Seattle Public Utilities
Official Yield Estimate and
Long-Range Water Demand Forecast

Inputs and Assumptions for the Firm Yield Estimate

Firm yield of the water supply system is estimated using a simulation model developed by Seattle Public Utilities called the Conjunctive Use Evaluation (CUE) model. Additional details of the model and inputs are documented in the preliminary draft report titled *Firm Yield of Seattle's Existing Water Supply Sources*, December 1, 2016, prepared by Seattle Public Utilities (SPU).

Model Inputs and Assumptions

⇨ Firm yield is based on the **98% reliability standard**—two shortfalls occur in the 87.5 years of historic record.

⇨ **Historic weekly inflows** reconstructed for water year 1929 through part of 2016 (October 1, 1928 through March 30, 2016) are used.

⇨ **Total system demand** is shaped on a monthly demand pattern based on the average of actual deliveries from calendar year 2006 through 2014.

⇨ **Sources of supply are operated conjunctively as a single system.**

⇨ **Operational assumptions include:**

- <u>Cedar River System:</u>
  Meet Cedar River Habitat Conservation Plan instream flow commitments below Landsburg, assuming flashboards in place on Overflow Dike.
  Fixed rule curve for Cedar Reservoir of 1550' for October-December and 1563' for March-August.
  Minimum levels for Chester Morse Lake: 1532'; Masonry Pool: 1510'
  Meet diversion limits specified by the 2006 Agreement with the Muckleshoot Indian Tribe.

- <u>South Fork Tolt System:</u>
  Meet instream flows from 1988 Tolt Settlement Agreement (with treatment project).
  Fixed rule curve 1754' for October-January; 1765' for March-August.
  Minimum level for South Fork Tolt Reservoir: 1710'
  Treatment/Transmission capacity: 120 MGD

- <u>Seattle Well Fields:</u>
  10 MGD withdrawn for 14 weeks as needed from July-December.
  5 MGD recharged for 14 weeks from January-March.

Results

Based on the above, **the system-wide firm yield is <u>172 million gallons per day</u>**.

Inputs and Assumptions for the Water Demand Forecast Model

SPU is using the same basic water demand forecast model that was developed and for the 2007 and 2013 Water System Plans. Following a 2006 literature review of demand forecast models used by other utilities, SPU settled on a "Variable Flow Factor" approach. As with simpler fixed flow factor models, current water demand flow factors are calculated by sector (single and multi- family residential, non-residential) for Seattle and each individual wholesale customer. However, like an econometric model, the Variable Flow Factor model reflects the impacts of variables such as price, income, and conservation on water flow factors for each sector over time. This approach takes advantage of past econometric analysis to provide estimates of how some of the variables (price and income) affect demand. SPU's Code, Standards & Market Transformation ("code" for short) Savings model, as well as estimates of programmatic conservation savings, are then used to estimate the impacts of code and programmatic conservation on the flow factors over time. The structure of the demand forecast model is summarized in the flow chart on the next page while the model inputs and assumptions are outlined, below.

The structure of the water demand forecast model is represented in the flow chart on the following page. Intermediate steps and final results are shown as rectangles. Model inputs are shown as ovals with the gray shaded ovals indicating which inputs are subject to uncertainty and modeled using Monte Carlo simulations.

Model, Inputs and Assumptions

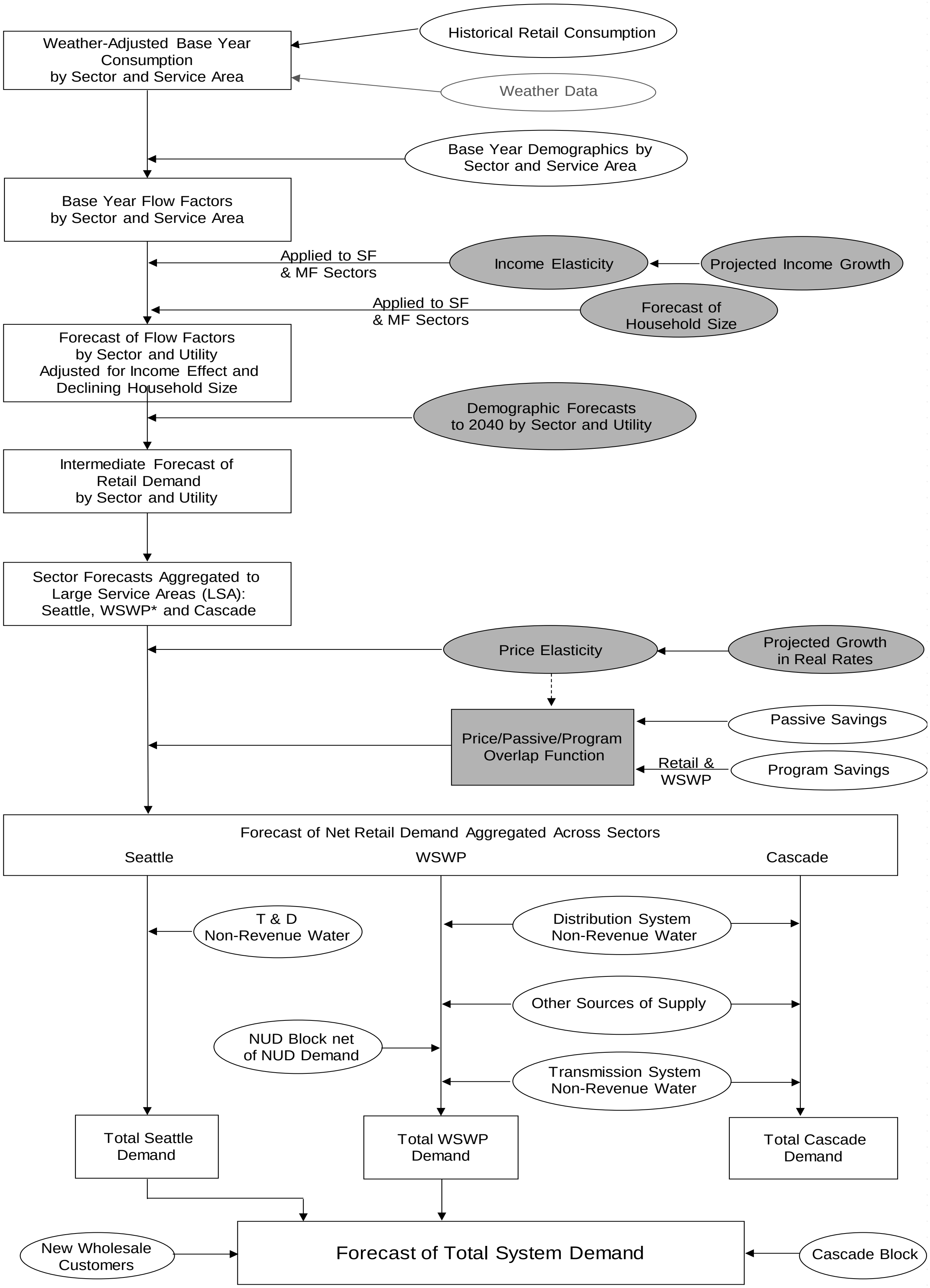
- **Weather adjusted base year consumption:**
  - By sector
    - single family residential
    - multifamily residential
    - manufacturing non-residential
    - non-manufacturing non-residential
  - By service area
    - Seattle retail service area
    - Individual wholesale customers
  - Base Year
    - 2016
  - Weather
    - Sea-Tac Airport monthly average daily temperature and total precipitation

  Sources: SPU billing data, Annual Purveyor Surveys, NOAA

- **Demographics: Current and projected single- and multi-family households and employment:** The model uses the Puget Sound Regional Council (PSRC) Land Use Baseline census-tract-level forecasts of population, households and employment to 2040 apportioned[1] to Seattle retail and individual wholesale service areas. (The forecast was published in 2014 and is the most recent version available. An update is expected in 2018.) A straight-line extrapolation of average annual growth between 2030 and 2040 is used to forecast beyond 2040. The base year for the water demand forecast is 2016. Several sources of information were used to estimate base year demographics. A first approximation was obtained by interpolating between the 2010 actuals and the 2020 forecasts in the PSRC forecast. This was compared to actual meter counts from SPU and wholesale customers for single family households as well as annual estimates of population

[1] The Land Use Baseline Forecast uses a parcel-based UrbanSim model. This made it possible for PSRC to calculate what percent of each census tract is within each utility's service area based on boundaries provided by SPU. These percents were then used to apportion the demographic forecasts to each utility.

WATER DEMAND FORECAST MODEL STRUCTURE



* WSWP = Wholesale members of the Saving Water Partnership

and households by census tract by the Washington State Office of Financial Management (OFM). Where there were significant discrepancies between the interpolated base-year forecasts of population and households and the estimates of 2016 actuals, adjustments were made to the base and early year demographic forecasts.

In the first table below is displayed PSRC's forecast of population, households, and employment in King County. The tables that follow contain these forecasts as they have been apportioned into water service areas. Separate tables are provided for all of King County, SPU's retail service area, and the service area of Full and Partial Contracts (F&P) wholesale customers.

Actual[2] & PSRC Forecasts of Population, Households, & Employment

King County

	Population	Households			Employment
		Single Family	Multifamily	Total	
2000	1,737,379	453,567	257,479	711,046	1,151,214
2010	1,931,249	497,853	291,379	789,232	1,181,537
2016	*2,105,100*	*525,028*	*334,476*	*859,504*	*1,375,054*
2020	2,169,389	539,741	357,808	897,549	1,467,620
2030	2,341,532	570,233	394,806	965,039	1,627,059
2040	2,527,589	600,611	470,624	1,071,235	1,897,261
2016-2040					
Growth	422,489	75,583	136,148	211,731	522,207
% Change	20%	14%	41%	25%	38%
Annual Rate	0.8%	0.6%	1.4%	0.9%	1.4%

As Apportioned to SPU's Retail Service Area and Full and Partial Contracts Wholesale Service Area[3]

	Population	Household			Employment
		Single Family	Multifamily	Total	
2000	1,012,625	260,529	173,859	434,388	750,861
2010	1,102,573	276,583	195,016	471,600	692,438
2016	*1,189,546*	*288,315*	*219,172*	*507,487*	*801,406*
2020	1,238,165	297,247	236,386	533,633	853,529
2030	1,317,522	307,628	257,721	565,349	938,206
2040	1,406,213	316,681	301,942	618,622	1,061,993
2016-2040					
Growth	216,668	28,366	82,770	111,136	260,587
% Change	18%	10%	38%	22%	33%
Annual Rate	0.7%	0.4%	1.3%	0.8%	1.2%

[2] Census data used for 2000 and 2010 population and households. 2010 employment is based on latest (2014) PSRC estimate of 2010 employment.
[3] This excludes the service areas of Northshore Utility District and Cascade Water Alliance members.

As Apportioned to SPU's Retail Service Area[4]

		Household			
	Population	Single Family	Multifamily	Total	Employment
2000	617,104	151,741	128,450	280,191	569,311
2010	662,635	159,146	145,669	304,815	509,171
2016	*743,796*	*162,005*	*162,839*	*324,844*	*592,115*
2020	750,000	165,396	175,396	340,791	626,889
2030	777,374	166,322	190,618	356,941	686,909
2040	817,906	168,293	214,991	383,284	762,232
2016-2040					
Growth	74,110	6,288	52,152	58,440	170,117
% Change	10%	4%	32%	18%	29%
Annual Rate	0.4%	0.2%	1.2%	0.7%	1.1%

As Apportioned to the Full and Partial Contracts Wholesale Service Area[5]

		Household			
	Population	Single Family	Multifamily	Total	Employment
2000	395,521	108,788	45,409	154,197	181,550
2010	439,938	117,437	49,348	166,785	183,267
2016	*474,492*	*126,310*	*56,333*	*182,643*	*209,290*
2020	496,911	131,851	60,990	192,842	226,640
2030	540,148	141,306	67,103	208,408	251,297
2040	588,308	148,387	86,951	235,338	299,761
2016-2040					
Growth	113,816	22,077	30,618	52,695	90,470
% Change	24%	17%	54%	29%	43%
Annual Rate	0.9%	0.7%	1.8%	1.1%	1.5%

In the 2013 Water System Plan forecast, household size was calculated for single and multifamily households in Seattle and for wholesale customers over the forecast period based on PSRC projections of single and multifamily households and population. Since the number of households was projected to grow faster than population through 2040, household size was projected to decrease significantly. Per household flow factors were then reduced each year by the percent change in household size times the elasticity of demand with respect to household size. This elasticity was estimated to be 0.38 based on data from an end-use study conducted by the Seattle Water Department in the mid-1990s. The same methodology is used in the current forecast though it has much less impact because PSRC's most recent demographic forecast has population and households growing at the same rate so there's very little change in household size over time.

⇨ **Base Year Flow Factors:** Base year flow factors are obtained by dividing the weather-adjusted base year consumption for each sector (e.g. single family residential) and service

[4] SPU's retail service area includes the City of Seattle and portions of the cities of Shoreline, Lake Forest Park and Burien, as well as portions of unincorporated King County south of the City of Seattle.

[5] For the two wholesale customers with block contracts, Cascade Water Alliance and Northshore Utility District, the total number of households is forecast to increase by 30% and 34%, respectively, from 2016 to 2040. Over the same period, employment is forecast to grow 54% within Cascade and 48% in Northshore.

area (e.g. Bothell) by the corresponding number of households or employees in the base year.

- **Elasticity of residential demand to changes in real (inflation adjusted) household income:** Household income is generally expected to have a positive effect on water demand. A review of the literature revealed a range of estimated income elasticities. An elasticity value of **0.27**, representing the middle of this range, was chosen. (This means that a 10% increase in household income would be expected to cause a 2.7% rise in residential demand.)

  Source: Results of 2006 literature review.

- **Forecast of annual growth in real median household income:** Beginning with the 2013 WSP demand forecast, the model has used *median* rather than *average* household income. The past 40 years has seen a widening gap between growth in average and median income. Both national and local time series on *real* per capita personal income (i.e., *average* per capita income) show rates of growth averaging about 2.0% per year. However, *median* household income in Washington State and King County adjusted for inflation has been essentially flat since reporting began in 1989.[6] There is additional evidence that this is not just true for the median household but for most households except those at the very top of the income distribution. Analysis by economists Saez and Piketty based on 90 years of IRS data reveals that *average* household income for the bottom 90% of households has had zero real growth since 1970. Over the same 4 decades, the top 10%, 1%, 0.1%, and 0.01% of households has seen their real incomes increase twofold, threefold, fivefold and eightfold, respectively. If that trend continues with all income growth going to the top 10%, median income – and the income of all but the top 10% of households – will remain flat in real terms. More optimistic scenarios would have this pattern of increasing income inequality (1) slowing down, (2) stopping, or (3) even reversing. Those conditions would correspond to rates of median income growth (1) greater than zero but less than the growth rate in average income, (2) equal to the average growth rate, or (3) greater than the average growth rate. For the demand forecast, it is assumed that household income will grow at **0.9%** per year based on the median or about half the historical growth rate in per capita personal income based on averages.

  Sources: U.S. Bureau of Economic Analysis, U.S. Census Bureau, Washington State Office of Financial Management, Dick Conway & Associates, Emmanuel Saez of UC-Berkeley.

- **Elasticity of demand to changes in real water rates (prices):** A considerable body of literature has developed concerning the effect of price upon water demand and the inverse relationship predicted by economic theory is now well established. However, a number of complications summarized in the literature review (complex rate structures, conservation impacts, etc.) have made it difficult to estimate price elasticity with much confidence. As a result, there is a wide range of estimates in the literature but as with the income elasticity, values towards the middle of the range have been chosen for this model. These are shown below. (The value of -0.20 for single family households means that given a 10% increase in water prices, demand would be expected to decline by 2%.)

[6] Note that real median household income hit a low in 2011 and has been growing since then. In 2015, it finally surpassed what is was in 1989.

	Single Family	Multifamily	Non-Residential
Price Elasticity	-0.20	-0.10	-0.225

Sources: Results of 2006 literature review, Seattle's 1992 econometric model.

- **Forecast of annual growth in real water rates (prices)**: Seattle and its wholesale customers have different water rates and different rate structures. Most customers face different marginal rates depending on whether they're residential or non-residential, what consumption block they fall in and what season it is. There is no single price of water. However, the model abstracts from all these complexities by using the average price of water, i.e., revenue requirements divided by billed consumption.

  The model takes into account the increases in water and sewer[7] rates already adopted through 2017 and the Strategic Business Plan rate path through 2023 as projected by the SPU Rates Unit in September 2017. After 2023, it is assumed that inflation-adjusted retail water/sewer rates and wholesale customer water rates will average about 0.6% per year.

Historical and Projected Annual Growth in Average Water Rates

	Seattle Retail*	Wholesale Customers*
1974-1995	2.9%	NA
1995-2016	4.0%	1.8%
2016-2023	2.1%	1.6%
2024+	0.6%	0.6%

* Seattle Retail reflects historical and anticipated increases in water and sewer rates. Wholesale is water rates only.

Sources: Historical rate and consumption data; Paul Hanna, SPU Rates 09/08/17.

- **Conservation - Reductions in Water Use due to Code, Standards and Market Transformation (code):** Some conservation savings occur each year without SPU intervention due to federal and state plumbing codes setting efficiency standards for showerheads, toilets, aerators, and clothes washers. As old fixtures and appliances are replaced with new ones in existing buildings and new fixtures and appliances are installed in new construction, water use efficiency improves and conservation savings accrue. In addition, fixtures and appliances available from the market at competitive prices often become increasingly more efficient than is required by codes, especially as more years have passed since the codes were updated. "Market transformation" refers to this phenomenon along with savings from standards adopted by manufacturers. The same model developed for the 2013 WSP forecast was used to estimate these savings through 2060.

  The model takes account of federal fixture and appliance codes adopted in 1992, 2002, 2007, 2012 and 2015.[8] The model also reflects the current proportion of fixtures and

[7] Because sewer bills in Seattle are based on metered water consumption, both water and sewer rates are assumed to impact water demand in the model. This is only the case for the retail service area, however. Many different cities and sewer districts provide sewer service in Seattle's wholesale water service area, each with different sewer rates and rate structures. Unlike Seattle's sewer rates that are entirely volume based, most other sewer providers have large fixed charges with much less of their revenue generated by volume rates. For that reason, as well as lack of information on past, current and anticipated sewer rates in the wholesale service area, the demand model for wholesale customers does not include sewer rates.

[8] The US Department of Energy adopted a two-phase residential clothes washer efficiency standard, with the first phase effective March 7, 2015, and the second, more stringent phase, effective for January 1, 2018.

appliances sold in the market that meet the more stringent Energy Star, Water Sense, and Consortium for Energy Efficiency (CEE) standards, as well as how those proportions are expected to continue shifting in the direction of higher efficiency over time. The model assumes that aerators, showerheads, clothes washers and toilets are, on average, replaced every 5, 10, 12 and 30 years, respectively.

Projected Savings from Code, Standards & Market Transformation in MGD

	Single Family	Multi-family	Non-Residential	Total
2020	1.2	0.8	0.2	2.2
2030	4.1	3.1	0.8	8.0
2040	5.9	4.8	1.4	12.0
2050	6.7	6.0	1.7	14.5
2060	7.1	6.8	2.1	15.9

Sources: Water Research Foundation, "Residential End Uses of Water," April 2016; U.S. EPA Office of Water; Alliance for Water Efficiency; Al Dietemann (personal communication)

⇨ **Conservation - Reductions in Water Use due to Programmatic Savings:** Based on an analysis of CIP spending and savings achieved during the 2012-2016 period, the Water Conservation office estimates savings from hardware (CIP) programs of **0.1 mgd** per year from 2017 through 2028. There are assumed to be no additional CIP program savings after 2028. These conservation savings only apply to Seattle and other members of the Saving Water Partnership. As is explained below, the Cascade Water Alliance has a block contract with SPU which limits its demand from the Seattle system. While Cascade is expected to pursue its own conservation programs, that doesn't affect the forecast of its demand from SPU which is assumed not to exceed the block.

⇨ **Price/Code & Standards/Programmatic Conservation Overlap:** In past forecasts, total conservation savings were adjusted downwards to account for the overlap between different types of conservation.[9] However in this iteration of the forecast, the "overlap function," which had resulted in an approximate 14% reduction in the estimate of total conservation savings, was turned off in order to offset the lack of estimates for several other types of conservation. The model does not include estimates of behavioral conservation savings from SPU public messaging and educational programs, or from outside sources of information and encouragement for the public to adopt water efficiency measures and develop a stronger conservation ethic. Neither has there been an attempt to explicitly capture the potential future impacts on water use of new technologies, green buildings, and decentralized systems. As a rough approximation, these other sources of conservation are taken into account by eliminating the overlap calculation.

⇨ **Non-Revenue Water:** Combined transmission and Seattle distribution system non-revenue water is assumed to start at **7** mgd in 2015 and increase uniformly to **9** mgd by 2060. This increase is expected to be caused by a growing number of leaks that will probably occur as the distribution system ages.

⇨ **Wholesale Customer Demands:**

- Wholesale customer distribution system non-revenue water is assumed to be a constant **6%** of retail water demand in the wholesale service area over the forecast period. This is added to the forecast of wholesale customers' retail demand.

  Source: Annual Surveys of Wholesale Customers, 1994-2016.

[9] The "overlap function" assumed that half of the price effect overlapped with code and programmatic savings as long as the total amount of overlap represented less than half of total code and programmatic conservation. However, if the price effect exceeded combined code and programmatic conservation, the amount of overlap was capped at 50%.

- Some wholesale customers have their own wells or surface water sources in addition to what they purchase from SPU. Water that wholesale customers expect to obtain from other sources of supply is subtracted from the forecast of their demand from the SPU system. This amount is currently about **19** mgd and is projected to level off at **21** mgd by 2040. Historically, Renton's water purchases from SPU have been negligible, but that is expected to change over time under the new contract as its demand begins to exceed its peak day capacity. Renton's estimated requirements from SPU are forecast to ramp up to 1 mgd by 2040. Highline states they plan to be purchasing 1 mgd from Lakehaven by 2019, augmenting their own groundwater supply and reducing demand from SPU.

Water Obtained from Other Sources of Supply in MGD: 2016-2040

	2016	2020	2030	2040
Cascade Total	**9.1**	**9.3**	**9.8**	**9.8**
Redmond	2.9	3.1	3.6	3.6
Skyway	0.3	0.3	0.3	0.3
Issaquah	1.4	1.4	1.4	1.4
Sammammish Plateau	4.5	4.5	4.5	4.5
F&P Total	**9.8**	**10.8**	**11.0**	**11.5**
Cedar River	0.1	0.1	0.1	0.1
Highline	1.8	2.7	2.7	2.7
Olympic View	0.4	0.4	0.4	0.4
WD 90	0.5	0.5	0.5	0.5
Renton	7.0	7.0	7.3	7.8
Total Wholesale	**18.9**	**20.1**	**20.8**	**21.3**

Sources: 2017 Survey of Wholesale Customers, Cascade Water Alliance Member Survey (Paula Anderson), direct communication with individual wholesale customers.

- Contract with the Cascade Water Alliance (Cascade). Under the Cascade contract as amended on May 30, 2013, Seattle will provide a fixed block of **33.3** mgd to Cascade through 2039. The block will then be reduced by **2** mgd per year for the three years beginning in 2040, and **1** mgd per year thereafter until it reaches **5.3** mgd in 2064. This has been incorporated into the forecast by subtracting the projected demand of Cascade members that are currently Seattle wholesale customers, and adding the Cascade block.

  The following cities and districts are members of Cascade[10]:
  - Bellevue
  - Kirkland
  - Issaquah
  - Redmond
  - Sammamish Plateau
  - Skyway
  - Tukwila

- Block contract with Northshore Utility District. Northshore Utility District also has a block contract under which Seattle will reserve a fixed block of **8.6** mgd for Northshore through the contract period which terminates in 2060. This has been incorporated into the forecast by subtracting Northshore's projected demand and adding the Northshore block. Note that current Northshore demand is about 3 mgd less than its block. By 2060, actual Northshore demand is expected to have grown to 7.4 mgd, still less than its block by more than 1 mgd.

- Forecasts of demand from potential new wholesale customers are based on data provided by them on their projected demand and existing supplies. In the past, Ames

[10] Covington Water District left Cascade Water Alliance in 2012.

Lake Water Association, the City of Carnation, and the City of Snoqualmie expressed interest in becoming new wholesale customers and purchasing treated water from SPU and their potential demand was added to the 2013 WSP forecast. However more recently, only Ames Lake has maintained its expression of interest. Demand from Ames Lake is expected to begin at zero ramping up to 0.5 mgd by 2033 and remaining constant thereafter.

Source: email from Robert Pancoast, Ames Lake Water Association dated 12/13/2016.

<u>Results</u>

The water demand forecast remains considerably below SPU's current firm yield of 172 mgd through 2060. The demand forecast starts out at **130** mgd, higher than actual demand in 2016 because the forecast includes the Cascade and Northshore blocks that currently exceed the actual demand of those customers by 9 mgd. Total demand is forecast to gradually increase to **136 mgd by 2039** and then decline with the initial reductions in Cascade's block. Water demand is then forecast to slowly decline for several years and then **stay relatively flat at about 132 mgd through 2060** as reductions in Cascade's block offset what would otherwise be a modest amount of growth in demand.

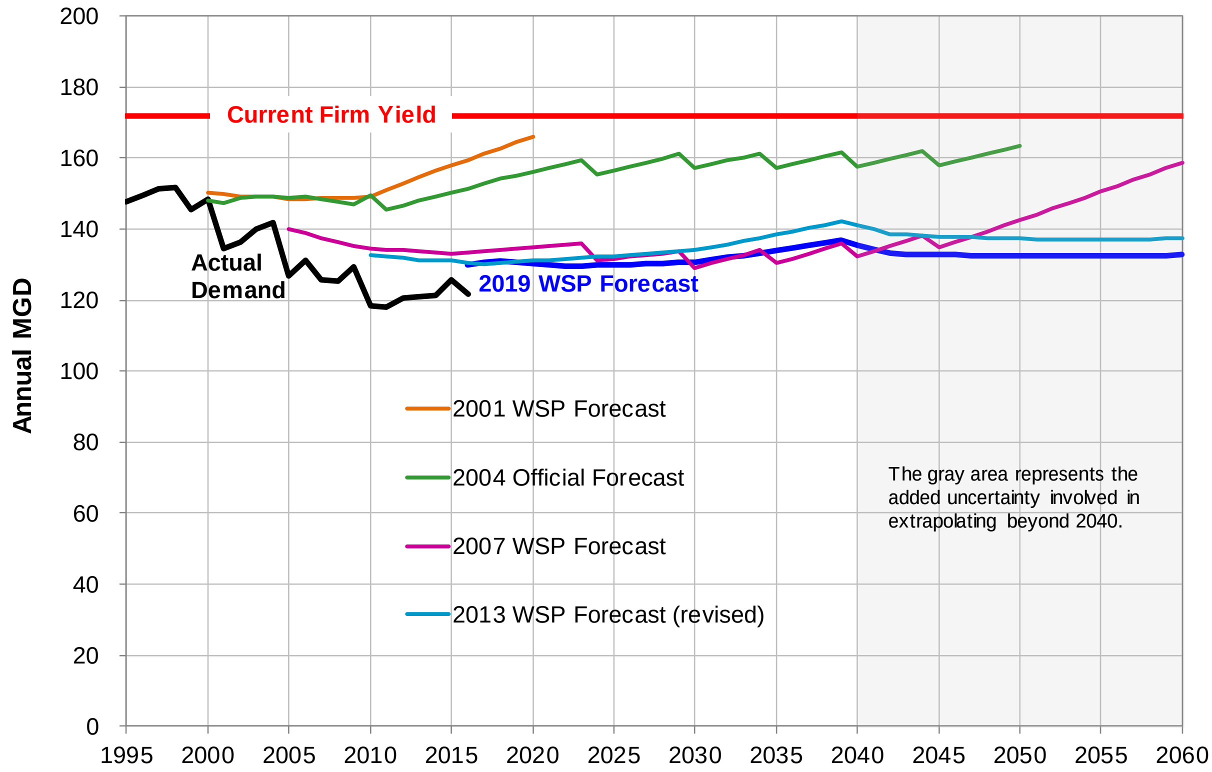
The 2017 Official Forecast broken down by sector is shown in the table and graphs below. The first graph shows the forecast of demand and supply out to 2060 along with previous WSP forecasts. The gray area between 2040 and 2060 represents the additional uncertainty involved in forecasting out more than 25 years. The second graph shows the various components that add up to the total demand forecast: Seattle retail, full and partial contract wholesale customers, the amounts specified in the Northshore and Cascade block contracts, and non-revenue water.

Components of Actual and Forecast Water Demand
All figures in millions of gallons per day (MGD)

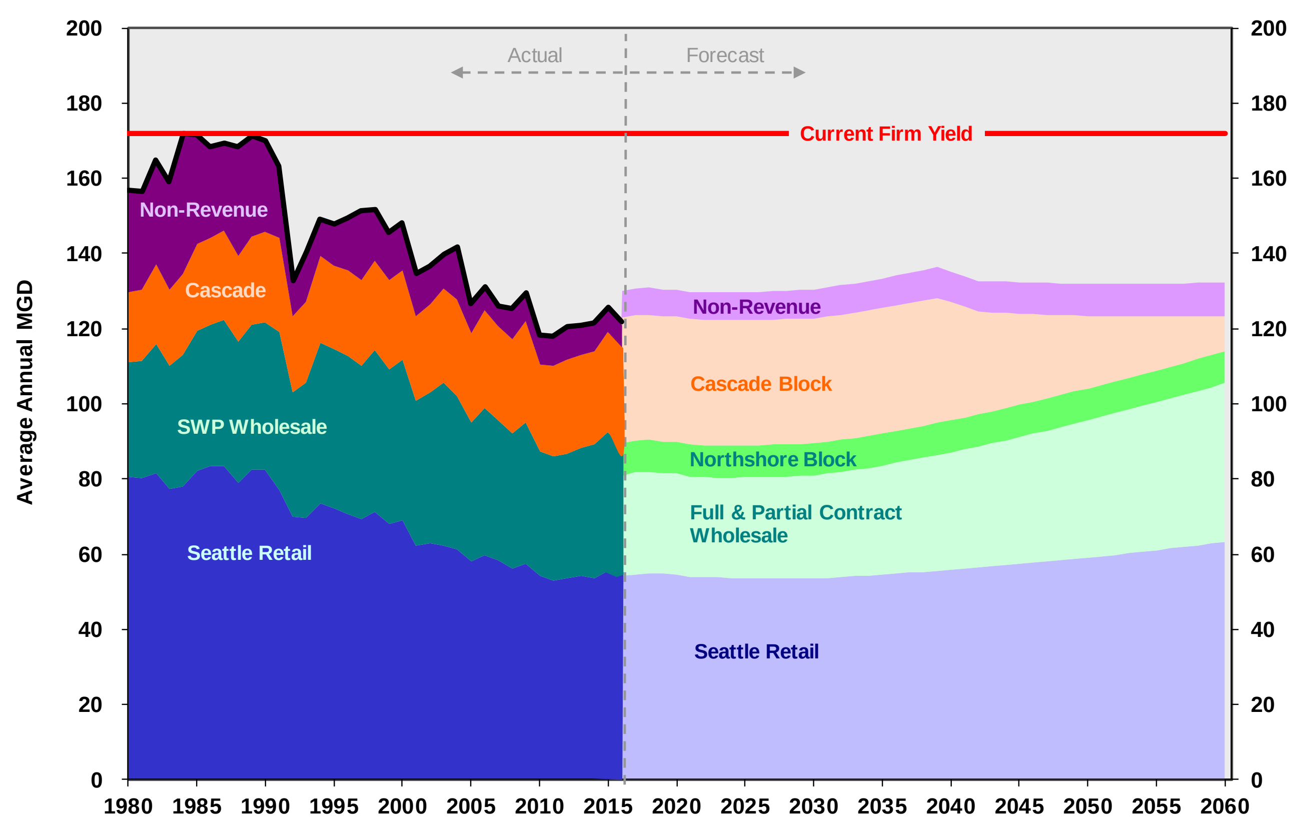
	Year	Billed Demand								Non-Revenue Water	Total System Demand	
		Seattle Retail				Wholesale					Annual Average[2]	Peak Day[4]
		SF Res	MF Res	Non-Res	Subtotal	F&P[1]	Block[2]	New[3]	Subtotal			
	2000	26.9	14.5	27.7	69.1	34.3	31.7	0.0	66.0	13.2	148.2	241.9
	2001	24.0	13.7	24.6	62.3	31.4	29.3	0.0	60.7	11.6	134.6	204.0
	2002	24.8	13.1	24.9	62.8	32.8	31.2	0.0	63.9	9.8	136.5	222.6
	2003	24.9	12.8	24.6	62.3	35.2	33.1	0.0	68.2	9.4	139.9	250.2
	2004	24.2	12.5	24.6	61.3	33.3	33.2	0.0	66.5	14.0	141.7	246.8
A	2005	22.6	12.2	23.2	58.1	30.1	30.8	0.0	60.9	7.7	126.7	210.4
C	2006	23.6	12.3	23.7	59.6	32.0	33.3	0.0	65.3	6.3	131.2	236.8
T	2007	22.7	12.0	23.6	58.3	30.5	31.9	0.0	62.4	5.2	125.9	227.6
U	2008	22.0	11.8	22.5	56.2	29.3	31.5	0.0	60.8	8.2	125.3	202.0
A	2009	23.2	11.6	22.6	57.4	30.7	34.0	0.0	64.7	7.5	129.5	241.9
L	2010	21.4	11.4	21.6	54.4	26.6	29.4	0.0	56.0	8.0	118.4	197.9
	2011	20.5	11.2	21.2	52.9	26.9	30.5	0.0	57.4	7.6	117.9	177.7
	2012	20.9	11.4	21.3	53.7	26.8	31.3	0.0	58.0	8.8	120.5	200.6
	2013	21.0	11.5	21.6	54.1	27.3	31.6	0.0	58.9	7.9	120.9	189.6
	2014	20.8	11.3	21.5	53.6	28.1	32.2	0.0	60.3	7.6	121.5	196.4
	2015	21.4	11.5	22.7	55.6	29.7	33.6	0.0	63.3	6.7	125.6	212.1
	2016	20.6	11.6	22.2	54.3	28.5	32.3	0.0	60.8	6.6	121.7	194.7
	2016	20.7	11.6	22.0	54.3	26.6	41.9	0.0	68.5	7.0	129.9	259.7
	2017	20.7	11.6	22.3	54.6	27.1	41.9	0.0	69.0	7.1	130.7	261.4
	2018	20.7	11.7	22.6	55.0	26.9	41.9	0.0	68.8	7.1	130.9	261.7
	2019	20.5	11.8	22.5	54.8	26.7	41.9	0.0	68.5	7.2	130.5	261.0
	2020	20.2	11.9	22.5	54.6	26.8	41.9	0.0	68.7	7.2	130.5	260.9
	2021	19.9	11.8	22.3	54.0	26.7	41.9	0.0	68.6	7.3	129.8	259.7
	2022	19.7	11.7	22.4	53.9	26.6	41.9	0.1	68.5	7.3	129.7	259.4
	2023	19.6	11.7	22.6	53.8	26.6	41.9	0.1	68.6	7.4	129.7	259.4
F	2024	19.4	11.6	22.7	53.7	26.7	41.9	0.2	68.7	7.4	129.8	259.6
O	2025	19.3	11.6	22.8	53.6	26.8	41.9	0.2	68.8	7.4	129.9	259.8
R	2026	19.2	11.6	22.9	53.6	26.9	41.9	0.2	69.0	7.5	130.1	260.1
E	2027	19.0	11.5	23.0	53.6	27.0	41.9	0.3	69.1	7.5	130.2	260.5
C	2028	18.9	11.5	23.1	53.6	27.1	41.9	0.3	69.3	7.6	130.4	260.8
A	2029	18.8	11.5	23.2	53.6	27.2	41.9	0.3	69.4	7.6	130.6	261.2
S	2030	18.7	11.5	23.4	53.6	27.3	41.9	0.4	69.6	7.7	130.8	261.7
T	2031	18.6	11.6	23.6	53.8	27.6	41.9	0.4	69.9	7.7	131.4	262.7
	2032	18.6	11.6	23.7	53.9	27.9	41.9	0.5	70.2	7.8	131.9	263.9
	2033	18.5	11.7	23.9	54.1	28.2	41.9	0.5	70.6	7.8	132.5	265.1
	2034	18.5	11.8	24.1	54.4	28.5	41.9	0.5	70.9	7.8	133.1	266.2
	2035	18.4	11.9	24.3	54.6	29.0	41.9	0.5	71.3	7.9	133.8	267.6
	2036	18.4	11.9	24.5	54.8	29.4	41.9	0.5	71.8	7.9	134.5	269.1
	2037	18.3	12.0	24.7	55.1	29.9	41.9	0.5	72.2	8.0	135.3	270.5
	2038	18.3	12.1	24.9	55.3	30.3	41.9	0.5	72.7	8.0	136.0	272.0
	2039	18.3	12.2	25.1	55.6	30.8	41.9	0.5	73.1	8.1	136.8	273.5
	2040	18.2	12.3	25.3	55.8	31.3	39.9	0.5	71.6	8.1	135.5	271.1
5	2045	18.3	12.7	26.3	57.3	33.8	32.9	0.5	67.1	8.3	132.8	265.5
	2050	18.3	13.2	27.5	59.1	36.5	27.9	0.5	64.8	8.6	132.4	264.8
Y	2055	18.4	13.9	28.7	61.1	39.2	22.9	0.5	62.6	8.8	132.4	264.8
R	2060	18.6	14.7	30.0	63.3	42.1	17.9	0.5	60.4	9.0	132.7	265.4

1. F&P refers to Full and Partial contracts wholesale customers.
2. The forecast of demand from Cascade Water Alliance (Cascade) and Northshore is equal to their blocks while the historical consumption data reflects water actually purchased from SPU by Cascade members and NUD. The blocks exceeded actual water purchases from SPU of Cascade members and NUD by 9.5 mgd in 2016.
3. Potential new wholesale customers (Ames Lake Water Association)
4. The forecast of peak day demand is based on a peak day factor of 2.0, the ratio of peak day to average annual demand in 2009 with a 5% allowance for hot, dry weather. The forecast of average annual demand under average weather conditions is multiplied by the peak day factor to estimate peak day demand with hot, dry weather.

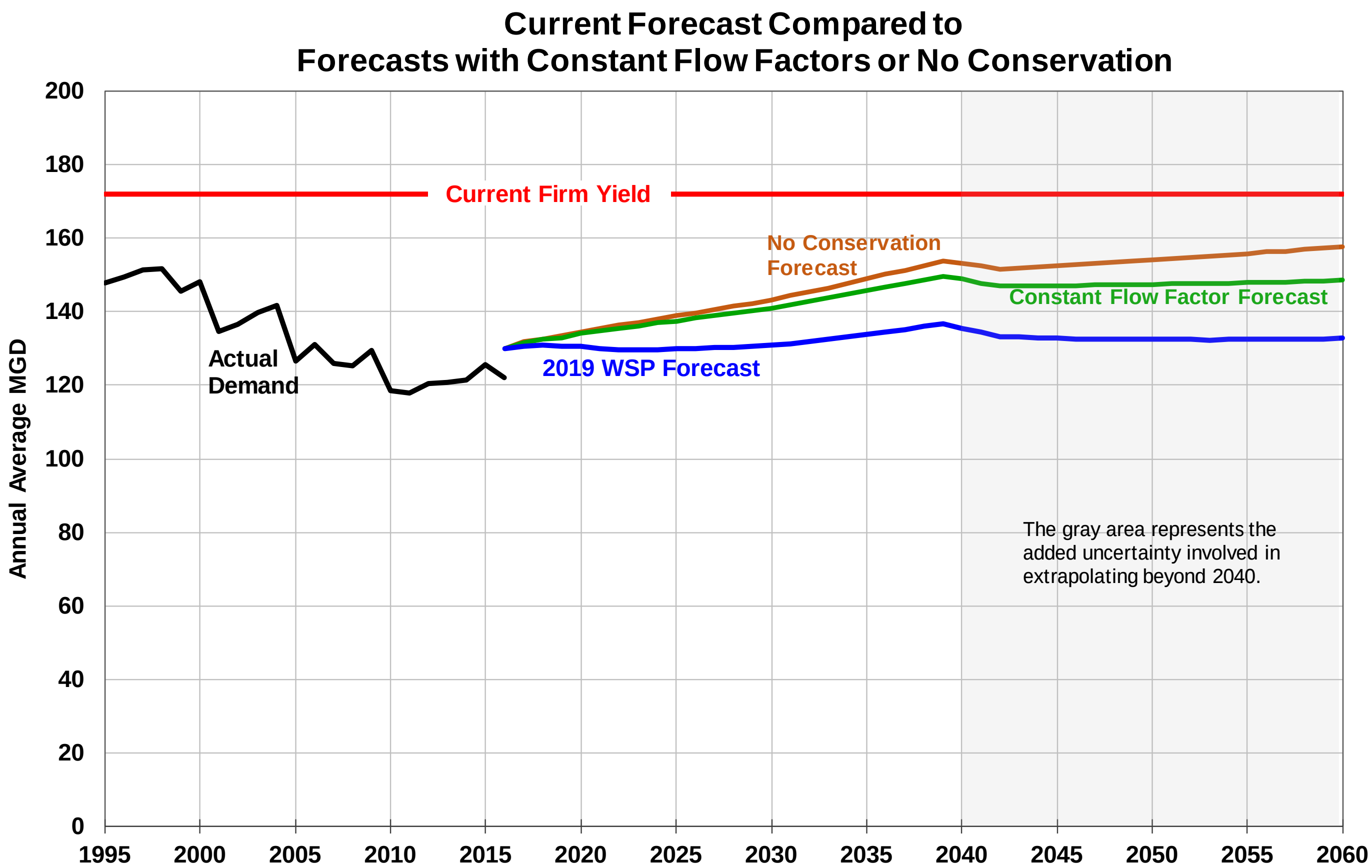
Current Forecast Compared to Earlier Forecasts



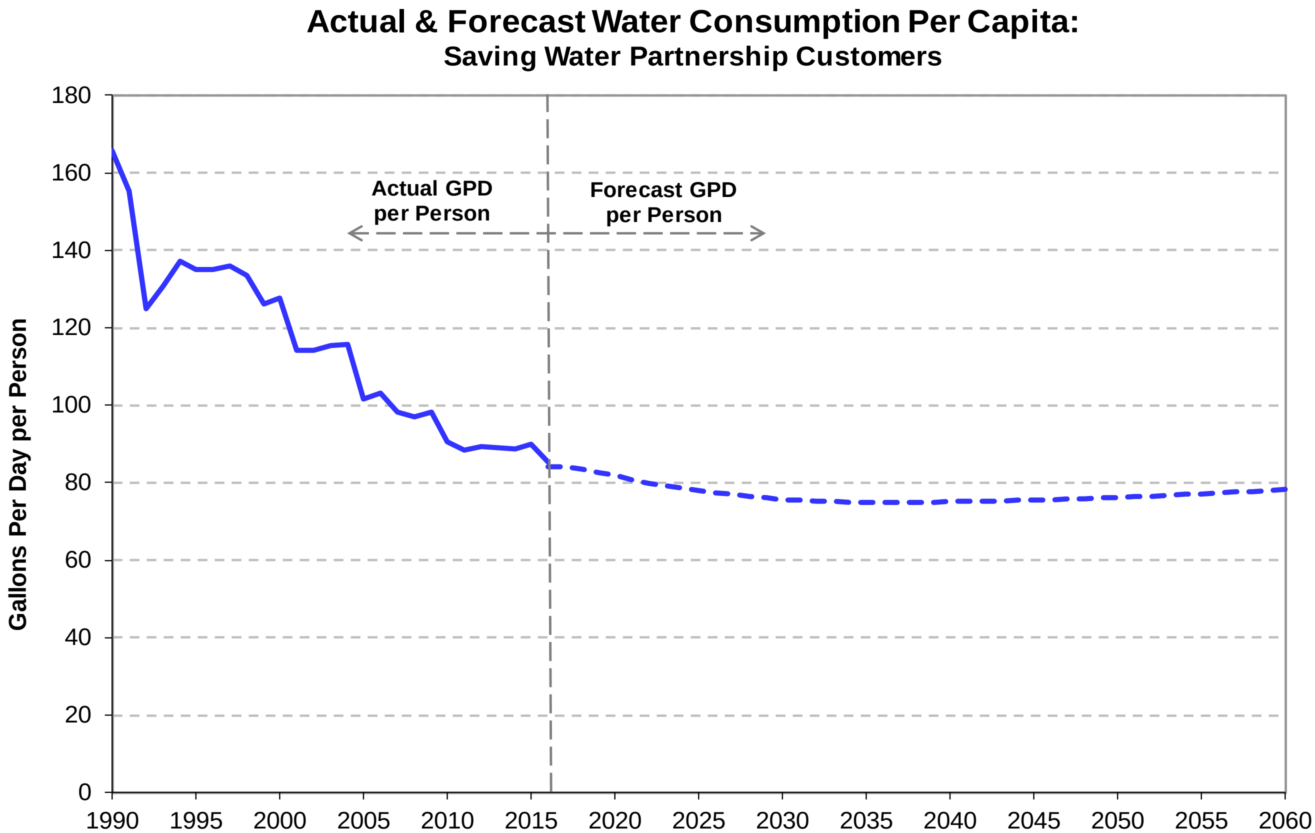
Components of Actual and Forecast Demand: 1980-2060



The graph below contrasts the official demand forecast with what it would be with constant flow factors and with no future conservation of any kind (i.e., no price effect, no code savings, and no programmatic savings). Note that the forecast with "no conservation" is slightly higher than the forecast holding water flow factors constant over time because the "no conservation forecast" includes the impact of income growth and changes in household size, which net to a small increase in flow factors. For the 2019 WSP forecast, all sources of conservation are estimated to produce a total reduction in water demand of about 25 mgd by 2060.



Finally, the implications of the new demand forecast for total system per capita water consumption are shown in the graph below. Due to anticipated programmatic conservation, code savings, and water and sewer rate increases, per capita consumption is forecast to continue declining over the next 20 years though at a slower rate than in the past. By 2033, per capita consumption is expected to level off at about 75 gpd (compared to 85 gpd currently) before slowly increasing after 2040 as the income effect begins to dominate the diminishing impacts of conservation. In contrast, between 1990 and 2016, total and per capita water consumption for Seattle and its non-Cascade wholesale customers declined 48% from 166 gallons per day (gpd) to 85 gpd.



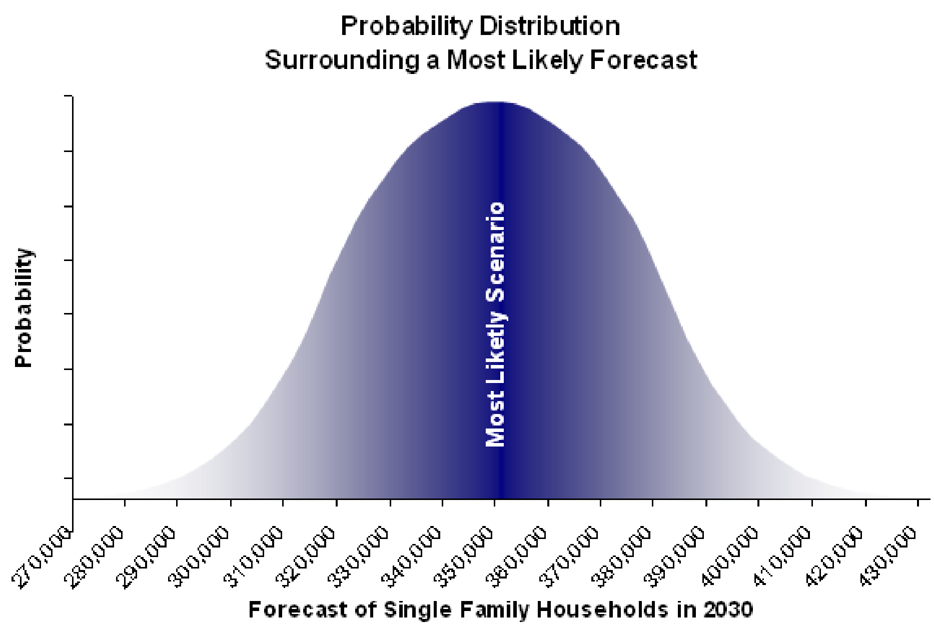
Forecast Uncertainty

What is most certain about a forecast out to 2060 is that it will be wrong. Actual demand in 2040 or 2060 is highly unlikely to be exactly what was forecast back in 2019. The official water demand forecast is itself based on forecasts of income, water prices, households and employment – all subject to uncertainty. Additional uncertainty surrounds the forecast model's assumptions about price and income elasticities, future conservation, wholesale customers' other sources of supply, and whether SPU will gain new customers and/or lose existing customers.

The Official Demand Forecast represents both SPU's policy intentions and its expectations of the future. However, it is prudent, especially in long-term planning, to consider the many uncertainties that could cause demand to be different from what's projected in the official forecast. These uncertainties fall into two categories – discrete and continuous – and are handled in two different ways.

The first category refers to those uncertainties that result from discrete events that produce significant and sometimes abrupt changes in customer demand. Discrete uncertainties represent occurrences that either happen or don't. They're on or off, yes or no (though there can be more than two conditions). An example of a discrete uncertainty is the block contract with Cascade Water Alliance. This and other discrete uncertainties are thought to be best handled by running individual "what-if scenarios" through the demand forecast model.

The second category consists of the continuous uncertainty that surrounds the various inputs to the model. An example would be the forecast of household growth. Actual growth over the forecast period could turn out to be lower or higher than forecast. These types of uncertainties can be represented by a continuous probability distribution around a mean or most likely value as illustrated below.



Modeling Continuous Uncertainty

A number of model inputs were identified as being subject to continuous uncertainty. (These are shown in the model structure flowchart on page 2 shaded in gray.) They include forecasts of single and multi-family households and employment; average annual growth rates for water prices and household income; price and income elasticities; the impact of code savings; and the extent to which price-induced conservation overlaps with code and programmatic conservation. Each uncertainty was modeled by specifying a probability distribution around the mean value of each variable. Many sources were consulted to define the range of uncertainty[11] and the shape of the distributions. The sources and assumptions used to characterize continuous uncertainties are outlined below.

Forecasts of Households and Employment: Two different sources were consulted to establish uncertainty ranges around the forecasts of long term demographic growth. In 2007 and again in 2012, the Washington State Office of Financial Management (OFM) produced high and low forecasts of population by county based on historical variability in net migration rates. Dick Conway and Associates developed high and low alternatives around the 2002 PSRC long term regional forecasts of population and employment (but not households) based on optimistic and pessimistic scenarios for the local and national economies[12]. In earlier uncertainty analysis for the demand forecast, the greater geographical specificity of the OFM forecasts was combined with the more rigorous methodology and wider range between low and high provided by Dick Conway's analysis. Unfortunately, there have been no updates to Conway's uncertainty ranges since 2002. However, the latest set of OFM uncertainty ranges is very similar to the earlier set (2007). Therefore, the same uncertainty ranges for demographic variables used in the 2013 WSP forecast are used here after being calibrated to 2016 so that low, medium and high forecasts all start of from the same point. The ranges of uncertainty around the projections of households, employment and population used in the demand forecast model are shown in the table, below.

Uncertainty Ranges Around Mean Values
Associated with High and Low Demographic Growth Scenarios

	2030		2060	
	Low	High	Low	High
Single Family Households	-4%	6%	-9%	16%
Multifamily Households	-11%	18%	-25%	42%
Employment	-5%	8%	-12%	21%
Population	-8%	12%	-18%	30%

The ranges around single and multi-family households were derived from the reported high and low population values and the assumption that variability around the single family forecast is less than for the forecast of multifamily households. Note that the potential variation from forecast values is expected to be greater on the high side than on the low side.

Growth in the Price of Water: System water rates are obtained by dividing each year's projected revenue requirement by projected demand. Uncertainty about future water prices derives from variability in both of these terms. The baseline assumption is that after significant increases in water and sewer rates already adopted or anticipated through 2023,

[11] Each range is characterized by a high and low value representing two standard deviations from the mean.
[12] Scenarios developed by Global Insights, Inc.

growth in inflation-adjusted retail water rates will ramp down to 0.6% per year by 2025 and remain there through the forecast period. This is slower than the average historical rate of growth. The range of uncertainty around this is skewed very much on the high side, **minus 67% to plus 200%,** resulting in projected annual growth rates in real prices of between **0.2%** and **1.8%**.

The model handles the impact on price of different levels of projected demand in a different way. Given the same set of revenue requirements, lower demand results in higher water prices and vice versa. That means that price effects would be expected to amplify swings in demand. For example, higher-than-projected demographic growth would cause demand to be higher than the official forecast, resulting in reduced prices and an additional boost in demand. The amount of the boost is determined by the price elasticity of demand and the amount by which prices fall. Incorporating this demand-price-demand-etc. feedback loop explicitly into the model isn't feasible because, as is explained in more detail below, the uncertainty analysis involves running 10,000 iterations of the demand model. However, the feedback loop has been approximated by widening the range of uncertainty around growth in households and employment. The amounts by which the ranges have been increased are **5.2%** on the high side and **5.3%** on the low side[13].

Price Elasticity: The uncertainty ranges around price elasticity represent a synthesis of the various estimates of price elasticity reported in the literature review. These are **plus or minus 50%** for single and multi-family elasticities and **plus or minus 33%** around the non-residential elasticity.

Uncertainty Ranges Around Mean Price Elasticities

	Single Family	Multi-Family	Non-Residential
Low	-0.10	-0.05	-0.15
Mean	-0.20	-0.10	-0.225
High	-0.30	-0.15	-0.30

Growth in Real Household Income: There is some uncertainty about future growth in average income but much more uncertainty around the distribution of that growth. As explained above, there has been a decoupling of average and median income growth over the past 4 decades. While overall per capita income has averaged 1.8% annual growth since 1970, median income and in fact, the income of the bottom 90% of households has grown very little if at all in real terms. Practically all the growth in national income has gone to households at the very top of the income scale in the last 40 years - the top 10%, 1%, 0.1%, and 0.01% of households seeing their real incomes rise twofold, threefold, fivefold and eightfold, respectively. The baseline assumption in the demand forecast is that median income will grow at **0.9%** annually, about half the rate expected for average income. This scenario represents a slowing of the rate at which the distribution of income gets worse. The continuation of present trends with all income growth going to the top 10% and **zero** income growth for median households is the most pessimistic scenario in the uncertainty analysis. At the high end is the assumption that income grows proportionally across all households and the increasing skewness in the income distribution comes to a halt. Here, annual growth in average income equals that for median income equals **1.8%.**

[13] These percents were obtained by calculating the percent changes in 2060 water prices that would result from the high and low growth scenarios relative to the baseline scenario and multiplying them by the average price elasticity.

Income Elasticity: As with price elasticity, the uncertainty band around income elasticity was derived from the various estimates of income elasticity in the literature review. A range of income elasticities from **0.19** to **0.35** (i.e., **plus or minus 30%**) around the mean value of 0.27 was chosen.

Savings from Code, Standards and Market Transformation (code): Code savings could be more or less than modeled. If market transformation towards fixtures and appliances that exceed code occurs slower than anticipated, code savings could be less than estimated for the baseline forecast. Alternatively, if additional codes are passed in the future, market transformation takes place more quickly, and green buildings become the norm for new construction, code savings could be more than estimated for the baseline forecast. A range of code savings from **9.5** to **22.3 mgd** (i.e., **plus or minus 40%**) around the mean value of 15.9 mgd was chosen.

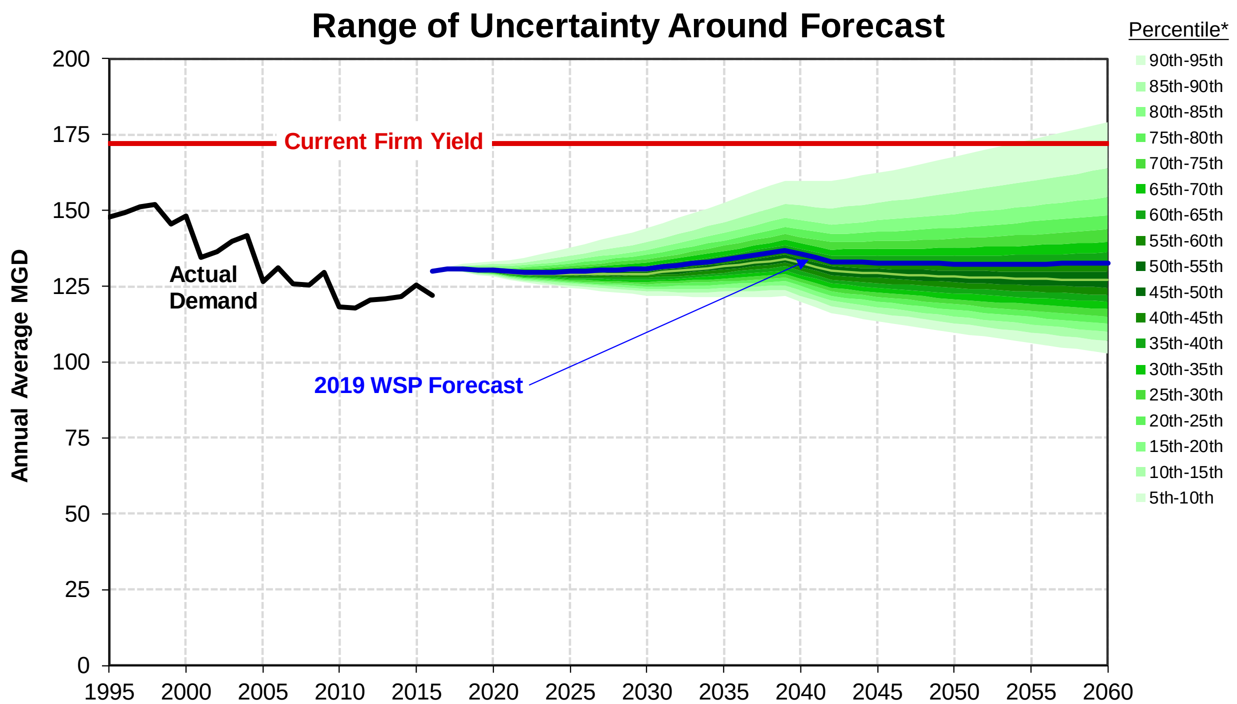
Modeling Uncertainty with @Risk: The uncertainty ranges described above are assumed to have normal or log-normal distributions,[14] with the endpoint values representing two standard deviations from the mean. These probability distributions become inputs to an aggregate uncertainty model using @Risk software (an add-in to Excel) which employs Monte Carlo simulation to characterize uncertainty around the official demand forecast. During each individual run of the Monte Carlo simulation, a value is randomly selected for each input variable based on the probability density function specified for that variable[15]. Then, the complete set of input values for that iteration is used to produce a water demand forecast. The simulation procedure performs a large number (10,000) of independent iterations, each generating a separate demand forecast. These forecasts are then pooled to obtain a probability distribution of forecast water demand through 2060.

The results of the Monte Carlo simulation are displayed in the graph on the next page. The green bands indicate the range of uncertainty around the official forecast with each band representing a 5% change in probability. For example, the bottom of the lowest band represents the 5th percentile. That means it's estimated there's a 5% chance actual demand will be below that point (and, thus, a 95% chance it will be above). The top band is the 95th percentile which corresponds to an estimated 95% probability that actual demand will be below that point. Taking a cross-section of the graph at 2060 produces the probability distribution around the official forecast shown below.

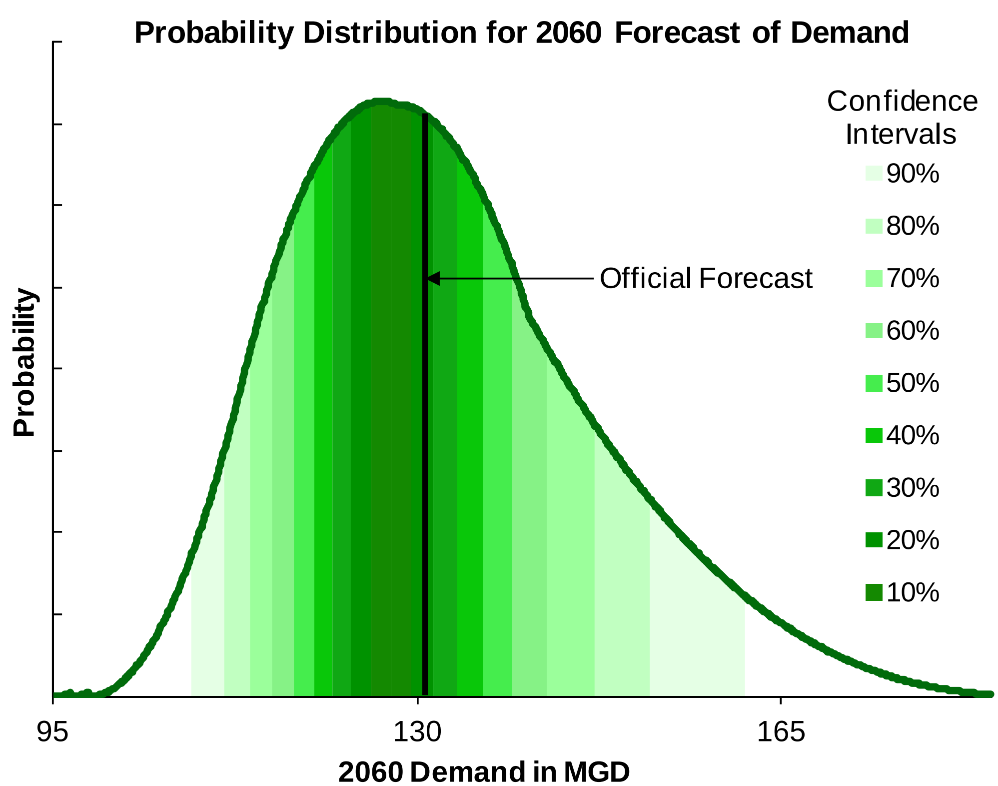
The uncertainty model represents a significant refinement over simply compounding all the high or all the low assumptions to create extreme high and extreme low scenarios. In the extreme high scenario, everything that could possibly cause demand to be higher than forecast is assumed to happen at the same time. The extreme low scenario is just the opposite with all low side assumptions applied simultaneously. These extreme scenarios overstate the actual uncertainty surrounding demand because they represent two highly unlikely combinations of events with essentially zero probability of occurring. The Monte Carlo simulation provides narrower bands of uncertainty and information about their estimated probabilities.

[14] Log normal distributions are used for the uncertainty around household and employment growth and average annual rate of growth in water prices because the high and low ranges exhibit positive skewness (i.e., the highs are higher than the lows are low).

[15] All variables with uncertainty are assumed to be independent except for growth in households and employment. These are linked in the model because they would be expected to move together.

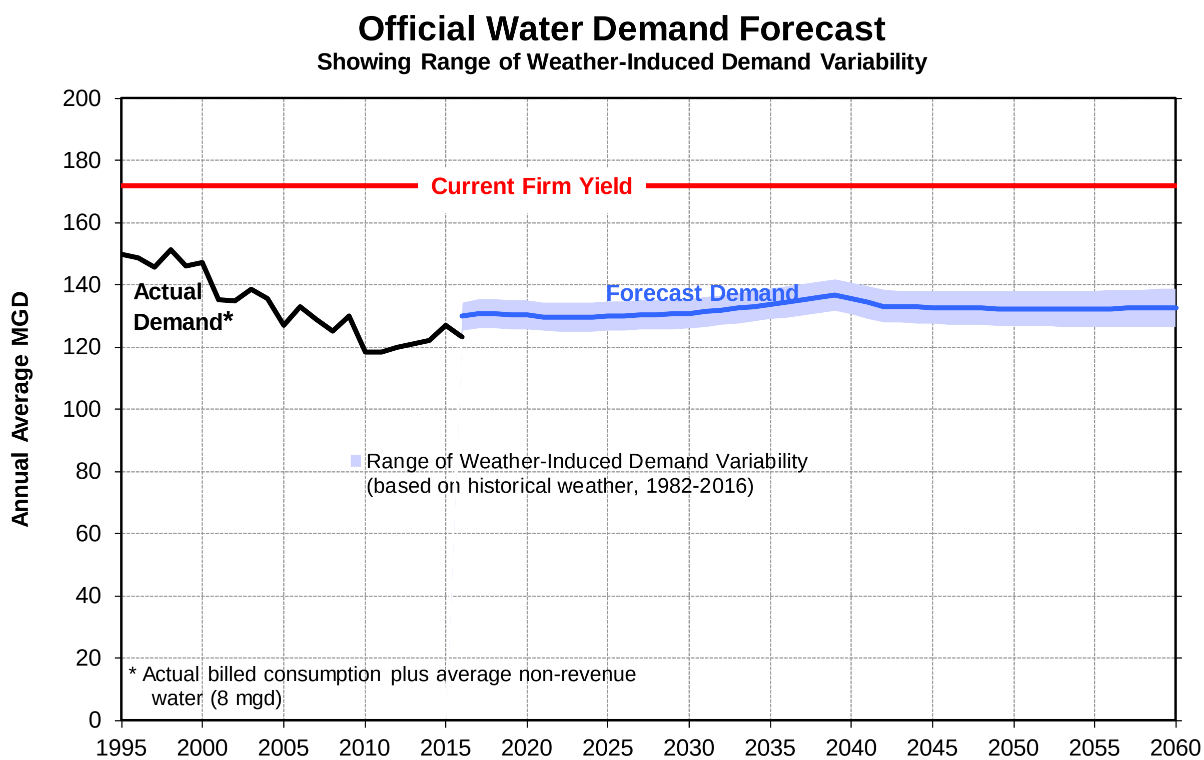


* Percentiles represent the probability that demand is less than the value shown. Ranges reflect uncertainty in projected household, employment, price and income growth; price and income elasticities; and conservation. Note that the Official Forecast is at about the 60th percentile.



<u>Implications:</u> Given the current firm yield estimate for SPU's existing supply resources and the official demand forecast, a new source of supply will not be needed until well after 2060. Even when taking demand uncertainty as modeled above into consideration, there is more than a 90% probability that a new water source will not be necessary before 2060. This analysis does not explicitly calculate the possible impact of the "discrete" category of uncertainties mentioned in the introduction, nor the potential impacts of all possible sources of uncertainty. Some additional sources uncertainty that could affect future water demand but which have not been accounted for in the uncertainty analysis are described below.

Weather-Induced Demand Variability: Another source of "haziness" in the forecast is weather-induced demand variability. This is not strictly a matter of uncertainty however because there is no doubt that summer weather will continue to vary from year to year, and that this variation will cause water demand to fluctuate around the trend. Because base year flow factors are calculated from weather-adjusted consumption data, the forecast represents demand under average weather conditions. In any one year though, summer weather variability would be expected to boost or depress demand relative to the forecast under average weather. Analysis of daily consumption data back to 1982 shows a maximum variability of about plus or minus **5%**. In other words, an extremely hot, dry summer would be expected to increase annual consumption *in that year* by up to 5% above the average trend. An extremely cool, wet summer would be expected to do the opposite, reducing that year's annual consumption by about 5% below the average trend. The amount by which actual demand is expected to be higher or lower than forecast due to variation in summer weather is shown as the blue band around the forecast in the graph below. Note this is based on historical weather variation and water use by customers. If the amount of weather variation around the average increases in the future due to climate change, the range of weather-induced demand variability might be expected to widen as well.



Climate Change: The water demand forecast model does not explicitly account for the potential impact of climate change on future demand, another source of future uncertainty. Climate modeling[16] suggests that by 2060, what now represents the high end for daily high summer temperatures could be the average weather condition (i.e., approximately 80°F over the three summer months). This means that in its hottest and driest years, the region has already experienced what could become average weather in 40 or 50 years of future climate change. Assuming the relationship between summer weather and water demand in the future remains similar to what it is now,[17] climate change might be expected to increase the forecast of *average-weather* water demand by approximately 5% over the forecast period, the upper end of the uncertainty band shown in the above graph of weather-induced demand variability under historic weather conditions. However, the climate models also project that weather variability will increase over time with a wider spread of summer temperatures from year to year. So, while climate change is not expected to bump *average* demand higher by more than the current range of weather-induced demand variability, weather variability – and therefore demand variability – will likely be greater in the future with wider fluctuations from year to year, again assuming no change in customer water use behavior.

The global impact of climate change could also bring about other significant but hard-to-predict changes to local water demand. For example, the Pacific Northwest could attract large numbers of people migrating from areas of the world hit harder by the deleterious effects of climate change. Loss of agricultural capacity worldwide could boost the importance of urban agriculture in the region and the demand for irrigation water. On the other hand, technological innovations in how we use water and energy could significantly reduce the demand for water from SPU's existing sources. Accounting for these types of uncertainty are beyond the scope of this analysis.

[16] The PUMA project, referenced in Section 2.4.1.3 of the WSP, involved downscaling climate projections from 20 different Global Climate Models (GCMs) run with two greenhouse gas emissions scenarios – one high (RCP8.5) and one low (RCP 4.5) – to several point locations in the Central Puget Sound region. Averaging the projections for SeaTac Airport from the 20 models using the high emissions scenario (RCP8.5) indicates that average air temperatures will be approximately 80 degrees Fahrenheit over in the June through August time period by 2060. Note that since this is the average of the high emissions projections, some of the models predict even higher increases in summer temperatures by 2060.

[17] Of course, that relationship could change and get stronger or weaker over time. On the one hand, the widespread practice of allowing lawns to go brown could become untenable as higher temperatures result in grass dying rather than going dormant without irrigation. On the other hand, hotter drier summers could induce people to plant more drought-tolerant landscaping or prod compensating public policies, programs or other efforts to help dampen water demand.