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watersmart INNOVATIONS 2020 Webinar Series

Integrating End Use Accounting and Econometrics for Long-Term Demand Forecasting

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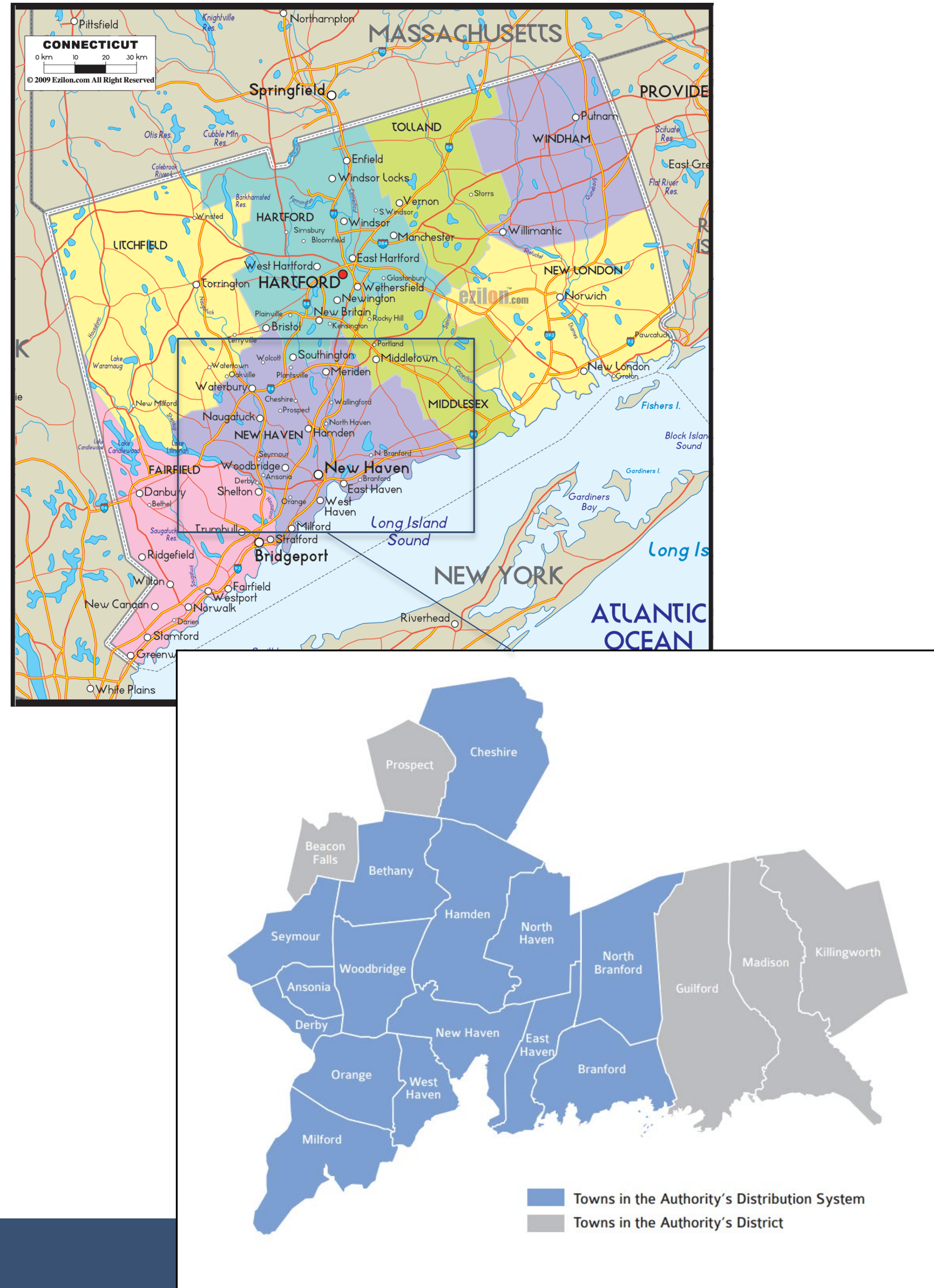
Regional Water Authority

Overview

- Project background
- Forecast objectives and challenges
- “Hybrid” forecast model development
  - End Use Model
  - Statistical Model
- Conclusions and recommendations

Regional Water Authority

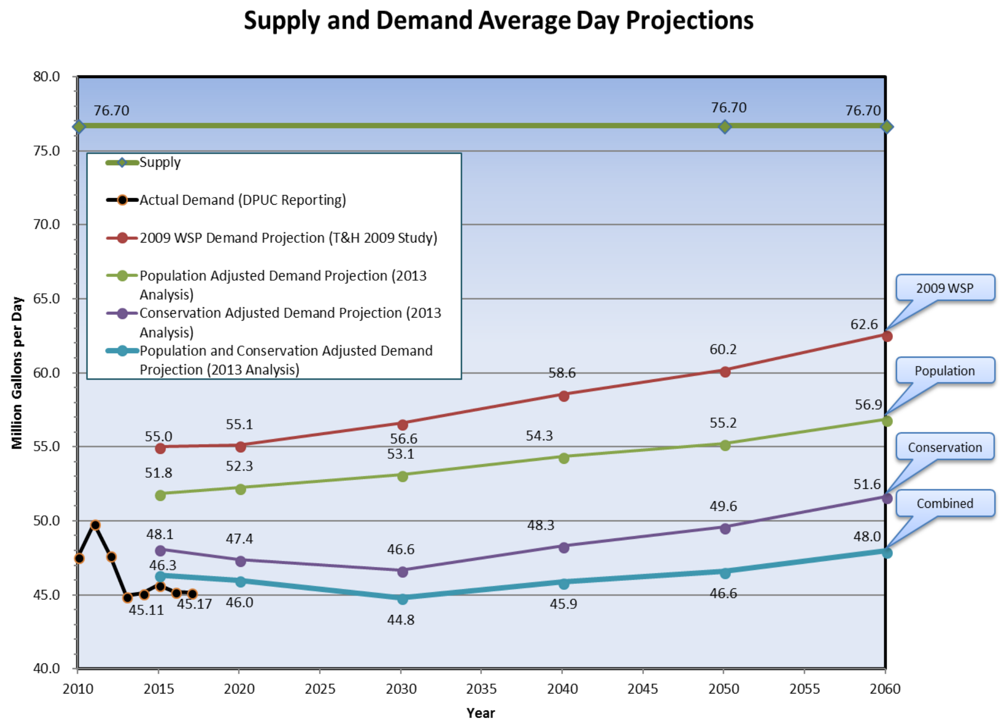
- South-central Connecticut
- 430,000 population
- 116,000 meters
- Provides water service in 15 Towns



Project Background

Need for a fresh perspective on demand forecasting

- Previous demand forecasts not tracking well in short run
- Short-run becoming “mismatched” with long-term forecast
- Updates to adjust forecasts downward



Project Background

Review of Past Demand Forecasting Efforts

- Concentrated on estimating population served
- Demand forecast a product of per capita usage rates and population
- Subsequent attempts to incorporate efficiency and economic factors

Forecast Objectives

- Differentiate “drivers” and unit usage rates by sector
- “Statistically-informed” models
- Consideration of water efficiency trends

Data Collection

Analysis and Modeling

Baseline Model

Point Regional Forecast

Challenges Influencing Forecast Model Development

- Single- and multi-unit dwellings combined into one residential billing class
- Historical time series data on more preferred “drivers” (e.g., dwelling units and employment) lacking
- Lack of data to explain Town-level variability in nonresidential use
- Consistent appraiser data unavailable for all Towns

Forecast Model Decisions

- Retain population as forecast driver
- Develop RWA-wide model of per capita use
- Informed by
  - ✓ Exploratory data analysis
  - ✓ Econometric modeling
  - ✓ Estimated efficiency trends
    - ✓ Stock Model
    - ✓ Residential End Uses of Water
    - ✓ Residential indoor end use model

Modeling Objectives

End Use Modeling

- ✓ Elegant way to track technology

Econometric Modeling

- ✓ Ideal way to evaluate variability

Hybrid Forecast Model

- ✓ Integrate best features of both

Components of Forecast Model

$$Total\ Production\ Demands = \frac{M\&I + Wholesale\ Use}{100 - \%NRW}$$

Non-revenue Water Adjustment

$$M\&I + Wholesale\ Use = \frac{M\&I\ Use}{100 - \%Wholesale}$$

Wholesale Water Adjustment

$$M\&I\ Use = Population\ Served * M\&I\ Per\ Capita\ Use$$

Population Served

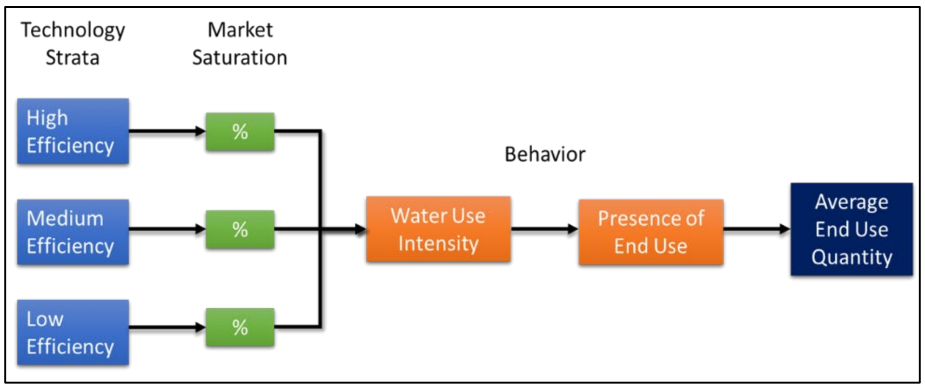
$$M\&I\ Per\ Capita\ Use = Base\ Residential\ Per\ Capita\ Use * k$$

$$k = f(Seasonality, Weather, Socioeconomics, Efficiency)$$ ❷

❶ $$Base\ Residential\ Per\ Capita\ Use = \sum_{i=1}^{j} P_i * V_i * F_i$$

Modeling Technological Change in Water Using Fixtures

End Use Models



Three Toilet Technologies—average gallons per flush

Fraction of toilets in each category

$$\mathit{Water\ Use\ for\ Toilets} = [3.5(0.30) + 1.6(0.55) + 1.28(0.15)] * [5(2.8)] * 1.0 = 29.7 \text{ gphd}$$

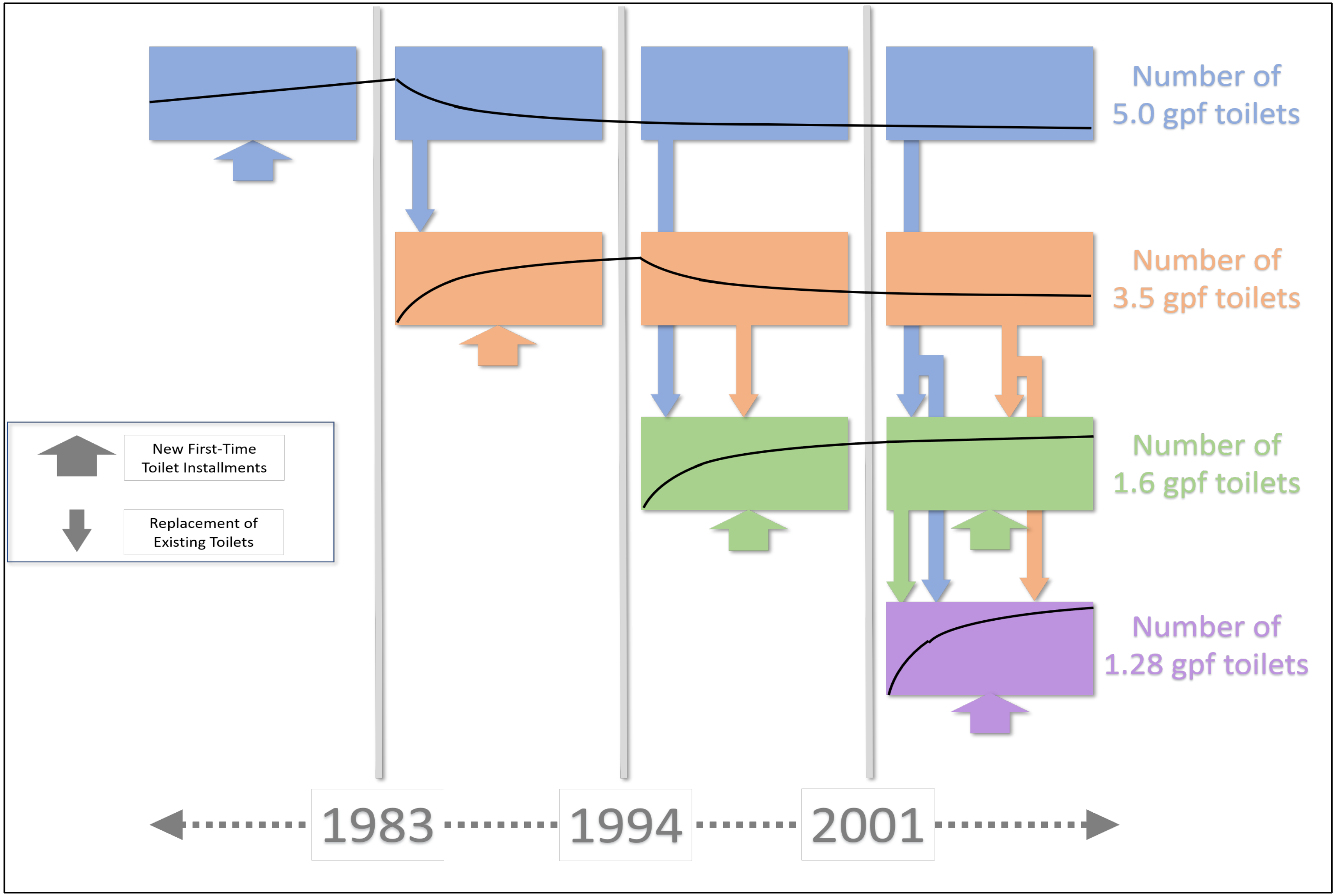
Average flushes per person per day

Average persons per household

Fraction of houses with toilets

Source: Kiefer, J.C., Dziegielewski, B. and C. Jones. [N.D.] *Water Demand Forecasting for Water Resources and Infrastructure Planning.* Denver, Colo.: Water Research Foundation. (forthcoming)

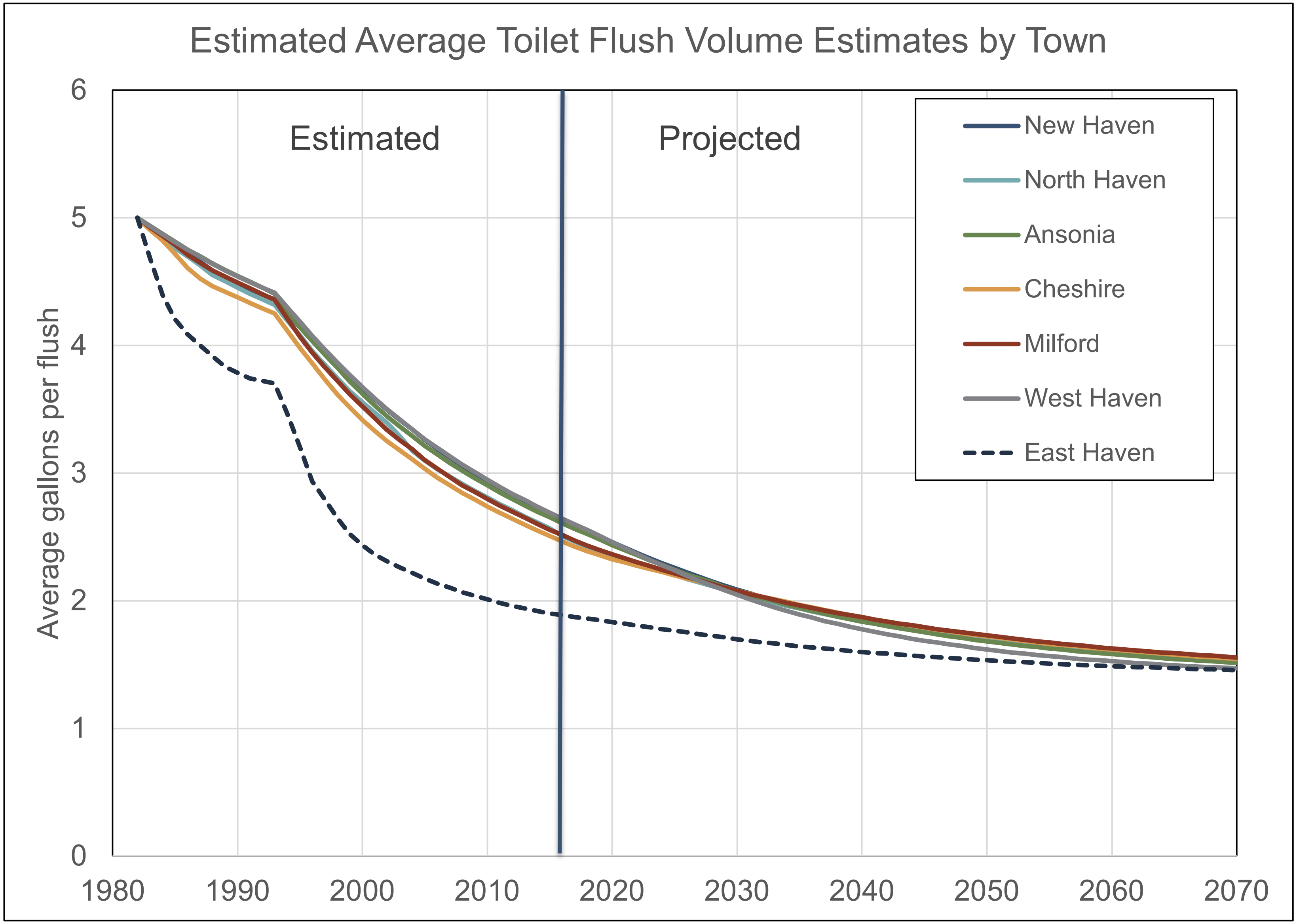
Illustration of "Stock Model" for evaluating trends in water efficiency



Toilet Stock Model

Creating an Indicator for Evaluating Technology Trends

- Primary basis for estimating effects of passive changes in water efficiency (e.g., standards, codes, remodels, etc.)
- Why toilets?
  - Toilets are ubiquitous among sectors
  - Available technology and efficiency standards correspond well with time
  - Year built information for residential structures often available from tax appraisers



Estimated Average Toilet Flush Volumes by Town

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❶ End Use Model of Base Indoor Residential Use

- Toilet stock model generates input for toilet flush volume
- Other basic assumptions from Residential End Uses of Water Study (2016 Update)
- Adjustments to presence of clothes washers and dish washers based on Census data
- Calibrated to 2017 minimum monthly residential per capita use

Uncalibrated Residential Base Indoor End Use Model

End Use	Assumed Presence	Frequency Measure	Assumed Frequency	Duration	Flow Measure	Estimated Flow	Estimated Use per Capita
Toilets	1	flushes per person/day	5	n/a	gallons per flush	2.52	12.62
Clothes washers	0.85	wash loads per person/day	0.3	n/a	gallons per load	31.00	7.91
Showers	1	showers per person/day	0.69	7.8	gallons per minute	2.10	11.30
Faucets	1	uses per person/day	20	n/a	gallons per use	0.50	10.00
Dish washers	0.72	uses per person/day	0.1	n/a	gallons per use	6.10	0.44
Baths	1	baths per person/day	0.07	n/a	gallons per bath	20.20	1.41
Leaks	1	events per person/day	43.3	n/a	gallons per event	0.15	6.50
						Indoor Total	50.18
						RWA 2017 Base Residential Use	53.01
						Balance	2.83

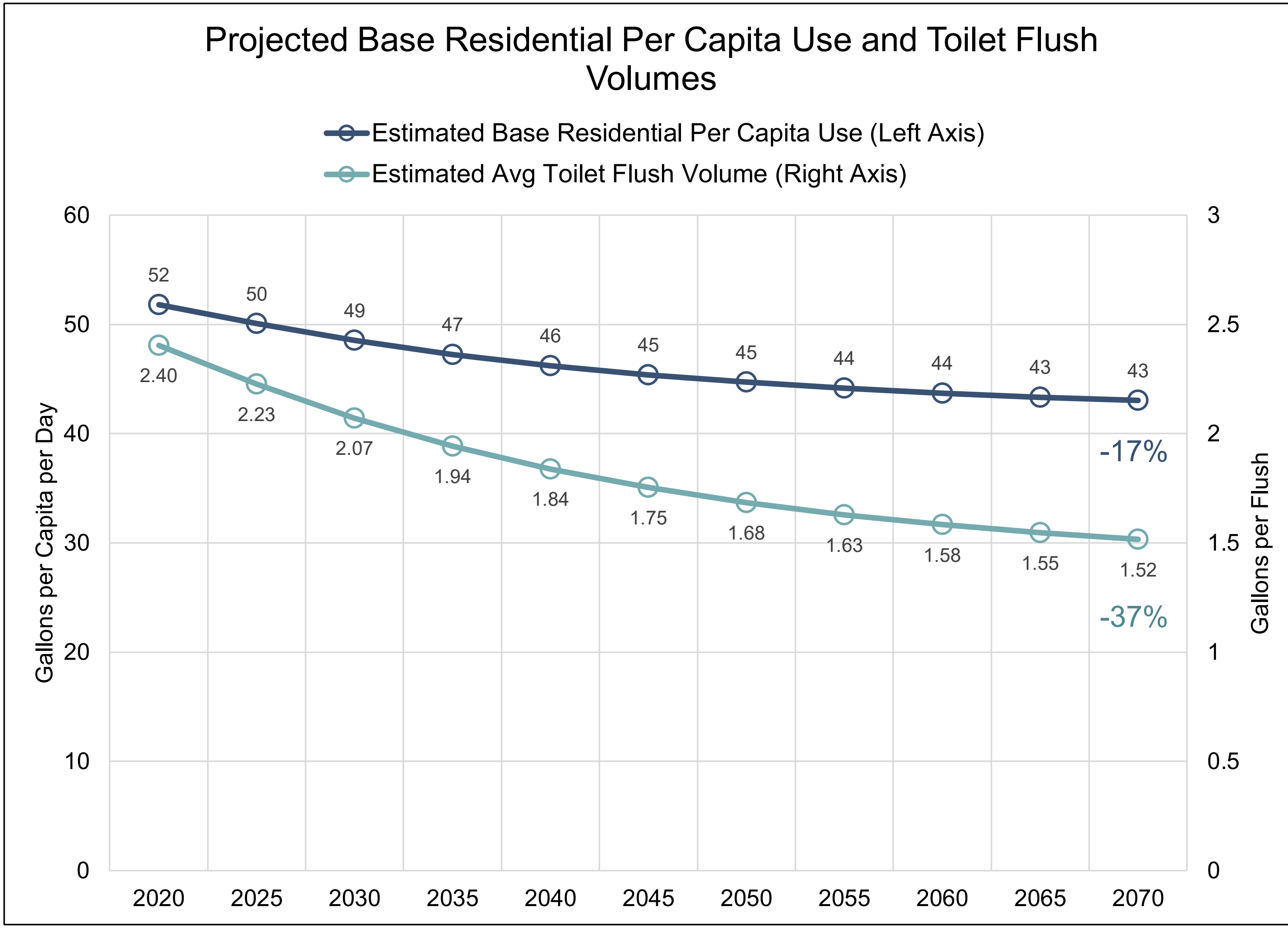
Calibrated Residential Base Indoor End Use Model

End Use	Assumed Presence	Frequency Measure	Assumed Frequency	Duration	Flow Measure	Estimated Flow	Estimated Use per Capita
Toilets	1	flushes per person/day	5	n/a	gallons per flush	2.52	12.62
Clothes washers	0.85	wash loads per person/day	0.3	n/a	gallons per load	31.00	7.91
Showers	1	showers per person/day	0.69	7.8	gallons per minute	2.10	11.30
Faucets	1	uses per person/day	20	n/a	gallons per use	0.50	10.00
Dish washers	0.72	uses per person/day	0.1	n/a	gallons per use	6.10	0.44
Baths	1	baths per person/day	0.07	n/a	gallons per bath	20.20	1.41
Leaks/Other	1	~~*events per person/day*~~	~~*43.3*~~	~~*n/a*~~	~~*gallons per event*~~	~~*0.15*~~	9.32
						Indoor Total	53.01
						RWA 2017 Base Residential Use	53.01
						Balance	0.00

Projections of Base Indoor Residential Use

- Future toilet flush volumes based on stock model
- Decrease in gallons per load for clothes washers proportional to estimated toilet flush volumes
- Leaks/other constant proportion of all other residential indoor end uses
- No changes in end use presence, behavior or mechanical efficiency levels of faucets, showers, baths, and dish washers

Year	Estimated End Use Consumption (gallons per capita per day)							Indoor Total (Base Residential Use)
	Toilet	Shower	Faucet	Clothes-washer	Dish-washer	Bath	Leaks /Other	
2017	12.62	11.30	10.00	7.91	0.44	1.41	9.32	53.01
2020	12.02	11.30	10.00	7.53	0.44	1.41	9.12	51.82
2025	11.14	11.30	10.00	6.97	0.44	1.41	8.81	50.07
2030	10.36	11.30	10.00	6.49	0.44	1.41	8.54	48.54
2035	9.71	11.30	10.00	6.08	0.44	1.41	8.31	47.26
2040	9.19	11.30	10.00	5.76	0.44	1.41	8.13	46.23
2045	8.77	11.30	10.00	5.49	0.44	1.41	7.99	45.40
2050	8.42	11.30	10.00	5.27	0.44	1.41	7.87	44.72
2055	8.14	11.30	10.00	5.10	0.44	1.41	7.77	44.17
2060	7.91	11.30	10.00	4.96	0.44	1.41	7.69	43.71
2065	7.73	11.30	10.00	4.84	0.44	1.41	7.62	43.35
2070	7.58	11.30	10.00	4.75	0.44	1.41	7.57	43.05



Projections of Base Residential Per Capita Use and Toilet Flush Volumes

❷ Statistical Model for Estimating Total M&I Use

- Model used to scale base indoor residential per capita use up to total M&I per capita use

- Dependent (or "left-hand-side") variable, *k*:

$$k = \frac{M\&I\ per\ Capita\ Use}{Base\ Residential\ Indoor\ per\ Capita\ Use}$$

$$M\&I = Residential + Commercial + Industrial + Public\ Authority$$

Statistical Model for Estimating Total M&I Use

$$k = f(Season, Weather, Socioeconomics, Efficiency)$$

- ✓ Seasonal, weather, socioeconomic, and efficiency components
- ✓ Monthly time step
- ✓ Simple linear form

- ✓ Final variable specification informed by Town-level exploratory analysis

Model Coefficient Estimates

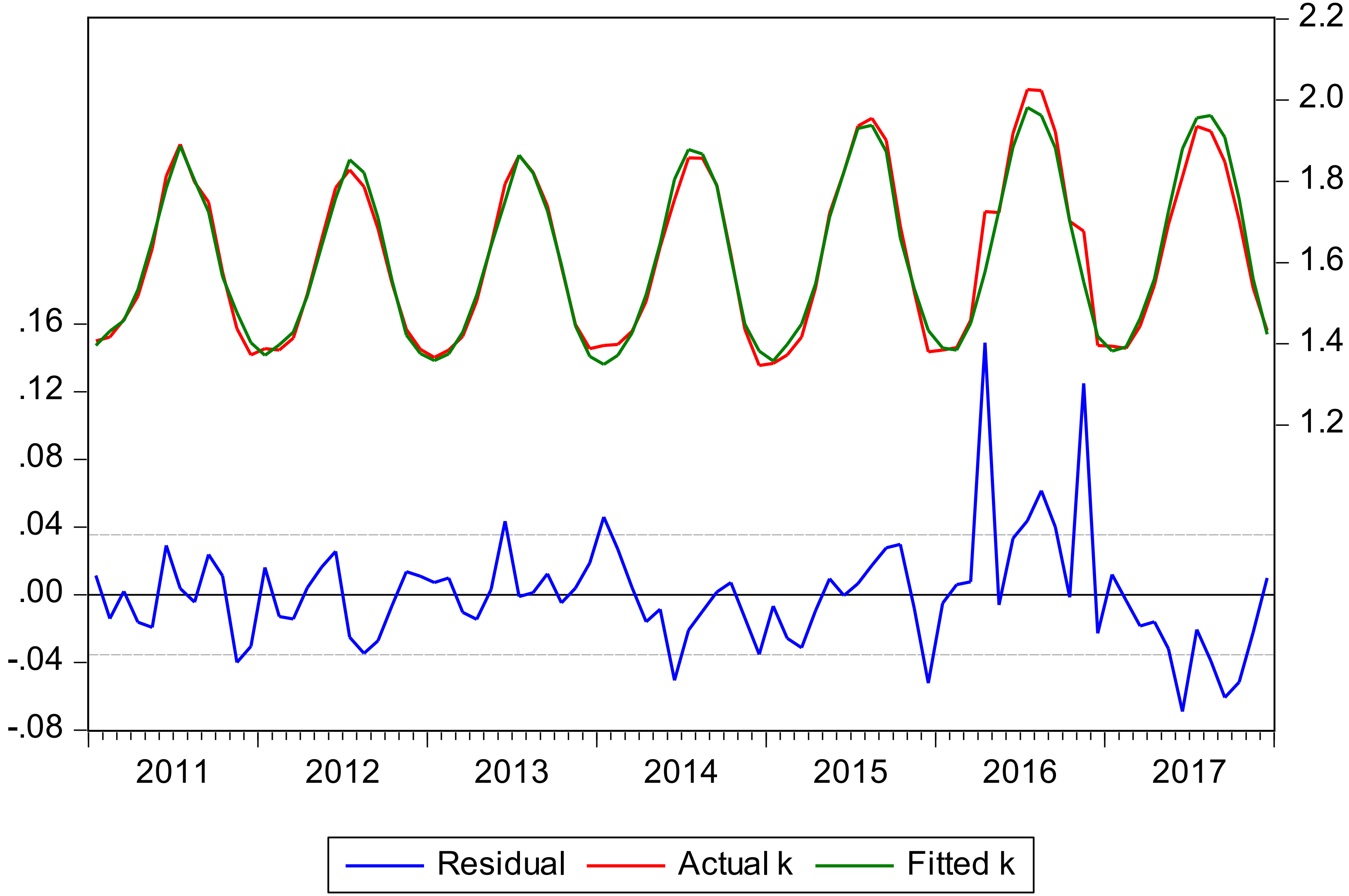
Implied Elasticities

- Price: -0.19
- Income: 0.55
- Unemployment Rate: -0.10
- Estimated Flush Volume: 0.43

Dependent Variable: k = (M&I Avg Daily Per Capita Use) /(Base Residential Avg Daily Per Capita Use)			
Model Component	**Independent Variable**	**Coefficient**	**t-Statistic**
	Intercept	0.4720	0.79
Seasonal	Annual Sine Harmonic (S1)	-0.2799	-11.22
			-11.19
Weather	A		2.35
	A		-2.87
	F		-1.81
Socioeconomic	F		3.16
			-1.72
			4.74
			1.85
	Unemployment Rate * Semi-Annual Cosine Harmonic (C2)	0.0060	5.82
	Residential Volumetric Price of Water (2015$)	-0.0848	-1.31
Efficiency	Estimated Average Residential Toilet Flush Volume (gallons per flush)	0.2623	1.13

- ✓ Expected signs
- ✓ Rational magnitudes ("elasticities")
- ✓ More signal than noise
- ✓ Good overall fit

Mean Absolute Percentage Error = 1.4%



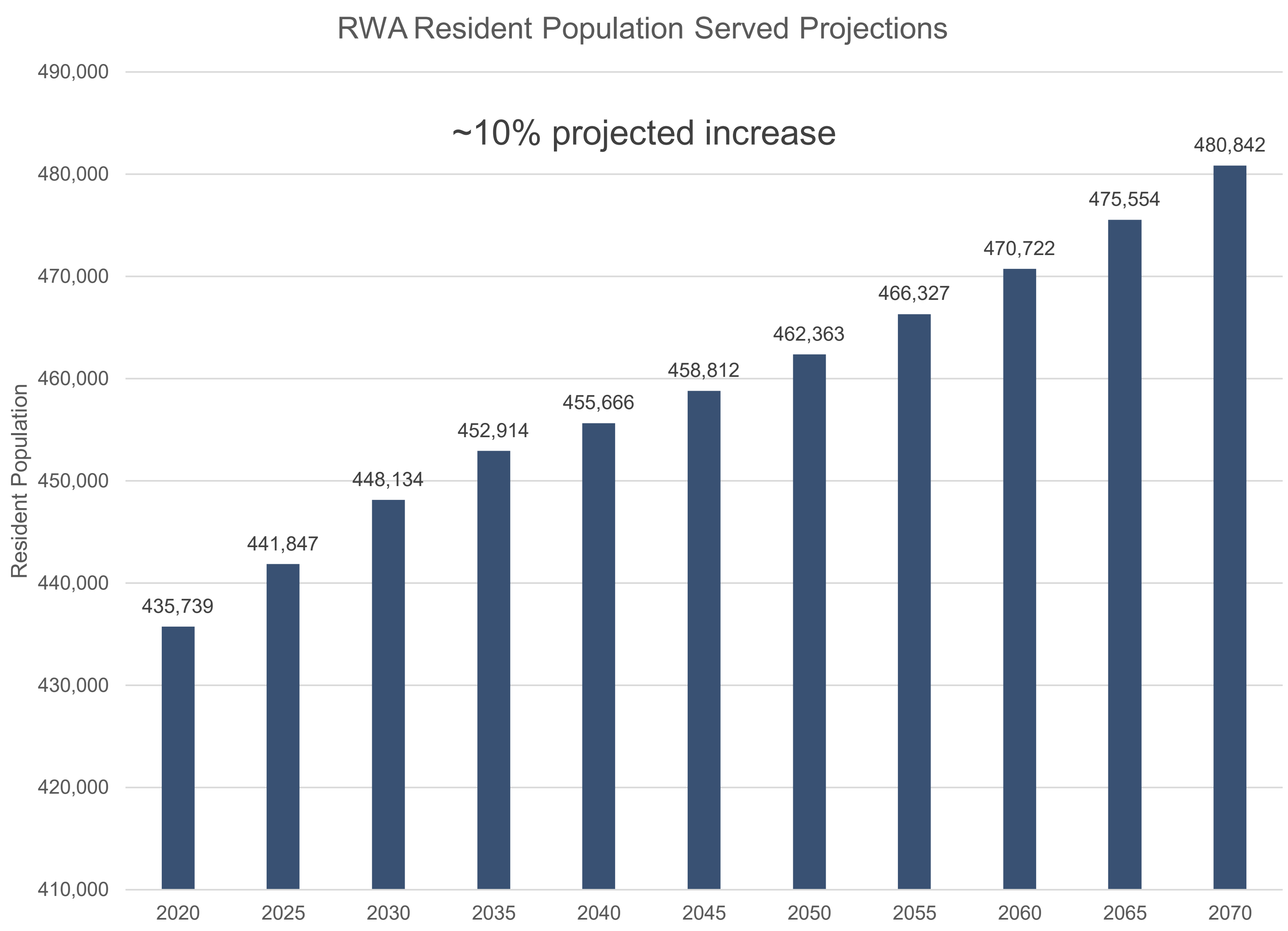
Plot of Predicted and Observed "k" parameter

Baseline Forecast Assumptions

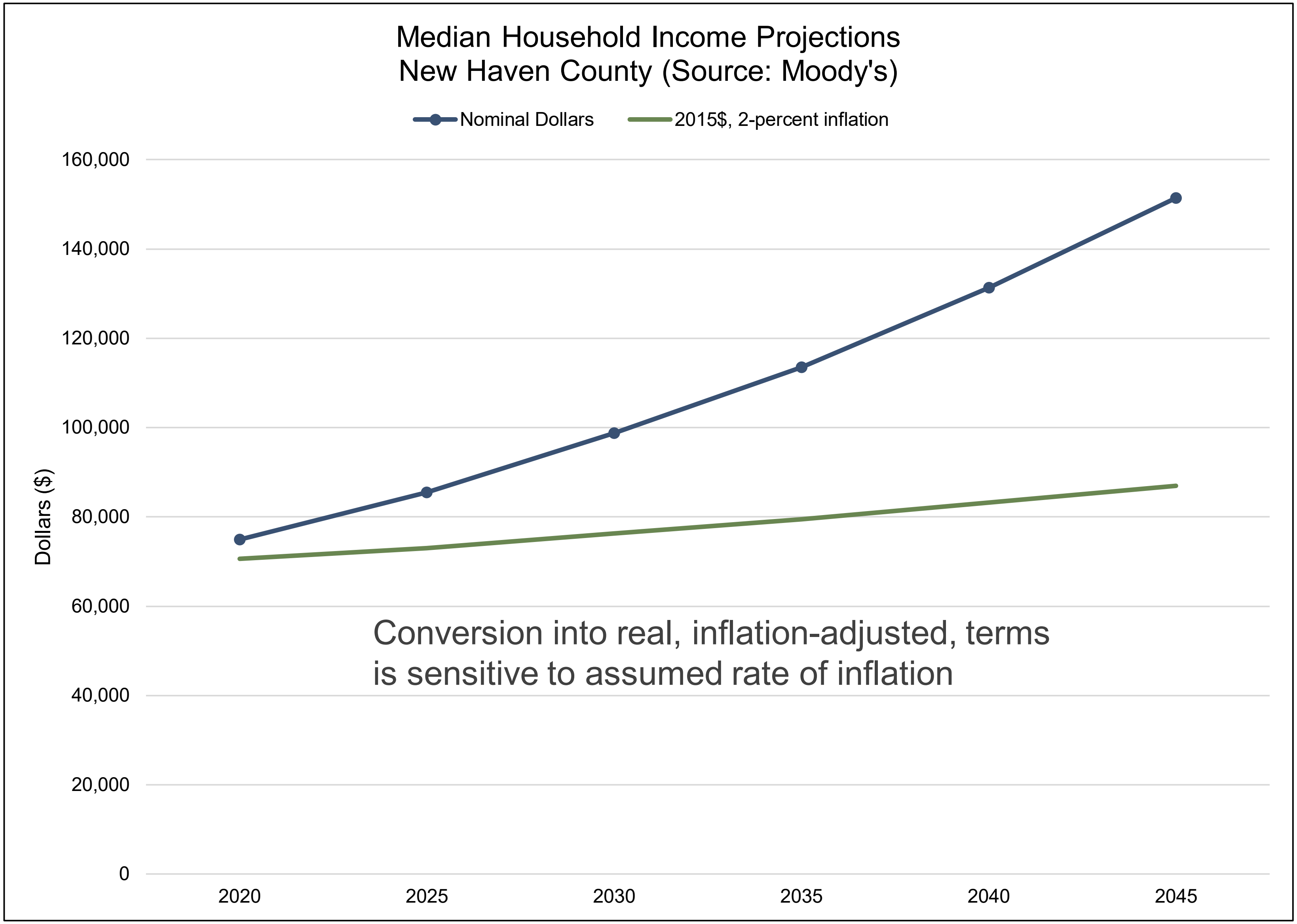
- Forecast horizon: 2070
- Normal weather (30-year historical average)
- Toilet flush volume from Toilet Stock Model
- Base Residential Use from End Use Model
- Population from CT State Data Center
    - Extrapolated to 2070
    - Percent served assumptions from historical average

Baseline Assumptions

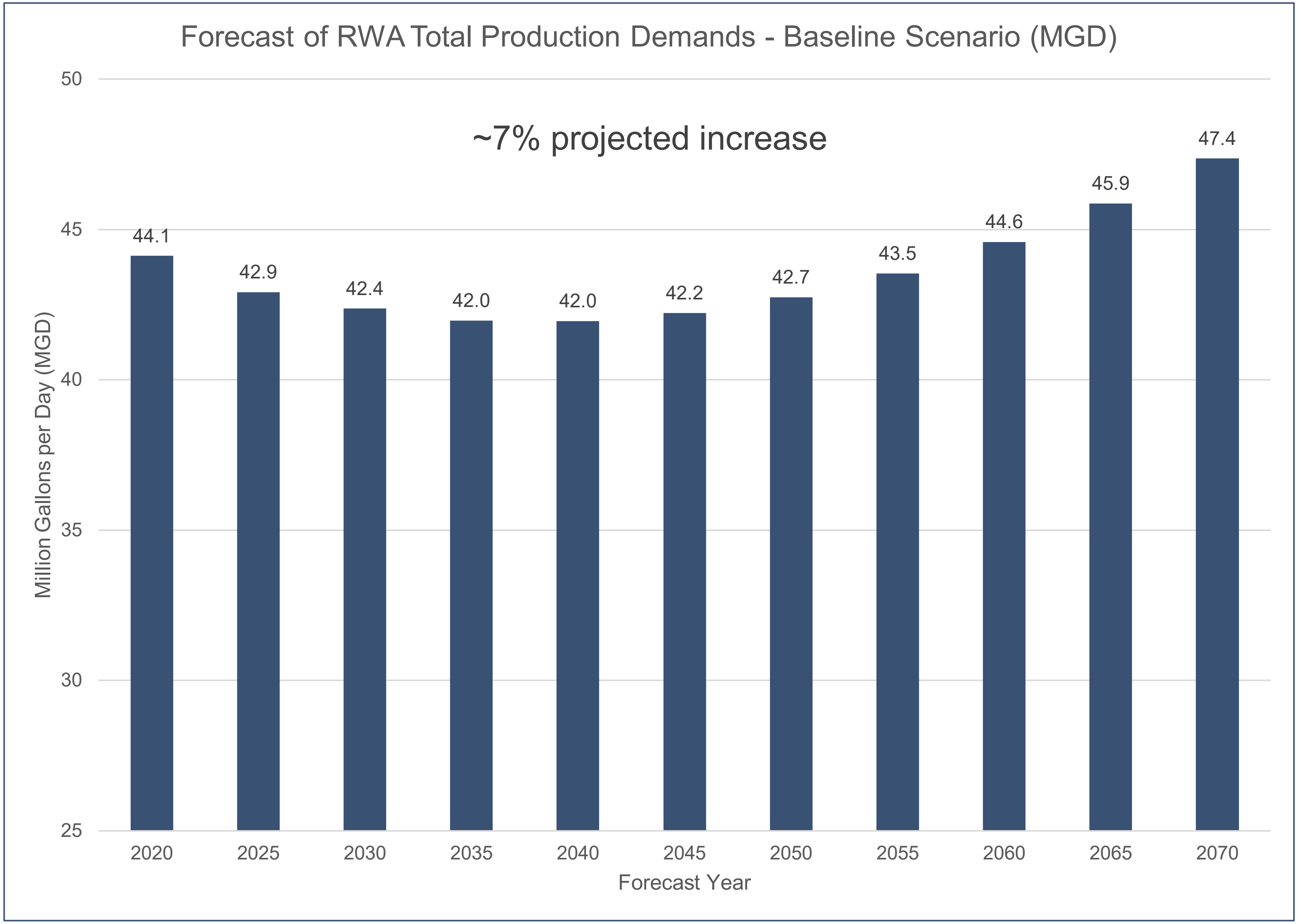
- Nominal Median Household Income from Moody’s
    - Adjusted assuming 2% annual rate of inflation
- Prices held constant in real terms
- Unemployment rate held constant at 4%
- Fraction wholesale water held constant
- Fraction non-revenue water held constant



Projections of Population Served DRAFT



Median Household Income Projections (Nominal vs Real under 2% assumed inflation)



Forecast of RWA Production Demands under Baseline Assumptions **WORKING DRAFT**

Conclusions

- “Hybrid” end use-statistical model provides RWA additional capabilities
  - Empirically incorporates observed and expected trends
  - Accounts for climatic and socioeconomic factors that influence production demands in the RWA region
  - Integrates the ability to account for decreasing trends in indoor Residential per capita use
  - Multiple explanatory variables permit scenario analysis of alternative futures

Conclusions

- Primary analytical challenges
  - Relatively short time series of historical data
  - Inability to differentiate single-family and multifamily residential accounts
  - Lack of complete information on drivers of water use other than population (such as dwelling units, employment, and other property attributes)

Recommendations

Uncertainty analysis

Water use and trends monitoring

Maintenance/extension of water use database

Refinement of models as new data and information management procedures evolve

Thanks!

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