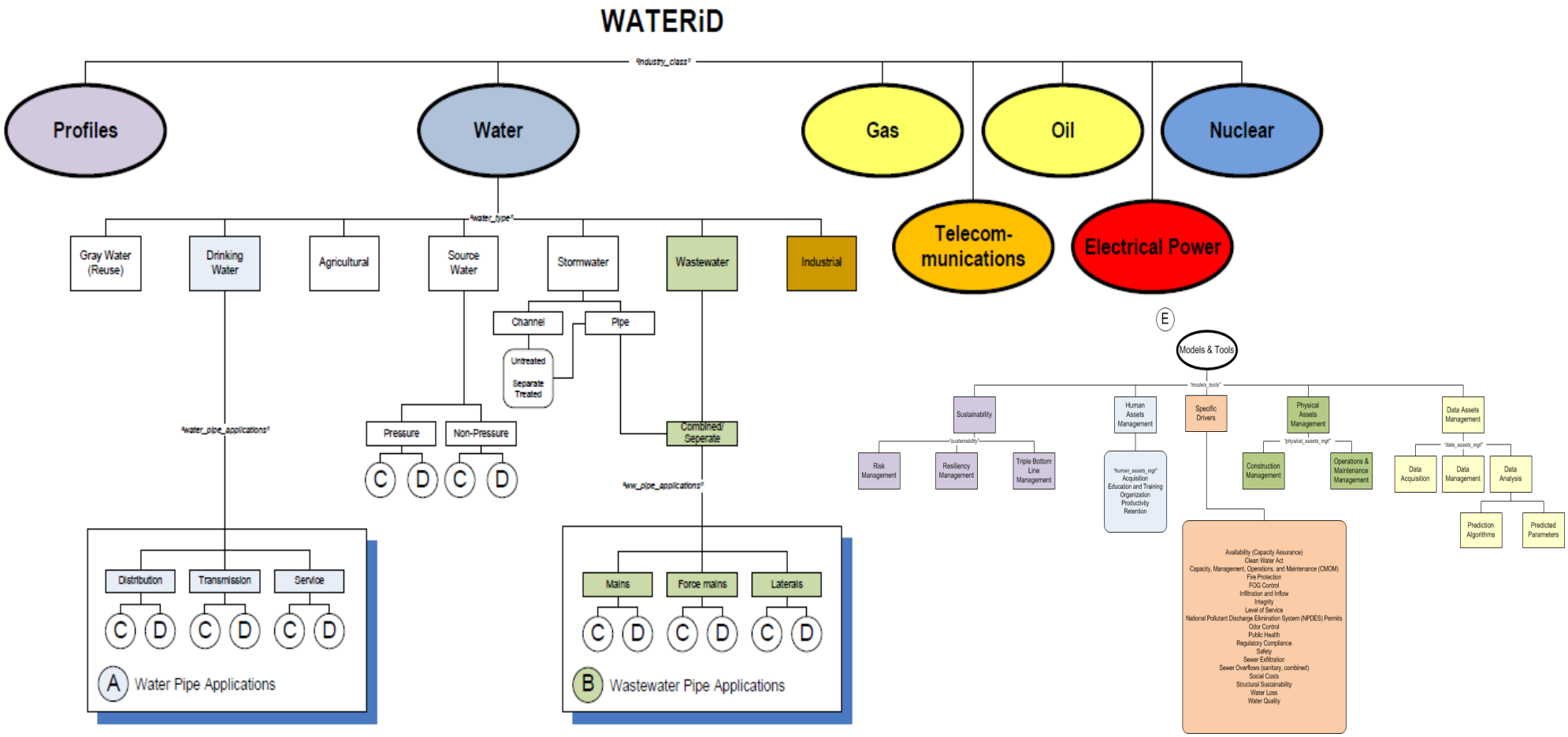
– Dr. Thomas F. Speth, Director, Water Division, U.S. EPA

Knowledge Database

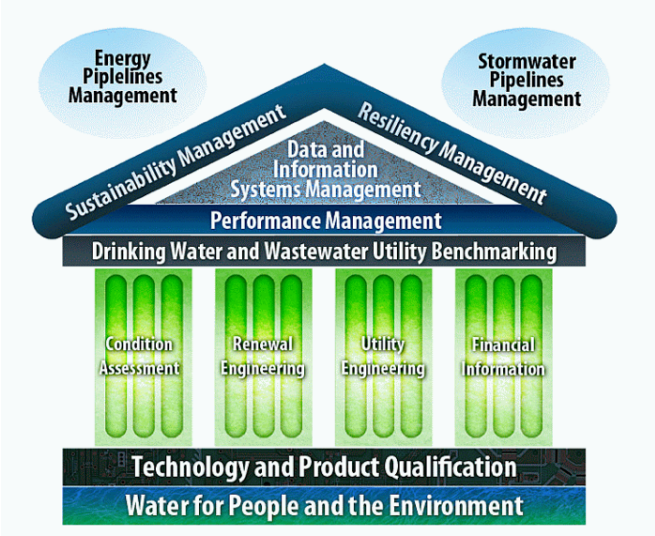


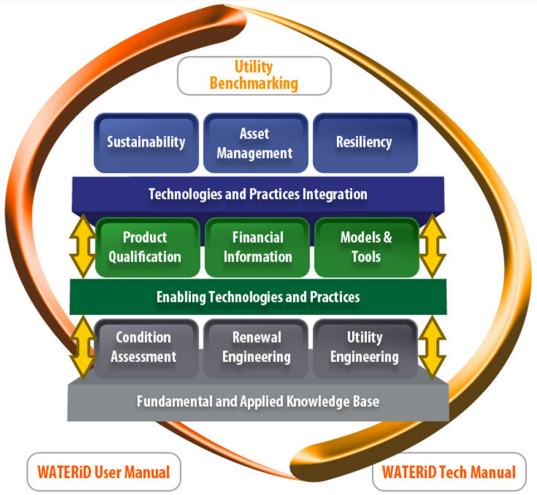


Knowledgebase Taxonomy

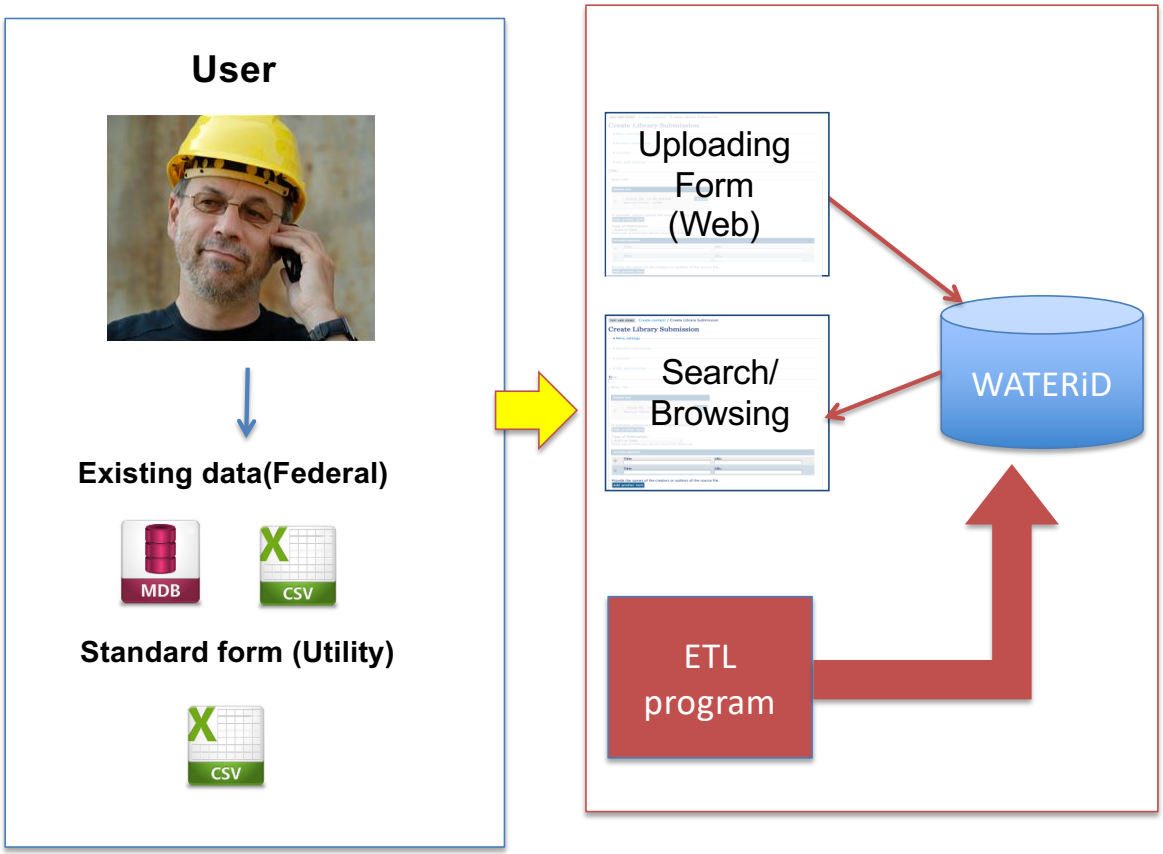


Water Infrastructure System Knowledge Database





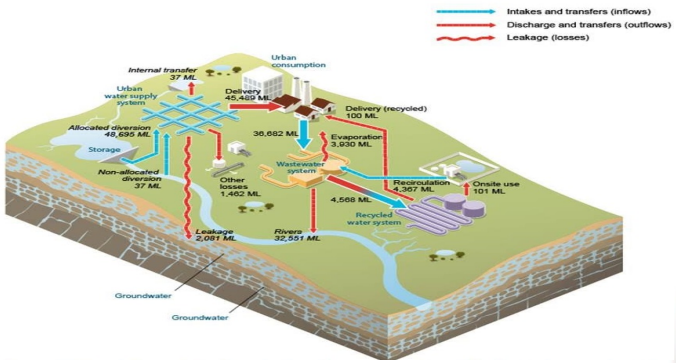
WATER*i*D ETL Process



Water Infrastructure Management

Water Research Foundation℠

To address deteriorating Water Infrastructure Systems by understanding current best management practices.



Participating Utilities' Benefit:

1. Be part of international database for water infrastructure
2. Learn from other utilities' success or mistakes
3. Information to handle aging/deteriorating infrastructure
4. Improved understanding of Risk based asset management
5. Up to date information on best practices and new technology

AECOM

CDM Smith
listen. think. deliver.

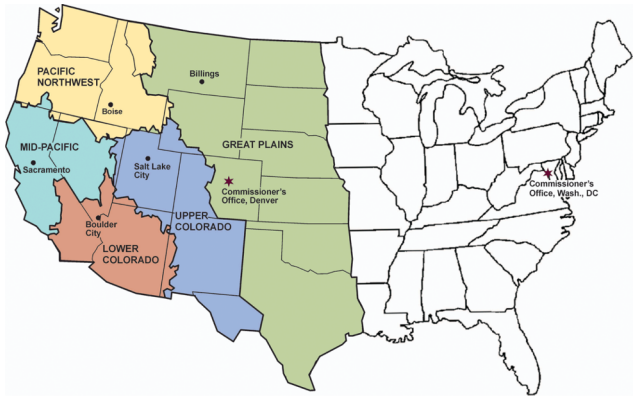
WaterOne
Water District No. 1 of Johnson County

100 Case Studies on:

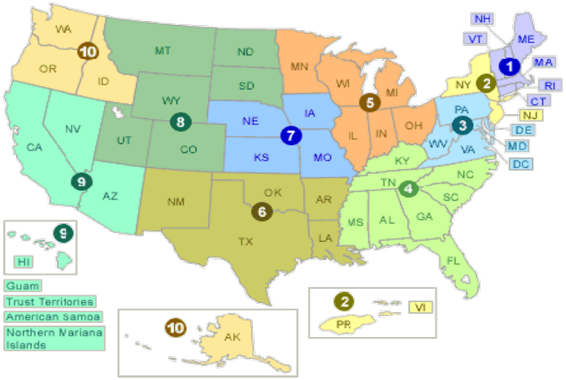
- **Condition Assessment**
- **Renewal Engineering**
- **Cost and Finance**
- **Risk Assessment**
- **Asset Management**

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

RECLAMATION
Managing Water in the West



100 Federal Facilities



500 Water Utilities

Federal Register - OMB Control Number: 1006-0031, Expires 10/31/2021

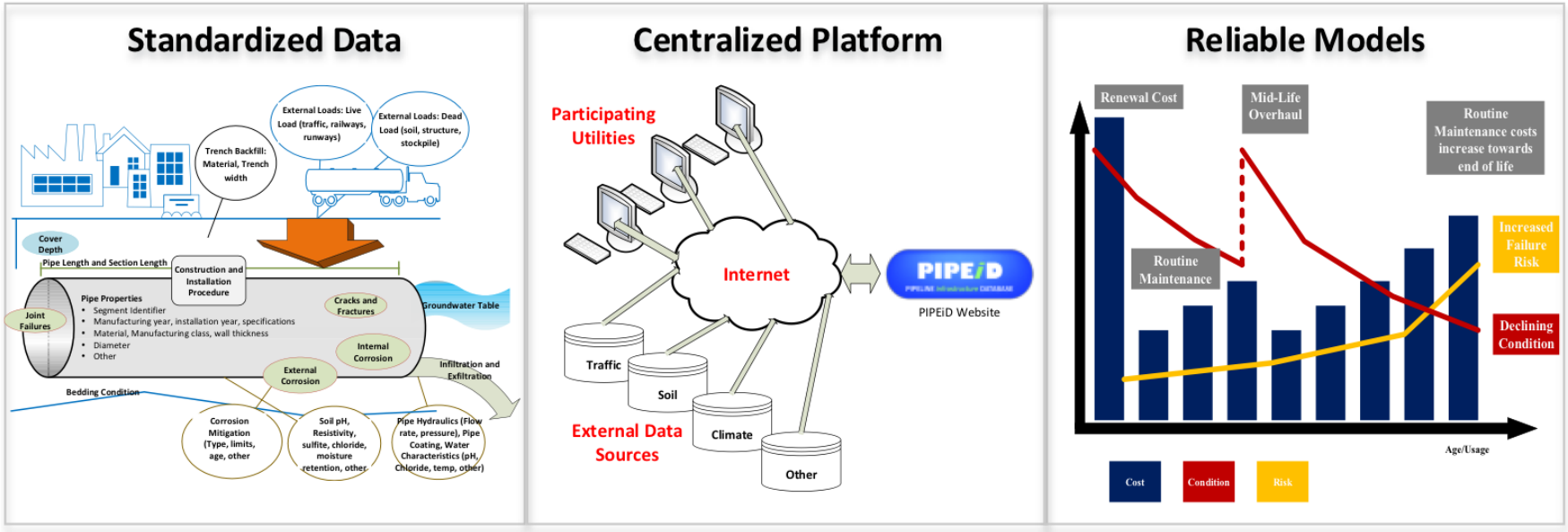
COLLECTION AND COMPILATION OF WATER PIPELINE FIELD PERFORMANCE DATA

- **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 studies and analysis of the performance of water pipeline infrastructure systems.**

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

NO COST FOR UTILITY TO PARTICIPATE IN THE NATIONAL WATER PIPE DATABASE PROJECT

Modeling Platform



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

PIPEiD Overview

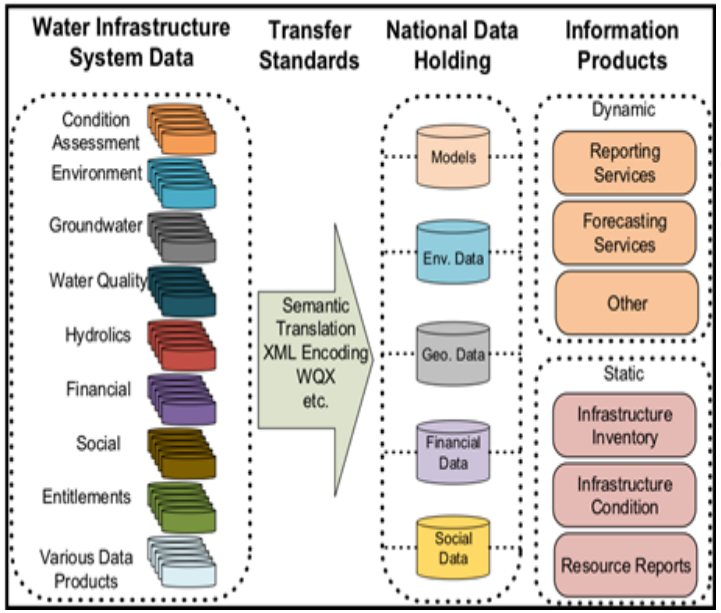
www.pipeid.org

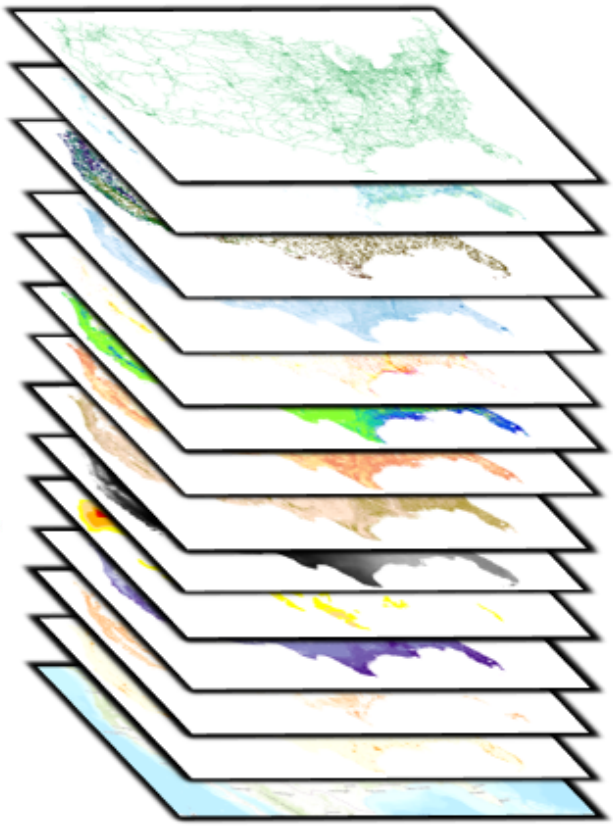
PIPELINE Infrastructure Database (PIPEiD) is envisioned to be "a Living Database Platform for Advanced Asset Management" addressing all three major management levels including strategic, tactical, and operational that will assist water utilities of all sizes to sustain targeted level of service.

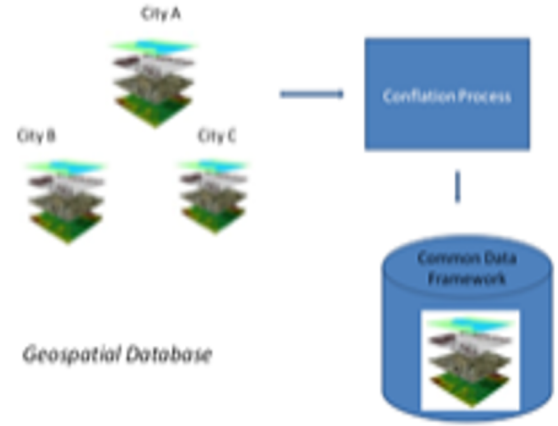
A centralized platform that utilizes a GIS-driven Web-based interface to support:

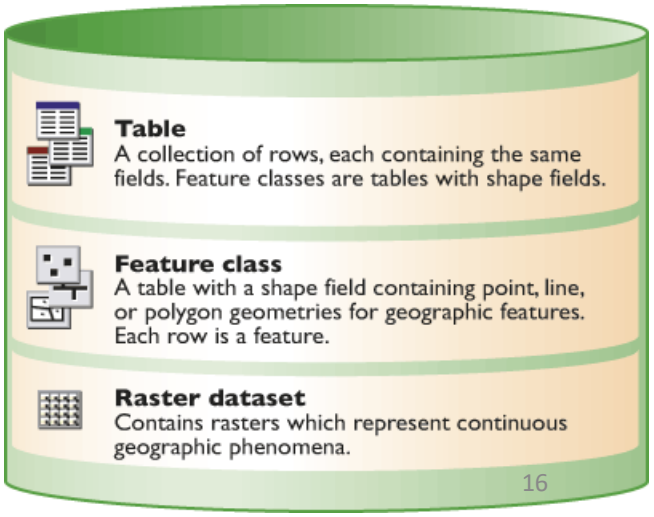
- **Standard Data Structures**
- **Integrate Data from Various Sources**
- **Existing and New Models**
- **Verify and Validate Models**
- **Visualize Results for Decision Support**

Data Storage & Mapping







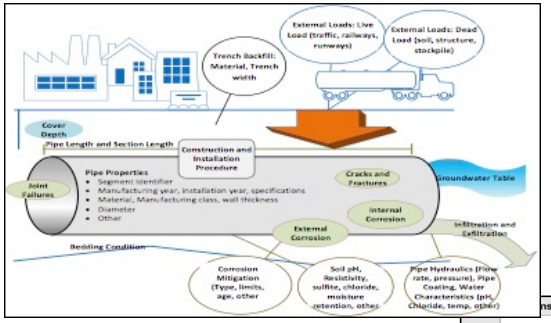


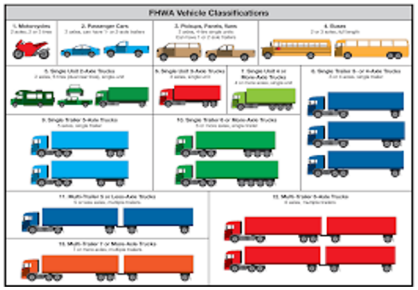
Benefits for Participating Water Utilities

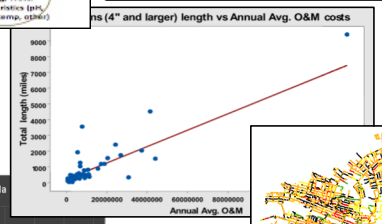
- **Standardized Data**
  - **Comprehensive Standardized Data**
  - ***External Data Service***
    - **Utility data will be combined with external data sources like EPA, USGS, SSURGO, NLCD, etc.**

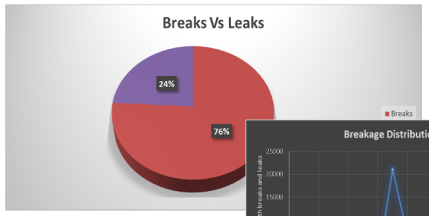
- **Data Analytics**
  - **Strategical – General Information**
  - **Tactical – Pipe Performance Analysis**
  - **Operational – Advanced Models/Tools**

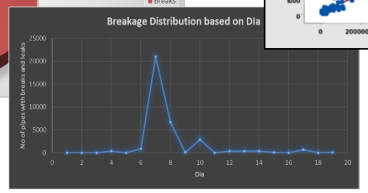
- **Decision Support**
  - **Preliminary Analysis of the Standardized Utility Data**
  - **Visualization of GIS Web-applications for decision support**

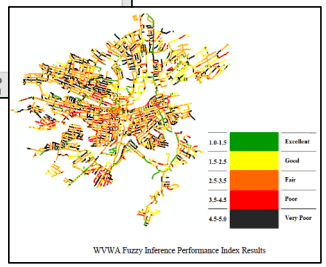


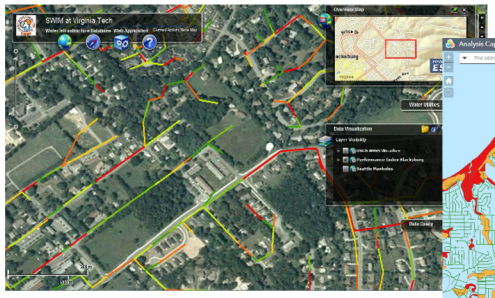


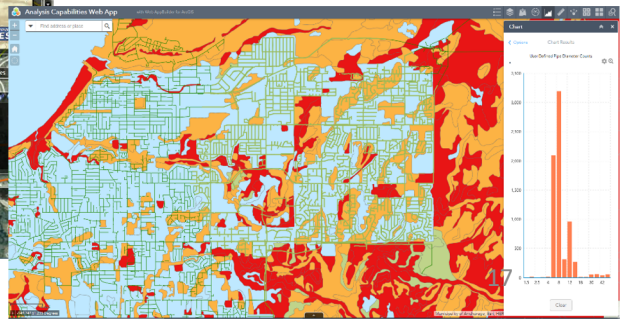










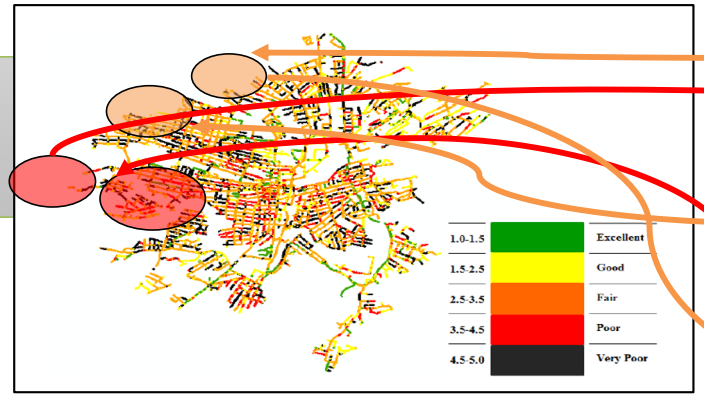


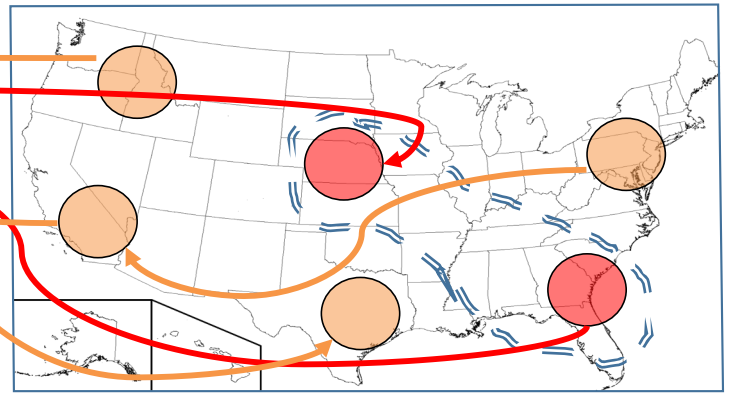
Water Utilities Engagement and Services

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

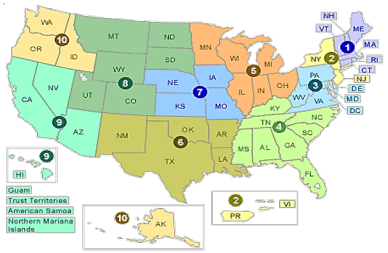
LOCAL ANALYSIS





REGIONAL ANALYSIS

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



GLOBAL ANALYSIS

Project Tasks and Activities

DATA CENTER

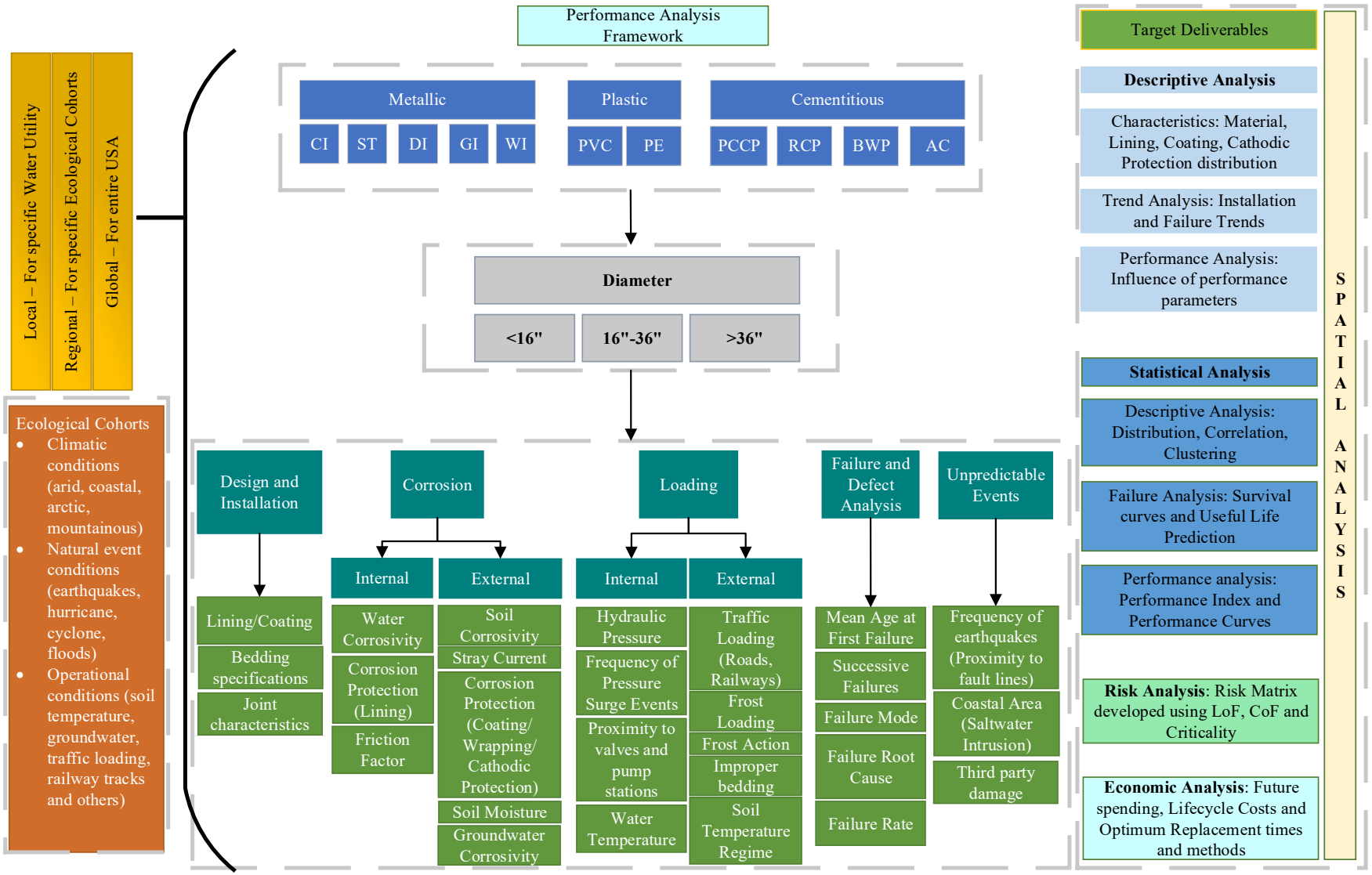
1. Set up Introductory Meeting with Utilities
2. Collect Data from Utilities
3. Collect Data from External Sources
4. Standardize Data (Utility + External Sources) according to SWIM Data Standards
5. Utility Data Warehouse – Standardized Comprehensive Data to Support Analysis

MODELING CENTER

6. Strategic Level Analysis for Water Pipe Performance
7. Tactical Level Analysis for Water Pipe Performance
8. Operational Level Analysis for Water Pipe Performance
9. Utility Modeling Platform – GIS-driven Platform to support Modeling & Visualization

INFORMATION CENTER

10. Project Deliverables – Final Report, PIPEiD Website, and User and Technical Manuals
11. Dissemination – Outreach and Training Program


Performance Analysis Framework
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)
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

Key Deliverables

1. Understanding the Pipeline Infrastructure Systems

2. Developing the data Standard to Support Analysis

3. Developing the Protocol for Database Management

4. Understanding the Pipeline Descriptive Analytics

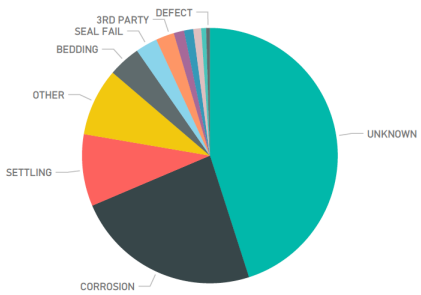
5. Understanding Pipeline Performance Characteristics

6. Understanding Risk & Life-Cycle Economic Analysis

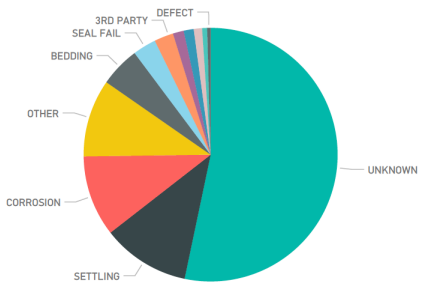
7. Developing Visualization & Decision-Support System

Root Cause of Failure

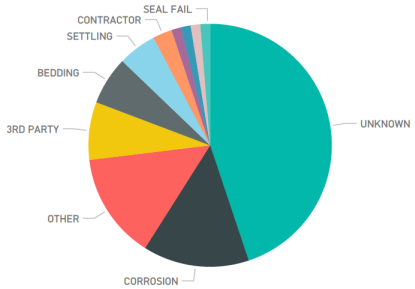
Overall by Root Cause

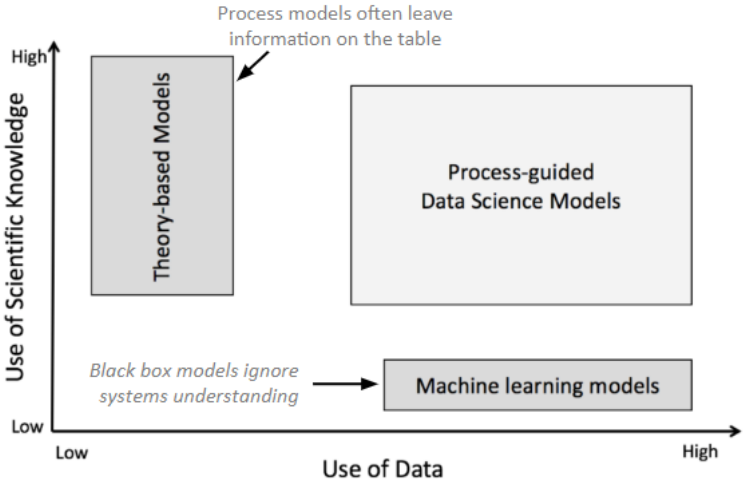


CI <16" by Root Cause

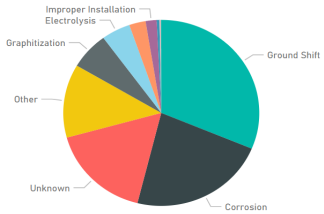


DI <16" by Root Cause

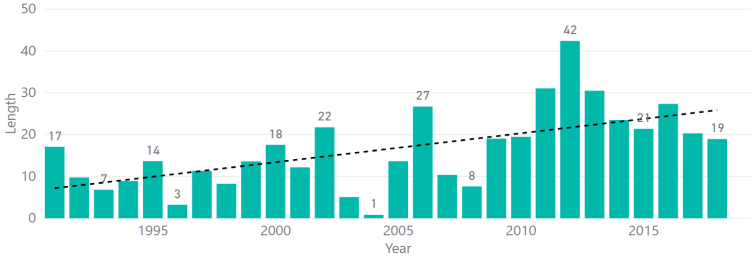




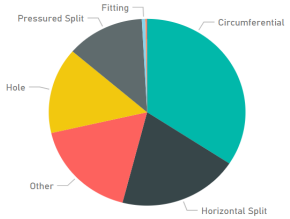
Root Cause of Failure for <16" CI



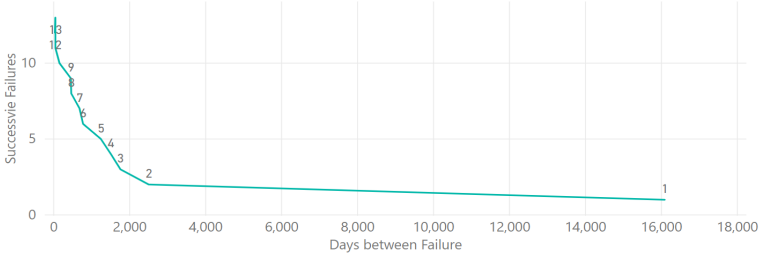
Number of Failures/Year for CI



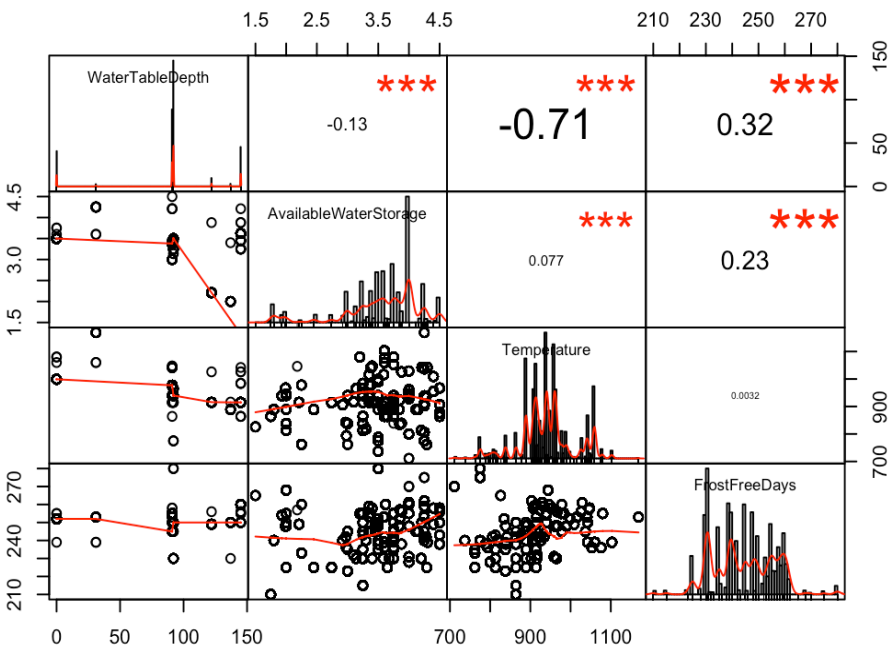
Failure Modes for CI <16"



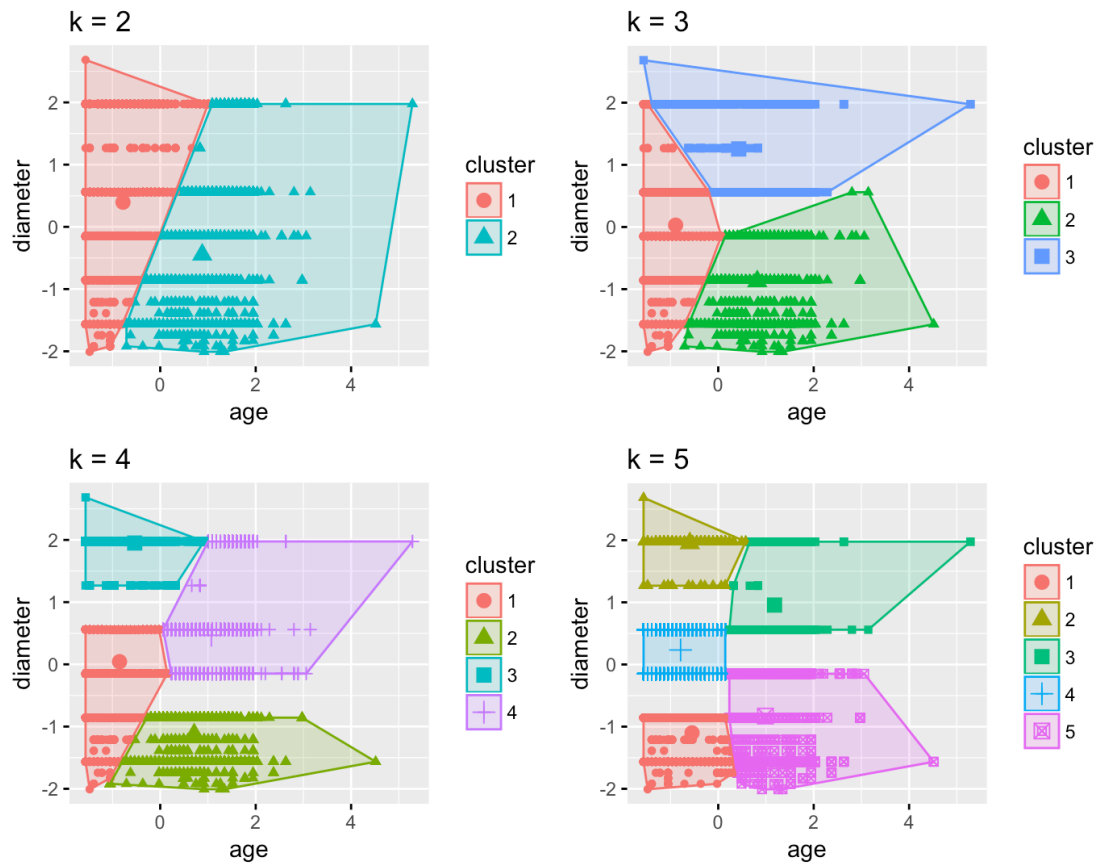
Mean Days between successive Failures



Correlation Analysis

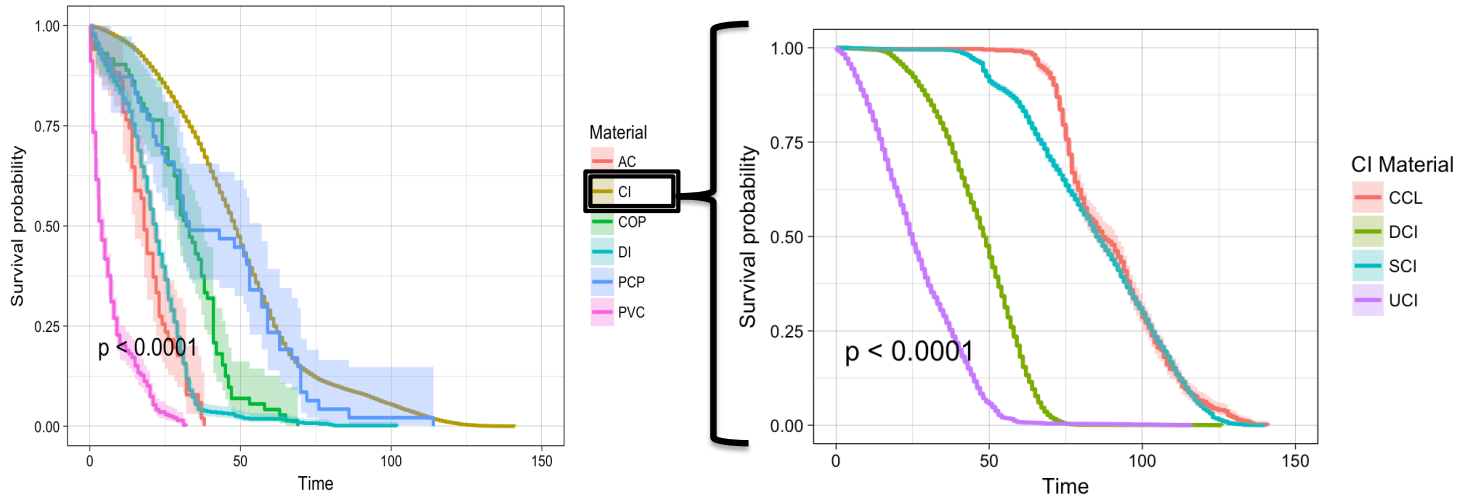


Clustering Analysis



Survival Analysis (CI Pipes)

- For CI pipes, **lined CI pipes** (CCL) are more durable than **unlined CI pipes** (DCI, SCI and UCI)



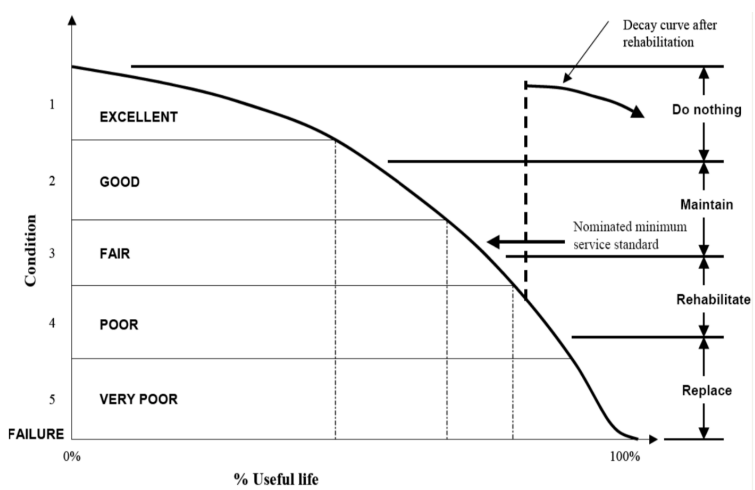
Subgroups of CI pipes

We are piloting to understand Survival function based on different material, diameter and ecological conditions

Performance Analysis - Practice

Given the different scaling methods, the 1-5 scale is mostly widely used, and it is also proved to be a balanced tradeoff between the granularity and statistical significance.

Grade	Representation	Range
1	Excellent	100-81
2	Good	80-61
3	Fair	60-41
4	Poor	40-21
5	Failed	20-0



RISK ANALYSIS - METHODOLOGY

- LoF values obtained from Performance model
- Research Team developed CoF model using different techniques like weighted factor and fuzzy logic
- LoF and CoF obtained on 1-5 scale
- 5x5 Risk Matrix
- CoF model takes a triple bottom line approach
  - 5 modules: Economic Impact, Environmental Impact, Social Impact, Operational Impact and Renewal Complexity capture 19 parameters
  - Models assumptions vary with diameter range
  - Model can be applied to all materials

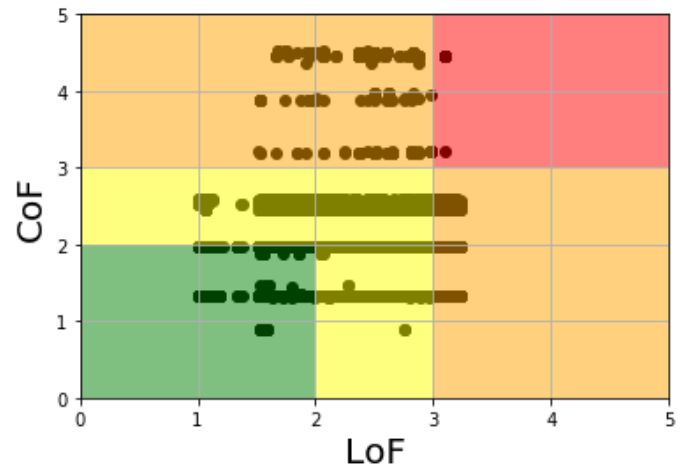
Likelihood of Failure Score	Description	Color
1	Very Good	Dark Green
2	Good	Light Green
3	Fair	Yellow
4	Poor	Orange
5	Very Poor	Red

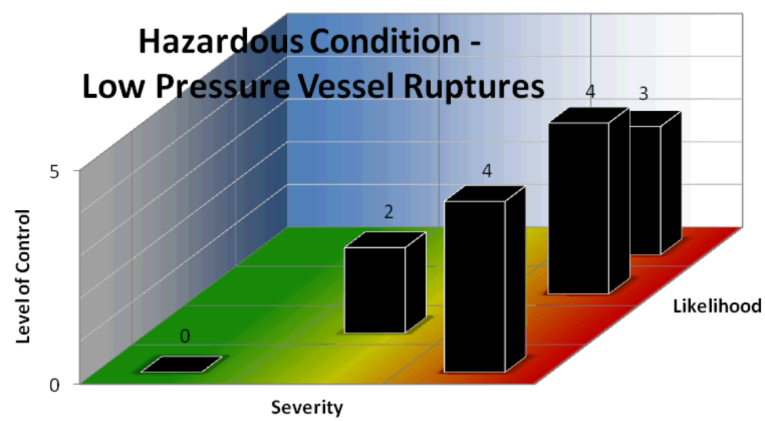
Consequence of Failure Score	Color Coding	Description
1	Dark Green	Insignificant
2	Light Green	Minor
3	Yellow	Moderate
4	Orange	Major
5	Red	Catastrophic

LoF					
5 (Almost Certain)					
4 (Likely)					
3 (Possible)					
2 (Unlikely)					
1 (Rare)					
	1 (Insignificant)	2 (Minor)	3 (Moderate)	4 (Major)	5 (Catastrophic)
	CoF				

RISK MATRIX DEVELOPMENT

- 5x5 risk matrix plotted with 4 different risk zones
  - Red- Very High Risk
  - Orange – High Risk
  - Yellow – Moderate Risk
  - Green – Low Risk
- Risk Matrices developed for different scenarios
  - Pipes in high corrosivity ecological cohorts
  - Serving critical infrastructures
  - Different pipe materials
  - Large and small diameter pipes
- Need to be updated into a 3D Risk Matrix to account for Risk Policy





ECOLOGICAL COHORTS

Water Pipeline Performance, Risk, and Economic Analysis based on Ecological Cohorts

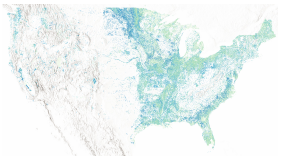
Soil Corrosivity Levels

- Low
- Moderate
- High

Soil Drainage Class

- Excessively Drained
- Somewhat Excessively Drained
- Well Drained
- Moderately Well Drained
- Somewhat Poorly Drained
- Poorly Drained
- Very Poorly Drained
- Subaqueous

Water Table Depth



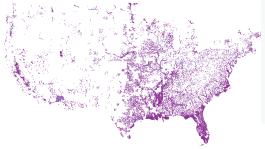
- 0
- 1 - 10cm
- 11 - 30cm
- 31 - 61cm
- 62 - 100cm
- 101 - 200cm
- over 200cm

Proximity to Railway Tracks

100 ft

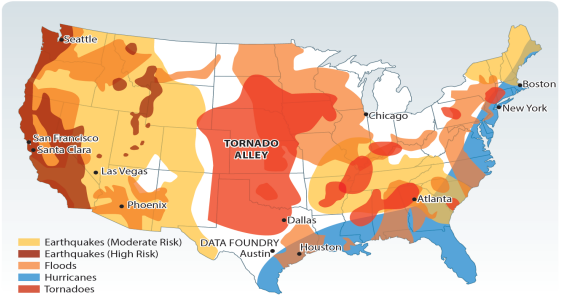
0 ft

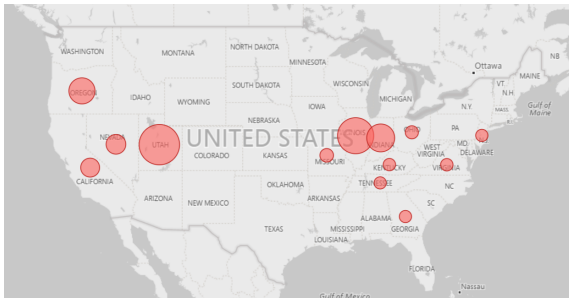
Flood Hazard Impacts



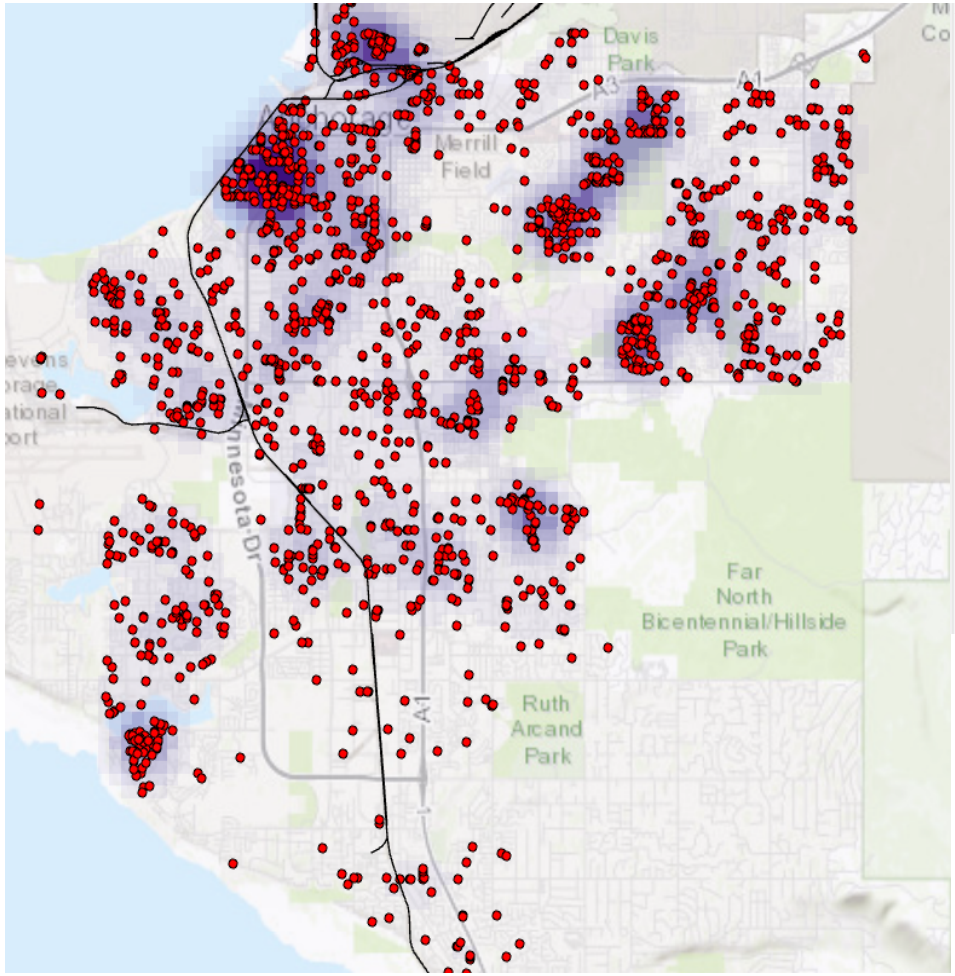
- 1% Annual Chance Flood Hazard
- 0.2% Annual Chance Flood Hazard
- Regulatory Floodway
- Special Floodway
- Future Conditions 1% Annual Chance Flood Hazard
- Area with Reduced Risk Due to Levee

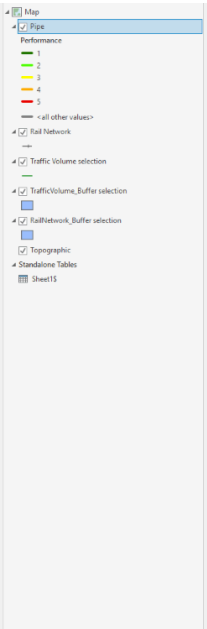
WATER PIPELINE SYSTEMS

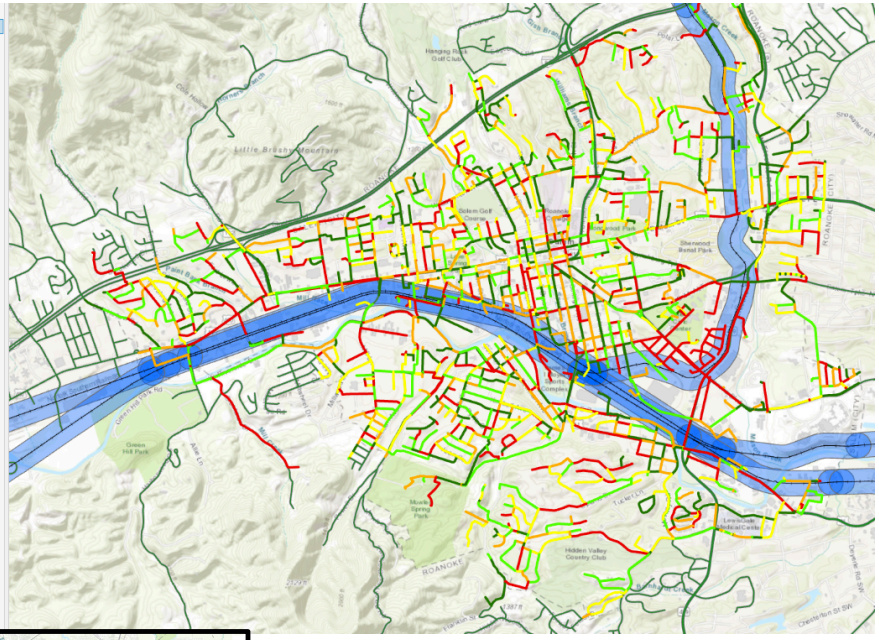


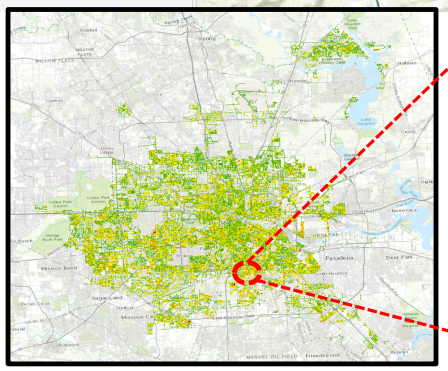


Spatial and Temporal Analysis

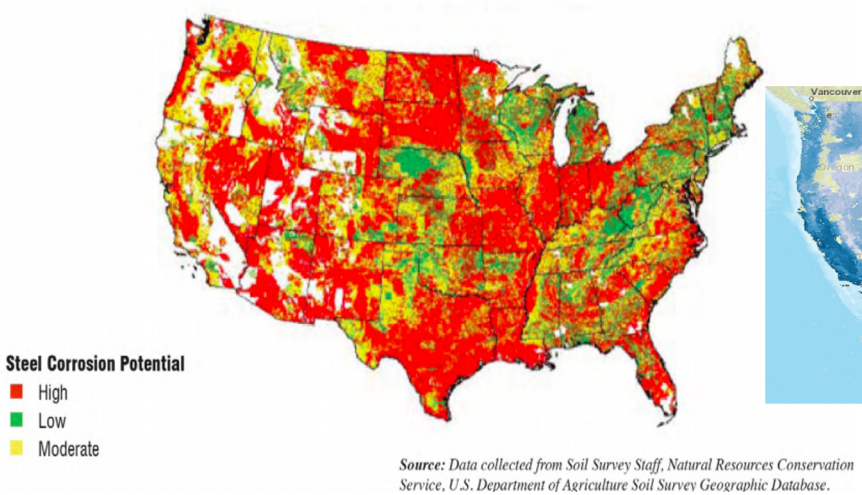




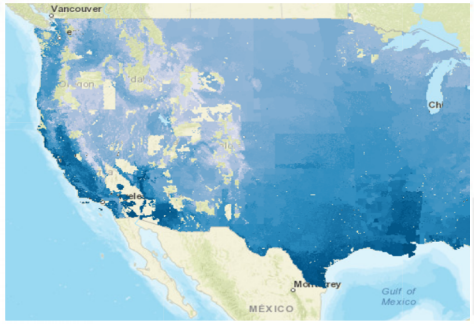


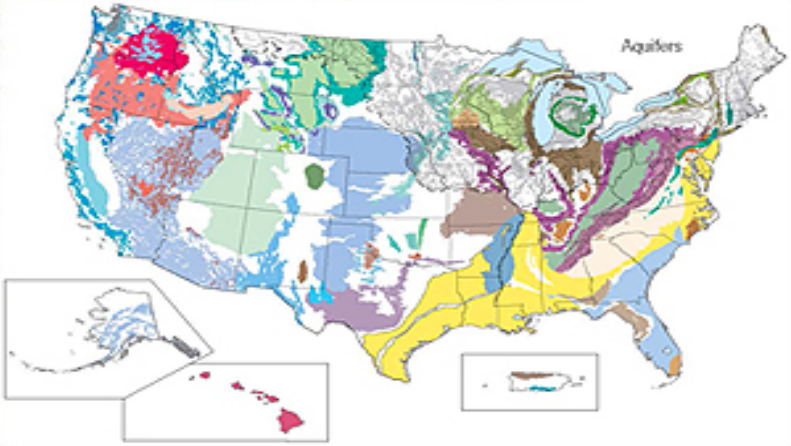


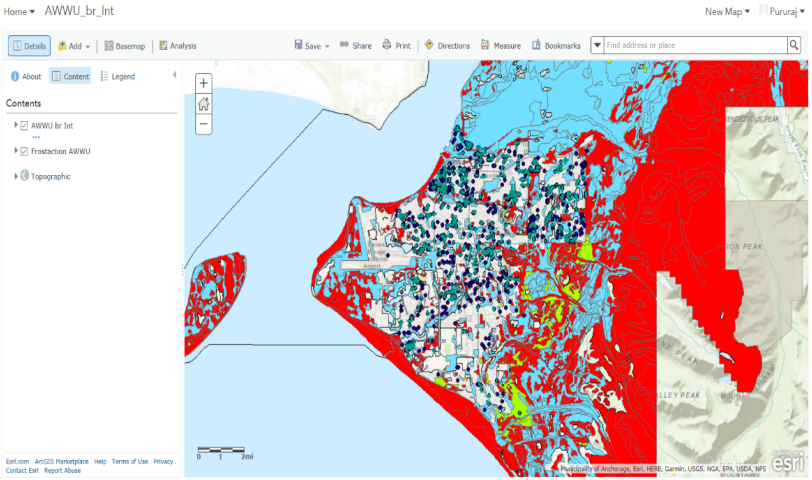
NATIONAL WATER PIPELINE PERFORMANCE



Source: Data collected from Soil Survey Staff, Natural Resources Conservation Service, U.S. Department of Agriculture Soil Survey Geographic Database.







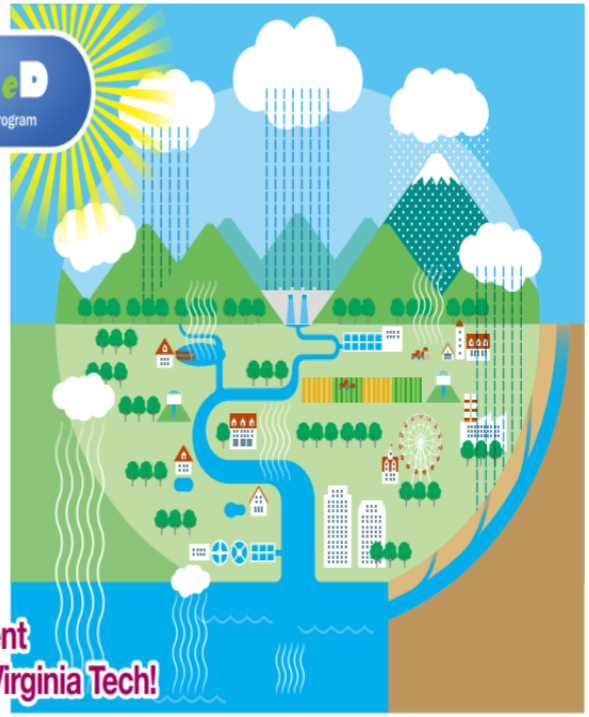
ALEXA FOR WATER SERVICES

30

SWIM Center Education & Outreach

SWIM
Sustainable Water Infrastructure Management

SWIMeD
SWIM education Program



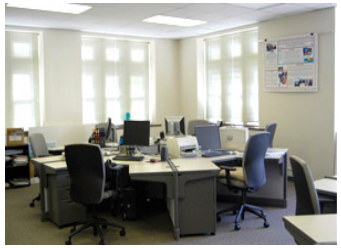
Excel in Your Professional Career! Learn the Latest Topics in Water Sector Asset Management.

The Sustainable Water Infrastructure Management (SWIM) Center at Virginia Tech offers an education program in Water Infrastructure Asset Management titled SWIMeD. The aim of the SWIMeD program is to broaden and deepen the body of knowledge for practicing drinking water, wastewater, and stormwater professionals.

Plus – Earn Your Asset Management Certificate and CEUs/PDHs from Virginia Tech!

BALLSTON ROOM

EAST/WEST FALLS CHURCH ROOM



CSIRO

MONASH University

Canada NRC·CNRC

UNIVERSITY OF WATERLOO

European Commission

SINTEF

UNIVERSITY OF BIRMINGHAM

GIAN
GLOBAL INITIATIVE OF ACADEMIC NETWORKS

Ministry of Human Resource Development
Government of India

सत्यमेव जयते

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

CONACYT
Consejo Nacional de Ciencia y Tecnología

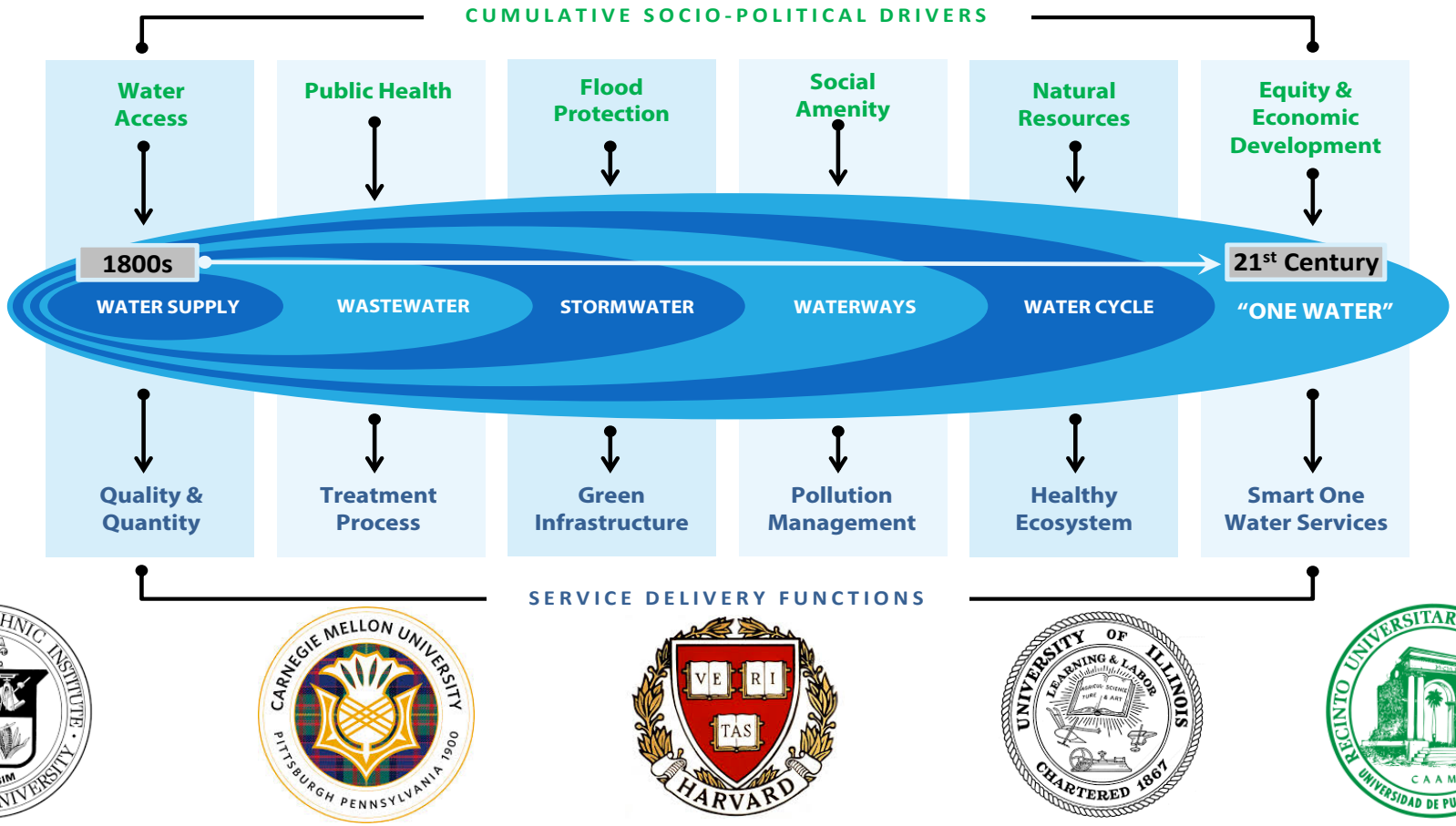
UNIVERSIDAD DE GUANAJUATO

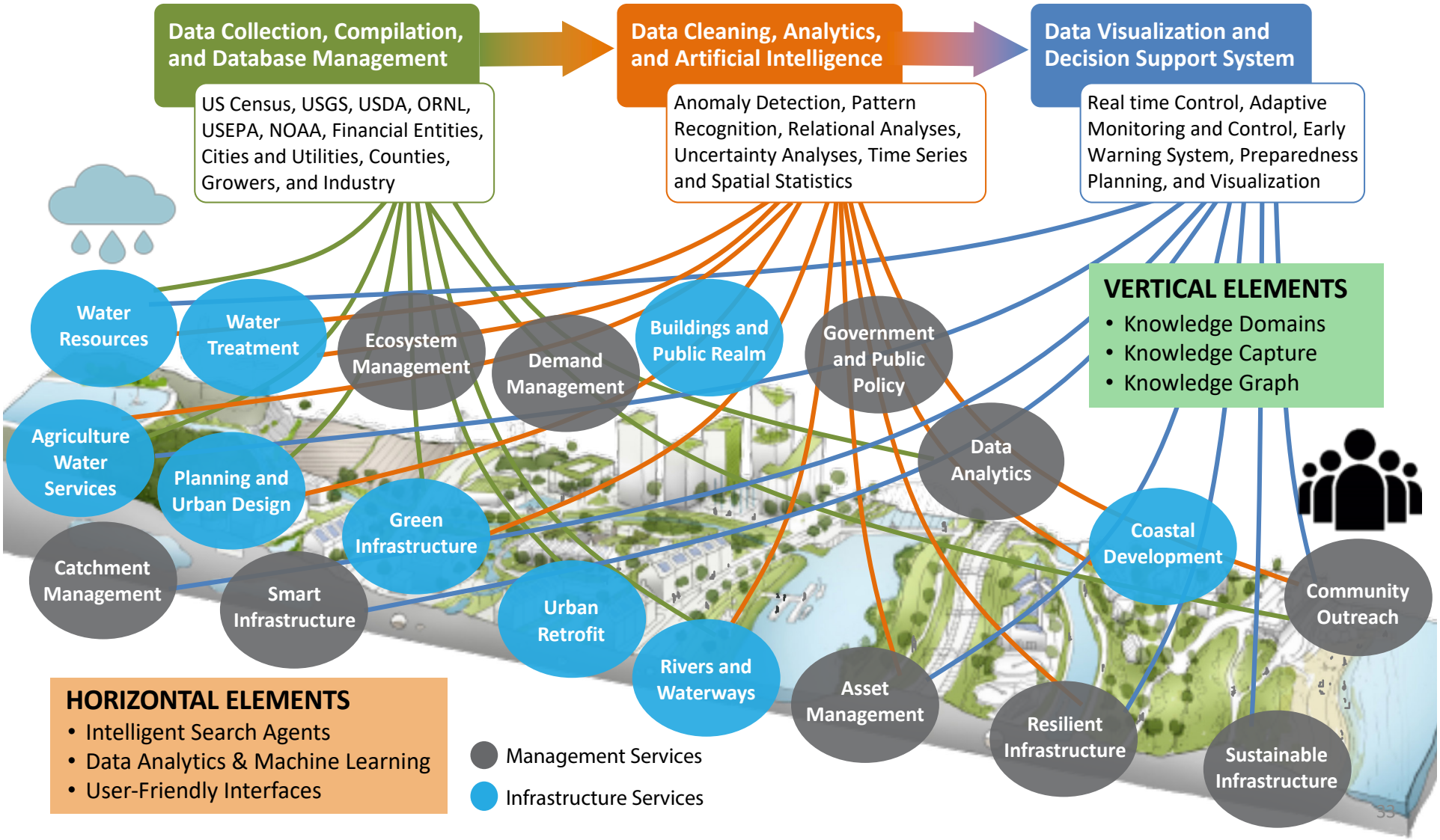
NSF-ERC SMART ONE WATER (S0W)

Siloed, heterogenous, and rigid infrastructure and institutions. Priority given to controlling environmental variation through stable operation and reactive response.

TRANSFORMATION

Integrated, homogenous, and flexible infrastructure and institutions. Priority given to maintaining resilience through adaptability and affordability.




Data Collection, Compilation, and Database Management
US Census, USGS, USDA, ORNL, USEPA, NOAA, Financial Entities, Cities and Utilities, Counties, Growers, and Industry
Data Cleaning, Analytics, and Artificial Intelligence
Anomaly Detection, Pattern Recognition, Relational Analyses, Uncertainty Analyses, Time Series and Spatial Statistics
Data Visualization and Decision Support System
Real time Control, Adaptive Monitoring and Control, Early Warning System, Preparedness Planning, and Visualization
VERTICAL ELEMENTS
• Knowledge Domains
• Knowledge Capture
• Knowledge Graph
Water Resources
Water Treatment
Ecosystem Management
Demand Management
Buildings and Public Realm
Government and Public Policy
Agriculture Water Services
Planning and Urban Design
Green Infrastructure
Data Analytics
Coastal Development
Catchment Management
Smart Infrastructure
Urban Retrofit
Rivers and Waterways
Asset Management
Resilient Infrastructure
Sustainable Infrastructure
Community Outreach
HORIZONTAL ELEMENTS
• Intelligent Search Agents
• Data Analytics & Machine Learning
• User-Friendly Interfaces
Management Services
Infrastructure Services

Grand Challenges for Water Research and Education

Recent floods, droughts, fires, tsunamis, tornadoes, earthquakes, and aging infrastructure remind us that natural, technological, and human-caused hazards take a high toll on communities. Costs in lives, livelihoods, and quality of life can be reduced by better managing risks through advanced water infrastructure systems planning, design, construction, operation, management, and renewal.

"How a nation built, operate, maintain, retrofit, and expand its water infrastructure systems will help determine the quality of life for future generations and that nation's competitiveness in the global economy."

We are now largely presumed to be living with the emergent fourth industrial revolution that is fusing our physical, digital, environmental, ecological, and societal experiences with an unprecedented pace of change and by integrating transdisciplinary research and education.

It will require use of "SYSTEM OF SYSTEMS APPROACH" & "BIG DATA ANALYTICS"

Thank You!!

ssinha@vt.edu; 540-231-9420

Sustainable Water Infrastructure Management

VIRGINIA TECH

NSF-ERC

Smart One Water

WATER infrastructure DATABASE

PIPELINE infrastructure DATABASE

SWIM education Program