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Forecasting the Future for Columbus Water Distribution Using Advanced Statistical Tools

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Agenda

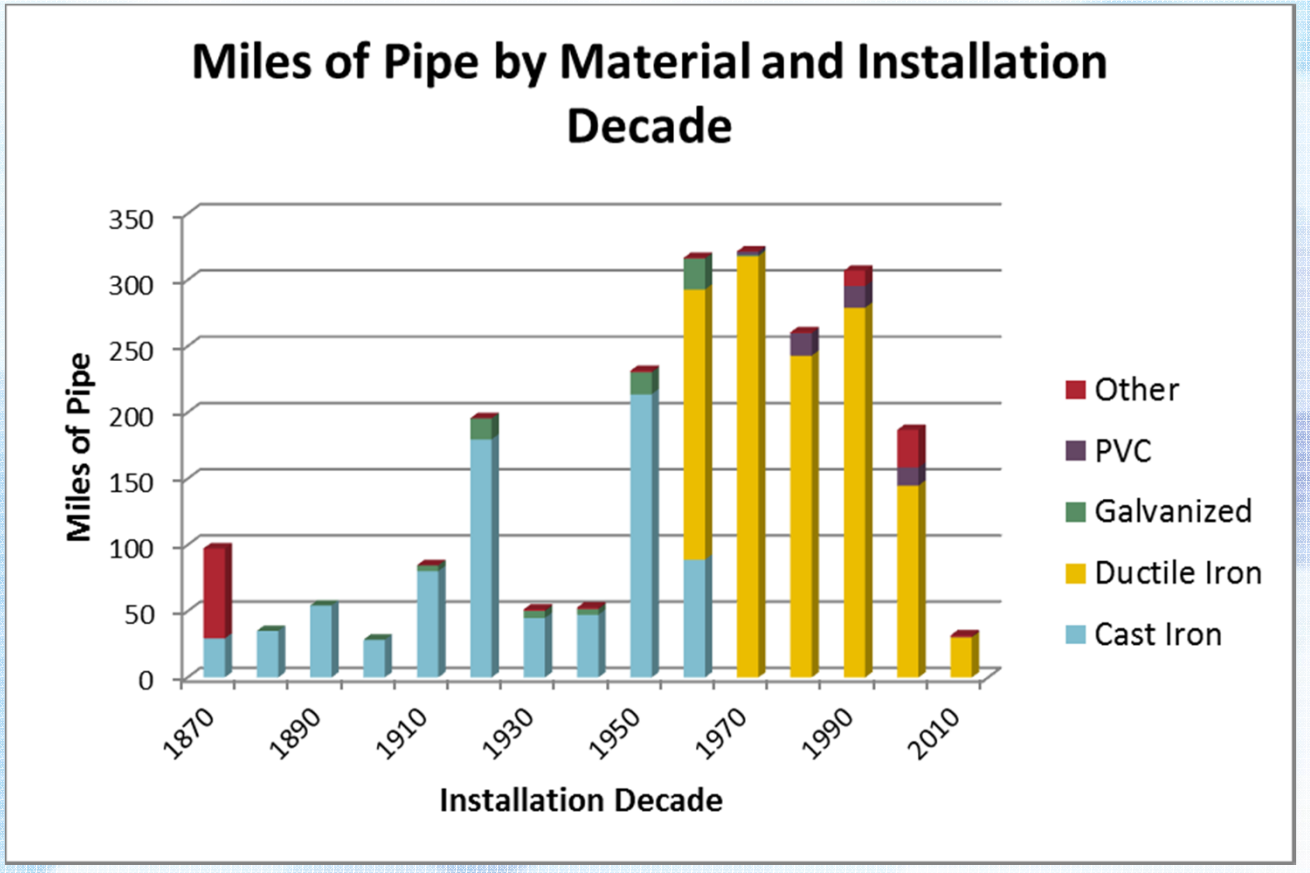
- About Columbus Division of Water
- Risk-Based Replacement Planning
- Initial Planning (2009)
- Updated Planning (2013)
- Outcomes and Comparison

About the Columbus, OH Division of Water

Columbus, OH Water Distribution System

- **Water System:**
  - 3,500 miles
  - 140 to 210 max MGD
- **Challenges:**
  - Maintain system performance
  - Identify the right water mains for replacement
  - Quantify long-term investment

Water Distribution System Characteristics Pipes <=16-inch



- 2,269 Miles
- Materials:
  - DIP = 54%
  - CIP = 36%
  - PVC, Galv. = 5%
  - Other = 5%
- 65% = 8-10 inch
- 73% post 1950

Project Timeline

- 2008 - Kickoff Water Master Plan Including Risk-Based Replacement Planning
- 2009 - Produce 50-Year Replacement Forecast and Near-Term Projects Over 5 Years
- 2010 - Recommendations for Improved Data Management
- 2013 - Enhanced Planning with More Data and LEYP Analysis

Risk-Based Replacement Planning

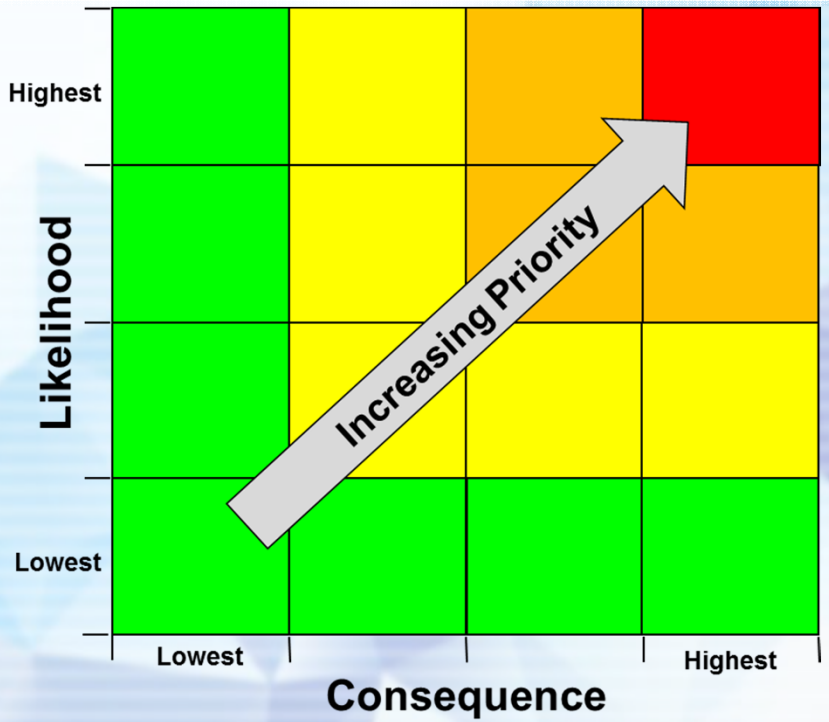
Risk-Based Planning

- Balance Limited Funds and the Long List of Capital Improvements

Funds

Needs

Risk = Likelihood of Failure * Consequence of Failure



Consequence of Failure

- Triple Bottom Line (TBL) Analysis

Likelihood of Failure

- Structural Behavior
  - Break Rate Captured from Work Orders
  - Breaks per 100 miles per Year
- Performance
  - Hydraulic Model Results
  - Pipes Causing Low Fire Flow

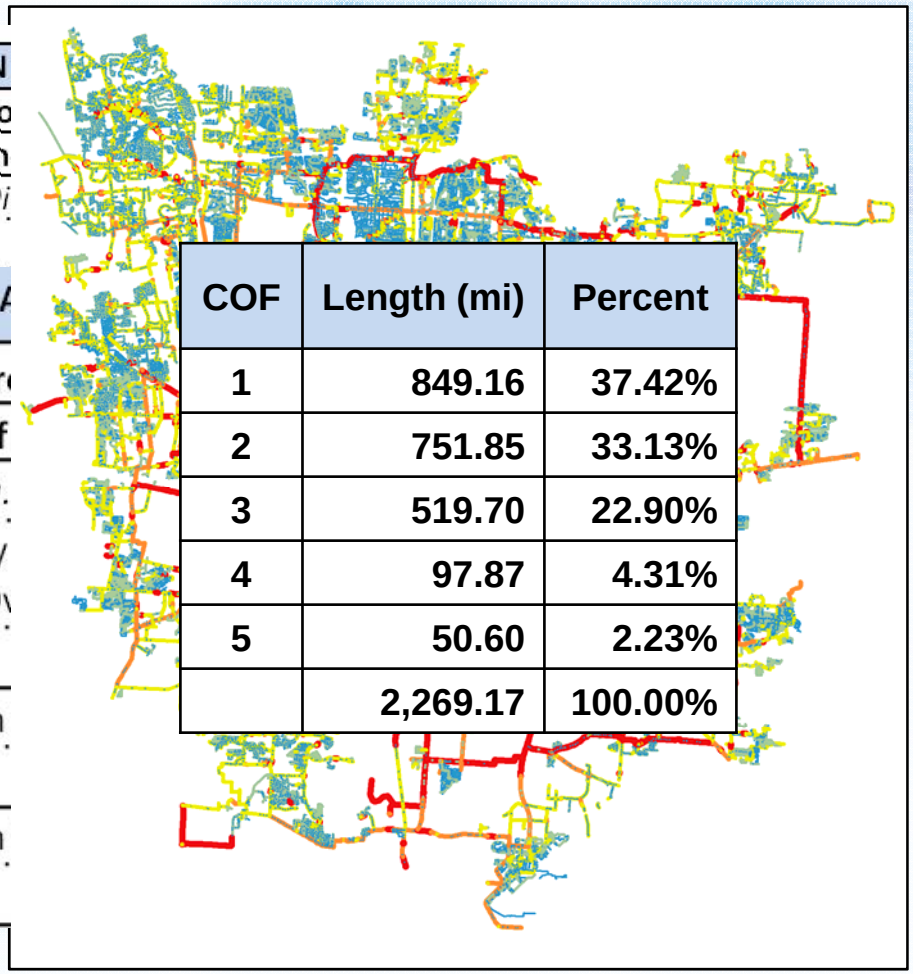
Initial Replacement Planning 2009

Triple Bottom Line Evaluation For Consequence of Failure Using GIS

CUSTOMER CRITICALITY CRITERIA - BASED ON			
Service to Customer Type	Score=5	Score=4	Sco
	Adj. & Dia.	*Adj.*	*A*
Top 20 Users	Mains on property		

PIPE CRITICALITY By DIAMETER

ADJACENCY CRITICALITY CRITERIA - BA			
Adjacency to	Score=5		Scor
			Miles of
	Adj. & Dia.	*Adj.*	*Adj. & Dia.*
Critical Users	Railways	Intersecting	Relatively ROW/Ov
		20.762	16.091	2.479
Healthcare Facilities	Water Bodies	Intersecting	w/in
		36.600	29.103	45.549
	Interstates	Intersecting	w/in
		23.457	20.760	5.410

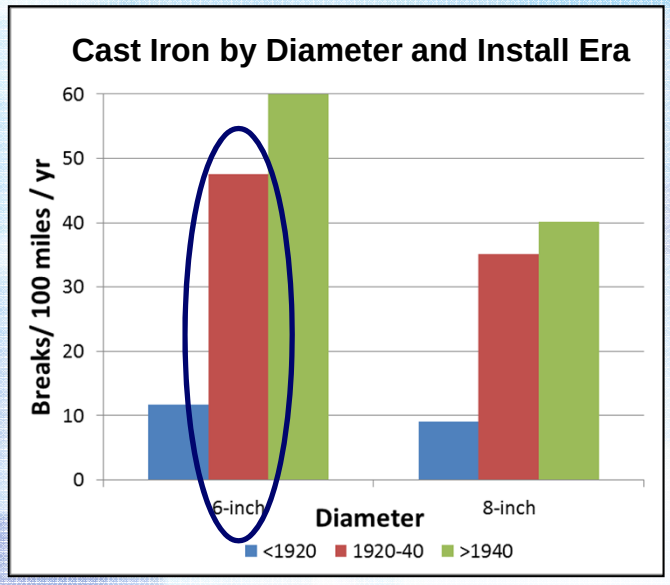


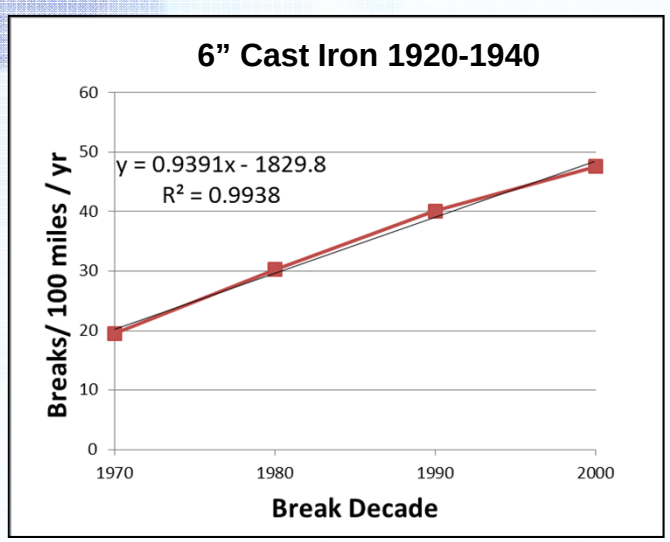
COF	Length (mi)	Percent
1	849.16	37.42%
2	751.85	33.13%
3	519.70	22.90%
4	97.87	4.31%
5	50.60	2.23%
	2,269.17	100.00%

Likelihood of Failure - Cohort Aging Curves Break History Regression Analysis

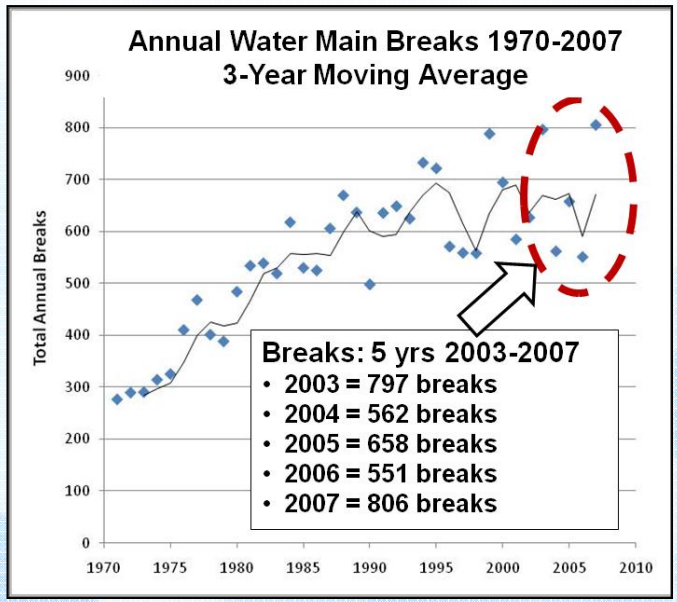
- 30 Years of Break History
- One Aging Curve per Cohort

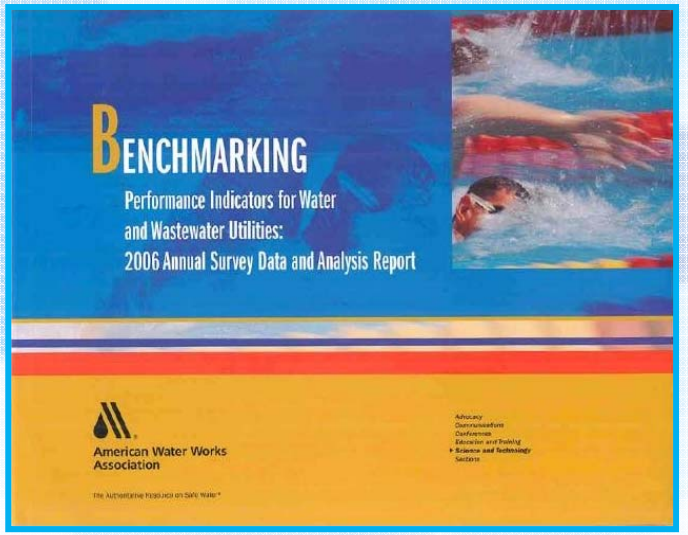
Material	Miles	Percent
Cast Iron Pre 1920	239	10.53%
Cast Iron 1920-1940 < 4”	8	0.33%
Cast Iron 1920-1940 6”	112	4.95%
Cast Iron 1920-1940 8”	70	3.06%
Cast Iron 1920-1940 10”-16”	36	1.59%
Cast Iron Post 1940 < 4”	3	0.12%
Cast Iron Post 1940 6”	150	6.62%
Cast Iron Post 1940 8”	162	7.13%
Cast Iron Post 1940 10”-16”	36	1.59%
Ductile Iron Unwrapped	1,044	46.00%
Ductile Iron Wrapped	175	7.72%
Galvanized	71	3.13%
Other	72	3.20%
PVC	91	4.02%
	2,269	100.01%





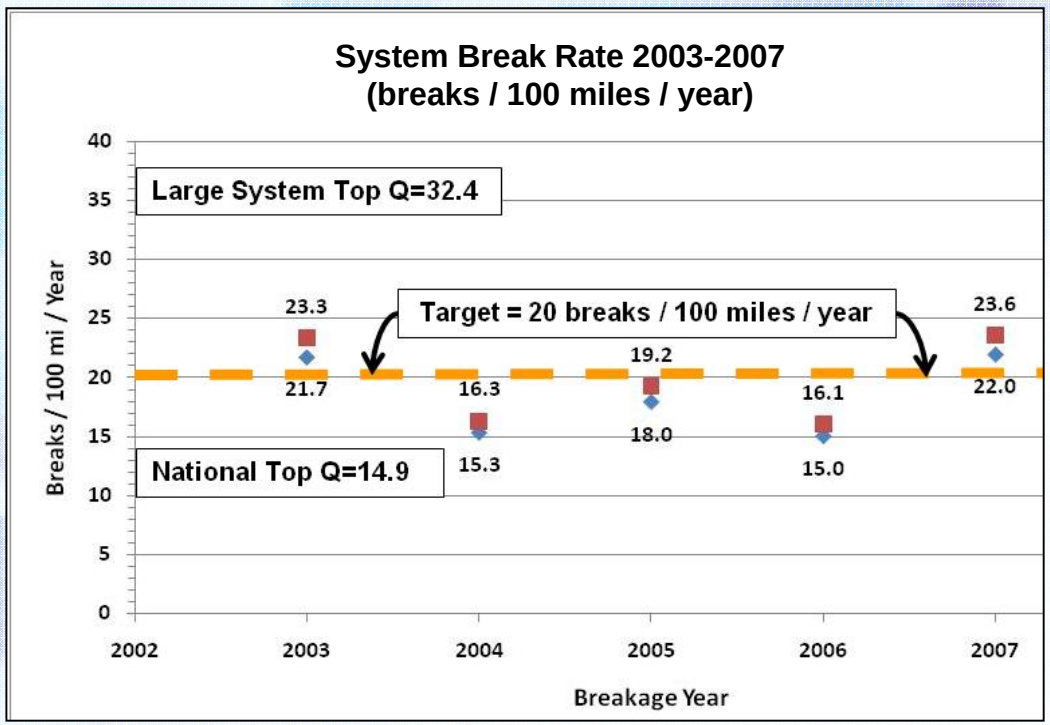
Benchmarking To Establish System Wide Break Rate Service Level





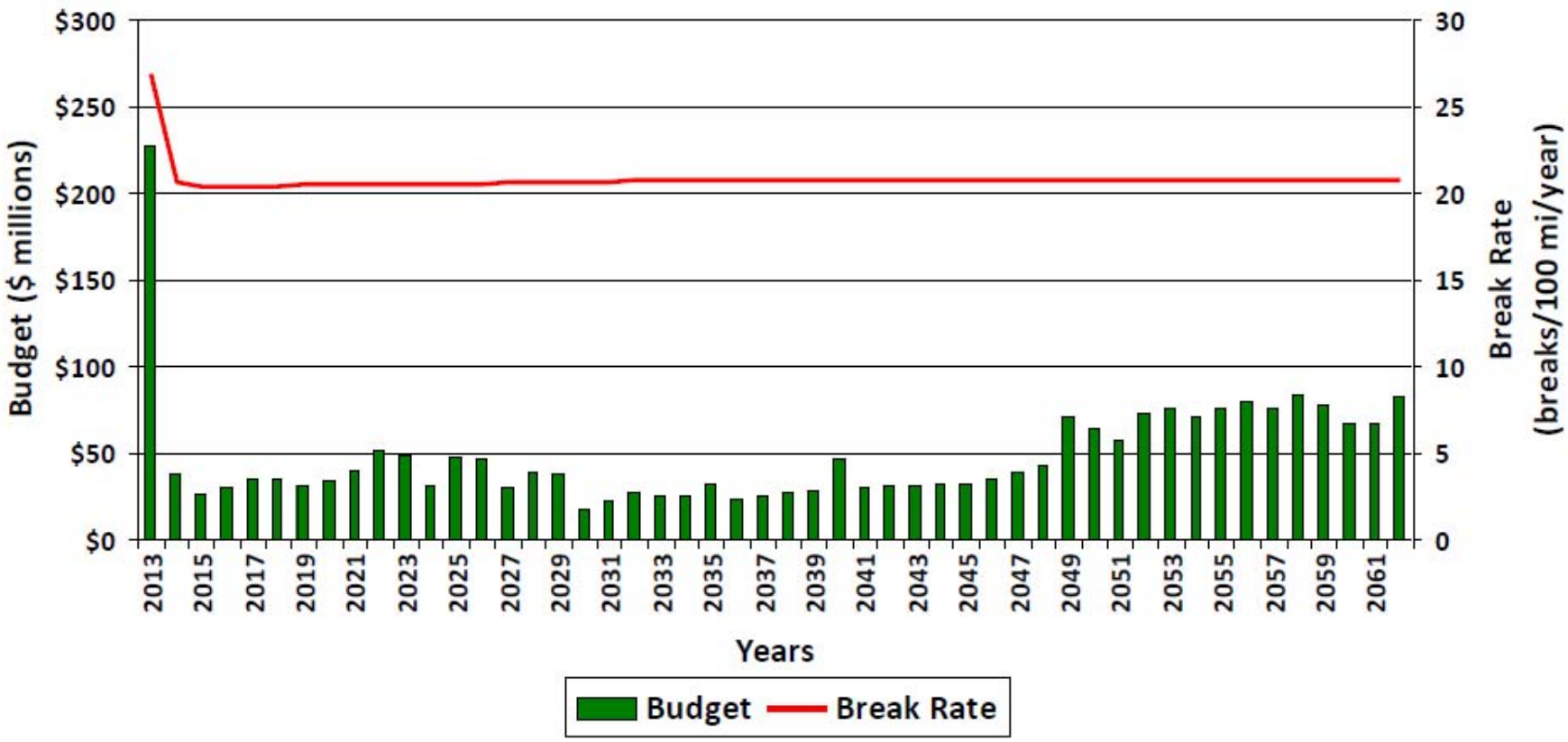
Service Level

20 Breaks / 100 miles / Year



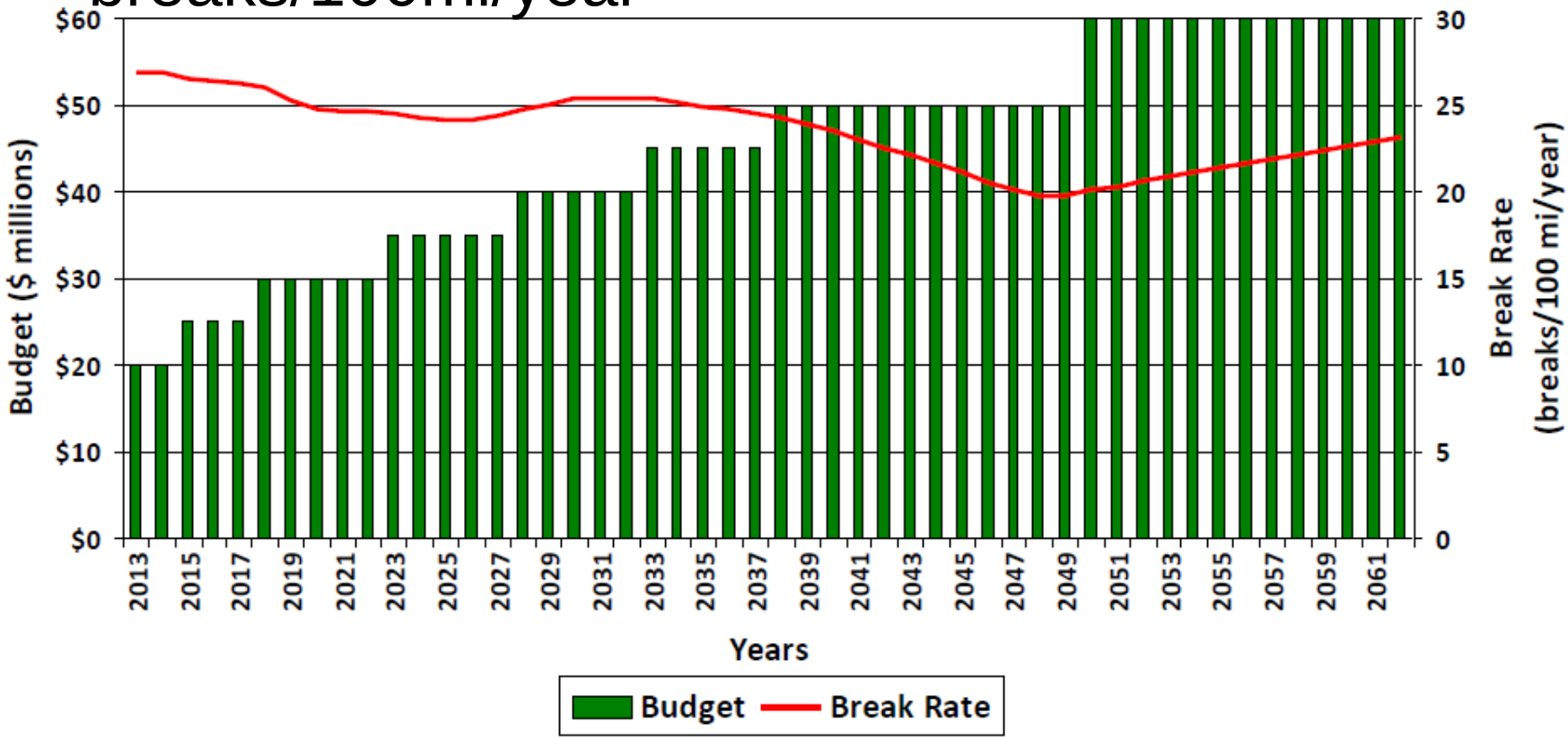
2009 Cohort Regression Analysis
50-Year Unlimited Budget

- Initial backlog of $227M
- Break Rate from 27 to 20 breaks/100mi/year

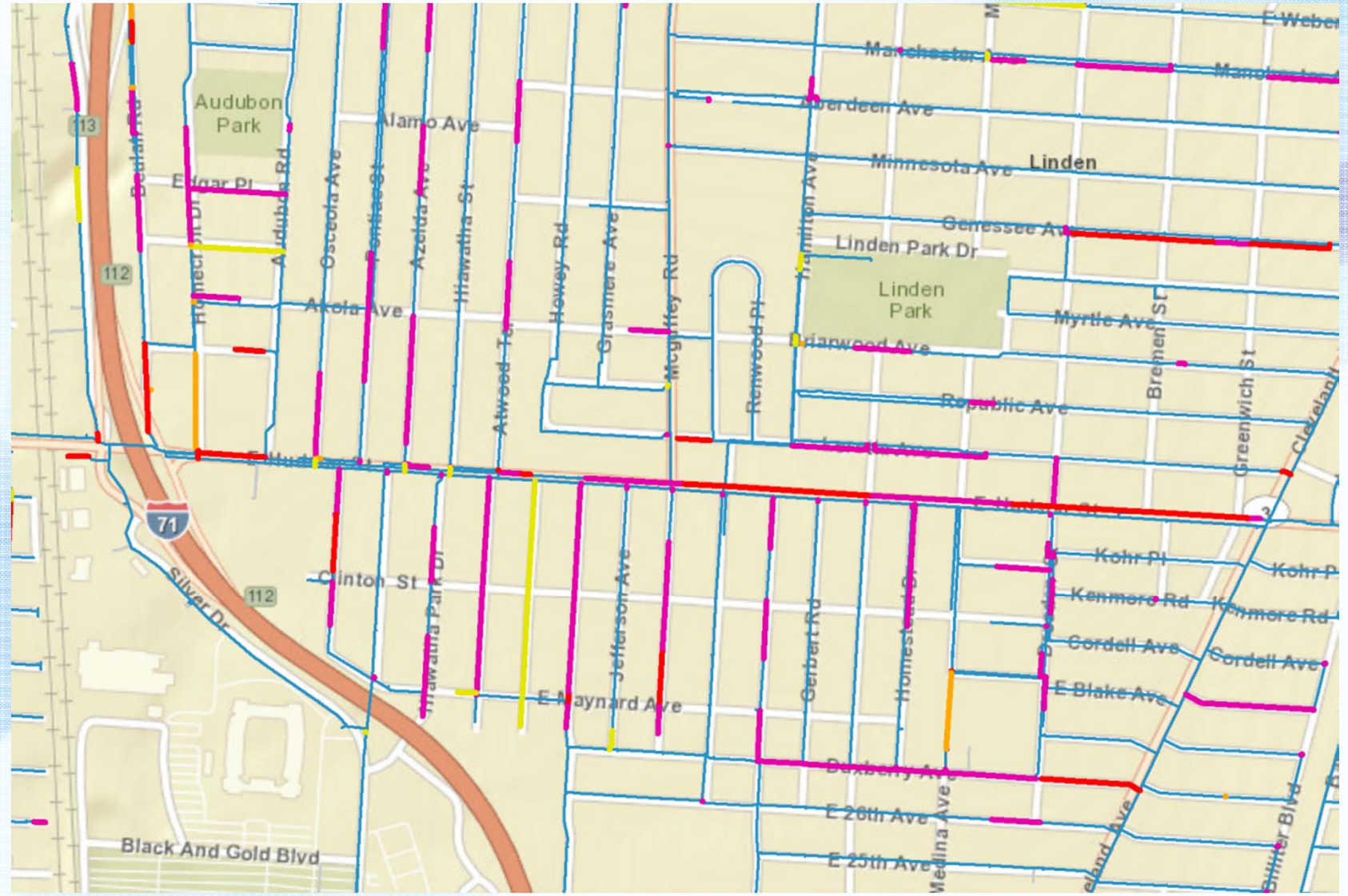


2009 Cohort Regression Analysis
50-Year Ramp up to $60M Budget

- Ramp up from $20M/year to $60M/year
- Break Rate from 27 to low of 20 breaks/100mi/year



GIS Selects “Right” Projects To Match Annual Budget And Goals



Initial Analysis Recommendations

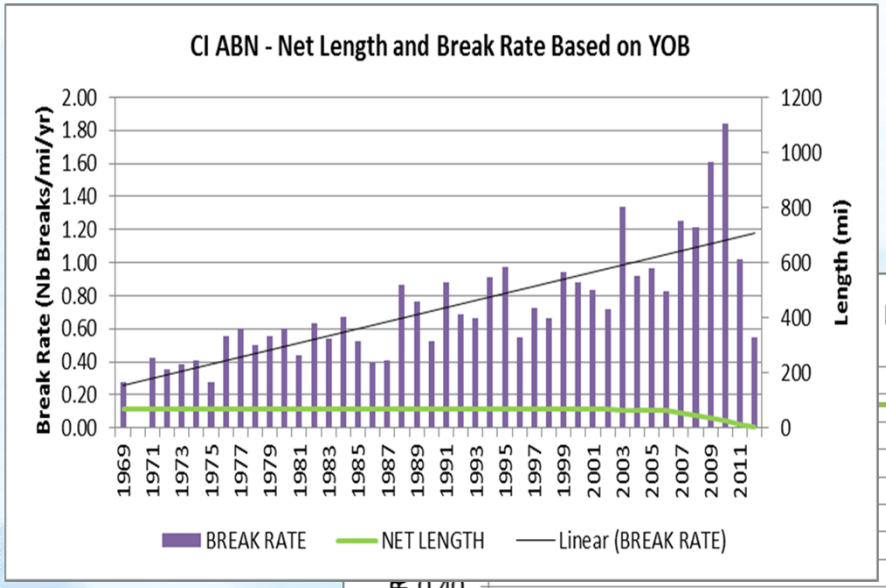
- Planned investment increase to $30M is adequate for immediate needs
- Enhance initial cohorts analysis with pipe level detailed statistical analysis
- Assign breaks to pipes instead of addresses
- Maintain history of removed and abandoned pipes

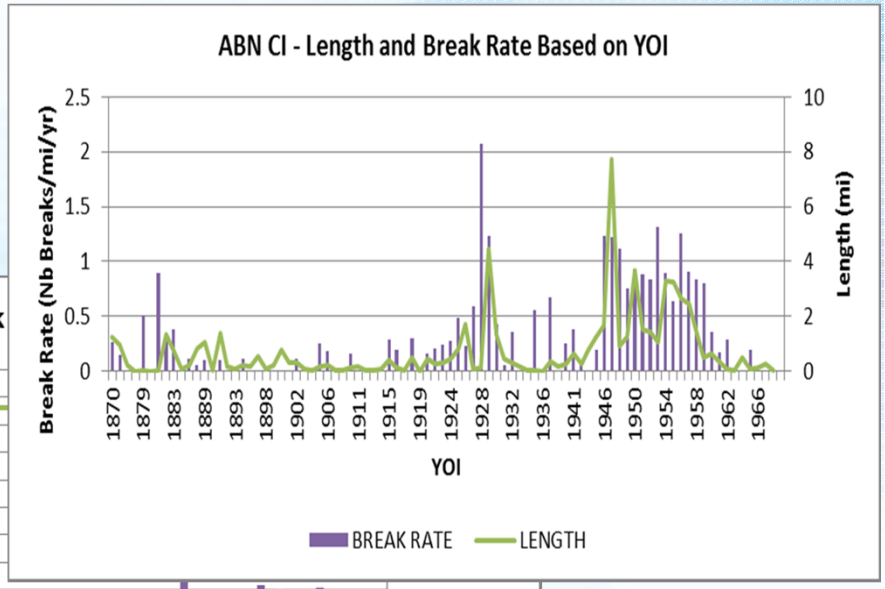
Updated Replacement Planning Using LEYP 2013

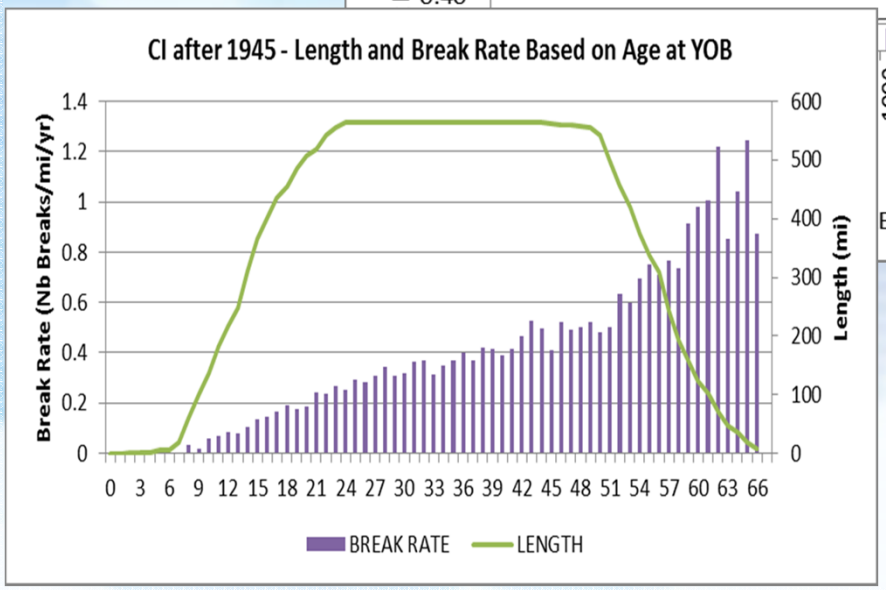
Failure Forecasting Model
Linear Extended Yule Process (LEYP)

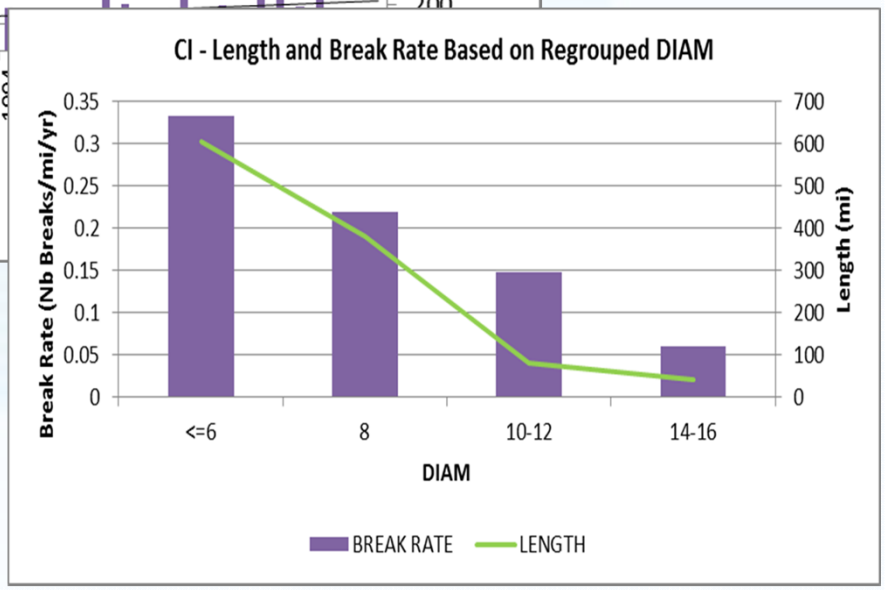
- Multi-variable regression model
- Predicts break numbers for each pipe in future
- Advantage: Takes all factors into account *simultaneously,* even pipes that never broke (90%?)
- Data Requirement:
  - Risk factors must be assigned to all pipes
  - Ideally pipes and break history must be available for all pipes (Active and Abandoned)
  - Breaks assigned to pipes – 5 years minimum
- Data must be cleaned up (50-75% of effort for first LEYP study)
- Preliminary statistical analysis is needed to calibrate model

Preliminary Statistical Analysis









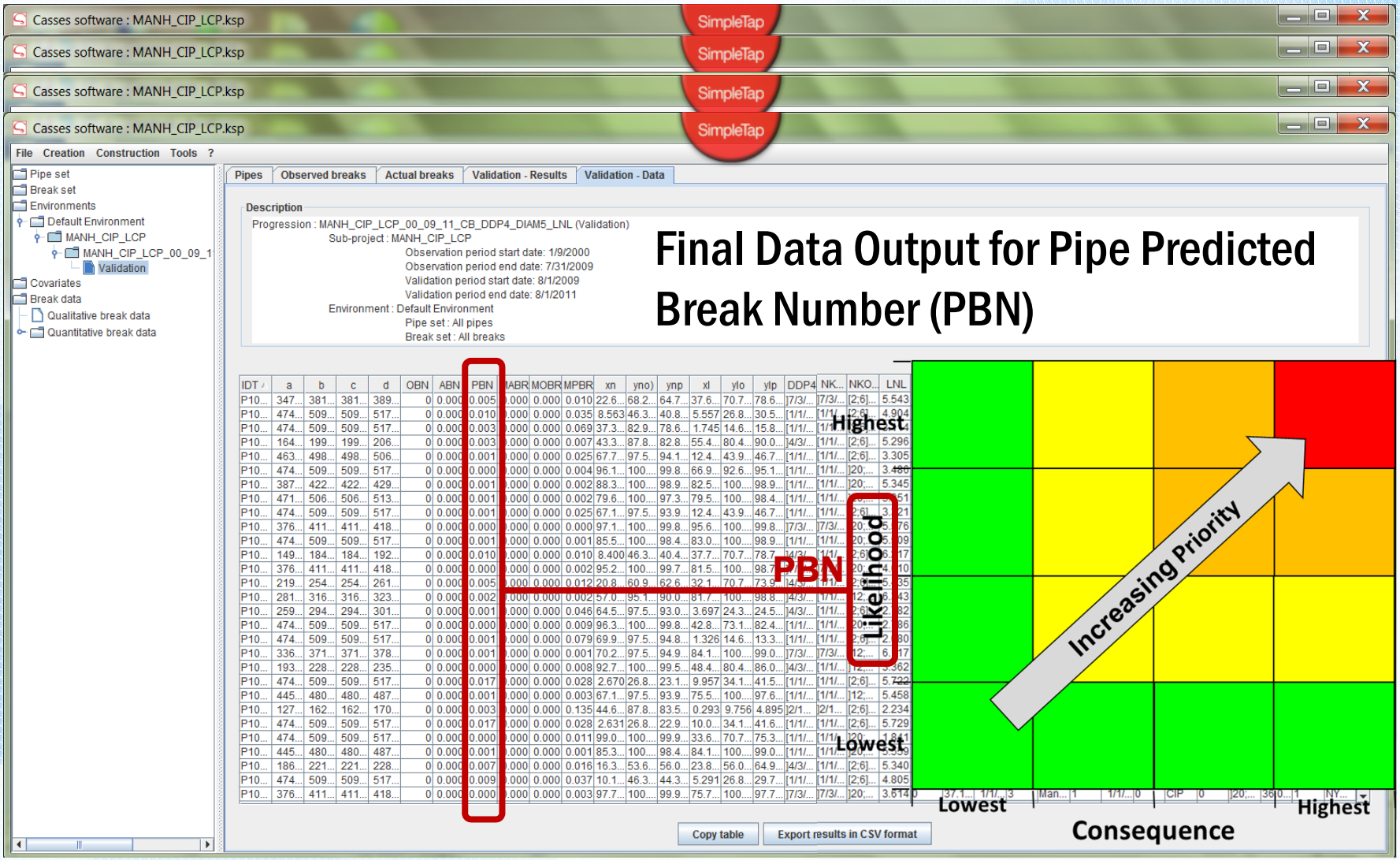
Failure Forecasting Model

$$\underbrace{\delta t^{\delta-1}}_{\text{Weibull Factor}} \quad \underbrace{(1+\alpha j)}_{\text{Yule Factor}} \quad \underbrace{\exp(Z^T\beta)}_{\text{Cox Factor}}$$

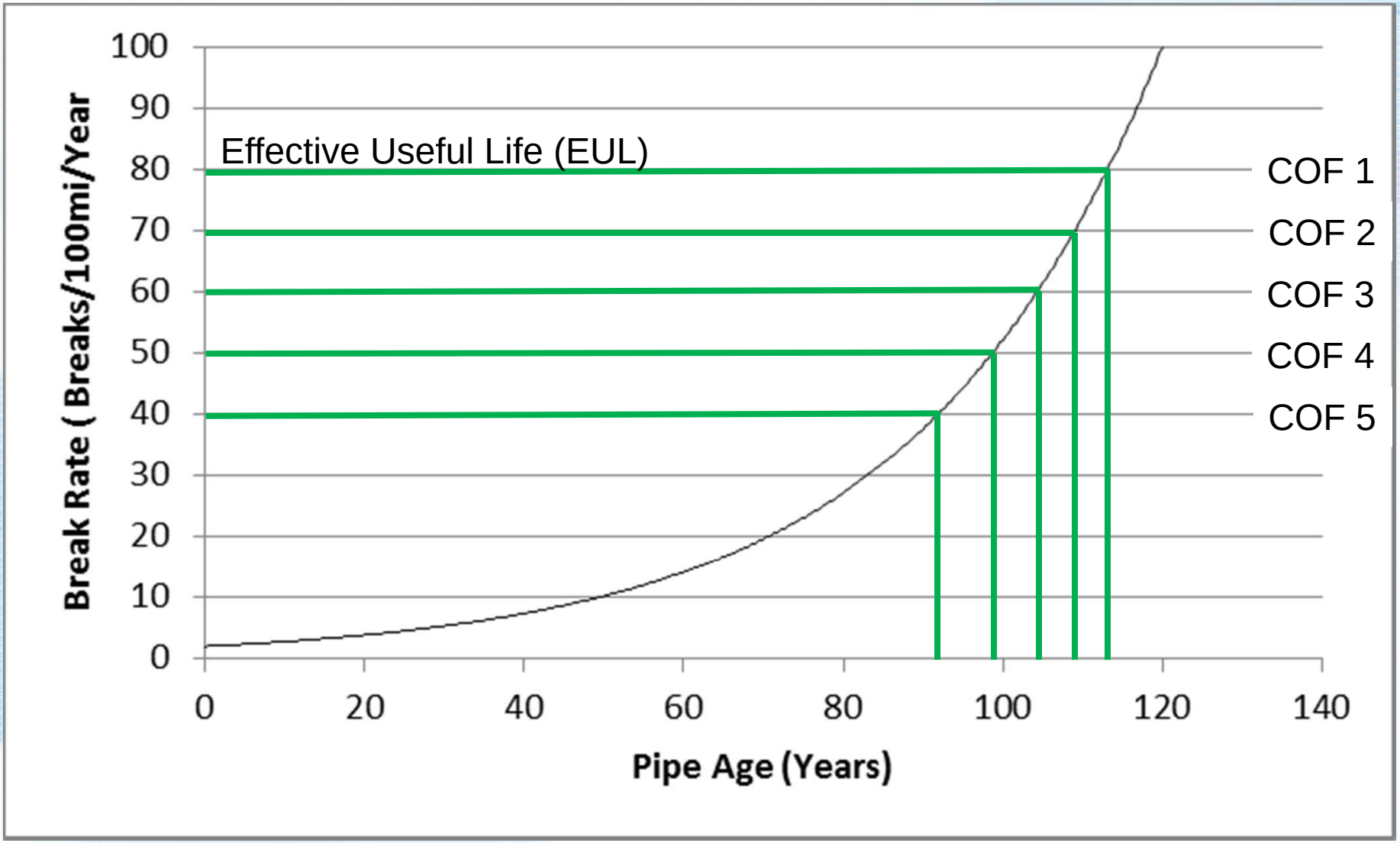
Aging (time) → **Break History** → **Risk Factors**

Predicted Break Number (PBN - likelihood of failure)
for every water main and for each year

The CASSES Software

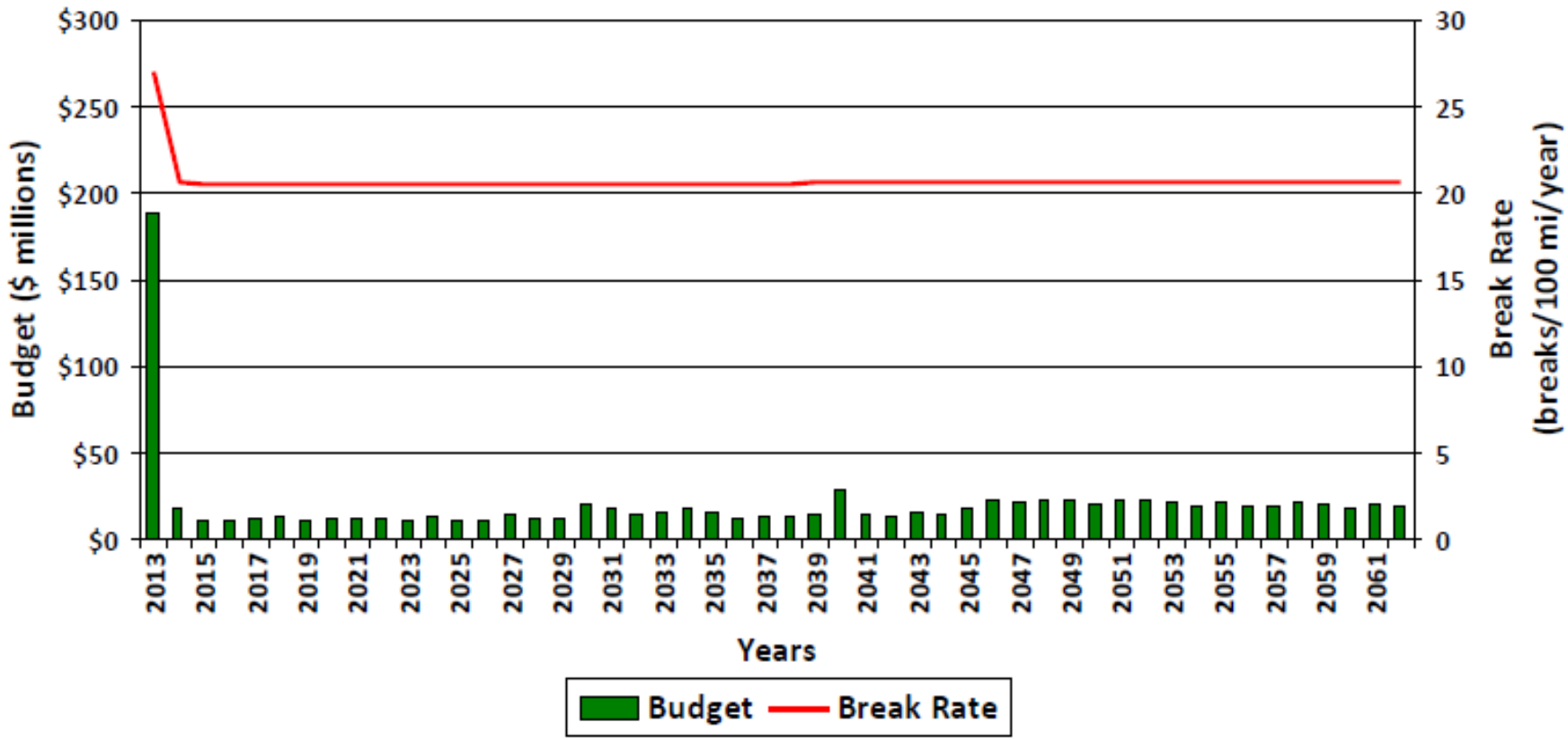


When to Replace
COF Related to Aging Curve



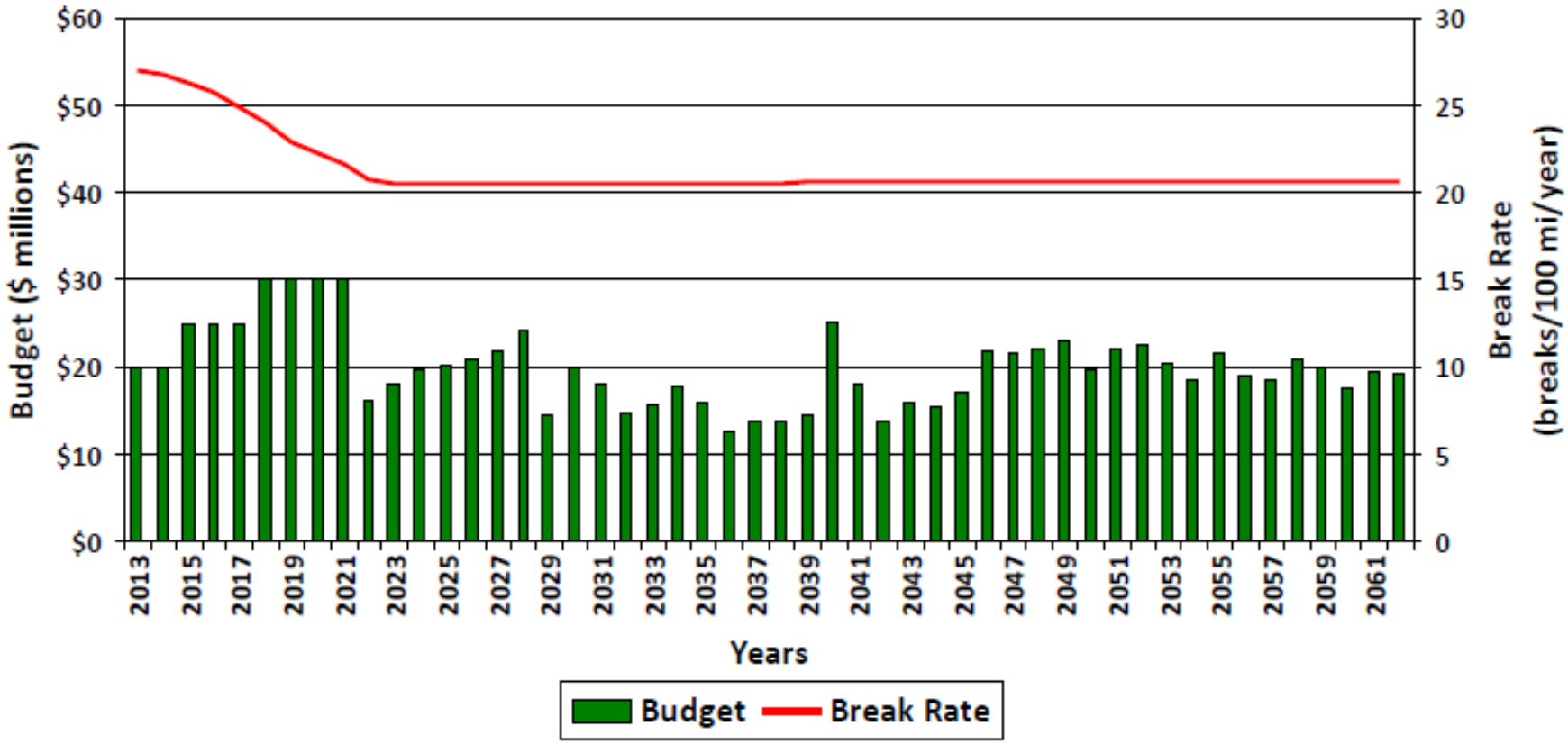
2013 LEYP Analysis
50-Year Unlimited Budget

- Initial backlog of $189M
- Break Rate from 27 to 20 breaks/100mi/year



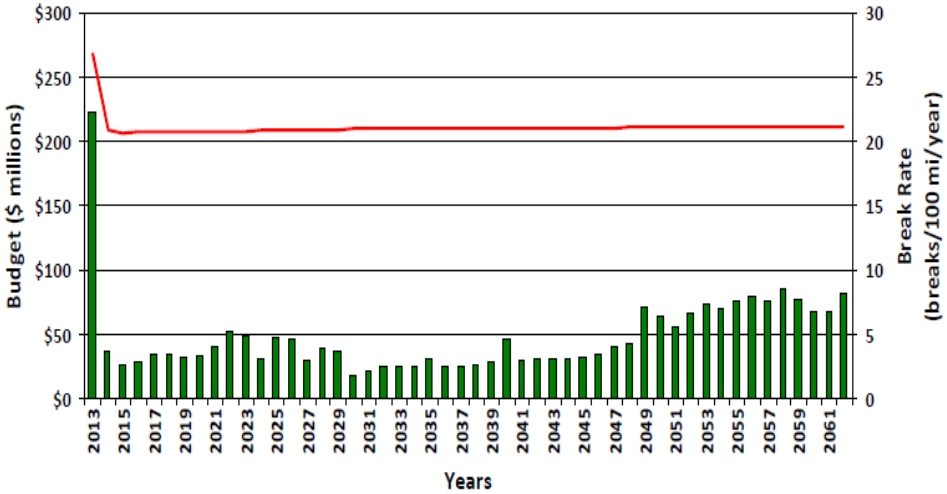
2013 LEYP Analysis
50-Year Ramp up to $30M Budget

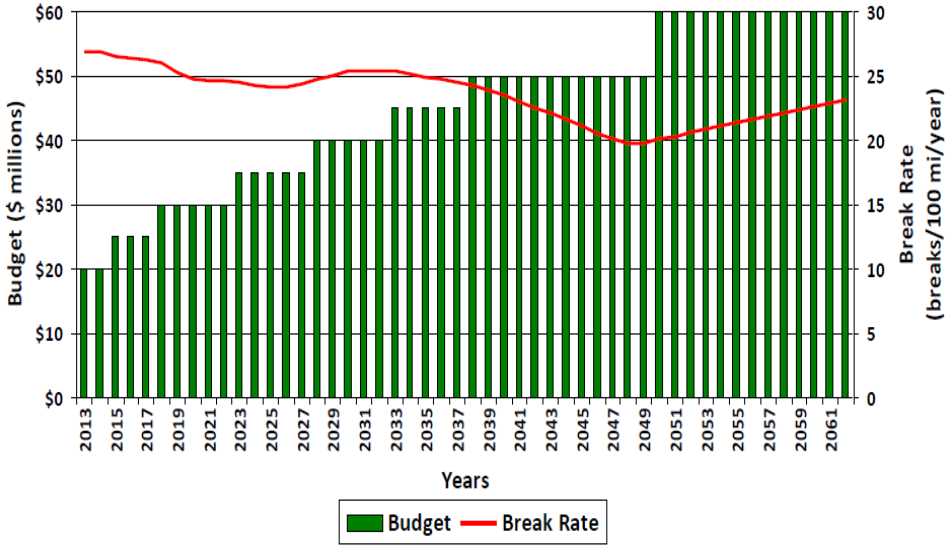
- Ramp up from $20M/year to $30M/year
- Break Rate from 27 to 20 breaks/100mi/year



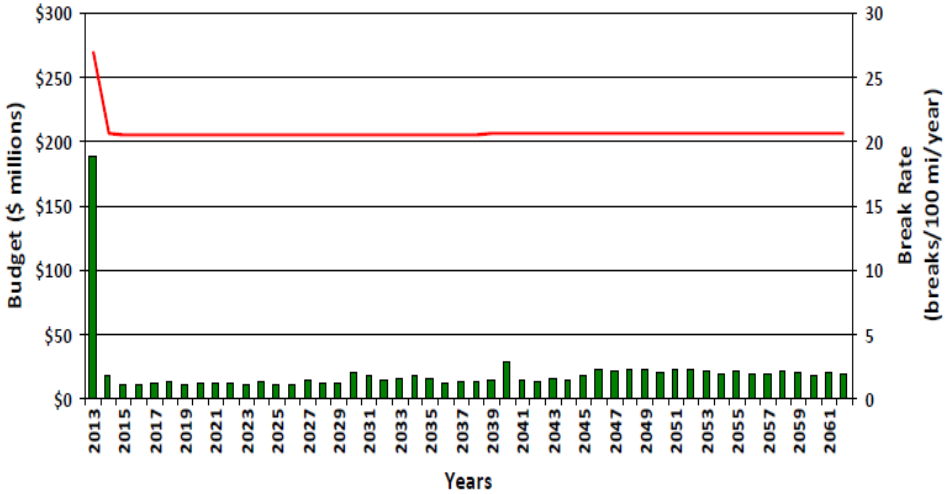
Comparison

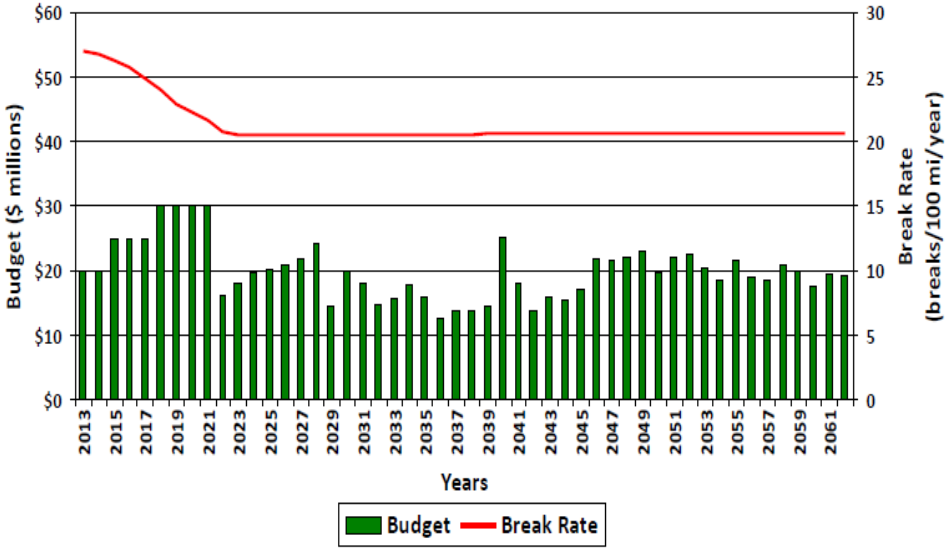
2009





2013





Columbus Outcomes

- LEYP targets poor performing pipes
- GIS provides clearly defined projects
- Planning approach improved coordination with road paving
- Backlog reduced through risk-based prioritization

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Questions?

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