Economic Model for Performance Standards: Data, Methods, and Assumptions

Ellen Bruno, Katrina Jessoe, Frank Loge, Amanda Rupiper, Joakim Weill

Preliminary draft of economic model: subject to change

June 7, 2019

Agricultural & Resource Economics UC DAVIS
UC DAVIS Center for Water-Energy Efficiency
Berkeley University of California College of Natural Resources
DEPARTMENT OF AGRICULTURAL & RESOURCE ECONOMICS

Introduction: Economic Framework

What amount of water loss reduction is efficient for each individual urban retailer?

- Answer involves estimation of both benefits and costs and how they accrue over time.
- Goal: Reach water loss recovery targets where net benefits are greatest.

Outline

Economic Model

- Benefits Overview
- Costs Overview
- Assumptions
- Determining performance standards

Benefits Estimation

- Illustration
- Components and assumptions
- Calculation for hypothetical utility

Costs Estimation

- Illustration
- Components and assumptions
- Calculation for specific utility

Data Needs and Gaps

- Benefits
- Costs

Benefits Estimation: Big Picture

Steps to estimating benefits:

1. Catalogue all potential benefits associated with reduction in losses
2. Quantify each benefit in monetary terms
   - Will vary by utility (population density, property values, etc.)
   - Will likely change over time
3. Estimate how benefits change with level of water loss reduction

Benefits Estimation: Time Horizon

Benefits will be estimated over both short-run and medium-run horizons.

Short run: 5 years

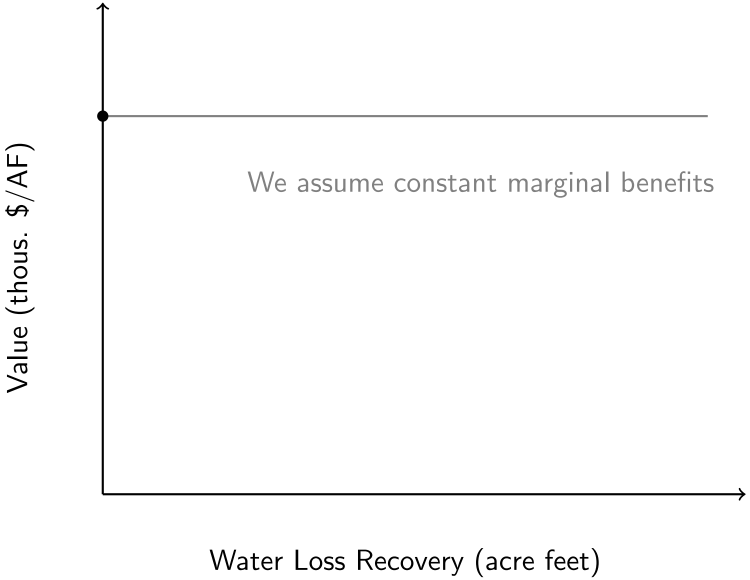
$$\text{Present Discounted Value} = \sum_{t=0}^{5} \frac{Benefits_t}{(1+r)^t} \tag{1}$$

Medium run: 20 years

$$\text{Present Discounted Value} = \sum_{t=0}^{20} \frac{Benefits_t}{(1+r)^t} \tag{2}$$

Assume a reasonable discount rate or range, i.e., 1-5%.

Benefits Estimation: Illustration



Benefits Estimation: Assumptions

1. Time Horizon
   - Short run: 5 years
   - Medium run: 20 years
2. Assume a discount rate or range, i.e., 1-5%.
3. Incremental benefit from an additional unit of loss recovery is constant across all recovery levels.
4. Impute benefits for utilities with missing data using data from 'similar' utilities

Costs Estimation: Big Picture

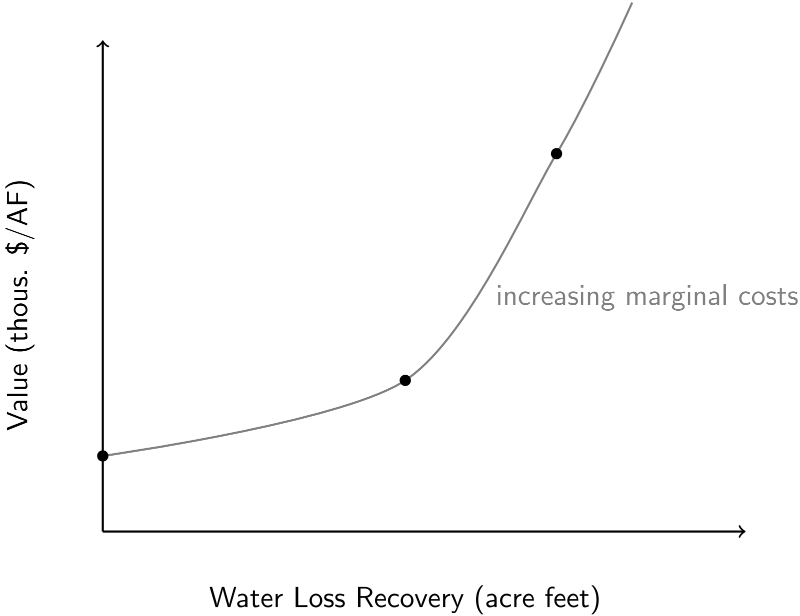
Steps to estimating costs:

1. Catalogue actions available to reduce losses
2. Monetize costs of each action
   - Depends on features of utility, current actions and current losses
3. Estimate how costs change with level of water loss reduction

Our approach:

1. Fix quantity of reduction
2. Calculate cost of each utility action
3. Choose cheapest action to trace out marginal cost curves

Costs Estimation: Illustration



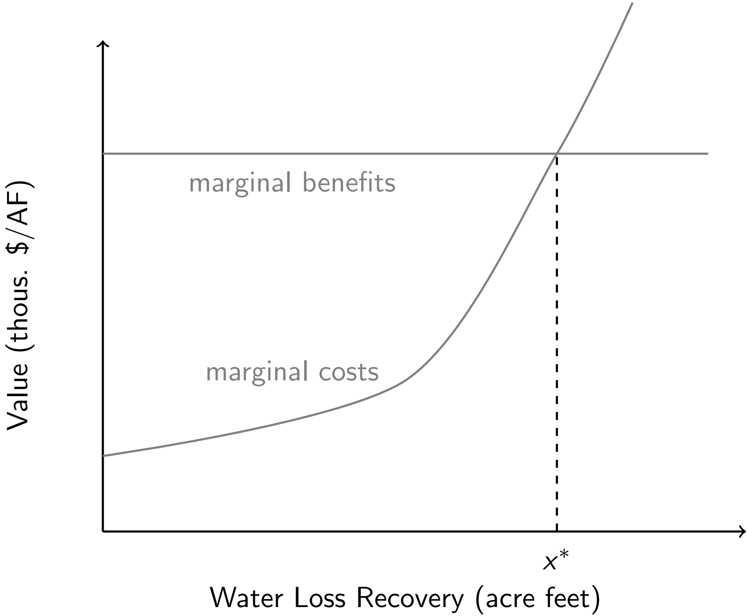
Cost Estimation: Assumptions

1. Time Horizon
   - Short run: 5 years
   - Medium run: 20 years
2. Assume a reasonable discount rate or range, i.e., 1-5%.
3. Utilities will pursue the cheapest technology first
4. Actions taken to reduce losses can be computed independently

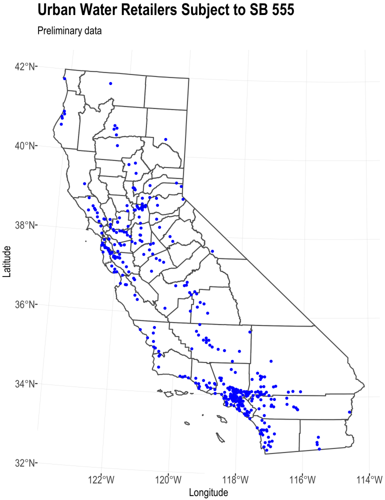
Economic model solves for cost-effective standards

1. Quantify benefits and costs (in dollar terms)
2. Estimate shape of curves
3. Determine optimal amount of water loss recovery
   - Occurs where total benefits exceed total costs by the largest amount, i.e., marginal benefits = marginal costs

Optimal Reduction: Illustration



Costs and Benefits Vary by Utility



- Must account for how curves change by utility.
- Benefits and costs vary with population size, depth to mains, pressure of system, etc.
- Rationale for individualized performance standards.

Pilot: Apply framework to a couple utilities

Apply model framework to subset of utilities for which we have all the necessary data.

- Use specific utilities to demonstrate how framework can be applied.
- Use utility data to identify all the necessary model inputs as well as their form.
    - What utility data is necessary for full benefit/cost calculations?
- Sensitivity analysis: How do our assumptions impact the output?

Arrive at tailored performance standards

Economic model determines where total benefits exceed total costs by largest amount.

Can apply other thresholds:

- Calculate a benefit-cost ratio (BCR) that is utility specific:

$$BCR = \frac{\text{Total benefits}}{\text{Total costs}}$$

- How much recovery can be done such that $BCR > 1$, $BCR > 1.5$, $BCR > 2$, etc.?

Outline

Economic Model

- Benefits Overview
- Costs Overview
- Assumptions
- Determining performance standards

Benefits Estimation

- Illustration
- Components and assumptions
- Calculation for hypothetical utility

Costs Estimation

- Illustration
- Components and assumptions
- Calculation for specific utility

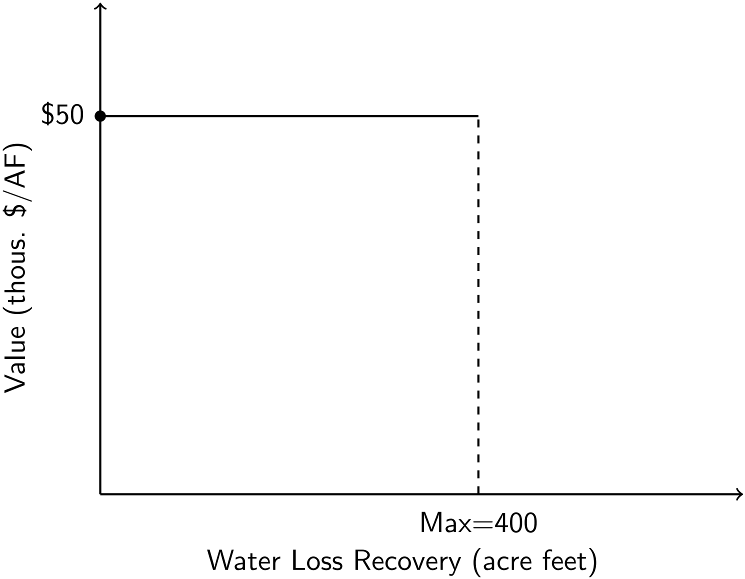
Data Needs and Gaps

- Benefits
- Costs

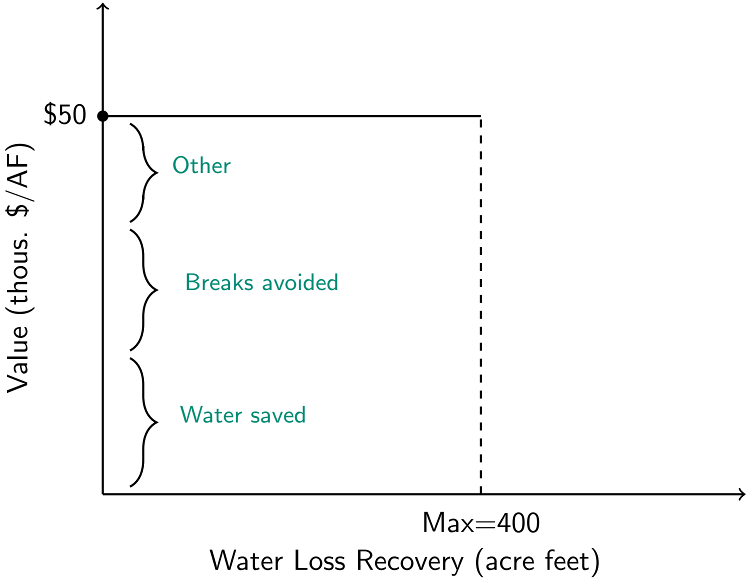
What comprises benefits?

- Water and energy saved
- Reduction in main breaks
  - Avoided property and infrastructure damage
  - Avoided outages (including reduction in ratepayer trust)
  - *Avoided traffic increase*
  - *Avoided public health impacts*
  - *Avoided reduction in firefighting capability*
  - *Avoided SWRCB fines*
- Carbon not emitted from energy saved
- Avoided cost of developing new water supply
- *Improved system hydraulics or extended infrastructure life*

Benefits Estimation: Illustration



Benefits Estimation: Illustration



Benefits Estimation: Assumptions

- Acknowledge but not monetize some benefits.
  - avoided traffic
  - public health impacts
  - changes in firefighter capability
  - changes in ratepayer trust
- Value of avoided outage is constant across utilities.
  - Buck et al. (2016) estimate welfare losses from supply disruptions to be $1,458/AF.
- Social cost of carbon
  - Auffhammer (2018) estimate value of damages per ton of C02 emitted = $42.
- Assume benefits change over time.

Proof of concept: Estimation for hypothetical utility

Let's do a back-of-the-envelope example for illustration.

Average utility has real losses of 806.4 AF and 470.2 AF are unavoidable.

Maximum utility can cut back = 336 AF annually

- What are the total benefits of reducing 336 AF in losses?
- What are the marginal benefits of each additional AF?

Benefits estimation for hypothetical utility

Benefits from water and energy saved

1. Start with estimate of value in one year:

   Avoided cost = (water saved AF) * (variable water supply cost $/AF)

   - Variable production cost = $1,035/AF
   - Total benefit = 336 AF * $1,035/AF = $347,760

2. Benefits include value in each future years as well, discounted to the present.

   - Need assumption on how supply costs change over time.

Benefits estimation for hypothetical utility

Benefits from water and energy saved

Assume costs increase by 3% each year and discount rate = 2%:

$$\text{Present discounted value} = \sum_{t=0}^{T} \frac{\$1,035(1.03)^t}{(1.02)^t}$$

Short-run (5yrs) marginal benefits ($/AF) from water saved

$$= \$5,655$$

Medium-run (20yrs) marginal benefits ($/AF) from water saved

$$= \$30,566$$

Benefits estimation for hypothetical utility

Benefits from reduction in main breaks

1. Start with estimate of value in one year:

   - Value of avoided damage = (cost to repair damage per area)*(average area affected in a year) = $200/sqft*10,000 sqft = $2,000,000

     Divide by 336 AF to get marginal value: $5,952/AF.

     Assume cost to repair damage scales with density, etc.

   - Value of avoided outages = 336 AF * $1,458/AF = $489,888

2. Benefits include value in each future years as well, discounted to the present.

   - Need assumption on how benefits change over time

Benefits estimation for hypothetical utility

Benefits from reduction in main breaks

Assume value of avoided outages increases by 1% each year and discount rate = 2%:

$$\text{Present discounted value} = \sum_{t=0}^{T} \frac{\$7,410(1.01)^t}{(1.02)^t}$$

Short-run (5yrs) marginal benefits from reduction in breaks

$$= \$36,710$$

Medium-run (20yrs) marginal benefits from reduction in breaks

$$= \$147,851$$

Benefits estimation for hypothetical utility

Benefits from avoided carbon emissions

1. Start with estimate of value in one year:

   Value of avoided carbon per AF = (marginal energy intensity kWh/AF) * (C02/kWh emitted) * (social cost of carbon) =

   2,500 kWh/AF * .000427 tons/kWh * $42/ton = $44.8/AF

   - Total benefit = 336 AF * $44.8/AF = $15,053

2. Total benefits include value in each future years as well, discounted to the present.

Benefits estimation for hypothetical utility

Benefits from avoided carbon emissions

Assuming no change over time and discount rate = 2%:

$$\text{Present discounted value} = \sum_{t=0}^{T} \frac{\$44.80}{(1.02)^t}$$

Short-run (5yrs) marginal social benefits from avoided carbon

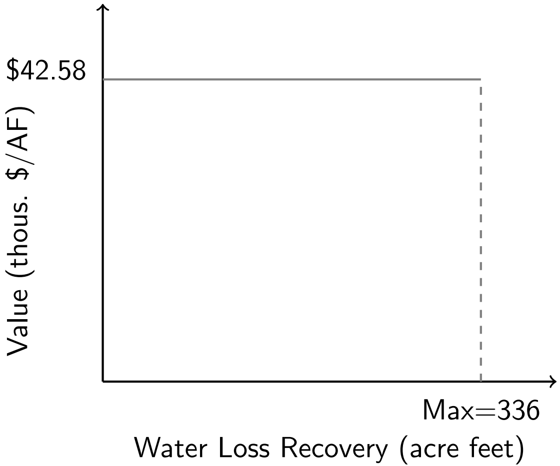
$$= \$211$$

Medium-run (20yrs) marginal social benefits from avoided carbon

$$= \$733$$

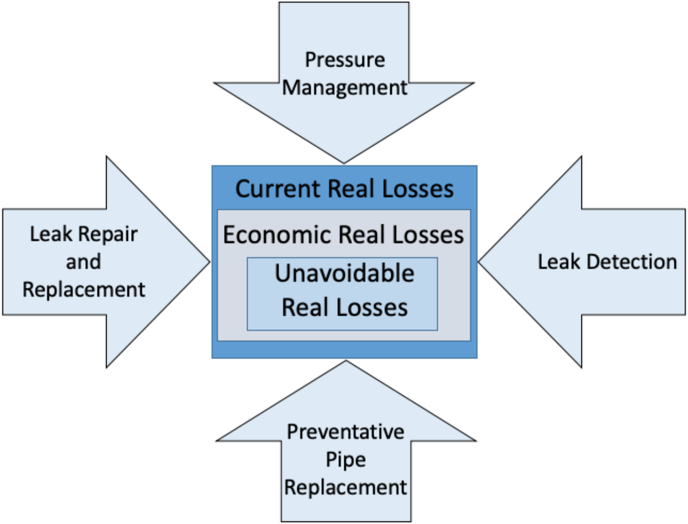
Benefits estimation for hypothetical utility

Short-run marginal benefits $= \$5,655 + \$36,710 + \$211 = \$42,576/AF$

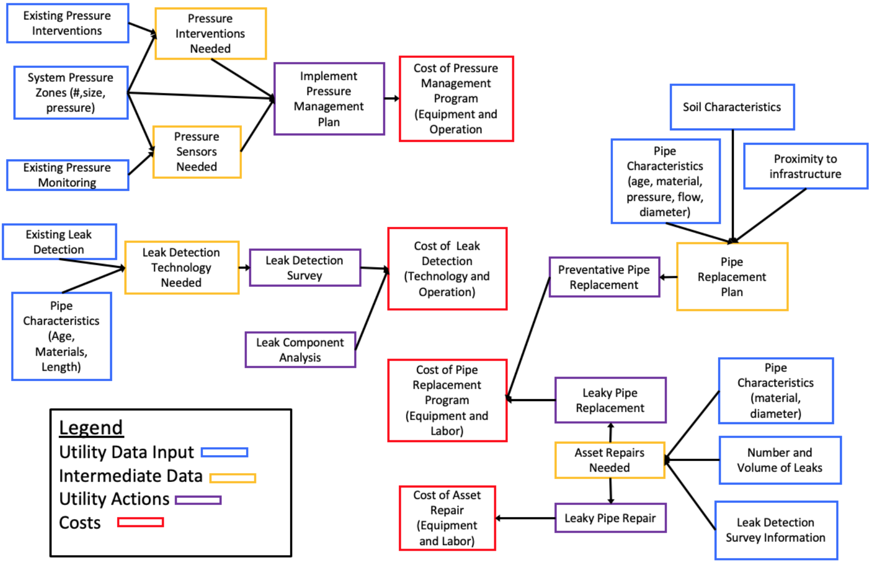


Outline

Components for Managing Real Losses



Components for Managing Real Losses



Leak Detection

Utility actions: Leak Detection Survey, Leak Component Analysis

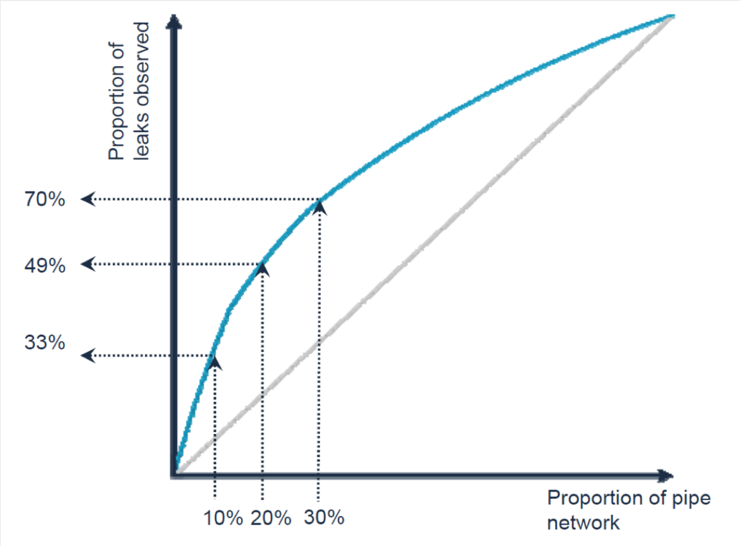
Utility Inputs

- Total system mileage
- Leak detection technology
- Past leak survey information (if available)

Assumptions

- Leak follow a certain distribution throughout the water system
- Leak detection depends on system characteristics and technology
- Survey done every year

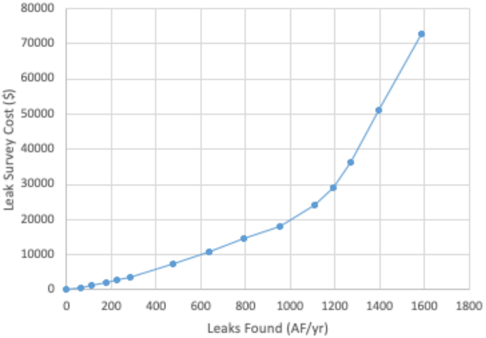
Leak Distribution



Cost Curve for Leak Detection Surveys

Example Utility Inputs

Total Leaks (AF/yr)	2268.6
Total Detectable Leaks (AF/yr)	1588.02
Total System Mileage	683
% of Leaks that are detectable	70
Leak Detection Technology Cost	
Leak Detection Labor/mi	
Average Contractor cost/mi ($)	320
Survey Frequency (per/yr)	1



Pressure Management

Utility actions: Pressure Management Plan (monitoring & reduction)

Utility Inputs

- Total system mileage
- Individual pressure zone average pressures
- System target pressure
- Volume of leaks

Assumptions

- Can reduce individual pressure zone averages down to target pressures
- Assume leak volume proportional to pressure zone size
- Assume capital costs of pressure reducing valves and variable speed drives spread over 5 or 20 years

Estimating Leak Reduction

Leak reduction follows the power law:

$$L_1 = L_0(\frac{P_1}{P_0})^{N_1}$$

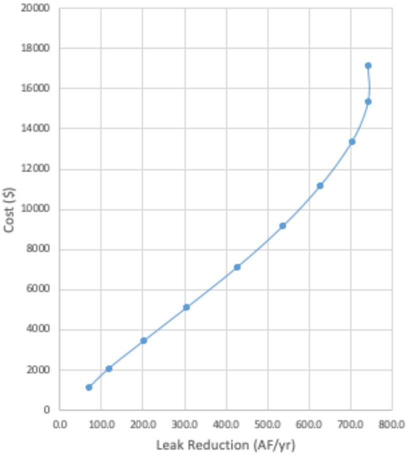
N1 depends on pressure zone size and pipe materials. International research has shown that N1 = 1.15 is a good estimate for large pressure zones with varied materials.

Cost Curve for Pressure Management

Example Utility Inputs

Total Leaks (AF/yr)	2268.6
Total System Mileage	683
System-Wide Target Pressure (psi)	60
Total System Sensor/Logger Costs	290695
Individual PRV Cost ($)	6000
Variable Speed Pump Cost ($)	3000
Total Pressure Management Operations Costs	
N1	1.15

Pressure Zone	Pipe Length (mi)	Average Pressure (psi)	Volume of Leaks (AF/yr)	Potential Reduction (psi)
1	31.9	150	106.0	90.0
2	23.3	140	77.4	80.0
3	42.5	130	141.2	70.0
4	57.8	120	192.0	60.0
5	73.1	110	242.8	50.0
6	75.1	100	249.4	40.0



Asset Management

Utility actions: Preventive Pipe Replacement

Utility Inputs

- Percentage of system by pipe material
- Pipe age
- Length of system
- Average time to fix a main break
- Average flows through mains

Assumptions

- Utilities will replace the pipes with the highest predicted break-rate first
- Only preventatively replace mains greater than 12"
- Average Cost to replace mains $500/ft
- Predicted pipe break-rates are a function of pipe material, age, and soil conditions

Predicting Break-Rates

In the absence of data:
USA Empirical Values for break-rates per 100 miles of pipe (Folkman 2018):

- Asbestos-Cement = 10.8
- Cast Iron = 33.2
- Concrete Steel Cylinder = 3.1
- Ductile Iron = 5.0
- PVC = 2.6
- Steel = 8.3

Given some data: Use pipe age, material, diameter, pressure, and soil corrosivity to estimate break-rates

Cost Curve for Asset Management

Example Utility Inputs

Plastic Pipe %	37.7
Plastic Pipe Age	26
Steel Pipe %	9.3
Steel Pipe Age	33
Cast Iron Pipe %	0.1
Cast Iron Pipe Age	45
Ductile Iron Pipe %	7.3
Ductile Iron Pipe Age	27
Concrete Cement Pipe %	1.3
Concrete Cement Pipe Age	50
Asbestos Pipe %	48.6
Asbestos Pipe Age	42
Length of Mains - miles	683
Average Flows in >12" Pipes (GPM)	200
Average Cost to Replace a Main ($/mi)	2640000
Average Time to Replace a Main Break (days)	7

Still Need:

An adequate way to estimate break-rate given our limited data.

Leaky Pipe Repair and/or Replacement

Utility actions: Repair or replace leaky pipes

Utility Inputs

- Total number of leaks
- Total volume of leaks
- Total system mileage
- Percent of water distribution system by pipe diameter
- Leak survey data (if available)

Assumptions

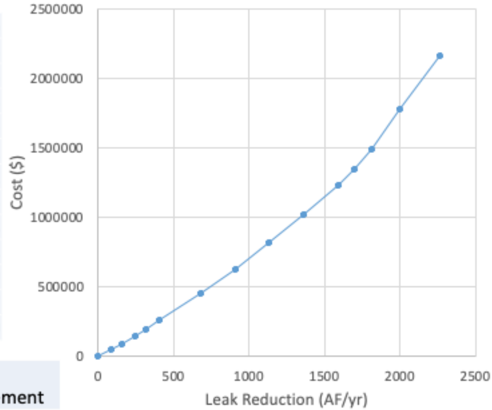
- Utility action depends of pipe failure type (37% circumferential cracks, 27% corrosion or holes, 22% longitudinal cracks) (Folkman, 2018).
- Leaks evenly spread among pipe diameter sizes.
- Leak sizes follow some distribution, utilities can update once complete a leak detection survey

Cost Curve for Pipe Repair/Replacement

Example Utility Inputs

Total Leaks (AF/yr)	2268.6
Total System Mileage	683
% of Pipe 3-8"	0.35
% of Pipe 10-12"	0.25
% of Pipe 14-24"	0.15
% of Pipe 27-36"	0.1
% of Pipe 42-48"	0.1
% of Pipe >48"	0.05
5-yr total leaks #	1794
5-year total leaks Volume (AF)	10034
Average Leak Size (AF/yr)	5.59
Average Leak Flow Rate (gpm)	3.47
Average Pipe Replacement Length (ft)	20

Repair/Replacement Options	Pipe Clamp	Pipe Patch	Pipe Replacement
3-8in Cost	2250.00	6000	7000
10-12in Cost	2500.00	6000	10000
14-24in Cost	6000.00	6000	11000



Outline

Economic Model

- Benefits Overview
- Costs Overview
- Assumptions
- Determining performance standards

Benefits Estimation

- Illustration
- Components and assumptions
- Calculation for hypothetical utility

Costs Estimation

- Illustration
- Components and assumptions
- Calculation for specific utility

Data Needs and Gaps

- Benefits
- Costs

Benefits Data - Literature and eAR/Audits

From academic literature or reports:

- Value of avoided outages (Buck et al. 2016)
- Social cost of carbon (Auffammer 2018)
- Marginal energy intensity and amount of carbon emitted per kWh

From Electronic Annual Reports (eAR) or audit data:

- Annual variable water supply costs and annual quantity supplied
- Real and unavoidable losses

Benefits Data - Utilites

- Damage repair estimates associated with main breaks.
  - Costs associated with outages, e.g., bottled water
  - Average size of area affected, length of time of outage, cost to repair damage
  - Pipe break records and GIS maps of asset locations
- Energy use
- Projections of water supply costs
- The cost of an additional acre foot from a new water source

Cost Data - Literature

- Leak distribution in a water system (Rezatek, 2019)
- Leak detection technology costs and limitations (Various)
- Relationship between pressure and leaks (Thornton et al., 2008)
- Pressure sensors, loggers, PRVs, VSD costs (Various)
- Pipe failure distributions (Folkman, 2018)
- Pipe repair and replacement costs (Various)

Cost Data - eAR and Audits

- Pipe characteristics (% of system material, pipe age by material type, to length of mains)
- Number of pressure zones
- Minimum operating pressure
- Average operating pressure
- 5-yr total number and volume of leaks
- Real losses
- Number of service connections
- Variable water production cost
- Unavoidable annual real losses

Cost Data - Utilities

- Pipe characteristics (% system diameters)
  - Improves cost calculations for leak repair and replacement
- Pressure Zone characteristics (size, pressures, pipe material)
  - Improves pressure management cost curve
- Historical pipe break records
  - Improves preventative pipe replacement cost curve
- Leak detection survey results
  - Improves assumptions about leak distribution and sizes
  - Impacts all four curves