Appendix L

Municipal Water Demand Forecast Model

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L.1 General Methodology and Equations

CDM reviewed several different water demand forecasting methods and presented these to the Forum's Water Demand Forecast Advisory Committee early in the project. These approaches were evaluated for the development of a regional water demand forecast based on three criteria:

1. Goals and Objectives – What is the purpose of the regional demand forecast and what information would be helpful to water supply stakeholders and the public?

2. Data Availability – What data is available or can be readily derived?

3. Budget and Constraints – Given the project budget and schedule, what parameters and approach provide the greatest value in a regional demand forecast?

Figure L-1 presents the demand forecast models that CDM evaluated. Based on the above criteria and input from the Demand Forecast Advisory Committee, CDM selected a modified unit use approach.

Figure L-1 Water Demand Approaches Considered for Regional Water Supply Outlook

Benefits of the modified unit use approach are:

- Ability to capture water use characteristics unique to the major sectors of water demand (i.e., single-family, multifamily, and non-residential)
- Drivers of demand (e.g., projections of single-family and multifamily households, and employment) are readily available from accepted data sources and can be used to estimated future water demands for each major sectors
- Ability to include changes in water demand over time due to price, income, weather and other factors

- Ability to conduct sensitivity analysis and present scenarios of water demand
- Ability to add other adjustment factors, if and when they become available, such as local elasticities, housing density, etc.

L.1.1 Water Use Factors

Based upon available water use data from the surveyed water utilities (purveyors) and the corresponding demographic data, base year (starting point of the forecast) water use was calculated as an average of 2004, 2005, and 2006 data. Inconsistency in survey reporting required that an average be computed in order to have a uniform set of water use factors between purveyors. For details on water use factors and their development see Appendix I.

The following formulas were used in calculating per unit water use (unit use) for the base year by purveyor for each sector (i.e. the following formulas were used to calculate the unit use for 2004, 2005, and 2006; an average was then taken of the three years to compute the base year):

1. Unit use (gallons per day per account) for single-family sector:

Equation 1 – Single-family Water Use Factor Computation

$$WUF_{SFp} = \frac{WU_{SFp}}{HU_{SFp}}$$

Where:

WUF_{SFp} = unit water use in the single-family *SF* sector by purveyor *p*
WU_{SFp} = total water use in the single-family *SF* sector by purveyor *p*
HU_{SFp} =total households in the single-family *SF* sector by purveyor *p*

2. Unit use (gallons per day per household) for multifamily (*MF*) sector:

Equation 2 –Multifamily Water Use Factor Computation

$$WUF_{MFp} = \frac{WU_{MFp}}{HU_{MFp}}$$

Where:

WUF_{MFp} = unit water use in the multifamily *MF* sector by purveyor *p*
WU_{MFp} = total water use in the multifamily *MF sector* by purveyor *p*
HU_{MFp} = total households in the multifamily *MF* sector by purveyor *p*

3. Unit use (gallons per day per employee) for the nonresidential (*NR*) sector

Equation 3 –Nonresidential Water Use Factor Computation

$$WUF_{NRp} = \frac{WU_{NRp}}{EMP_p}$$

Where:

WUF_{NRp} = unit water use in the nonresidential *NR* sector by purveyor *p*
WU_{NRp} = total water use in the nonresidential *NR* sector minus large users NR by purveyor
EMP_p =total employment in the nonresidential *NR* sector by purveyor *p*

A process was used to apply unit water use factors to those utilities that did not report water use in the survey using water use factors from similar utilities from within the same sub-region.

L.1.2 Model Drivers

The *driver* in a water use equation represents the number of water users (or growth) in a given sector. Changes in the number of users are projected over time, and thus drive changes in the water use forecast. For the residential sectors, the *drivers* are the number of occupied single-family and multi-family units. For the nonresidential sector, the *driver* variables are total employment.

In some instances, not all single-family households within a purveyor's boundary are serviced by the purveyor. To account for this, CDM calculated the percentage of single-family households within the purveyor's ultimate boundary that is serviced by the purveyor as described in Appendix F.

For all sectors, sub-region *drivers* are calculated in the model by summing the given sector's *drivers* from each purveyor that falls within the sub-region for each forecast period (2010, 2020, etc.).

L.2 Step-by-Step Model Calculations

The Forum's Water Demand Forecast Model calculates the regional and subregion water demand through a series of data computations as illustrated in Figure L-2. These steps are detailed as follows.

Demographics and Drivers

- Utilities are assigned to sub-regions in the Provider Matrix
- Demographic projections, input at the utility level, are summed for each sub-region
- Weather data by station is assigned to each sub-region

- Future income and price growth rates are set for the entire region
- Single-family households are adjusted for each sub-region by the percent single-family households served within the utilities ultimate boundary; those not assumed to be served by the utility are self-supplied

Unit Use Factors and Preliminary Demand

- Water use factors are calculated for each utility by taking the billing data for single-family, multifamily and non-residential, and dividing by the corresponding demographic driver (e.g., households or employment)
- Those utilities that did not provide billing data were assigned a water use factor based on similar and/or neighboring utilities that had billing data
- Note that non-residential water use factors for providers with large non-residential water users were adjusted prior to model data entry (water use and employment were subtracted, and an adjusted water use factor was estimated
- Water use factors for single-family and multifamily are adjusted using income and price elasticities
- Non-residential water use factors are adjusted for employment mix and price elasticities
- Single-family (SF), multifamily (MF) and non-residential (NR) water use factors are multiplied by corresponding demographics (households and employment) by sub-region for each forecast year
- Water use for large water users (if any in sub-region) is added back as a constant demand
- Non-revenue water (NRW) is calculated for each sub-region, based on a percent entered for each provider
- SF, MF, NR, large water users, and NRW demands are summed to provide preliminary <u>annual</u> demand for each sub-region and forecast year

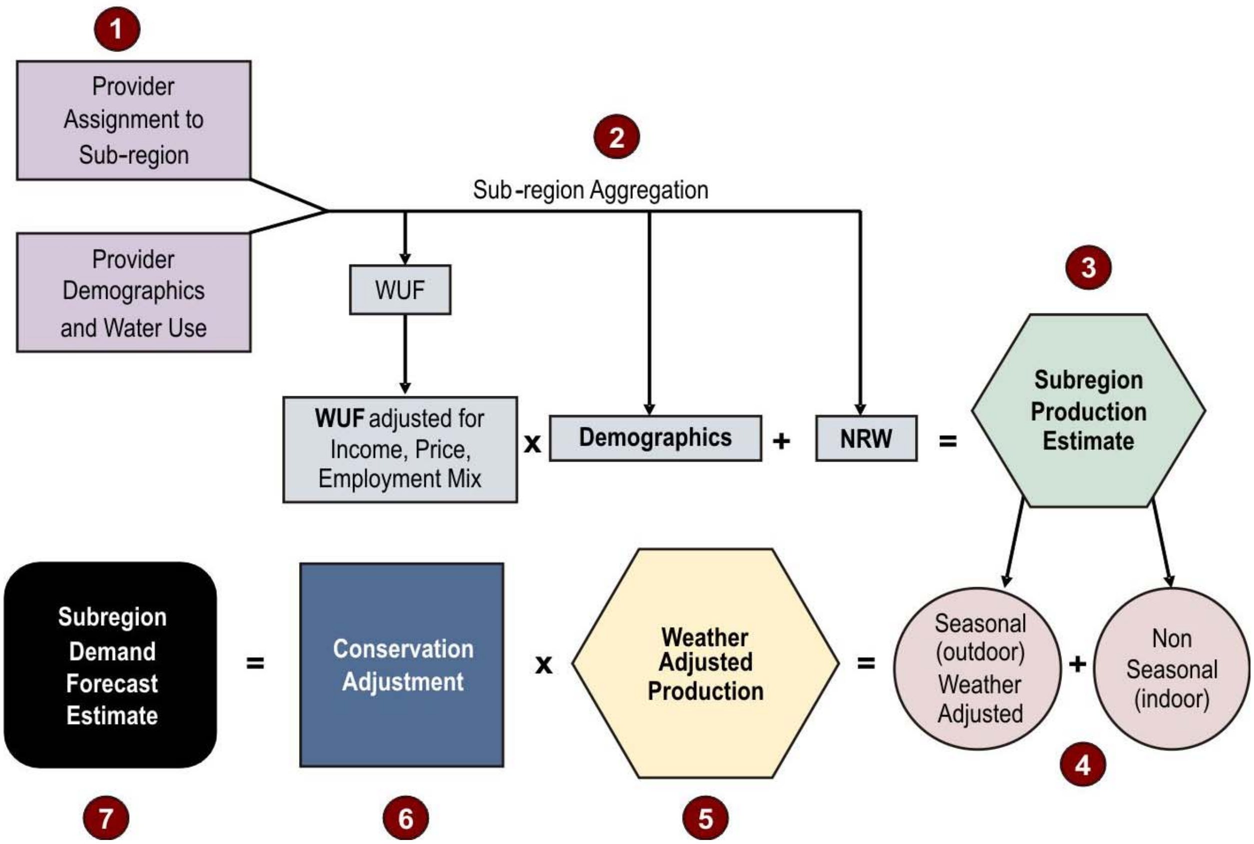
Adjustment for Weather

- The preliminary annual demand for each sub-region is allocated into monthly demand by applying seasonal percentages
- Indoor and outdoor water use is estimated by month for each sub-region using minimum month method
- Estimated outdoor water use in May - September is adjusted for weather conditions in those months for each forecast year
- Adjusted outdoor use is added back with estimated indoor use to produce the total monthly demand adjusted for weather for each sub-region
- Monthly demands are totaled to produce weather-adjusted annual demands for each sub-region and forecast year

Adjustment for Conservation

- Weather-adjusted annual demands are reduced by passive conservation
- Annual demands with passive conservation are reduced by utility goals conservation

Figure L-2 Central Puget Sound Water Supply Forum Water Demand Forecast Model Flow Diagram



L.3 Sector Demand Models

L.3.1 Single-Family

Single-family water demand is adjusted for price and income using Equation 4. In the demand model, single-family adjustments are applied to the annual water use factor.

Equation 4 –Single-Family Demand Model

$$QSF, p = \left[N_{SF_p}^{hu}\right] \bullet \left[\left(WUF_p\right) \left(\frac{MP_{Fp}}{MP_{Bp}}\right)^{\beta mp} \left(\frac{Inc_{Fp}}{Inc_{Bp}}\right)^{\beta inc} \right]$$

Where:

QSF,p = annual total water demand in the single-family *SF* sector for purveyor *p*
N_{SFp} = number if households *hu* in the single-family *SF* sector
WUF_p = base year unit water use factor for purveyor *p*
MP_{Fp} = marginal price of water for forecast period *F*
MP_{Bp} = marginal price of water for base year period *B*
Inc_{Fp} = income growth for forecast period *F*
Inc_{Bp} = income growth for base year period *B*
β = elasticities for marginal price and income, respectively

L.3.2 Multifamily

The multifamily model follows the same methodology as the single-family model and has the same variables, as shown in Equation 5. While the models are structured the same, the elasticities are different. For example, price and income elasticities for the multi-family sector are less than the elasticities for the single-family sector. A lower elasticity implies that the multifamily sector is less sensitive to changes in income and price.

Equation 5 –Multifamily Demand Model

$$QMF, p = \left[N_{MF_p}^{hu}\right] \bullet \left[\left(WUF_p\right) \left(\frac{MP_{Fp}}{MP_{Bp}}\right)^{\beta mp} \left(\frac{Inc_{Fp}}{Inc_{Bp}}\right)^{\beta inc} \right]$$

Where:

QMF,p = total water demand in the multi-family *MF* sector for purveyor *p*
N_{MFp} = number if households *hu* in the multi-family *MF* sector
WUF_p = unit water use factor for purveyor *p*
MP_{Fp} = marginal price of water for forecast period *F*
MP_{Bp} = marginal price of water for base year period *B*
Inc_{Fp} = income growth for forecast period *F*
Inc_{Bp} = income growth for base year period *B*
β = elasticities for marginal price and income, respectively

L.3.3 Nonresidential

The nonresidential model uses the number of total employees as the driver variable. As a sensitivity, the overall water use factor for nonresidential is adjusted based on the projected change in industry mix as well as price of water as shown in Equation 6. The adjustment factor for changes in employment assumes generalized water use per employee for different employment groups. As the mix of employment among these groups change over time for a given sub-region, the adjustment factor adjusts accordingly. For example, If 40 percent of a sub-region's employment is industrial employment, which has a high per employee rate of water use, and employment in 2020 is only 10 percent industrial employment, then the 2020 adjustment factor is less than 1.0 for that sub-region.

Equation 6 –Nonresidential Demand Model

$$Q_{NR}, p = \left[N_{NR_p}^{empl}\right] \bullet \left[\left(\frac{WU_{NRp}}{EMPL_p}\right)\left(\frac{MP_{Fp}}{MP_{Bp}}\right)^{\beta} \Delta\right]$$

Where:

Q_{NR}, p = annual water use in the nonresidential *NR* sector by purveyor *p*
N_{NRp} = number of employees *empl* in the nonresidential *NR* sector by purveyor *p*
$WU_{NRp}/EMPL_p$ = water use *WU* per employee *EMPL* in the nonresidential sector *NR* by purveyor *p*
MP_{Fp} = marginal price of water for forecast period *F*
MP_{Bp} = marginal price of water for base year period *B*
β = elasticity for the water use factors
Δ = adjustment factor for changes in employment mix

L.3.4 Large Water Users

Water use among individual large water using customers is included in the water demand forecast for those sub-regions for which data were available. Water use by large users is held constant through the forecast years. Large user water use is added as a line item to individual sector forecasts. (Specific information on large water users is provided in Appendix J.)

L.4 Non Revenue Water

Non revenue water (NRW) use represents the difference between the amount of water produced and the amount of water reported as billed consumption. A NRW percentage is entered into the model for each provider (as shown in Appendix I) and weighted for each sub-region based on the population served. NRW use for the sub-region is estimated after the individual sector forecasts have been generated and summed, as shown in Equation 7. NRW use is then added into the sub-region demand projections.

Equation 7 – Non Revenue Water Estimation

$$Q = \left[\frac{f}{1-f}\right]\left[Q^{SF} + Q^{MF} + Q^{NR} + Q^{LgUser}\right]$$

Where:

Q = non revenue water

f = non revenue water percentage

Q^{SF} = single-family consumption

Q^{MF} = multifamily consumption

Q^{NR} = nonresidential consumption

Q^{LgUser} = large user

L.5 Summation of Total Water Demand

Estimated water use for the single-family, multifamily, and nonresidential sectors are added with large water use and estimated non-revenue water for each sub-region. This is considered to be a preliminary annual water demand estimate to be adjusted for weather effects and conservation.

L.6 Adjustment for Weather Effects

The initial water demand estimate by sub-region is adjusted for the impact of temperature and precipitation on seasonal water demand. (Appendix I discusses the analysis of the impact of weather on water demand.) Results of that analysis show that outdoor water use during summer months May through September changes with respect to changes in monthly average maximum daily temperature and monthly total precipitation in those months.

To incorporate this weather effect, monthly outdoor use must be approximated from the estimated annual water demand. Monthly water use as a percent of total production was computed from survey data, as previously shown in Table I-7. The monthly water use percentage was used to estimate monthly water demand. The minimum month water use or was assumed to approximate non-seasonal use and anything greater than minimum was considered seasonal use. This approach is an approximation since actual use data is not available by month, and is based upon a sample of providers.

The initial annual water demand estimate is disaggregated into monthly use and monthly seasonal and non-seasonal use according to percentages. Estimated monthly seasonal water use is adjusted for changes in monthly temperature and precipitation using the elasticities determined by the production-weather analysis (discussed in Appendix I). Thus a weather-adjusted seasonal water use is derived. The adjusted seasonal use for each month is added back to the minimum month use to provide the estimated weather-adjusted monthly demand.

L.7 Elasticities and Other Adjustments

Central to the modified unit use approach is the adjustment in unit water use over time to account for various factors that influence water demand. Based on a survey of water demand models throughout the country, the leading factors that influence water use factors are:

- Weather (temperature and precipitation)
- Income
- Price of water
- Family size
- Housing density
- Employment mix

Choosing which factors to account for in the regional water demand forecast for the *2009 Regional Water Supply Outlook* depended on the following:

Benefits in terms of regional demand forecasting? – recognizing that regional forecasts for planning purposes are more generalized than utility-level forecasts for design purposes

Are the data for the forecast adjustments (e.g., income, housing density) readily available and recognized by regional planning agencies as good quality? – recognizing that over time, data that are currently not available may become so.

Is there an established relationship that is transferable to this region between the forecast adjustment and water demand? – recognizing that without such a relationship it might be speculative on how the forecast adjustments would affect water demand.

Based on the above considerations, **price, income, and employment mix** were incorporated into the demand models as adjustments to the per unit water use. **Weather** was incorporated into the demand models as an adjustment to total seasonal water use only. There is an established relationship between these factors and water demand in this region and the data were readily obtained.

While family size could have been computed, it was not considered to add a significant value to the model and was not included. The Demand Forecast Advisory Committee discussed housing density at some length; however data on existing housing density were not readily available, and more importantly predictors for changes to housing density were not available. Consequently, housing density was not included in the model. Note that housing density, measured as the number of housing units per acre, is essentially the inverse of lot size (e.g., four units per acre translate into ¼ acre lots).

To adjust the unit water use over time for price, income, and weather, three pieces of information were required:

- An elasticity – which represents how the factor affects water demand
- Base year value for the factor
- Future year value for the factor

In general, the mathematical equation for incorporating price and income is:

Equation 8 – Income and Price Adjustment to Water Use Factor

$$WUF_f = WUF_c \left(\frac{WF_f}{WF_c} \right)^{\beta}$$

Where:

WUF_f = unit water use in future year *f*
WUF_c = unit water use in base year *c*
WF_f = water adjustment factor such as price or income (future year)
WF_c = water adjustment factor such as price or income (current year)
f = future year value for water adjustment factor
c = current year value for water adjustment factor
β = the elasticity for the water use factor

Elasticities can be numbers less than or greater than 1, and are either positive or negative values. The elasticity for price is usually negative, meaning that as price increases, water use would *decrease*. Income elasticity, on the other hand, is usually positive, meaning that as income increases water use would *increase*. A price elasticity of -0.20 implies that if the real increase (above inflation) in price increases by 10 percent, water demand would decrease by 2 percent.

The change in water demand due to changes in weather conditions, specifically temperature and precipitation, in future years is also adjusted using elasticities, however, weather adjustments are only applied to estimated seasonal water use. Adjustments are applied in this manner to be consistent with the production-weather analysis model described in Appendix I. Seasonal water use is approximated based on historical monthly production data from the utility survey.

Future changes in **employment mix** are accounted for in the model as an adjustment factor rather than elasticity. The adjustment factor is calculated using generic gallons per employee per day (GED) values. Table L-1 shows an example of how a sub-region's employment mix adjustment factor is calculated. The generic

GED values were obtained from CDM/Planning and Management Consultants, Ltd. (1995) *IWR-MAIN 6.1: User's Manual and System Description. Appendix D*.

Table L-1 Calculation of Employment Mix Adjustment Factor

Example--2050 Adjustment Factor for Sub Region A	Retail	FIRES	GovtEd	WTCU	Mnfg	SUM
Sub Region A						
Base Year Employment	22,374	27,757	16,871	10,118	6,402	83,523
% of Category to Total	27%	33%	20%	12%	8%	100%
Sub Region A						
2050 Employment	30,160	64,097	19,837	16,846	9,800	140,740
% of Category to Total	21%	46%	14%	12%	7%	100%
Generic GED	71	139	102	46	132	
	Weighted GED (% x Generic GED)					Weighted GED
Base Year	19.1	46.2	20.7	5.5	10.1	101.6
2050	15.3	63.3	14.4	5.4	9.2	107.6
Adjustment Factor						
Sub Region A						
2050 =	(Future Weighted GED / Base Year Weighted GED) =					1.06

As shown above, a weighted GED for the base year and forecast year is computed by multiplying a sub-region's given year categorical percent of total employment by the generic GED. The resulting categorical GEDs are then summed to derive the weighted GED. The weighted GED result for the future year is then divided by the weighted GED for the base year, thereby creating an adjustment factor. This process accounted for the change in water use that is associated with changes in employment mix. The formula is as follows:

Equation 9 –Employment Mix Adjustment Factor Computation

$$EmployMixAdjust = \left[\left(GenericGED_{Cateogy} * \left(Employ_{Category} \div Employ_{Total}\right)\right)_{ForecastYears}\right] \div \left[\left(GenericGED_{Category} * \left(Employ_{Category} \div Employ_{Total}\right)\right)_{BaseYear}\right]$$

L.8 Conservation Calculations

Conservation savings are applied uniformly to all sub-regions. Water saved from conservation is differentiated between *passive* and *utility goals* conservation measures. The baseline water demand estimate includes both passive and utility goals conservation reduction. Model reduction from both levels of conservation is discussed in the following sections.

L.8.1 Passive Savings Calculations

Efforts to improve water use efficiency including manufacturing standards for plumbing fixtures are considered passive conservation measures. In Washington, these types of measures went into effect in two steps—intermediate standards that took effect July 1, 2000, and final standards that took effect July 1, 2003. The state standards anticipated federal standards that took effect in January 1994, under the National Energy Policy Act of 1992. These plumbing standards affect all toilet, urinal, showerhead and faucet fixtures used in new construction and retrofitted homes, as well as restrooms of commercial and industrial buildings.

One hundred single-family households were surveyed in 1996 and 1997 in Seattle as part of the American Water Works Association Research Foundation (AWWARF) study of *Residential End Uses of Wate*r (Meyer et al., AWWARF 1999). These households showed an average water use of 207 gallons per household per day, and approximately 57 gallons per day per capita (gpcd) for indoor use. More recent studies for the EPA indicate that a water efficient household would use about 40 gallons per person per day for indoor use. The AWWARF survey results of 57 gpcd per household represents a blend of efficient and non-efficient households.

Census data were used to estimate the approximate number of households built in the central Puget Sound region prior to 1994 by county and thus approximate the percent of water efficient homes about the time of the AWWARF survey. An assumption was made regarding the point in time in the future when all households would be water efficient and using 40 gpcd for indoor water use. The percent of total housing that was water efficient in a given year between the base year and future total efficiency year provided an adjustment factor that decreased the average household water use over time until the maximum indoor efficiency was achieved. The adjustment factor from passive conservation savings is shown in Table L-2.

Table L-2 Passive Conservation Savings Adjustment Factor

	2005	2010	2020	2030	2040	2050	2060
% savings from 2005 base	0.0%	2.0%	5.2%	7.6%	9.5%	9.7%	9.8%
adjustment factor (2005 base)	1.000	0.980	0.948	0.924	0.905	0.903	0.902

It was determined that passive conservation measures should be applied equally to all sub-regions but differently at the sector level. For single-family and multifamily, the passive conservation adjustment factor applies to all monthly nonseasonal water use. However, in the nonresidential sector passive conservation adjustment factors only apply to the percent of monthly nonseasonal water use that is used for toilets, showers and faucets (TSF), i.e. passive savings do not apply to water used for manufacturing. In order to account for this, the following steps were taken:

1. Determine percent of demand that is single-family, multifamily, and nonresidential by sub-region.

2. Calculate percent of nonresidential water use per employee that is from TSF by sub-region based on assumption of 20 GED for TSF use and the sub-region nonresidential GED.

3. Multiply percent of nonresidential demand to total demand by percent of nonresidential demand TSF to get the percent of demand that is nonresidential TSF demand.

4. Add the percent of total demand that is TSF (calculated in the previous step) to the percent of total demand that is single-family and multifamily to get the percent of total water use to be adjusted for passive savings.

5. Multiply previous value by the passive conservation adjustment factor.

Total water demand with passive conservation impacts is calculated as the sum of outdoor use adjusted for weather, indoor use not adjusted for conservation, and indoor use adjusted for conservation. These calculations of incorporating passive savings into the water demand forecast are illustrated in Figure L-3.

L.8.2 Utility Goals Calculations

The water demand estimate with passive conservation is then adjusted for utility goal conservation savings to determine the utility goals demand forecast. CDM recommended a percent reduction from 2005 to capture utility goals conservation savings attributable to the conservation programs discussed in Appendix I. The recommended percent reduction was approved by the Demand Forecast Advisory Committee.

The percent reduction in regional water demand due to utility goal-based conservation programs is shown in Table L-3. These savings are applied to the total monthly water demand adjusted for passive conservation, i.e., the utility goals conservation forecast includes both passive conservation and the percent reduction targeted by water purveyors. Utility goals conservation adjusts all sectors equally, including large users.

Table L-3 Utility Goals Conservation Savings Adjustment Factors*

	2005	2010	2020	2030	2040	2050	2060
% savings from 2005 base	0.0%	5.0%	10.0%	12.0%	12.0%	12.0%	12.0%
adjustment factor (2005 base)	1.000	0.950	0.900	0.880	0.880	0.880	0.880

*Utility goals conservation adjustment only, does not include passive savings.

For the central Puget Sound Water Demand project, the base demand forecast includes savings from both passive conservation and utility goals conservation.

Figure L-3 Passive Conservation Diagram