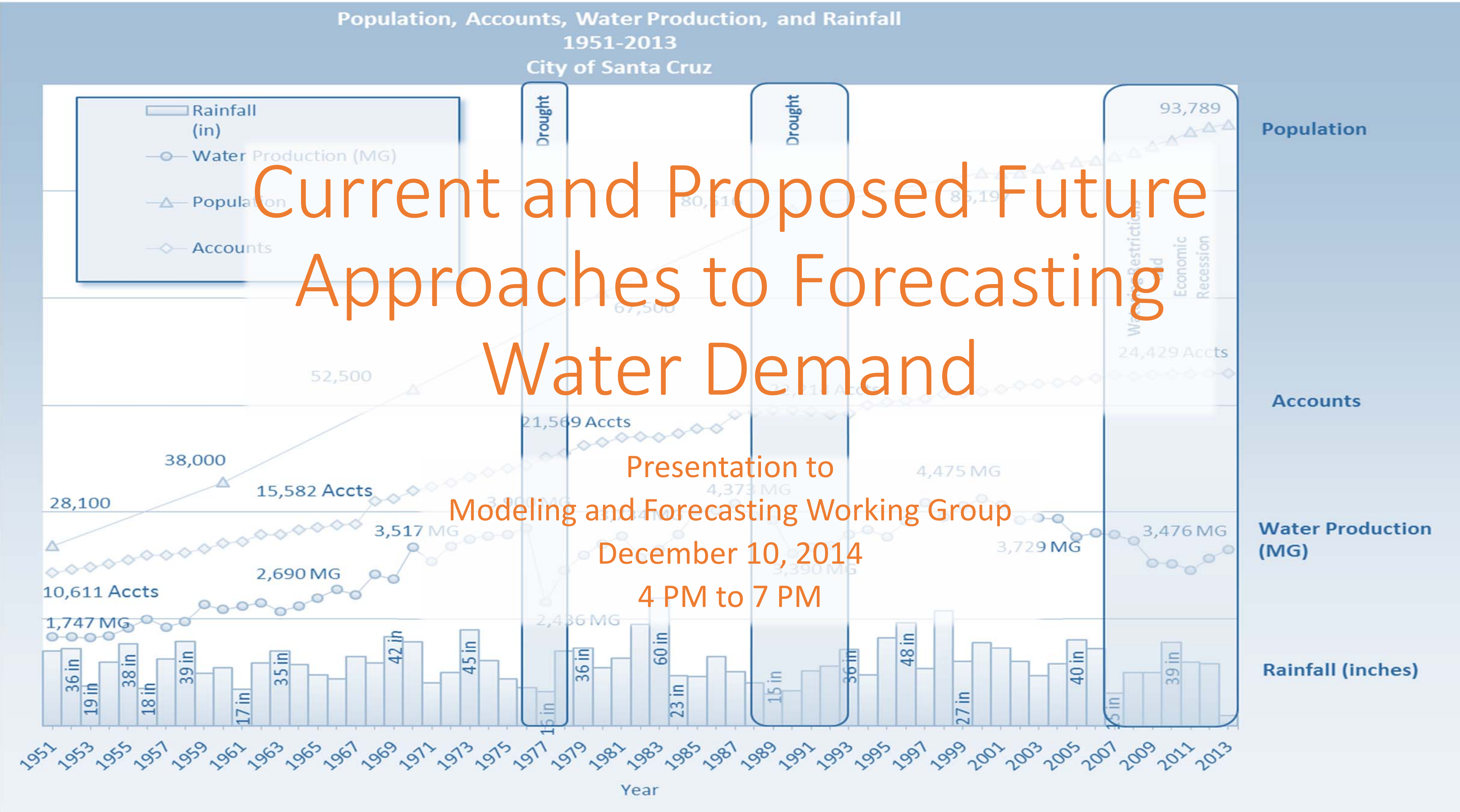
Current and Proposed Future Approaches to Forecasting Water Demand

Presentation to

Modeling and Forecasting Working Group

December 10, 2014

4 PM to 7 PM



Introductions

- Presenters:
  - Toby Goddard, City of Santa Cruz
  - David Mitchell, M.Cubed
- Workgroup

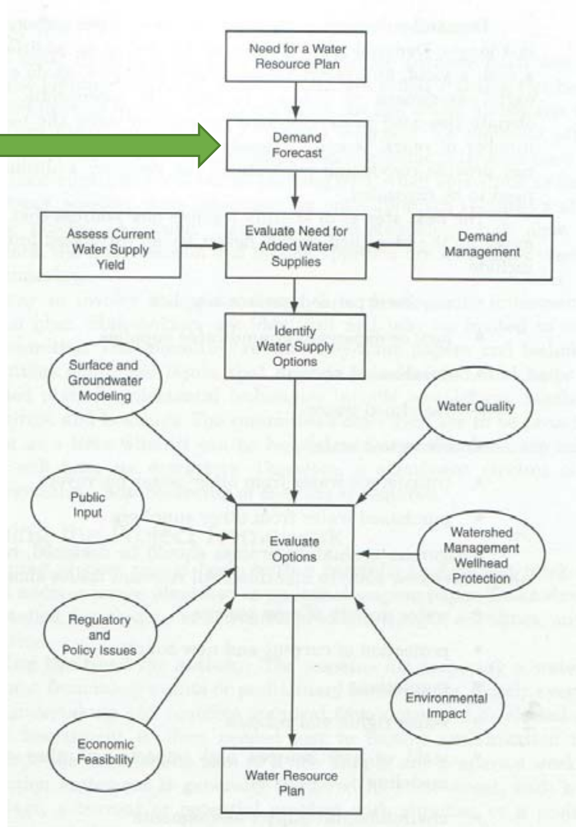
Objectives of Session 3

- Provide understanding of
  - Role of demand forecasts in water resources planning
  - Primary drivers of urban water demand now and in the future
  - Methods and data used to prepare urban demand forecasts
  - Sources and quality of data used by the City to model and forecast demand
  - Potential improvements to City's demand forecast, including development of statistically-based demand models
  - Importance of climate and weather in demand models and forecasts
  - Importance of land use, water rate, and other economic factors in demand models and forecasts
  - Demand Forecast Update Process

Role of Demand Forecast in Water Resources Planning

Demand Forecast Foundational to Good Water Resource Plan

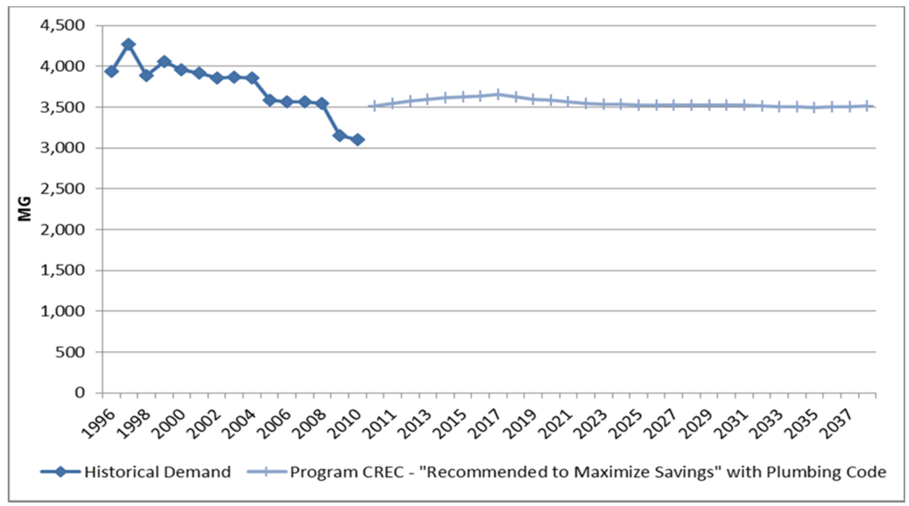
You are here



- Links directly to assessment of future supply need
- Consequences of being wrong – too high or too low -- need to be understood and evaluated (risk assessment)
- Demand is a moving target. Reasonable people looking at same set of facts may draw reasonable but different conclusions about future path of demand
- Transparency and understanding why forecasts differ critical to reaching consensus

The 3.5 Billion Gallon Question(s)

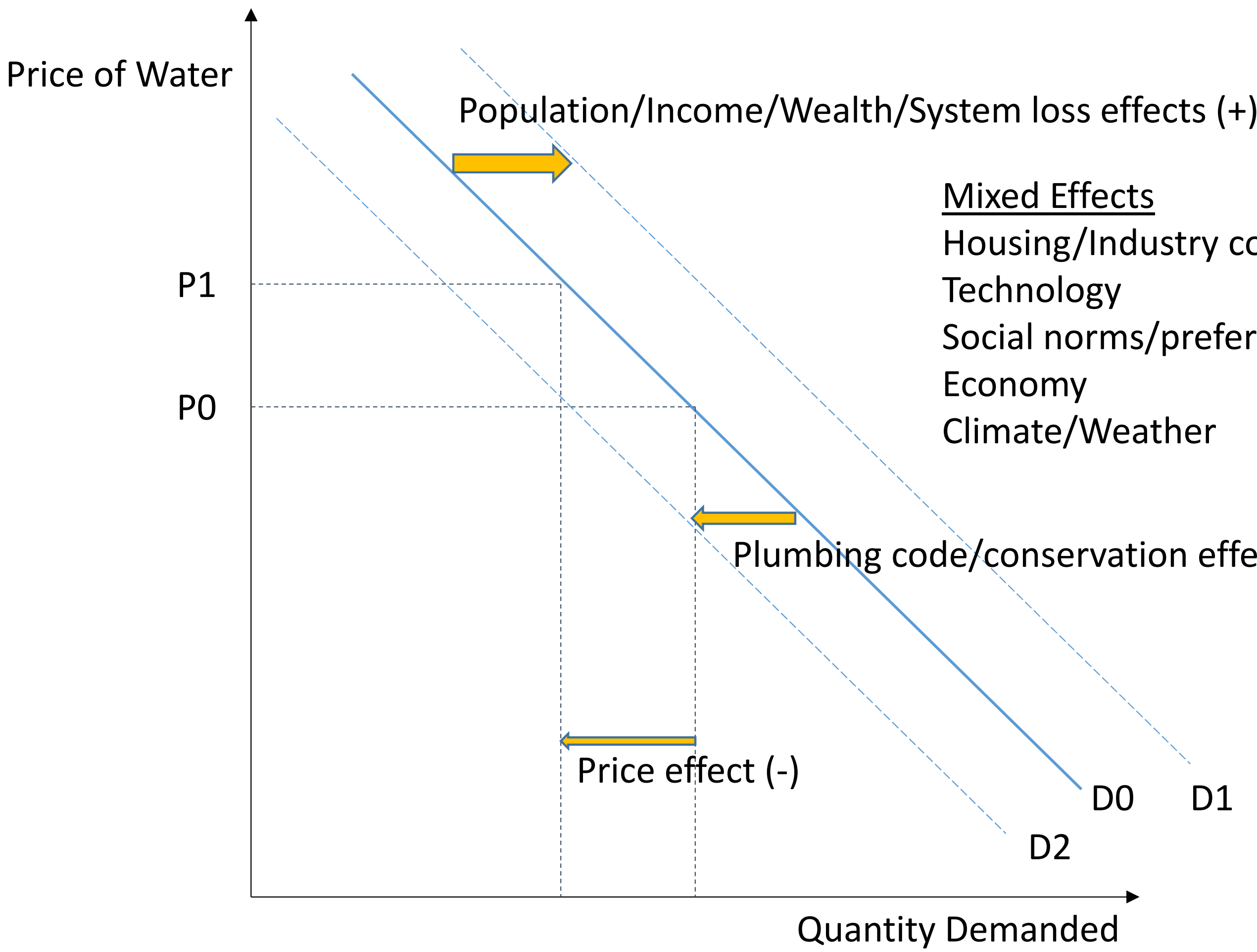
- Is this the right forecast?
- If not, too high or too low and by how much?
- How much confidence should we place in it? What is the margin of error?
- What data and methods were used to develop it?
- In what ways might we improve our data and methods?



Before we can forecast we need to know the key drivers of water demand?

- Demographics
  - Population
  - Land use
  - Housing composition
  - Industry composition
- Climate and Weather
  - Season
  - Rainfall, temperature, ET
- Technology
- Behavioral norms
- Price and rate structure
- Wealth and income
- Efficiency and conservation
- Water system maintenance and water loss

Graphical Depiction of Demand Drivers



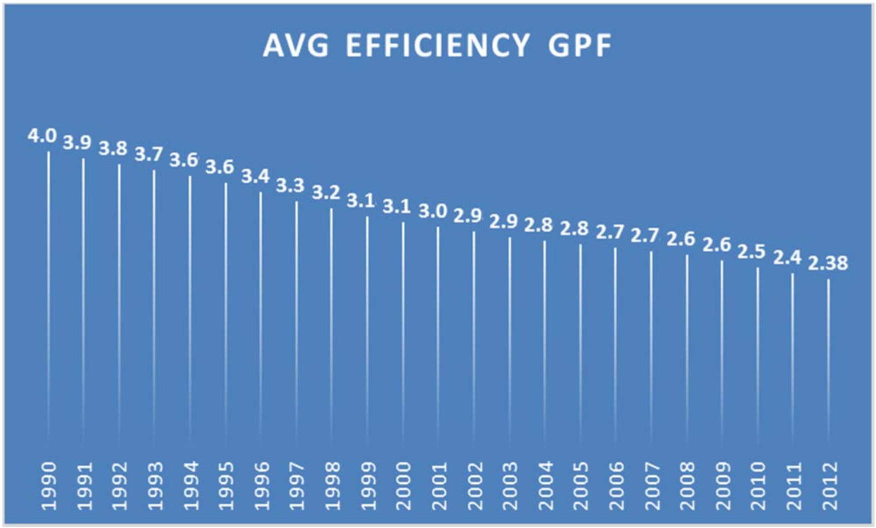
Mixed Effects

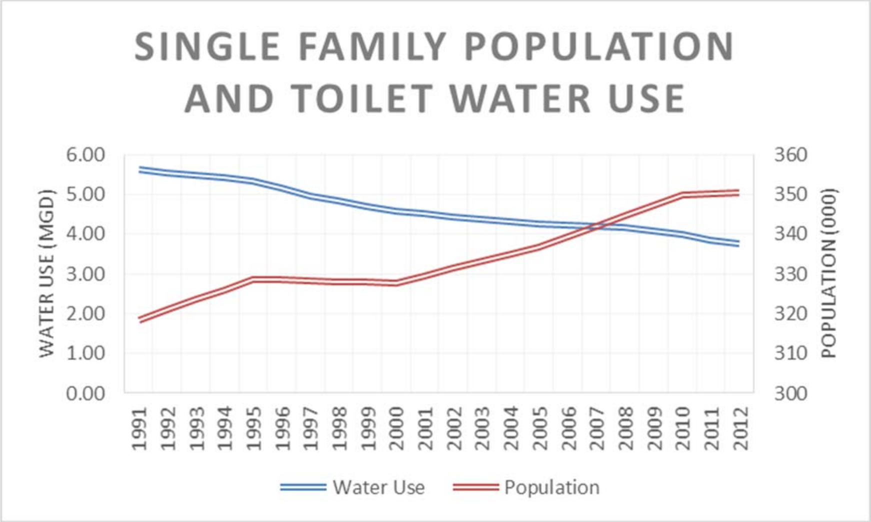
Housing/Industry composition	(+/-)
Technology	(+/-)
Social norms/preferences	(+/-)
Economy	(+/-)
Climate/Weather	(+/-)

Technology Effects: Some Examples

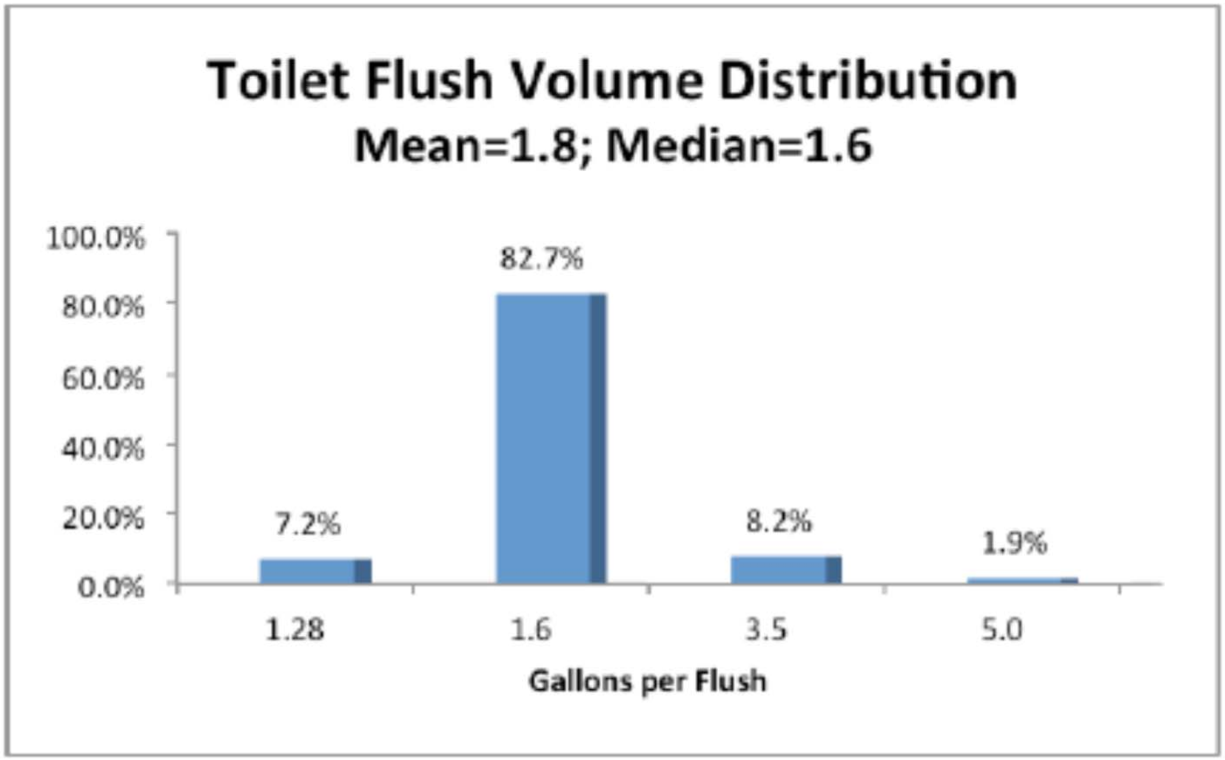
Technology	Change in Use
Toilets	Pre 1980: 3.5+ gal/flush 1991: 1.6 gal/flush 2014: <= 1.27 gal/flush
Urinals	Pre 1980: > 1 gal/flush 1991: 1.0 gal/flush 2014: <= 0.5 gal/flush
Clothes washers	Pre 2000s: 42 gal/load Mid 2000s: 21 gal/load Current: 12-21 gal/load
Irrigation Controllers	• "dumb" controllers have been found to increase water use. Households using manual watering typically under irrigate. Households with controllers often over irrigate. • "smart" controllers have been found to reduce water use if they replace "dumb" controllers and are properly calibrated. May increase water use if they replace manual watering

Example: Water Use by Single Family Toilets in San Francisco





Fixture Replacement in Santa Cruz will Continue to Push Per Capita Demand Down



Demand Forecasting Methods and Data

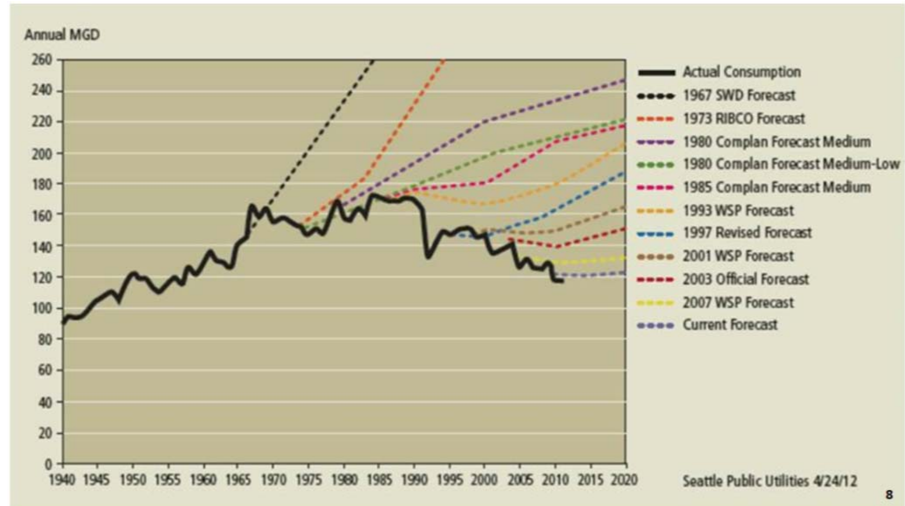
What's in the Forecaster's Toolbox?

- Trend Analysis
- Per Capita and Unit Use
- End Use Models
- Causal/Structural Econometric Models
- Hybrids of above models

All models are wrong, but some are useful. George E. P. Box, pioneering statistician

Trend Analysis

- Future based on extrapolation of past
- Only works if future is essentially similar to past
- Not good for long-run forecasting – time by itself is a poor predictor

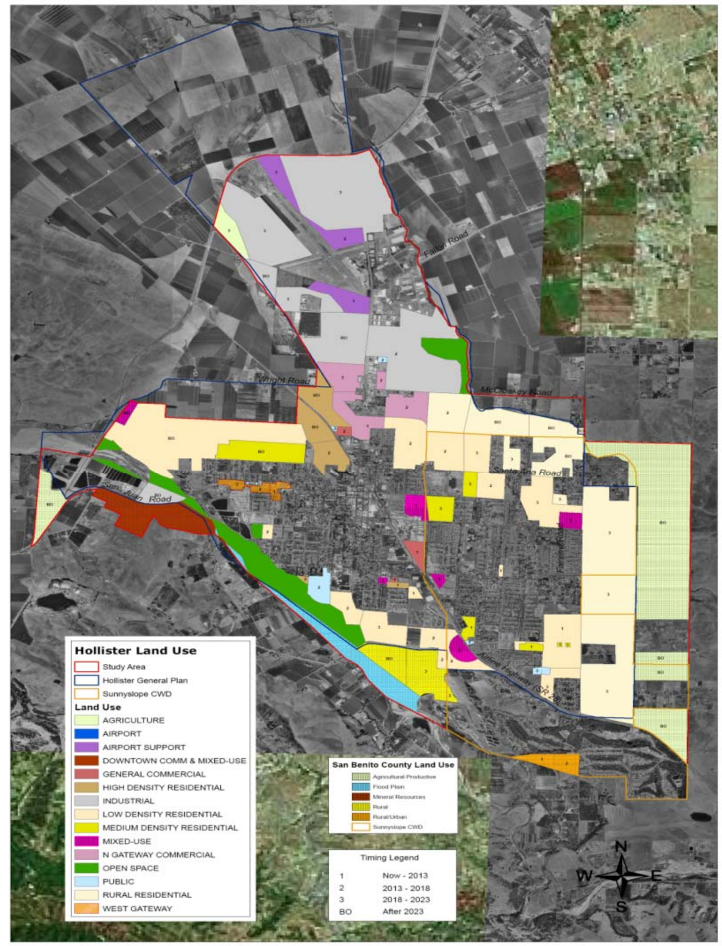


It attempts to explain water use in terms of a variable, time, which by itself explains nothing. The method is much too simplistic for virtually any application, and is highly sensitive to changes in the structure of water use.

Baumann, et al. Urban Water Demand Management and Planning

Unit Use Approaches

- Unit use coefficients calculated for land use or customer categories – e.g. residential, commercial, industrial
- Forecast = coefficients x number of units
- Common in water industry. Often combined with land use plan
- Implemented with GIS
- Most effective if coefficients adjusted to reflect changes in use over time
- Forecasts based on static coefficients tend to be biased upward



End Use Models

- Build forecast from inventory of water-using appliances, fixtures, landscapes
- Model change in inventory over time
- Good for modeling effects of plumbing codes, appliance standards, conservation programs – City has end use model for this purpose

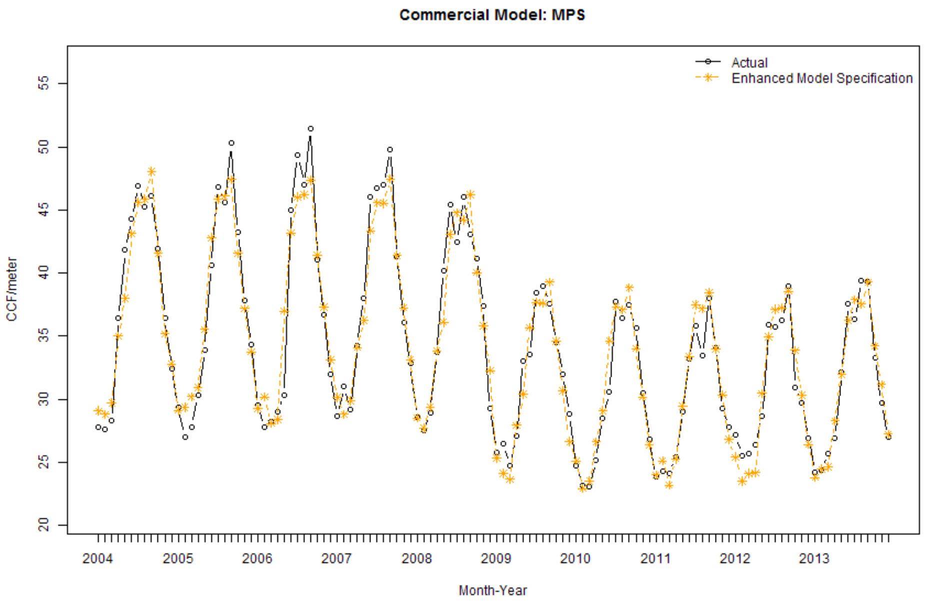
Table 1-2 End-use composition of single-family residential water demand

End-use	Percent of Total Use (likely range)	Gallons per Person per Day (likely range)
Indoor Uses		
Toilet flushing	20–25	15–25
Showering/bathing	15–20	10–20
Washing machine	10–15	10–20
Dishwasher	2–5	0–5
Faucet	5–10	5–20
Evaporative cooler	0–2	0–5
Humidifier	0–2	0–5
Leaks and drips	0–5	0–10
Outdoor Uses		
Lawn and garden watering	25–30	25–35
Swimming pool	0–5	0–5
Car washing	0–5	0–5
Driveway cleaning	0–2	0–2

Source: AWWA (1993).

Causal/Structural Econometric Models

- Estimates expected water use conditional on:
  - Population, climate, weather, price, income, land use, conservation investment, etc…
- Estimated using multiple regression methods
- Can place statistically-based confidence intervals around forecast
- Especially good for understanding effects of price/rate structure, income, climate, and weather on water use



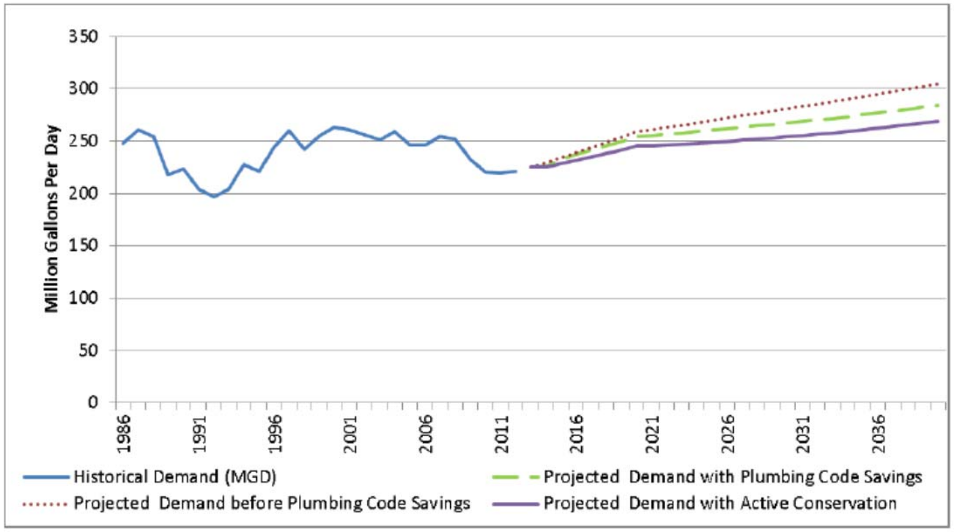
Hybrid Forecasts

Econometric model of demand

+

End Use Forecast of Conservation from Codes and Programs

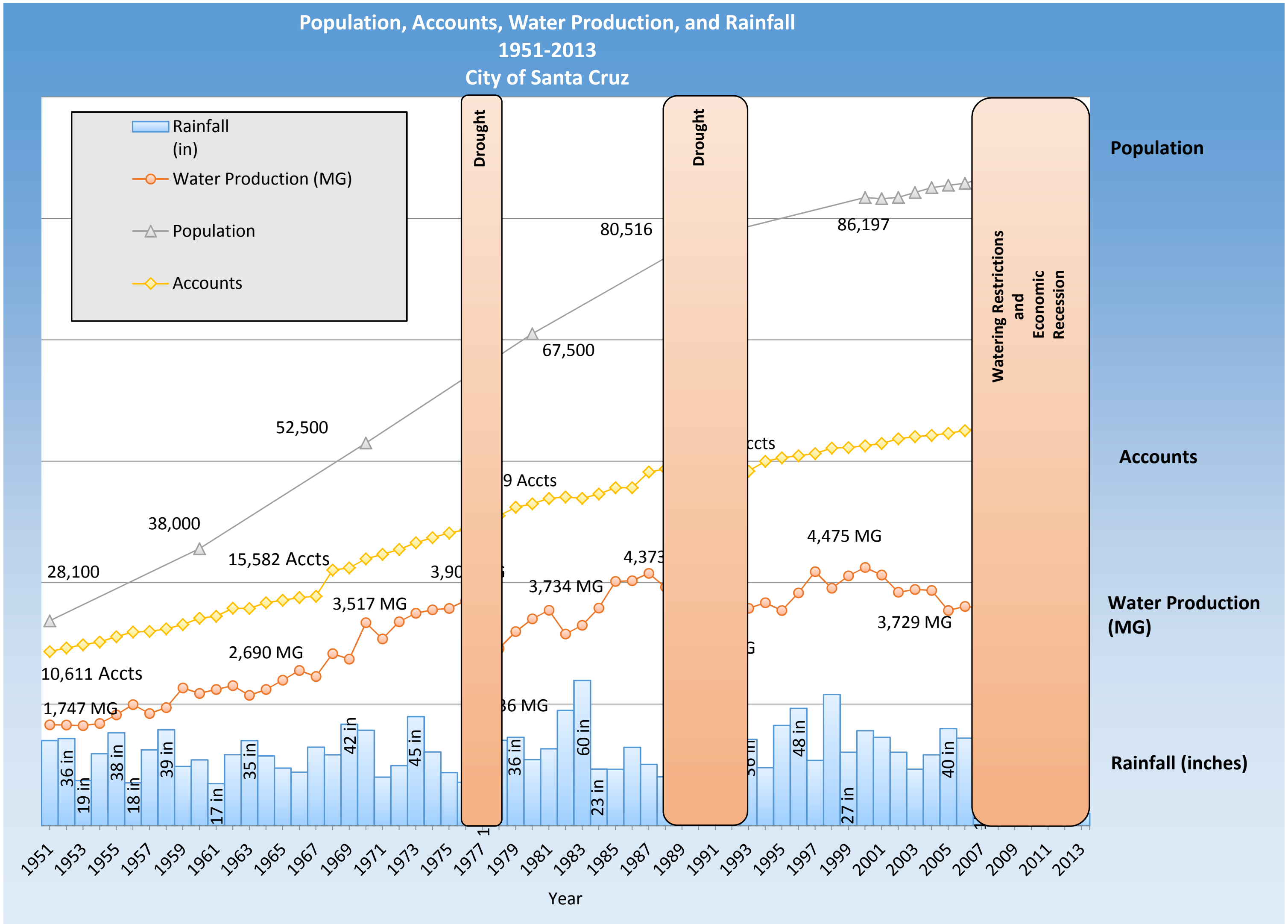
Figure 7. BAWSCA Region Wide Baseline Demands with Active Conservation Savings to 2040



Forecasting Principles and Constraints

- Principles
  - Parsimony – choose simpler over more complicated whenever possible. Avoid being fooled by over fitting the data with an overly-complex model
  - Disaggregation – separate demand into component parts and develop explanations of typical water use of customer groupings
  - Noise – aggregate behavior is less noisy than individual behavior. Forecasting average use easier than forecasting individual use
  - Balance – balancing tradeoffs of parsimony, disaggregation, and noise key to good models
- Constraints
  - Data – nearly always a limiting factor to any forecasting approach

City’s Demand Forecasting Methodology



Population, Accounts, Water Production, and Rainfall
1951-2013
City of Santa Cruz
Rainfall (in)
Water Production (MG)
Population
Accounts
Drought
Drought
Watering Restrictions and Economic Recession
28,100
38,000
52,500
67,500
80,516
86,197
10,611 Accts
15,582 Accts
1,747 MG
2,690 MG
3,517 MG
3,734 MG
4,475 MG
3,729 MG
36 in
19 in
38 in
18 in
39 in
17 in
35 in
42 in
45 in
36 in
60 in
23 in
48 in
27 in
40 in
Year
Population
Accounts
Water Production (MG)
Rainfall (inches)

Regulatory Background

Urban Water Management Planning Act

CA Water Code 10631 e:

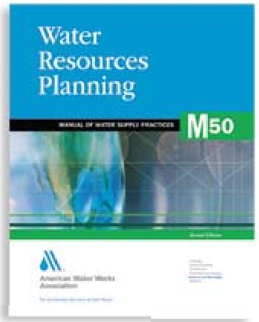
- Projected water use
- 5-year increments to 20 years
- By water use sector
- Update every 5 years – due again in 2016

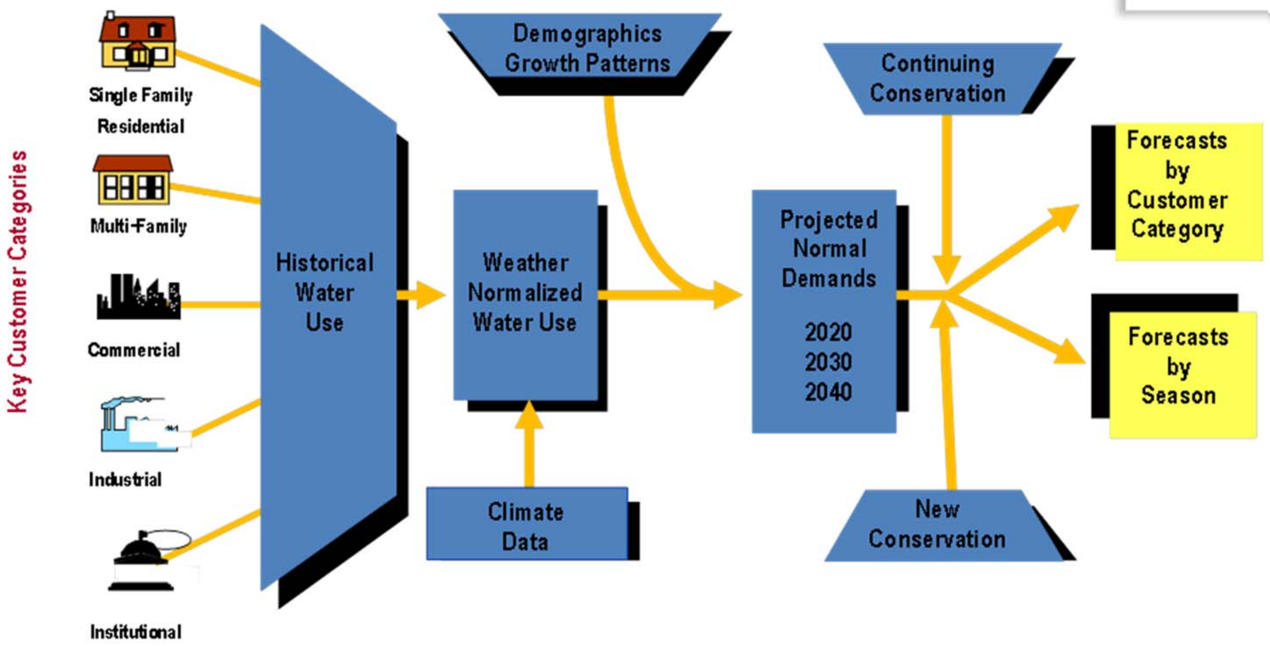
SB 610 of 2001

Coordinate local water supply and land use decisions

Regional Housing Needs Allocation (RHNA)

Flow of Information





Basis for Current Projections

Two Purposes w/ Shared Planning Horizon – 2030

1. City's General Plan & EIR
2. 2010 Urban Water Management Plan

Two primary components:

1. Existing Demands as of 2010
2. New Demands expected between 2010 and 2030

Breakdown

1. Inside and Outside City
2. Customer Category

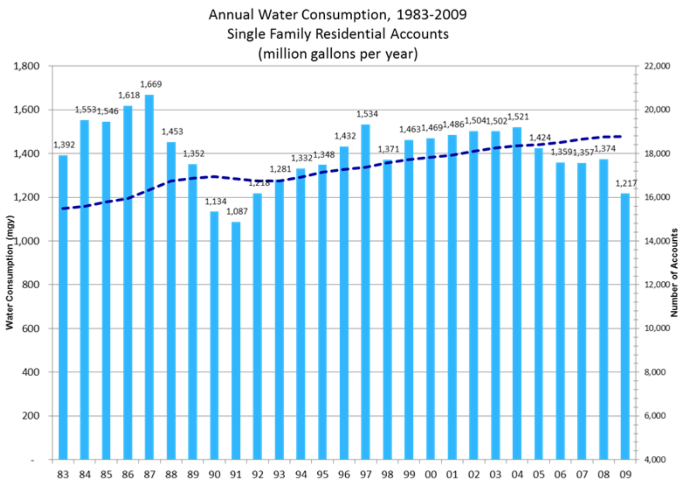
Existing Water Demand

Primary information:

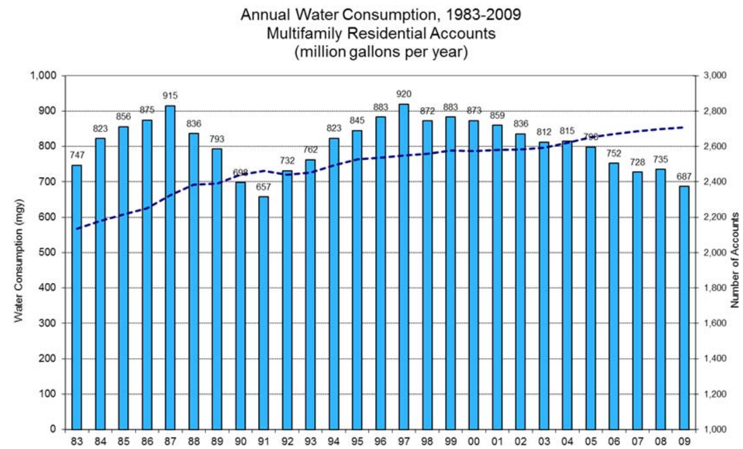
- Number of accounts (utility billing system)
- Average water use per account per day (utility billing system, tracking models)

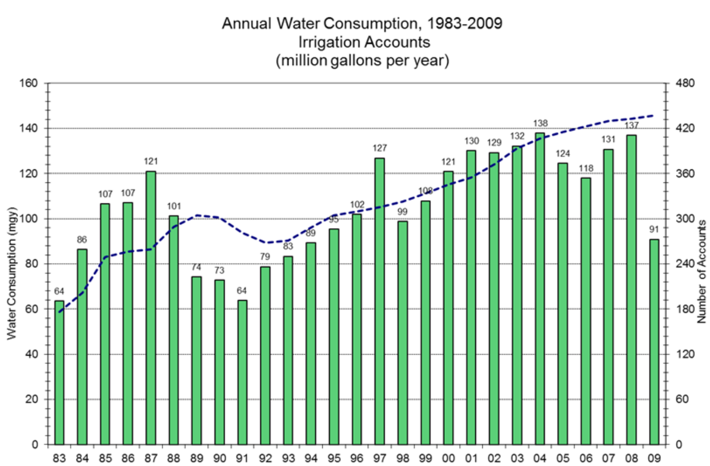
Billing frequency

- Inside City - monthly since 2005
- Outside City – bimonthly up to 2014
- → Separate tracking models

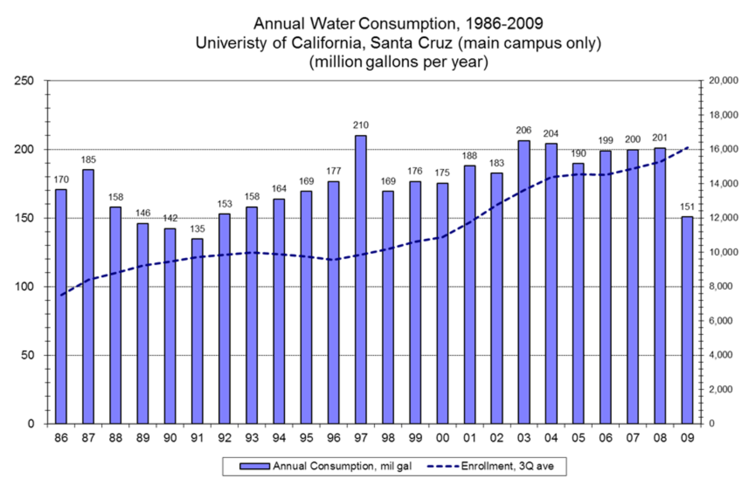


Sharp decline in residential use per account starting mid 2000s





Irrigation and UC use per account steady until 2009 when it sharply drops



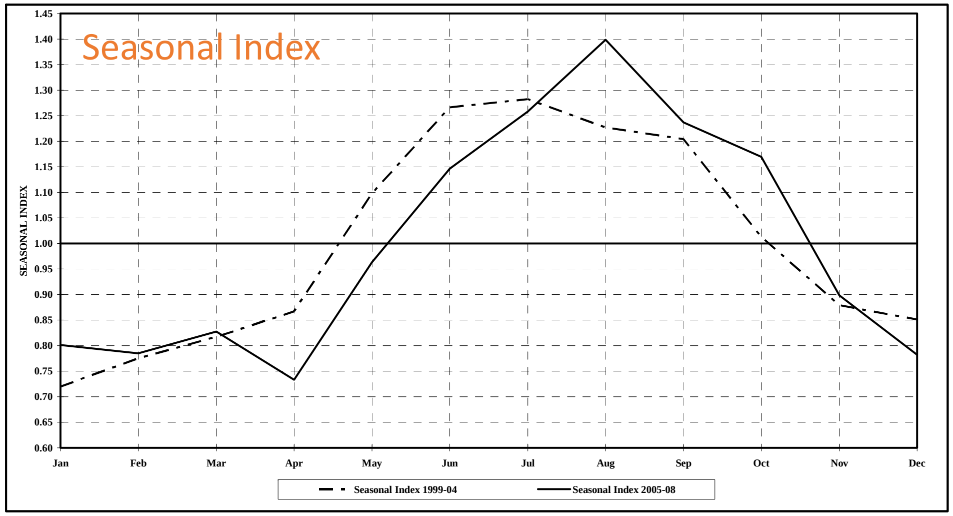
Weather Normalizing Historical Use

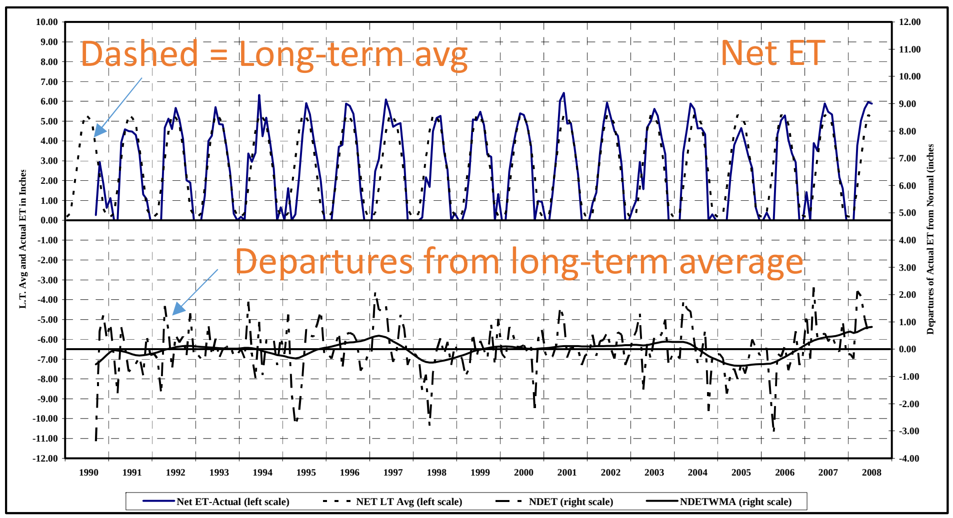
- Period of Record: monthly use 1999-2004
- Construct seasonal index (SI)
- Calculate 3-month moving average of deviation from normal in net ET (DET)
- Regress monthly use on seasonal index and deviation in net ET

$$Use_t = \beta_0 + \beta_1 SI_t + \beta_2 DET_t + \varepsilon_t$$

- Net ET = ET – Effective Rainfall
- Normalized Use:

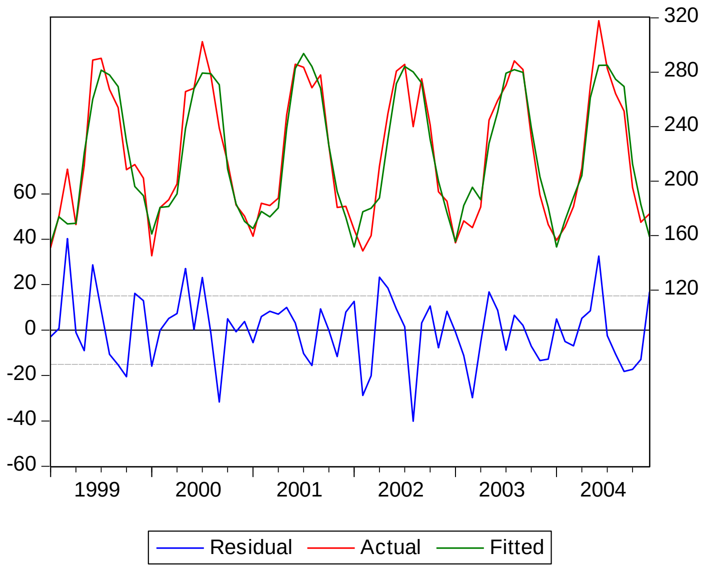
$$NormUse_t = \hat{\beta}_0 + \hat{\beta}_1 SI_t$$

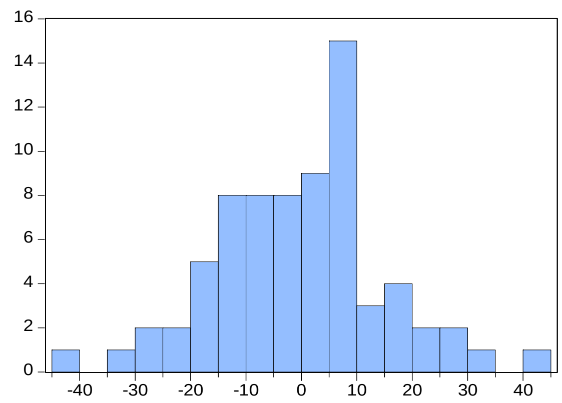




Predicted vs Actual Use and Model Residuals

Single Family – Inside City

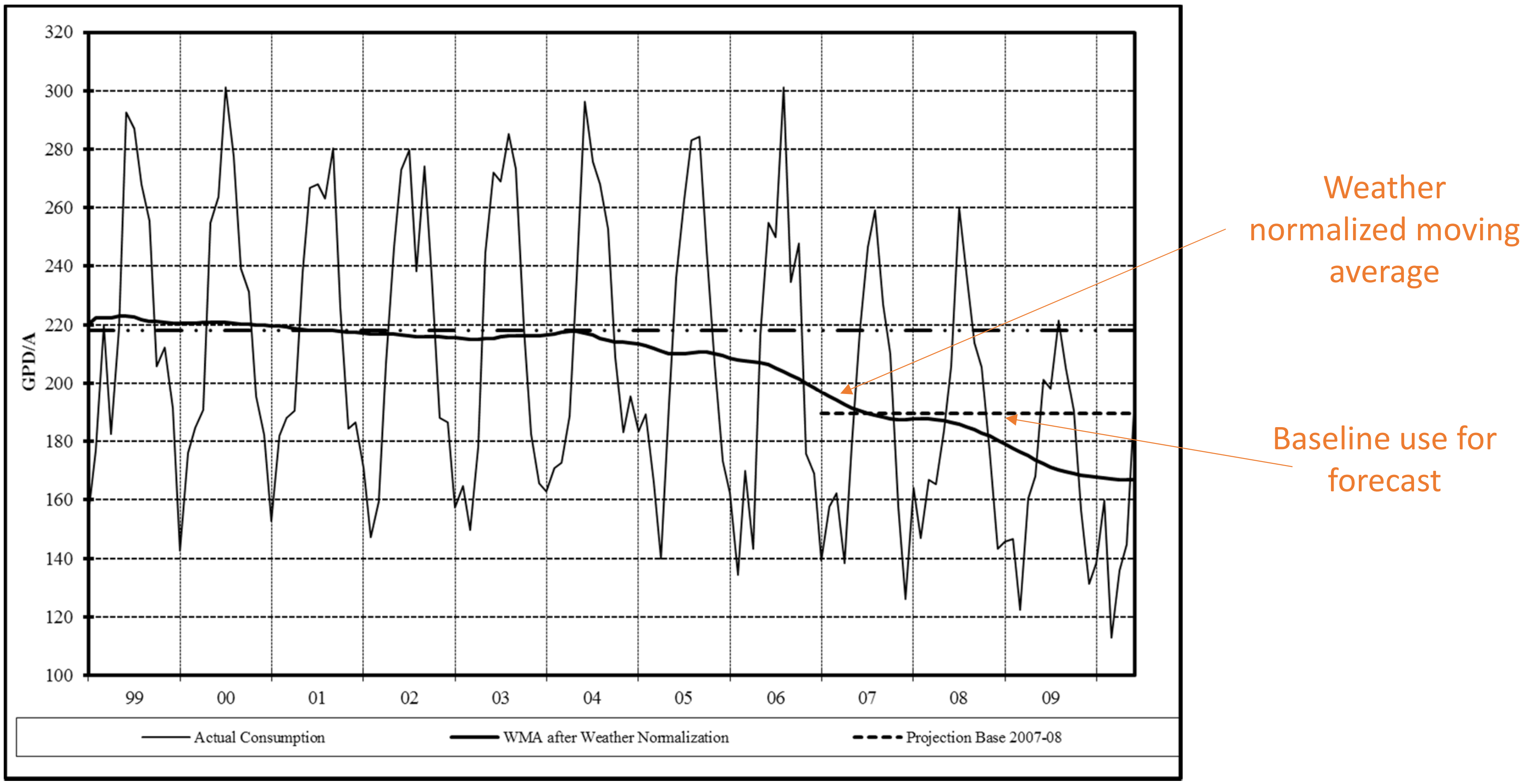




Series: Residuals
Sample 1999M01 2004M12
Observations 72

Mean	0.118168
Median	0.472204
Maximum	40.32324
Minimum	-40.16805
Std. Dev.	15.02112
Skewness	-0.025436
Kurtosis	3.384809
Jarque-Bera	0.451997
Probability	0.797719

Single Family – Inside City



Example: SFR Inside City

12,121	Accounts inside City (2010)
x 189.7	Gallons per account per day
x 365	Days/year
= 839	Million gallons per year

Similar 2010 normalized use forecasts developed for inside/outside city multifamily, business/industrial, irrigation/golf, municipal

Model Demo

2030 Forecast

New Demands to 2030

- **Inside the City**
  - Estimated General Plan 2030 build-out projections
  - Water demand factors for residential and commercial development
- **Outside the City**:
  - Scaled up residential and business sectors by 8% in accordance with AMBAG population projections
- **University of California**
  - Existing demand 212 mgy (200 mgy main campus)
  - Additional demand 2020: 126 mgy per its water supply assessment
  - Additional 10 mgy from 2020 to 2030

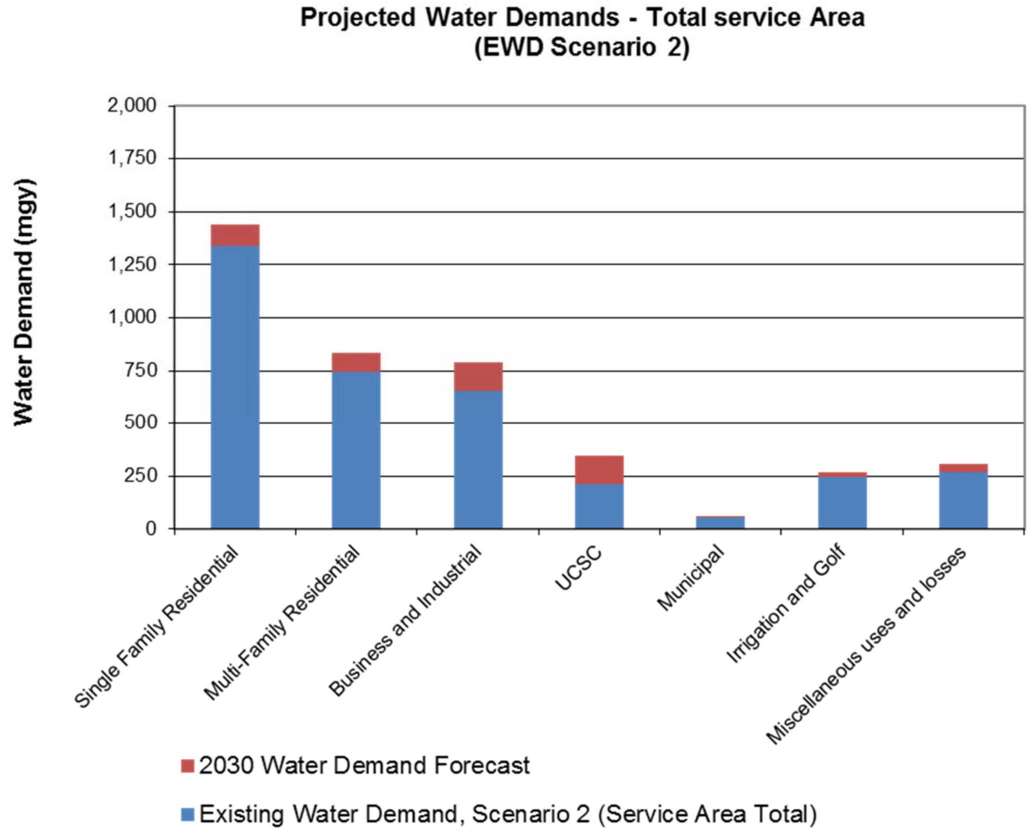
New Demands to 2030

- Inside the City: Estimated General Plan 2030 Buildout (DC&E, 2009)

General Plan 2030 Water Demand

	Buildout Projections (a)	**Water Factor**	**Water Demand (mgy)**
Single Residential (b)	840	194 gal/unit/day	59.6
Multiple Residential (b)	2,510	70 gal/unit/day	64.3
Business/Industry:			
- Commercial Sq Ft	1,087,983	66 gals/ft^2/year	71.8
- Hotel Rooms	311	93 gal/room/day	10.6
- Office Sq Ft	1,273,913	18 gal/ ft^2/year	22.9
- Industrial Sq Ft	776,926	12 gal/ ft^2/year	9.3
Total			**238.5**

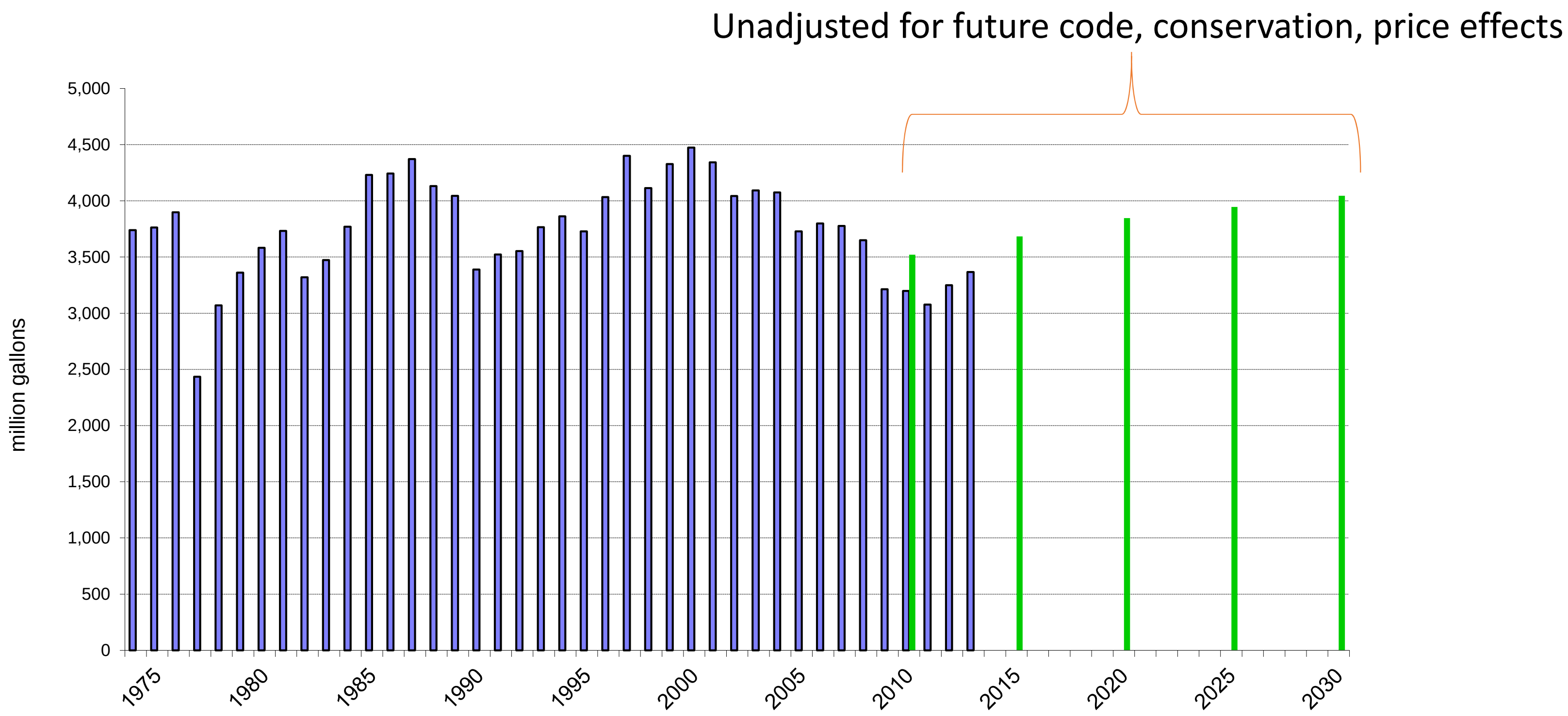
2030 Water Demand – Unadjusted for future code, conservation, price effects



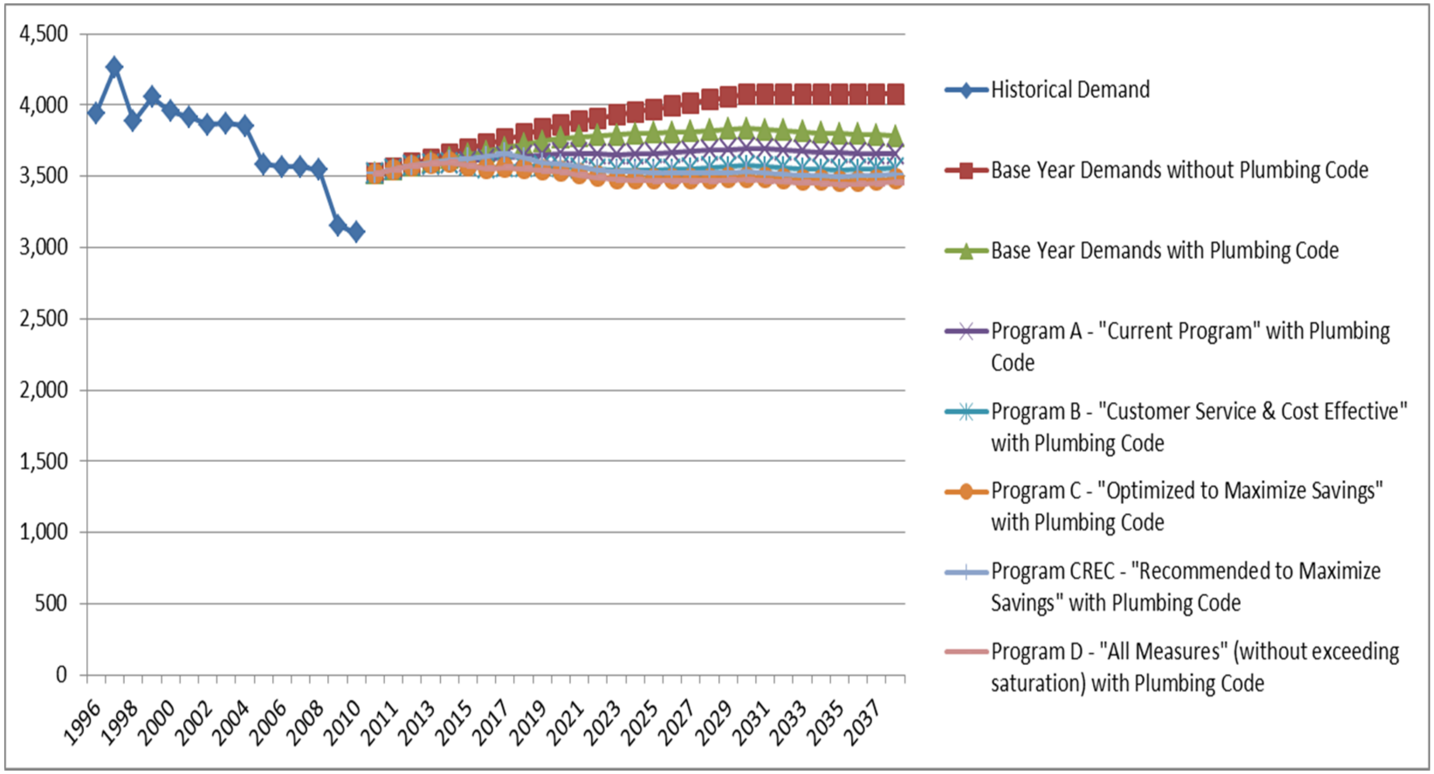
Total System Demand – Unadjusted for future code, conservation, price effects

Location:	Customer Class	2010	2015	2020	2025	2030
City of Santa Cruz	Single Residential	839	854	869	884	899
	Multiple Residential	408	424	440	456	472
	Business/Industry	425	454	483	511	540
	Municipal	54	54	55	55	56
	Irrigation/Golf	115	118	120	122	125
	UC Santa Cruz	212	276	339	344	349
Inside City Subtotal		**2,055**	**2,180**	**2,306**	**2,373**	**2,441**
Outside City: *County, Capitola, & North Coast Irrigation*	Single Residential	502	513	523	533	543
	Multiple Residential	336	343	350	357	364
	Business/Industry	231	236	240	245	250
	Municipal	-	-	-	-	-
	Irrigation/Golf	130	133	135	138	141
Outside City Subtotal		**1,199**	**1,224**	**1,248**	**1,273**	**1,297**
Other miscellaneous uses including water losses		268	280	292	300	307
Total System Water Demand		**3,522**	**3,684**	**3,847**	**3,946**	**4,046**

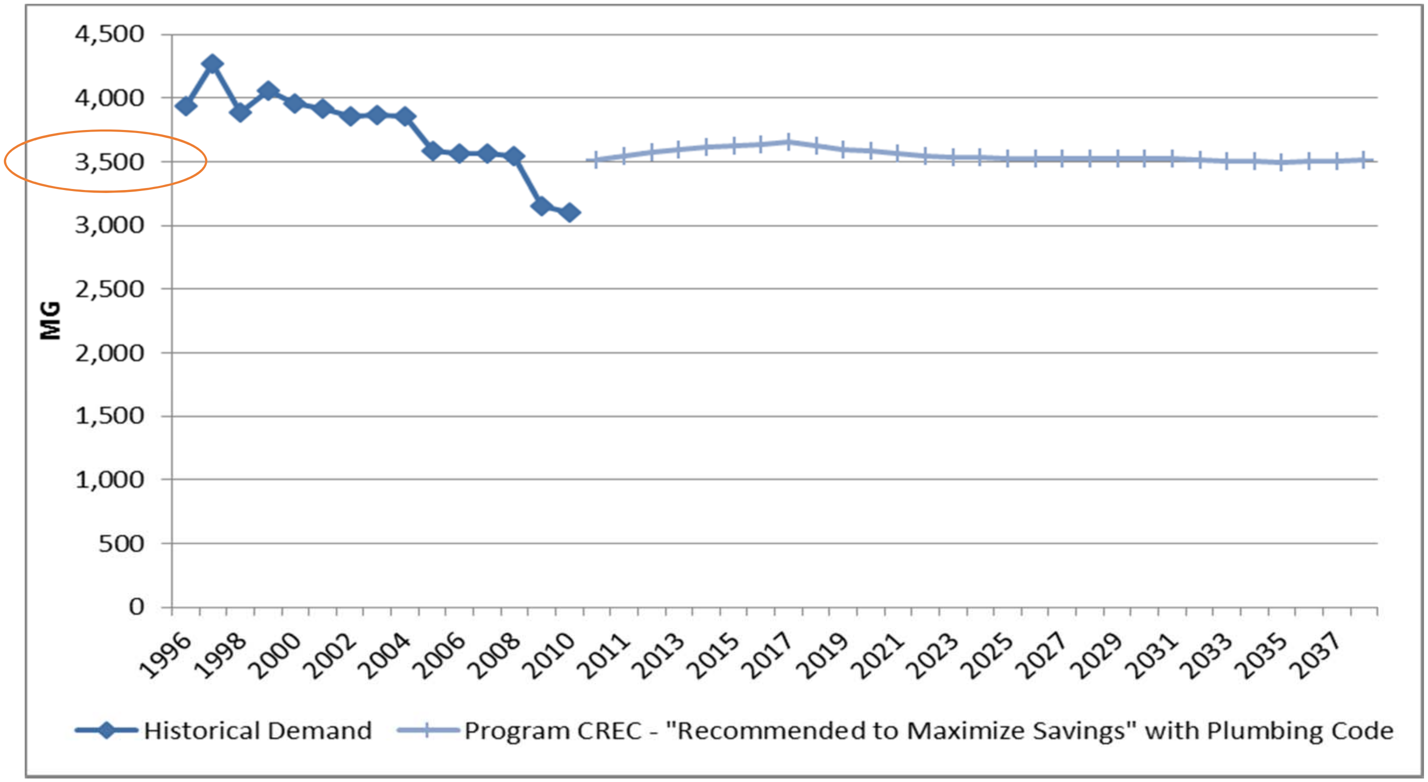
Historic and Projected Water Demand



Code and Conservation Adjustments



This is how the 3.5 bgy forecast was generated



Who's that elephant standing in the corner? UCSC growth and water use projections

- UCSC Projecting Use to Increase 65% between now and 2030
  - 1986-2008 (22 yrs) use increased 18%. Over same period enrollment approximately doubled
  - Need better understanding of UC's assessment of future use
- Status of Legal and Policy Issues of UCSC Development Plan
- Implication for demand forecast
  - Uncertainty about UC future demand can be bounded with low and high demand scenarios
  - For sake of discussion, assume UC use continues to grow at historical rate: 2030 UC demand = 240 mgy instead of 349 mgy
  - Is this a plausible lower-bound?

Five Things City Could Do In Relatively Short Order to Improve Forecast

1. Update population, land use, housing projections to most current (in process)
2. Adopt new weather normalization methodology consistent with CUWCC GPCD Weather Normalization Methodology. Control for price, income, employment, and conservation effects
   a) Part of developing an econometric model of demand, which we will discuss after the break
3. Re-examine average use of new development. Update as necessary
4. Adjust forecast for effects of
   a) plumbing codes and appliance standards (doing now)
   b) planned conservation programs (doing now)
   c) planned rate increases
   d) forecast changes in household income (must be mindful of shifting income distribution)
5. Bound UCSC future demand with low/high forecasts

Let’s Take a Break

Statistically-Based Demand Models

What the heck is an Econometric Demand Model, anyway?

- Uses historical data on water use and variables thought to be related to water use to statistically estimate an equation explaining water use in terms of the other variables

- $Use = f(pop, climate, weather, price, income, \ldots) + error$

- Estimated with regression methods (e.g. OLS, GLS, Panel Estimation)

An Actual Model Specification

$$\tilde{y}_{it} = y_{it} + \widehat{conservation}_{it}$$

$$ln(\tilde{y}_{it}) = \beta_{0i} + \beta_1 ln(price_{it}) + \beta_2 ln(income_{it}) + \beta_3 unempl_{it} + \beta_{4i} reclass_{it} + \beta_{5i} trend_t + climate_{it} + weather_{it} + \varepsilon_{it} \quad (5)$$

Captures seasonal effects on use given normal weather

$$climate_{it} = \sum_{t=1}^{12} \alpha_{it} month_t \quad (3)$$

Captures weather effects on use when weather departs from normal

$$weather_{it} = \sum_{s=1}^{3} \gamma_s precip_{it} \times season_s \times TPF_i + \sum_{s=1}^{3} \delta_s temp_{it} \times season_s \times TPF_i \quad (4)$$

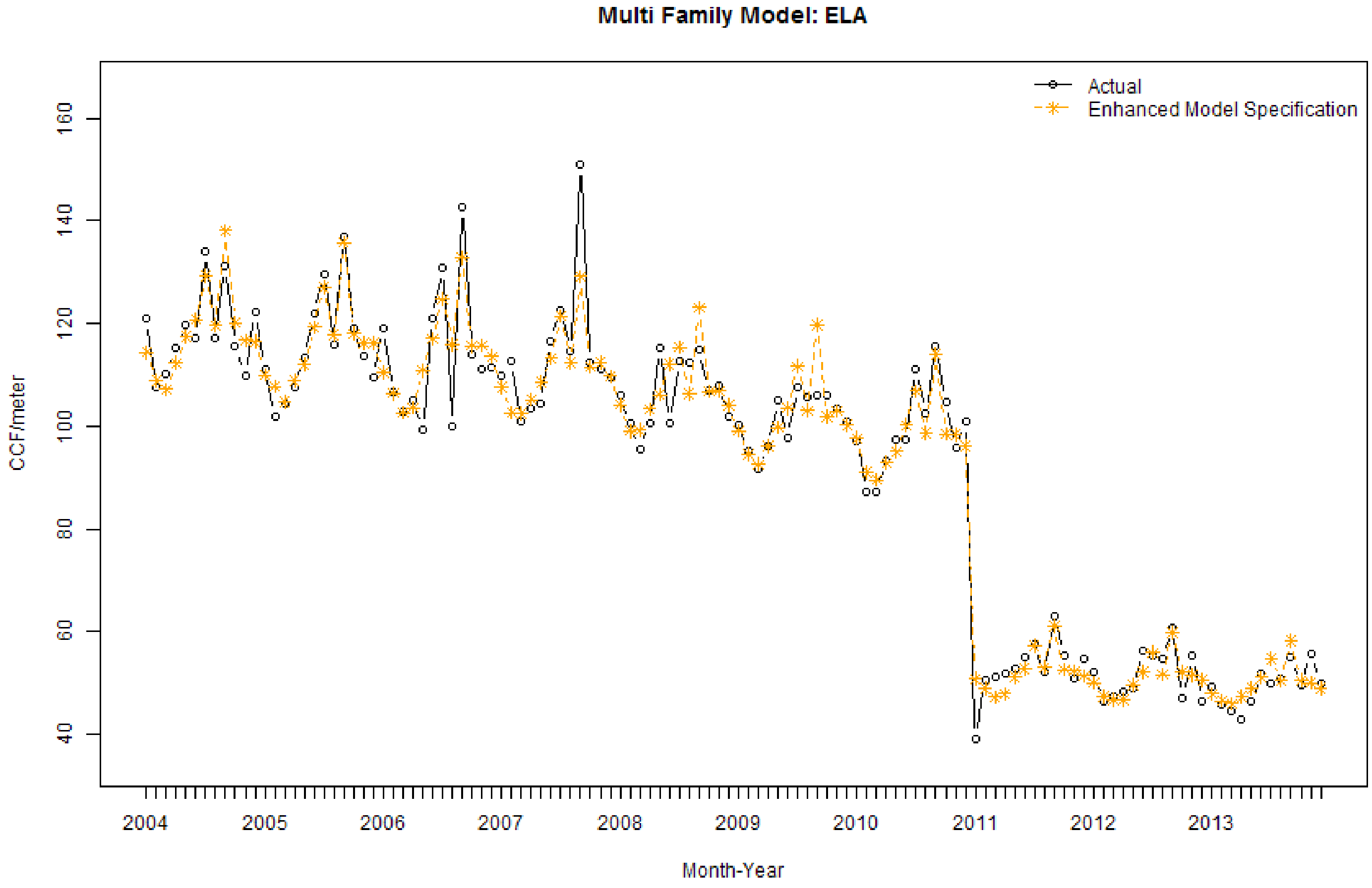
Predicted Use

$$\hat{y}_{it} = exp\left[\hat{\beta}_{0i} + \hat{\beta}_1 ln(price_{it}) + \hat{\beta}_2 ln(income_{it}) + \hat{\beta}_3 unempl_{it} + \hat{\beta}_{4i} reclass_{it} + \hat{\beta}_{5i} trend_t + \sum_{t=1}^{12} \hat{\alpha}_{it}\, month_t + \sum_{s=1}^{3} \hat{\gamma}_s precip_{it} \times season_s \times TPF_i + \sum_{s=1}^{3} \hat{\delta}_s temp_{it} \times season_s \times TPF_i\right] - code\widehat{savi}ngs_{it} \quad (6)$$

Weather Normalized Predicted Use

$$\hat{y}_{it}^{N} = exp\left[\hat{\beta}_{0i} + \hat{\beta}_1 ln(price_{it}) + \hat{\beta}_2 ln(income_{it}) + \hat{\beta}_3 unempl_{it} + \hat{\beta}_{4i} reclass_{it} + \hat{\beta}_{5i} trend_t + \sum_{t=1}^{12} \hat{\alpha}_{it}\, month_t\right] - code\widehat{savi}ngs_{it} \quad (7)$$

Predicted Use Graph



Data requirements

- Water use – from billing system records
- Weather – NOAA, CIMIS stations
- Price – historical utility rates
- Income – Census
- Employment – BLS
- Household size – Census, American Housing Survey, direct survey
- Household characteristics – direct survey, American Housing Survey
- Conservation/Code Savings – End use model

Estimation Pitfalls

Omitted and Unobserved Variables – can bias estimated parameters

Solution: include major demand drivers in model; fixed-effects estimation to control for unobserved variables

Serially Correlated and Heteroskedastic Errors – can bias standard errors of estimated parameters and lead to incorrect confidence intervals

Solution: Reexamine model specification for omitted variables. Estimate model using robust regression methods to get correct errors

Data Outliers – can bias estimated parameters

Solution: screen and clean data prior to estimation. Estimate using robust regression methods to downweight outliers

This seems hard. Why do it?

- Allows us to quantify effects of variables that cause water use to go up or down
- We can then examine the effect each variable had on observed water use – e.g. how much of observed change because of weather, change in price, change in employment?
- We can use the estimated relationships to forecast future water demand using forecasts of the independent variables – e.g. if price is expected to increase 40% over next 10 years, what effect will this have on water use?
- We can quantify the uncertainty of our prediction – e.g. we can put statistical confidence intervals on the forecast. This gives a good measure of how much faith to put in the forecast.

Example: Effect of economic downturn on BAWSCA members water sales

Independent Variable	Coefficient	Std. Error	t-statistic
Ln(Marginal Price)	-0.168	0.010	-16.3
Ln(Unemployment Rate)	-0.051	0.004	-12.5

Model indicates that water use decreases ½ percent for each 10% increase in unemployment

From 2007 to 2010, unemployment in San Francisco-San Mateo-Redwood City Metropolitan Area went from 4.0% to 9.0%, an increase of 125%.

$\%\Delta Use = (-0.051\% \pm 0.008\%) \times 125\% = -6.375\% \pm 1.00\%$

Climate/Weather Factors

What do we know about how climate/weather effect demand

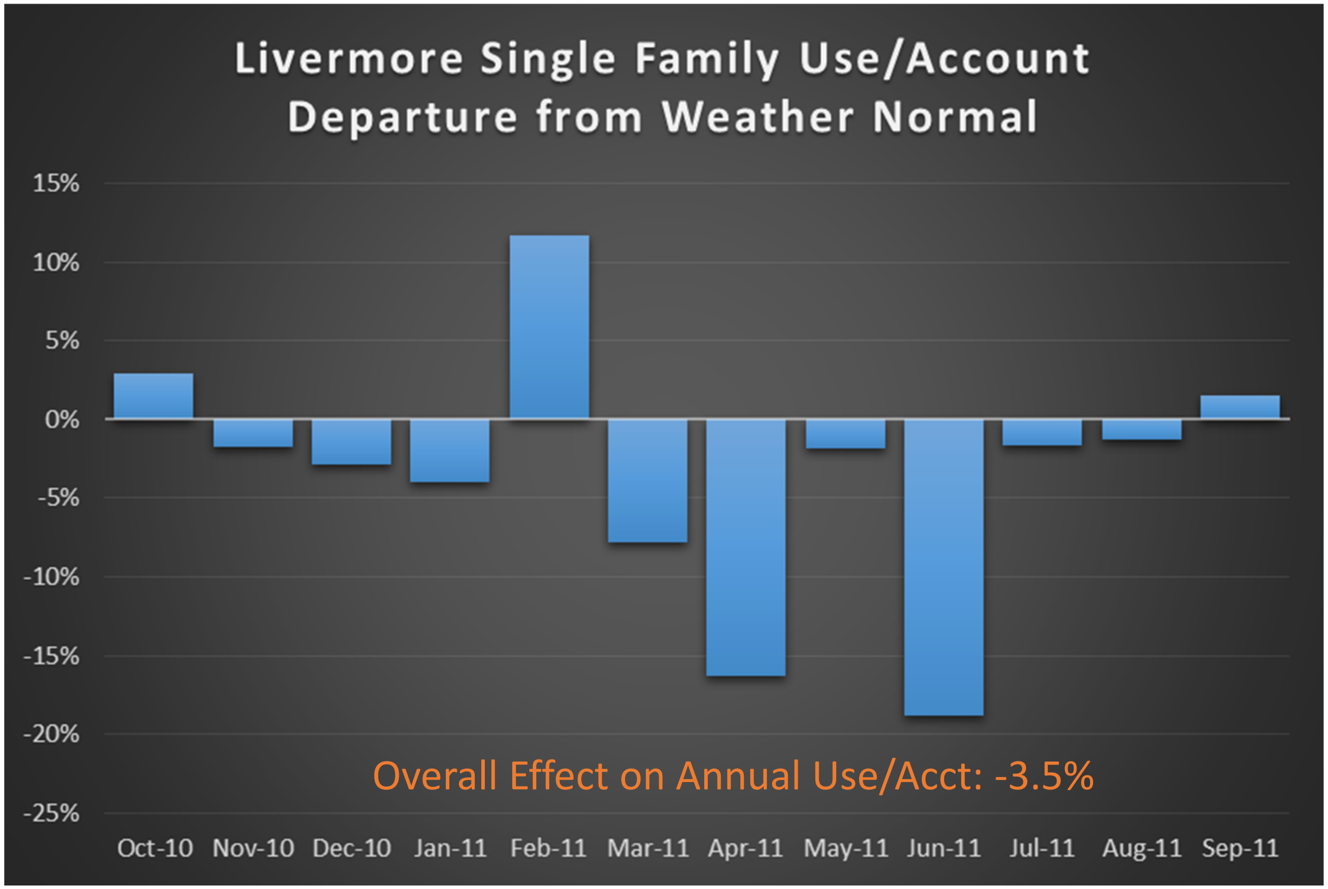
CUWCC GPCD Weather Normalization Study

Based on sample of 18 CA urban water suppliers

Table 5 Estimated weather impacts by season and peaking factor

Peaking factor	Nov-Mar	Apr-Jun	Jul-Oct	Nov-Mar	Apr-Jun	Jul-Oct
	Weather Normalization based upon temperature and rainfall					
	Per 1° temperature deviation			Per 1" rainfall deviation		
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	1.26%	1.32%	0.70%	-0.31%	-3.86%	-2.16%
3	1.69%	1.77%	0.93%	-0.42%	-5.11%	-2.87%
4	1.90%	1.99%	1.05%	-0.47%	-5.73%	-3.22%
5	2.03%	2.13%	1.12%	-0.50%	-6.10%	-3.44%
6	2.11%	2.22%	1.16%	-0.52%	-6.35%	-3.58%
	Weather normalization based upon rainfall adjusted reference ETo					
	Per 1" deviation					
1	0.00%	0.00%	0.00%			
2	5.26%	11.25%	6.03%			
3	7.07%	15.27%	8.13%			
4	7.99%	17.30%	9.19%			
5	8.54%	18.60%	9.83%			
6	8.91%	19.44%	10.26%			

Weather Effects: Oct 2010 – Sep 2011



	Actual	Normalized for Weather
WY 2010	185.4	190.0
WY 2011	182.0	188.7
% Diff	-1.8%	-0.7%

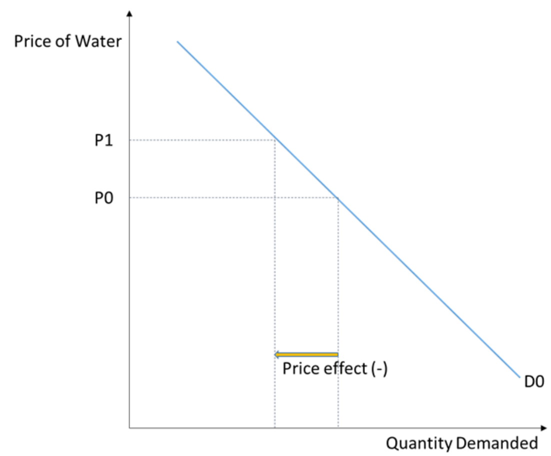
More than half observed % decrease from WY 2010 to WY2011 due to weather

Economic Factors

Effect of Price on Demand

- Need vs Demand: Utility planners often think in terms of water needs, but very little water use is based on need – about 23 gpcd according to UN estimates (1976)
- Water Service is a Normal Good: The Law of Demand applies
- Demand curve slopes downward

Water industry did not believe this to be true for first 80 years of its existence

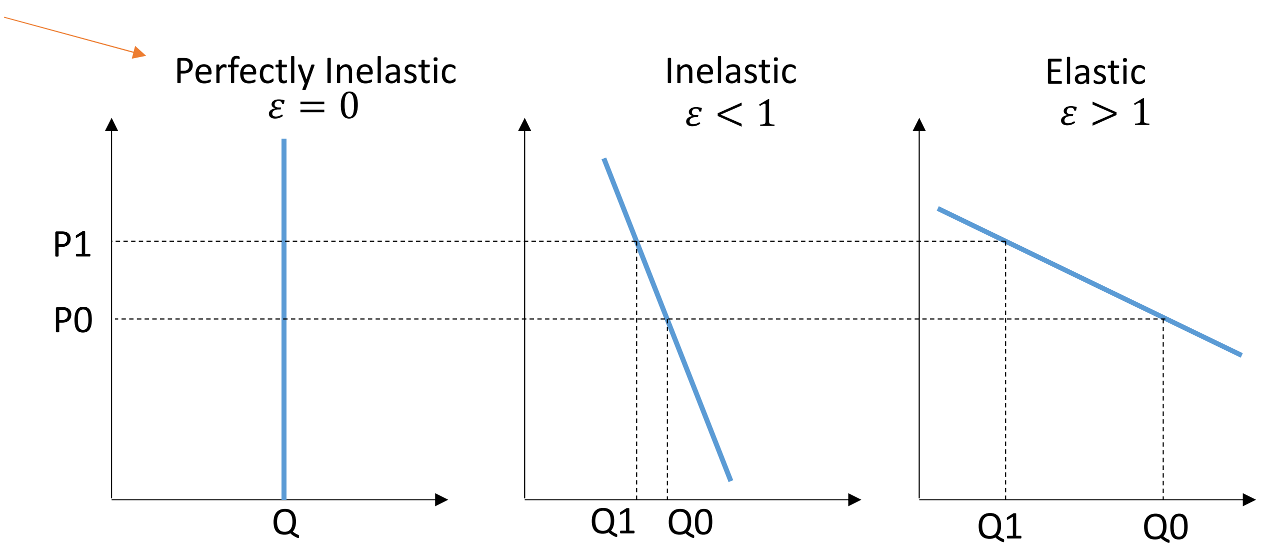


Price Elasticity

- Measures responsiveness of demand to change in price

water utilities often wrongly make this assumption when forecasting demand

$$\text{Price Elasticity} = \frac{\%\Delta Use}{\%\Delta Price}$$



Typical Price Elasticity Ranges for Residential Water Demand

CUWCC Conservation Rate Structure Handbook Guidance

TABLE 8-9

SUMMARY OF LONG RUN ELASTICITY ESTIMATES FOR PLANNING PURPOSES

Single Family Residential Customers	*Range of Estimates*
Winter season	-.10 to -.30
Summer season	-.20 to -.50
Multiple Family Residential Customers	
Winter season	-.00 to -.15
Summer season	-.05 to -.20

Source: Dziegielewski et al. (1991)

TABLE 8-10

RECOMMENDED SHORT RUN ELASTICITY ESTIMATES FOR CONSERVATION RATE DESIGN

Single Family Residential Customers	Range of Estimates
Winter season	-.00 to -.10
Summer season	-.10 to -.20
Multiple Family Residential Customers	
Winter season	-.00 to -.05
Summer season	-.05 to -.10

Source: Author's construct.

Water demand is price inelastic, but not perfectly inelastic

Recent Empirical Price Elasticity Estimates

- BAWSCA Total Demand: -0.17 ± 0.02
- Cal Water (25 service districts)
  - Single Family: -0.22 ± 0.06
  - Multi Family: -0.14 ± 0.11
  - Commercial: -0.07 ± 0.09

These studies included controls for change in water use due to plumbing codes/appliance standards and utility conservation programs

Price Effect vs Price + Conservation Effect

- Published elasticity estimates often based on studies with inadequate controls for plumbing code/appliance standard/conservation program effects
- Consequence: price effect overstated
- Risk to forecast: forecast may double count effects of code/appliance standard/conservation if these effects also enter explicitly into the forecast

Implication of Price Effects for Demand Forecast

- Rates projected to increase 10%/yr over next 5 years
- Net of inflation, increase of 44%
- Short-run demand adjustment: 44% x -0.2 ≈ -9%
- Long-run demand adjustment: 44% x -0.3 ≈ -13%

Income Effects

- Income is positively correlated with demand. Higher income communities use more water per person, all else equal.
- Income effects offset price effects to some degree
- More concentrated income distribution may change historical relationship – make demand less responsive

Another elasticity

$$Income\ Elasticity = \frac{\%\Delta Use}{\%\Delta Income}$$

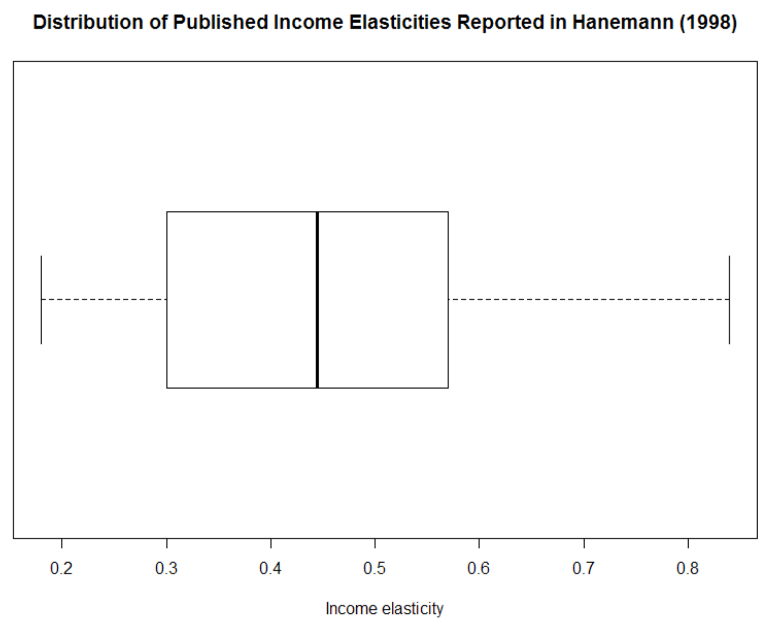
Income Elasticity Empirical Estimates

- Cal Water

  Single Family Demand: 0.21 ± 0.15

- Published Estimates

  Income elasticities reported by Hanemann are mostly from studies published in 1970s and 1980s.



Implication of Income Effects for Demand Forecast

- Cal Trans Santa Cruz County Economic Forecast: Real per capita income increase of 35% by 2030
- If single family income elasticity is 0.3, then change in single family demand = 35% x 0.3 = 10.5%
- Change in total demand = 10.5% x 0.41 (single family share of total demand) = 4.3%

Employment Effects

- Employment is positively correlated with commercial/industrial use
- BAWSCA Unemployment Rate Elasticity: -0.051
  - Relative to total demand
- Cal Water Unemployment Rate Elasticity: -0.065
  - Relative to commercial/industrial demand

Implication of Employment Effects for Demand Forecast

- Cal Trans Santa Cruz County Economic Forecast: Unemployment rate decrease by 40% by 2023 (relative to 2013)

- If unemployment elasticity is -0.051, then change in total demand by 2023 = -40% x -0.051 = 2.0%

Summary of Back-of-Envelope Economic Adjustments

Effect	% Change in Demand
Price (long-run)	-13.0%
Income	+4.3%
Employment	+2.0%
Total	-6.7%

A Forecast of Next Steps

Updating City's Long-Range Demand Forecast

- Near-term (next 3 months)
  - Adjust current forecast to reflect
    - Updated population/land use forecasts
    - Expected effects of plumbing code/appliance standards/conservation
    - Price/income/employment effects using published elasticities
- Longer-term (next 6-8 months)
  - Develop new econometric demand model using historical data on consumption, weather, and other demand drivers
  - Estimate Santa Cruz economic adjustment factors