Central Puget Sound Water Suppliers' Forum

Independent Review of Water Demand Forecast Model

Final Report

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INTRODUCTION

In order to lay the foundation for an update to the 2001 Central Puget Sound Regional Water Supply Outlook, the Central Puget Sound Water Suppliers' Forum engaged the services of CDM to perform a municipal water demand forecast. CDM began work in 2007 under the oversight of the Forum's Water Demand Forecast Advisory Committee. The forecasting study includes a region-wide data collection phase, the development of an appropriate forecasting model, and the use of that model to prepare forecasts through the year 2060. As the study progressed, the Forecast Advisory Committee decided to commission an independent technical review of the water demand forecasting model, to be managed by a Subcommittee of the Forecast Advisory Committee. This report presents the results of that technical review.

The review was accomplished in two phases.[1] Task 1 addressed CDM's approach, including examination, as needed, of the water use model, data requirements, and data collection protocols. The water use model is understood to be the set of mathematical relationships that are used to estimate and forecast water use. Task 1 also reviewed proposed forecasting assumptions and other work products available through December 7, 2007. The Task 1 Memorandum was submitted on December 19, 2007.[2]

Task 2 continued this review based on CDM work products completed between December 7, 2007, and April 17, 2008. This report, in addition to presenting the Task 2 review, repeats much of the information from the Task 1 Memorandum, updated as necessary to reflect changes made by CDM since December 7.

The results of the independent technical review were presented to the Subcommittee and to other interested Forum members in a half-day workshop, held at Mercer Island on May 14, 2008. Following that workshop, the report was edited to incorporate comments and corrections, and to provide requested clarifications.

1 The Scope of Work for the review is included as an Appendix to this memorandum.
2 Boland, J.J., and B.K. Boland, "Task 1 Technical Memorandum," December 19, 2007 (cited as Task 1 Memorandum). As noted, much of the content of the Task I Memorandum is repeated in this report.

THE PROCESS OF WATER USE FORECASTING

Water use forecasting consists of two discrete steps: **explanation** and **prediction**. In the first step, analysts collect data on past water use and on selected determinants of demand, then specify and estimate a mathematical model which explains water use in terms of the chosen determinants (explanatory variables). The form of the mathematical model defines the data requirements, which in turn determine the cost and complexity of the approach. The planned use of the water use model for forecasting purposes imposes further requirements on the data, since the model should not utilize variables that cannot be reasonably projected for future years. As a general rule, more complex models are expected to have more explanatory power, while simpler models involve lower costs. The requirements of each individual application determine the choice of the water use model.

Obtaining a reliable water use model may involve some amount of verification and calibration. In many applications, the reliability of the model is demonstrated by backcasting historical water use. Once the water use model is complete and deemed acceptable, it can be used to forecast future water use. This is done by first projecting the values of the explanatory variables then, using those values, computing the forecast future value of water use. Obviously, there is a great deal of judgment involved in this exercise, beginning with the judgment that the derived water use model is an appropriate basis for computing water use 25 or 50 years in the future. Beyond that major decision, each explanatory variable requires a further exercise of judgment as to its likely future value. It is worth noting that, while the explanation step is a largely objective, quantitative process, the use of the explanatory model to forecast future water use is an entirely subjective step, relying on consensus views and the experience and judgment of the analyst to obtain a reasonable result.

This report attempts to summarize both the requirements for a regional water use forecast for the Central Puget Sound area and the approach taken by CDM. It supersedes and/or incorporates material previously submitted as the Task 1 Technical Memorandum. The report concludes with a summary of the issues as well as recommendations for the future use and development of the forecasting model.

CDM'S FORECASTING MODEL

The following discussion pertains to the water use model which CDM has developed for use in forecasting future water use (described in CDM documents as the "forecasting model"). The quality and utility of the resulting forecasts depend critically on the explanatory power of this model. In evaluating the characteristics of the water forecast model, it should be noted that the model is developed as a part of a regional water supply assessment, not as a tool for utility-level planning or decision-making.

SCOPE OF FORECAST

Because the water use model will be used for forecasting, it must be selected with the required scope of that forecasting application in mind.

Geographical Scope

The Forum has requested a regional water use forecast, covering Snohomish, King, and Pierce Counties and including water users served by public water systems as well as self-supplied users. The geographical scope, therefore, consists of the service areas of at least 118 water purveyors plus the residual areas of each county. It is important to note here that this is a regional forecast; it is not intended to be an aggregation of utility-level forecasts.

Included Water Users

The forecast is expected to address water use by those entities that are now, or are expected to become connected to one of the public water systems in the forecast area, as well as self-supplied users in other areas of each county. This requires that forecasts consider not only growth in the number of residential and non-residential users, but also growth in the fraction of all properties served by public utilities.

CDM collected data on the fraction of all single-family residences in each water provider service area that are not served from the public system in 2005. In preparing the forecast assumptions, the fraction unserved is steadily reduced over a 55-year period, as described in the Technical Appendix.[3]

The documentation makes an implicit assumption that there are no unserved multi-family or non-residential users within purveyor service areas. Puget Sound Regional Council (PSRC) data and projections for these categories are used without adjustment.[4] It is not possible to verify this since the spreadsheet model does not include these calculations.[5]

3 CDM, "Water Demand Forecast Technical Appendix," (draft report), April 7, 2008 (cited as Technical Appendix), pp. 3-5 and 6-3.
4 Technical Appendix, pp. 5-1, 5-4, and 5-5.
5 Spreadsheet model examined May 2, 2008.

Temporal Scope

The forecast base year is 2005. Because of data problems, some of the base year data may be estimated for 2005, or may be 2004-2006 averages.

The forecast will extend to 2060, with intermediate forecasts at ten-year intervals.

LEVEL OF DISAGGREGATION

Because water is used for many purposes, by many kinds of users, and in response to many different factors, the explanatory power of any model is strongly related to the degree of disaggregation of water use, and on the way in which that disaggregation has been accomplished.

Use Sector

CDM proposes disaggregating water use into four sectors:

- Residential – single-family
- Residential – multi-family
- Non-residential
- Non-revenue water (unmetered service, meter misregistration, leakage)

The goal of disaggregation is to segregate users whose water use has similar structure and explanation, such that differences are larger between sectors than within them. Certainly that is true for the residential vs. non-residential sectors. The degree to which the single-family sector differs from the multi-family sector depends on what kinds of water users are placed in each of these categories. Most water utilities utilize a multi-family category, but the definition of this category may vary widely from one utility to another.

The principal sources of CDM's water use data are the responses to the Water Utility Survey questionnaire. That survey asks that each utility identify the number of single-family accounts, billed water for single-family customers, billed water for multi-family customers, and whether multi-family use is included in non-residential use. This format leaves many questions unanswered:

- Are individually metered duplexes, triplexes, townhomes, condominium apartments, etc., considered single-family or multi-family customers? Or does the single-family sector consist only of detached single-family residences?

- Are all master metered residential structures placed in the multi-family category?

- If multi-family uses have been included in non-residential use, how have they been separated, if at all?

Available documentation does not provide answers to these questions. Ideally, given the constraint of no more than two residential sectors, the multi-family sector would consist only of master-metered residential structures (or groups of structures), whereas the single-family sector would include all individually metered units. It seems doubtful that CDM would have been able to accomplish this separation, given the quality of available data.

The result is that the two residential sectors, while differing with respect to average water use and average sensitivity to drivers such as price, may also have a large overlap. Furthermore, it appears that the multi-family unit water use factor has been derived by dividing utility reports of multi-family use by PSRC counts of households. To the extent that utilities define the multi-family sector differently from PSRC, this produces biased water use factors for both multi-family and single-family sectors.[6]

Generally, inconsistent definitions of the multi-family sector reduce the explanatory power of the model and will likely result in biases in the forecast, particularly as growth changes the mix of units in and between each of the two sectors.

Spatial

In any large-area forecast, spatial disaggregation is essential because of the spatial variability of many of the explanatory variables. Spatial disaggregation also provides a partial correction for some omitted variables, provided that they also vary spatially. But defining sub-regions is inevitably a challenging task.

PSRC has divided the planning area into 938 Transportation Analysis Zones (TAZs), providing historical and projected data for population, housing units, and employment by TAZ. But other data, such as median household income and more detailed employment data, are only available for each of the three counties. CDM initially identified seven weather stations, scattered throughout the study area, with suitable weather data. Ultimately, data from five of these weather stations were used.[7] Finally, the water connection, water use, and price data pertain to utility service areas. Using GIS techniques, CDM extrapolated and interpolated these data, in some cases using land use information to assign data to particular TAZs. The TAZ-level data were then aggregated to 118 utility service areas or divisions thereof.[8] Subsequently, the data were further aggregated to 23 forecasting sub-regions, of which seven are combinations of the other 16.[9]

Note that unit use coefficients are calculated at the utility service area level and it would have been possible to estimate demographic and economic variables for those same service areas. However, CDM rejected the idea of a spatial disaggregation by utility service area. There are good reasons for this decision. CDM pointed to the complexity and added cost of dealing with 118 sub-areas. A regional forecast is not expected to have the level of detail needed for a utility-level forecast. But perhaps a more important issue is that a utility-based regional forecast would invite inappropriate comparisons between the regional forecast and independent utility-generated forecasts, potentially undermining the credibility of both. The fact that these two types of forecasts are performed for

6 PSRC utilizes the U.S. Bureau of the Census definition of the multi-family sector: two or more households per structure. Thus the PSRC data include individually metered duplexes, townhouses, condominiums, etc. in the multi-family sector.

7 Technical Appendix, p. 4-1.

8 Technical Appendix, pp. 3-4 to 3-5.

9 Technical Appendix, pp. 2-1 through 2-3.

different purposes, using potentially different water use models, different assumptions and different data sets, does not mean that one forecast is more credible or more reliable than the other.

Seasonal

Seasonal disaggregation reflects the fact that warm weather water use (summer water use) responds to certain weather variables that have little to no impact on non-summer water use. The preferred method of dealing with this relationship is to segregate weather-sensitive water use and place it in a separate use category, explaining it with a separate model. CDM has adopted a form of this method. Seasonal water use for any month from May through September is defined as the excess of total actual use over 7.0% of annual production.[10] Because the segregation of seasonal use relies on production data to identify seasonal variation, seasonal water use cannot be disaggregated according to user sectors.

WATER USE EXPLANATION

The quality of every forecast depends on the explanatory power of the underlying model. In this case, the water use model must match the scope and level of disaggregation chosen for the forecast, but there are a number of other characteristics and criteria which, together, determine the explanatory power of the model.

Model Specifications

In developing water use models, CDM employed a modified unit use approach. Each sector model begins with a single-coefficient unit use model, which is then modified to incorporate additional explanatory variables. For the two residential sectors, the unit use coefficient is water use per household; for the non-residential sector, the unit use coefficient is water use per employee. The base (unmodified) water use in each residential sector is found by multiplying the number of households by the unit use coefficient; in the non-residential sector, the total number of employees is multiplied by the unit use coefficient. Large non-residential users are computed separately. Non-revenue water is estimated as the difference between production and the sum of residential and non-residential water use.

The base estimates of water use are then modified to reflect additional explanatory variables, as follows:

10 Aggregate statistics for the region indicate that monthly water production from October through April averages about 7.0% of annual production (Technical Appendix, p. 5-23). Seasonal use is defined in the Technical Appendix at p. 5-26.

Use Sector	*Additional Explanatory Variables*
Residential – SF	Price Income
Residential - MF	Price Income
Non-residential	Price Adjustment factor for changes in employment mix
Seasonal	Temperature Precipitation Employment

Residential Water Use Models

The general form of the residential water use models as presented in the Technical Appendix is as follows:[11]

$$Q_F = \left[N_F * WUF\right]\left[\left(\frac{MP_F}{MP_B}\right)^{\beta_{price}}\right]\left[\left(\frac{Inc_F}{Inc_B}\right)^{\beta_{inc}}\right]$$

Where:

Q_F = Water use for a specific sector, selected subregion, year F
N_F = Number of units for the selected sector, subregion, year F
WUF = Water use factor for selected sector and subregion (gpd/unit)
MP_F = Marginal price of water and sewer in year F
MP_B = Marginal price of water and sewer in year B
Inc_F = Median household income in year F
Inc_B = Median household income in year B
β_{price} = Price elasticity of demand
β_{income} = Income elasticity of demand

In this adjustment, year B is the base year of the forecast, the year for which the water use factor (WUF) has been calculated.

For purposes of the baseline forecast, the following elasticities are applied[12]:

Use Sector	*Price*	*Income*
Residential - SF	-0.25	0.30
Residential -MF	-0.075	0.15

11 Technical Appendix, pp. 6-4 and 6-5.
12 Technical Appendix, p. 7-1.

Non-Residential Water Use Model

Using the same slightly simplified notation, CDM's non-residential model is as follows:[13]

$$Q_F = \left[N_F * WUF\right]\left[\left(\frac{MP_F}{MP_B}\right)^{\beta\, price}\right]\Delta$$

Where: N_F = Number of employees for subregion, year F
Δ = adjustment factor for changes in employment mix

The water use factor (WUF) for the non-residential sector is defined as follows:[14]

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

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

If water use by large users is excluded from the numerator of this formula, the number of employees at those establishments should be excluded from the denominator. Since actual base year water use for the affected subregions is not provided in the Technical Appendix or in the spreadsheet model, it is not possible to verify that this computation was performed correctly. As stated, the formula would produce a water use factor that is biased downward.

The baseline forecast uses the following elasticity:[15]

Use Sector	***Price***
Non-Residential	-0.225

The adjustment factor (Δ) is intended to reflect future changes in non-residential water use that result from structural changes within the sector. For example, an increase in the fraction of total employment associated with the relatively low water use WTCU industries (wholesale, transportation, communications and utilities) can be expected to reduce average water use for the non-residential sector. Similarly, an increased fraction of total employment in high water use industries (e.g., manufacturing) would increase average water use in the sector.

13 Technical Appendix, p. 6-5.
14 Technical Appendix, p. 6-3.
15 Technical Appendix, p. 7-1.

The computation of the adjustment factor is based on PSRC projections of future employment for five groups of industries (Retail, FIRES, GovtEd, WTCU, and Mnfg). These employment projections are used to weight water use factors taken from a national study.[16] Weighted water use is normalized so that the base year value of the adjustment factor is 1.0. The calculation is performed separately for each county.

Seasonal Water Use Model

In order to reflect the effect of weather and other factors on seasonal water use, the unadjusted forecast of total water demand is allocated to calendar months, seasonal use is extracted, adjusted for the effect of other factors, and then added back in.[17] The adjustment is performed month by month, using the following equation:[18]

$$Q_{adjusted\ seasonal} = \left[Q_{seasonal}\right] \cdot \left[\left(\frac{M_x Temp_F}{M_x Temp_B} \right)^{\beta_{Temp}} \left(\frac{Precip_F}{Precip_B} \right)^{\beta_{Precip}} \right]$$

Where: $Q_{seasonal}$ = water use in month in excess of 7.0% of annual use
MxTemp = monthly average of daily maximum temperatures
Precip = monthly total precipitation
β = elasticities

(F and B refer to forecast and base years, respectively)

Based on the results of a regression on monthly data for the 1990-2006 period (excluding 1992 due to mandatory restrictions), the following elasticities were determined:[19]

Use Sector	*Temperature*	*Precipitation*
Seasonal Use	+5.855	-0.033

Discussion of Water Use Models

Price Adjustment to Non-Seasonal Water Use

All three water use sectors utilize models that incorporate a price adjustment. As presented in the Technical Appendix, these models appear to utilize the ratio of future to base year marginal prices for water and sewer service. The price elasticity of demand is applied as an exponent to the price ratio. However, none of the documents reviewed suggest that any price data were collected.

16 The computation of the adjustment factor is described in the Technical Appendix at p. 6-9. The water use factors for industry groups are taken from CDM/Planning and Management Consultants, Ltd., "IWR-MAIN 6.1: User's Manual and System Description: Appendix D," 1995.
17 The procedure is described in the Technical Appendix at pp. 5-29 and 5-30.
18 Technical Appendix, p. 5-30.
19 The elasticities are obtained from the "Weather-Production Function" described in the Technical Appendix, p. 5-28.

Instead, CDM has used the assumed growth rate of real price (1.0%/year in the baseline forecast) to compute the price ratio.[20] For example, the factor for 2060, assuming 1.0%/year growth for 55 years, is $(1 + 0.01)^{55} = 1.7285$. When the assumed price elasticity of -0.25 is applied to this ratio, the result is a decrease in year 2060 unit water use of 12.8%, other things being equal.

CDM's use of growth rates is computationally equivalent to the more common method of projecting future prices and calculating ratios with respect to actual base year prices. But the method tends to obscure some implicit assumptions that may be important to understand in evaluating forecasts. Specifically, the growth rate in real water and sewer prices is assumed to be constant over all sub-regions and over all water providers.

Other assumptions would have been possible: for example, utilities with relatively low prices in their size class could have been assigned higher price growth rates. Two rationales can be offered for this assumption.

- A lower-than-average price level within a size class might indicate a significant departure from full cost pricing, suggesting that the utility will require larger-than-average price increases in the future in order to maintain and replace infrastructure.

- New regulatory requirements tend to have approximately the same unit cost for utilities in a given size class. The imposition of these requirements, therefore, will have a larger percentage impact on utilities with lower-than-average prices.

Examination of base year price data would indicate whether modified price growth assumptions would have been useful. However, available documentation does not indicate that any price data were collected, so this examination is not possible.

Price and income elasticities were originally taken from literature surveys of demand studies performed throughout the U.S. CDM selected elasticities that seemed appropriate to the Pacific Northwest. Later, some adjustments were made to reflect Seattle's experience and other comments.[21] The elasticities, as presented, appear plausible. The only significant question arises from uncertainty regarding the structure of the multi-family sector. Water use forecasts are based on PSRC projections of units in multi-family dwellings, which apparently comprise a mixture of individually metered and master-metered buildings. The selected elasticity implies that the sector is dominated by master-metered structures.

The price elasticity assumptions are expected to be constant for all forecast runs and all forecast years. Sensitivity analyses are proposed for the price growth assumption, with values ranging from 0.0% to 2.0% per year.[22]

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20 CDM's use of this procedure was verified by examination of the model on May 1, 2008.
21 CDM, "Revised Growth Rates and Elasticities for Price and Income," November 28, 2007, p. 4.
22 Technical Appendix, p. 3-9.

Seasonal Water Use Model

CDM's somewhat complex method for adjusting seasonal water use is made necessary by the fact that no data exist for seasonal water use at the sectoral level. Computationally, CDM's approach is appropriate and consistent with the other elements of the forecasting model. However, the adjustment model itself raises some questions.

The elasticities used in the adjustment model were obtained from a "Weather-Production Function" which was, in turn, estimated from 17 years of historical data for eight utility service areas.[23] The purpose of this function was to obtain elasticities for two weather variables: monthly average of maximum daily temperature and monthly total precipitation. In deriving this function, CDM noted a temporal decline in non-seasonal and per capita use, which was attributed to increasing water use efficiency. In order to control for this trend, an employment variable was added on the basis of the argument that "the trend toward more efficient use may also be a result of changes in the economy of the region."[24]

The addition of the employment variable is likely a misspecification for several reasons. The principal causal connection between employment and water use trends would be through the mechanism of increased or decreased water use in the non-residential sector. Although aggregate sectoral data are not reported in the text, non-residential water use appears to be a comparatively small fraction of total water use. Furthermore, the expected impact of employment variations on water use would pertain primarily to non-seasonal use. While there are seasonal uses in the non-residential sector, they are not expected to dominate. The regression is specifically performed on seasonal use water, where employment should have little or not effect.

Thus the causal connection between employment and seasonal water use is weak, but the regression implies a relatively strong correlation between these variables. It can be concluded that the employment variable is serving as a proxy for other, unnamed explanatory variables. It is also possible that the employment variable is picking up some variance from the weather variables themselves and thus biasing the elasticity estimates for those variables.

The premise for including the employment variable was that it was a "trend" variable that would partially explain an observed negative time trend in the data. But the reported observations of a time trend pertained to non-seasonal water use (Figure 5-3) and per capita total water use (Figure 5-4).[25] No data are presented which would support the notion that there is a negative time trend in seasonal water use, which is the subject of the regression analysis. In any case, the regression coefficient for the claimed "trend" variable has a positive sign, suggesting that it is trying to explain a positive trend.

A further problem with the seasonal water use model is that it fails to include a price variable. The water demand literature is clear on this issue: seasonal water use is significantly more elastic than non-seasonal water use. This is particularly noted for single-family residential users, where the price elasticity for seasonal use may be in the range of -0.75 to -1.25. The problem would be in deciding

23 Technical Appendix, p. 5-28.
24 Technical Appendix, p. 5-21.
25 Technical Appendix, pp. 5-21 and 5-22.

how to reflect this. The data base used to derive the weather production function would likely not have been sufficient to develop a useful empirical estimate of seasonal use price elasticity, even if the necessary price information could have been collected.[26]

The other approach would be to develop a consensus estimate of this parameter, based on literature reports and on local experience. Since all water use equations in CDM's model are multiplicative, a price adjustment term could be placed in the seasonal water use adjustment model. The elasticity for this term would be the estimated elasticity of seasonal water use minus the weighted average elasticity of sectoral non-seasonal uses.

Omitted Variables

In terms of explaining historic sectoral water use, CDM's model utilizes three explanatory variables for residential sectors and two for the non-residential sector. In addition, the forecast will deal separately with seasonal water use and water conservation. This level of simplification is perhaps a reasonable compromise for a large-area regional forecast, but the possible impact of omitted variables should be examined.

In the case of the residential sectors, the omitted variables include further details on housing characteristics, household size, and housing density (or irrigable area). All of these have been shown to be important explanatory variables in water use models. Housing characteristics can be better reflected through additional disaggregation into, for example, detached single-family housing, non-detached or semi-detached individually metered housing, and master-metered housing. Household size is defined by the number of persons per housing unit, although some analysts have suggested grouping household members by age. Density measurements indicate the potential for lawn and garden irrigation and are strongly correlated with seasonal water use.

The non-residential model is based on total employment, an aggregation of employment over numerous commercial, manufacturing, government, and service categories. Water use per employee differs widely from one non-residential category to another, often by one or more orders of magnitude. Even within an industry category, there are large differences from one type of firm to another, and among firms of the same type. A global water use factor for all non-residential users submerges all of these differences, providing one number that is, in effect, a weighted average of many industry-specific factors. CDM has included an adjustment factor which attempts to reflect these differences to some degree, although it is limited by available employment projections to five groups of industries.

Moreover, non-residential water use depends on other variables, in addition to employment. For manufacturing firms, these include such things as quantity of product, type of process, degree of self-supply, recycle ratio, etc. Water use in restaurants depends on the number of meals served; water use in schools depends on the number (and age) of students; water use in office buildings depends on the presence or absence of a cafeteria/lunchroom; etc.

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26 Given the lag in price response, and also considering the several years of partial voluntary restrictions, the available record would not have been long enough to produce an estimate of long run price elasticity.

The consequence of not including variables such as those just mentioned is that all forecasts are based on the assumption that none of these variables change. More specifically, the residential forecasts assume that the mix of housing units remains the same as at the base year: there is no trend to denser housing, more townhouses or condominiums, etc., or the reverse. These forecasts assume that family sizes will remain the same. Non-residential forecasts assume that the structure of the economy within each of five groups of industries and within each subregion will be unchanged throughout the forecast period.

The literature demonstrates clearly that seasonal water use is much more elastic with respect to price than is non-seasonal use. But the model used to adjust seasonal water use for weather variations does not contain a price term. The reviewed documents contain no reference to the price elasticity of seasonal water use. Arguably, this response may be built into the sector models, as the elasticities proposed for the various sectors can be described as weighted averages of elasticities for seasonal and non-seasonal use. But these weighted average elasticities are assumed fixed over time even as the weights may change. If there is any significant change in the fraction of seasonal water use in the future (e.g., because of climate change), the proposed elasticities may be too low.

Obviously, some of the decisions to omit variables are very strong assumptions. If more detailed models are not feasible, the only way to address the impact of missing variables is to repeat the forecast at regular intervals in the future, re-estimating the models with updated current data. This allows near-term forecasts to track changes in the structure of housing and of the economy, but does not improve the accuracy of the long-term forecasts.

Water Conservation

The Technical Appendix describes two levels of water conservation for purposes of this study[27]: Both conservation levels are included in the baseline demand scenario and in all other scenarios defined thus far.

- Passive conservation.--indoor water use is adjusted in compliance with the provisions of the Federal Energy Policy Act of 1992 which, after 1994, requires water efficient plumbing fixtures (toilets, showerheads, and faucets) in new and retrofitted structures.

- Utility goals.--the set of water conservation policies and practices already implemented by water utilities, or planned for implementation by the utilities.

Passive Conservation

The effectiveness of passive conservation is estimated by CDM using aged inventories of housing units (based on census data), data collected from water utilities, as well as additional data from the literature and from CDM's experience. Passive conservation grows in effectiveness through the forecast period, as housing units are constructed or rehabilitated.

27 Technical Appendix, pp. 6-10 and 6-11.

CDM's calculation of the effectiveness of passive conservation is based on at least two studies: (1) a Seattle single-family residential study (sample size=100) performed in 1996-1997 as part of a larger study of residential end users of water;[28] and (2) an incompletely cited EPA study or studies. CDM summarizes the pertinent data by noting that an American Water Works Association Research Foundation study showed that average household water use was 207 gallons per household per day, with indoor usage of approximately 57 gallons per capita per day (gpcd). This figure represents a mix of households, some with efficient water-using fixtures, some without. CDM states that recent EPA studies indicate that a "water efficient" household has indoor water use of about 40 gpcd.[29] Without the ability to review the EPA study there is no way to verify that the 40 gpcd figure is appropriate for the Puget Sound region. At face value, however, the number appears to fall within the range of reasonableness.

Passive conservation was estimated for the residential sectors by using census data to determine the number of homes built prior to 1994, all of which are presumed to lack water efficient fixtures. These homes are then phased out over a number of years as they are demolished or rehabilitated. New homes built after 1994 and rehabilitated homes are assumed to comply with the water efficiency standards. Using the estimated reduction in water use attributed to efficient fixtures, CDM calculated an increasing increment of passive conservation savings through the year 2060, reflecting a 2.0% annual increase and using a 2005 base.[30] Water use savings range from zero in 2005 to 9.8% in 2060. These increments are said to apply to single-family and multi-family indoor water use. [31]

Passive conservation for the non-residential sector begins with the assumption that water use for toilets, showers, and faucets (TSF) is 20 gallons per employee per day without water efficient fixtures.[32] It is assumed that non-residential establishments phase in efficient fixtures at the same rate with the same effect as previously projected for residential users.[33] This produces a projection of passive conservation savings for non-residential users.

The method used to compute passive conservation savings for non-residential users is described in the Technical Appendix as a five-step procedure.[34] However, the text does not accurately describe the computations contained in the spreadsheet model.[35] Moreover, there are further errors in the spreadsheet:

- Rather than making individual sectoral computations for passive conservation, a single overall adjustment factor is derived. The derivation assumes that fractional water use reductions from passive conservation will be uniform over both residential sectors as well as the TSF portion of non-residential use. This clearly understates the impact on the non-residential sector, since the fraction reduction was derived for residences where only a part

28 Meyer, et al., "Residential End Uses of Water," AWWARF, 1999.
29 No citation was provided for this study and it could not be located in EPA's web site.
30 Technical Appendix, p. 6-10.
31 Technical Appendix, p. 6-10.
32 No source is provided for this number.
33 This assumption is not stated in the Technical Appendix; it was confirmed by examination of the spreadsheet model on May 2, 2008.
34 Technical Appendix, p. 6-11.
35 Confirmed by examination of the spreadsheet model on May 2, 2008.

of total water use is affected by water-efficient fixtures, while the TSF portion of non-residential use is, by definition, 100% covered by efficient fixtures.

- While the text states that passive conservation affects indoor water use only, the weighting of the adjustment factors is based on total water use (indoor plus outdoor). If seasonal water use is not distributed uniformly across sectors (e.g., if most seasonal water use is due to single-family residential uses) the result is a set of adjustment factors which overstate the effect of passive conservation.[36]

- While the actual passive conservation adjustment is correctly based on indoor water use, the computation of indoor water use employed here is incorrect. The Technical Appendix states the conventional definition: indoor water use is equated with nonseasonal use and is measured as the average level of water use for the months October through April.[37] However, for purposes of the passive conservation adjustment, the spreadsheet redefines indoor water use as equal to the level of water use in the minimum month (March, in this case). This has the effect of understating base year indoor water use by approximately 8%, and of understating passive conservation savings by a similar amount.

- The use of the same adjustment factors for residential and non-residential sectors implies that non-residential activities will replace or rehabilitate facilities at the same rate as housing units when, in fact, the turnover rate would likely be much faster. This results in understating the savings due to passive conservation in non-residential uses.

The overall effect of these errors cannot be determined without further analysis, but it should be noted that three of these problems act to understate passive conservation savings, while one likely results in some overstatement.

Utility Goal Conservation

This category comprises the set of conservation policies and practices already implemented by water utilities, or planned for implementation by the utilities. CDM prepared a list of such measures for 67 utilities and took note of the collective efforts of 13 utilities, organized by Seattle Public Utilities and known as the Saving Water Partnership.[38]

The Technical Appendix provides a table which shows the overall percentage savings and associated adjustment factors expected from utility goal conservation over the forecast period.[39] In this case, the savings were estimated subjectively, rather than being based on explicit assumptions and computations. Assumed percentage savings rise from zero in the base year to 12.0% by 2030 and remain at that level thereafter. The text states that the utility goal conservation factors are applied to all water use sectors, including large users. It is first stated that these factors are applied to total

36 Note that in computing indoor water use by sector, the spreadsheet incorporates the assumption that seasonality is identical for all sectors. Therefore, recomputation of the adjustment factors using the spreadsheet data for indoor use would not change the result. It would be necessary to reallocate seasonal use among the sectors more realistically in order to obtain an unbiased set of adjustment factors.

37 Technical Appendix, pp. 5-23 and 5-26.

38 Technical Appendix, pp. 5-31 through 5-39.

39 Technical Appendix, p. 6-11.

water demand "adjusted for passive conservation," but the same sentence then says that utility goal conservation savings "include both passive conservation and the percent reduction targeted by water purveyors."[40] However, examination of the spreadsheet model confirms that passive conservation and utility goal conservation reductions are separately applied.[41]

Washington State Municipal Water Law

The Municipal Water Supply—Efficiency Requirements Act of 2003, better known as the Municipal Water Law, mandates certain water conservation policies and actions by utilities.[42] Among other things, the Law requires water use efficiency planning and water use efficiency goal setting and performance reporting. These are both actions that are being carried out by the utilities and are reflected in the Central Puget Sound Regional Water Supply Outlook studies, including the water demand forecast study. But the Law also makes some very specific requirements:

- Any water utility which lacks meters on its sources or on its customer service connections must install such meters on new connections immediately and on existing connections by January 22, 2017.[43]

- All municipal water suppliers must maintain their distribution system leakage at or below 10 percent of production.[44] Distribution system leakage is defined as non-revenue water less any unmetered uses that are tracked and accounted for. Systems that are not fully metered will be given until three years after completion of metering to meet this standard.

CDM mentions the existence of the Municipal Water Law, but there is no reference to the two requirements noted above.[45] In particular, there is no information as to which utilities, if any, are not fully metered. Metering is not part of passive conservation, as defined by CDM, and is not included in any utility's conservation goals. If any utility in the region is required to meter in the next nine years, it is reasonable to expect a pronounced drop in water use for that utility. No such drop has been considered.

With respect to distribution system leakage, CDM collected data on non-revenue water where possible, but set an upper bound of 20% of production.[46] At least 18 utilities reported more than 20%. It should be noted that, prior to the passage of the 2003 Law, it was the policy of Washington State to encourage water systems to reduce non-revenue water to 20% or less. The 2003 Municipal Water Law changes that standard to 10% (with exceptions for specific tracked uses and losses from reservoirs and transmission mains) and makes it mandatory. It is reasonable to assume that all utilities with more than 10% distribution system leakage will take steps to reduce this amount in the

40 Technical Appendix, p. 6-11.
41 Spreadsheet model examined May 2, 2008.
42 Office of Drinking Water, "Summary of the Water Use Efficiency Rule," DOH PUB. #331-302, (update), Washington State Department of Health, Division of Environmental Health, July 2007.
43 Office of Drinking Water, "Water Use Efficiency Rule: Metering Requirements," DOH PUB. #331-306, (update), Washington State Department of Health, Division of Environmental Health, July 2007.
44 Office of Drinking Water, "Water Use Efficiency Rule: Distribution Leakage Standard," DOH PUB. #331-304, (update), Washington State Department of Health, Division of Environmental Health, July 2007.
45 Technical Appendix, p. 5-30.
46 Technical Appendix, p. 1-3.

near future. These reductions are not explicit in CDM's conservation adjustments and they are not discussed in the Technical Appendix.[47]

Reclaimed Water

The Forum's utility survey identified a number of possible users of non-potable water.[48] It is unclear whether or not reclaimed water, if provided, would displace potable water drawn from a public supply system. It is understood that this subject will be dealt with in the water supply study, so that it will be unnecessary to adjust the water demand forecast.[49]

47 At the May 14, 2008, workshop, Forum Project Manager Don Wright indicated that the 20% non-revenue water cap was obtained by assuming that all utilities would reach 10% distribution losses, as specified by the Washington State Municipal Water Law, and that tracked non-revenue uses (including reservoir management losses) could reach an additional 10% in some cases.

48 CDM, "Central Puget Sound Regional Water Supply Outlook: Task 2.5 Self-Supplied and Large Water Users," July 30, 2007.

49 Information provided at May 14, 2008, workshop.

DEMONSTRATING EXPLANATORY POWER

VERIFICATION AND CALIBRATION

The suitability of a water use model for forecasting depends on a number of things, including the choice of explanatory variables, flexibility, transparency, etc. But one of the most important qualities is the explanatory power of the underlying model. A model which does not adequately explain water use in the past is not likely to produce credible estimates of water use in the future. Explanatory power is tested in two steps: verification and backcasting.

Verification tests whether the model is capable of reproducing base year water use, subregion by subregion, sector by sector, season by season. This requirement is more or less demanding, depending on the modeling approach chosen. For example, in the case of a very simple unit use model, verification is essentially redundant: it merely repeats the calculation used to derive the unit use factor. This may also be true for the type of modified unit use method employed by CDM, since the price and income adjustment factors are equal to 1.0 for the base year. However, there are at least two characteristics of CDM's study that argue for performing a formal verification: (1) the considerable spatial complexity of the study, which included computing weighted averages of water use factors and developing various aggregations of data, and (2) the inclusion of a separate set of computations for reflecting the effect of weather on seasonal water use. For these reasons, a verification should be performed, if only as a check on computations.

Verification is expected to reproduce base year water use very closely, in all its dimensions. For forecasts utilizing a modified unit use model, such as the Central Puget Sound forecast, verification should reproduce actual water use almost exactly. In the event of a significant error, it is necessary to calibrate the model: to determine the cause of the error and to adjust the model to eliminate that problem. Calibration is an important step for some kinds of models, particularly those using econometric demand functions, but it is unlikely to lead to major changes in CDM's models.

BACKCASTING

Successful verification demonstrates that a model is capable of reproducing base year water use, but not necessarily able to reproduce water use in any other year. In the case of CDM's model, only the water use factors and seasonal use manipulations would have been tested in verification. In order to test other aspects of the specification, including the price, income, and weather coefficients (elasticities), it is necessary to perform backcasting over some representative period of time. In this case, observed values of the explanatory variables (number of residential accounts, total employment, water and sewer price, median household income, temperature, precipitation, etc.) are used to generate a water use estimate for one or more prior years. The resulting water use estimates are compared--subregion by subregion, sector by sector, season by season—with actual water use for these same years.

Backcast water use estimates will never match actual water use exactly. But they should be reasonably close in aggregate as well as approximating spatial, sectoral, and seasonal differences. If this is not the case, and particularly if the backcast errors appear to be growing as the time between the backcast year and the base year increases, the cause of the errors should be investigated. This process provides a final check on the reasonableness of such assumptions as price and income elasticities. If these adjustments tend to track actual water use changes in the past, they can be expected to do so in the future.

Note: if there have been abrupt changes in price or income in the past, backcast water use estimates may overstate the effect of those changes for several years. This is the result of a difference between short run and long run price and income effects. Forecasts properly assume the long run response to price and income. The short run response may be noticeably smaller, until such time as water users fully adjust to the new parameters.

FORECASTING WATER USE

BASELINE FORECAST

After the water use model is complete, forecasts are generated by providing projected future values for each of the explanatory variables. Some of these variables are demographic (number of single-family water accounts, number of multi-family water accounts) and economic (total employment, price, income). Others are climatologic (rainfall, precipitation), or related to existing or anticipated conservation measures. Projections of demographic variables and employment are obtained from the PSRC for forecast years up to 2040, then extended at constant growth rates thereafter. The baseline forecast incorporates these assumptions as well as specific assumptions about other explanatory variables, as follows:

- Long-term normal values for weather variables: average maximum daily temperature and total monthly precipitation.
- Weather elasticities of +5.85 for temperature and -0.033 for precipitation, assumed for all sub-regions and all forecast years.
- Real median household income is projected to grow at 0.5%/year.
- Real marginal price for water and sewer is projected to grow at 1.0%/year.
- Income elasticity of demand is +0.30 for the single-family residential sector and +0.15 for the multi-family sector.
- Price elasticity of demand is -0.25 for the single-family residential sector, -0.075 for the multi-family sector, and -0.225 for the non-residential sector.
- Existing large users will remain constant in water use and employment, but will be impacted by conservation and weather effects.
- Conservation savings will include both passive and utility goal efforts, and will be uniform through the region.

FORECAST SCENARIOS

The proposed forecast scenarios were first described in detail in an October 2007 presentation.[50] Nine scenarios were listed: three involving weather, three involving demographic growth, and three specifically dealing with climate change. Shortly after this meeting, a somewhat different plan was set forth in a Technical Memorandum.[51] At that time, eight scenarios were mentioned: a baseline scenario (implied but not discussed in the memorandum) and seven alternative scenarios. Two of

50 CDM, "Water Production Weather Model," a presentation given on October 18, 2007.
51 CDM, "Demand Forecast Scenarios," October 23, 2007.

the alternatives would utilize different rates of demographic growth, two would utilize different climate assumptions, and three would address different assumptions regarding conservation. The subject was discussed again in December 2007.[52] At that time, forecasts were presented showing future water use under no less than nine scenarios.

The Technical Appendix presents results for eight scenarios: baseline, low demographic growth, high demographic growth, cool and wet, hot and dry, GISS climate change, ECHAM climate change, and IPSL climate change. However, despite being labeled as scenario analyses, the preparation of these alternative forecasts are more properly described as an exercise in sensitivity analysis. Each "scenario" considers changes in only one or two explanatory variables as compared to the baseline forecast, and none present an integrated description of a possible future.

Scenario Planning

The use of forecast scenarios is an excellent way to facilitate appropriate consideration of the uncertainty inherent in key forecast assumptions. Scenarios convey much more information to planners than single-point forecasts, helping to identify the most likely range of possible outcomes, showing the relative importance of various assumptions, answering many kinds of "what if" questions.

There is an important difference between scenario planning and sensitivity analysis. Sensitivity analysis explores the mathematical relationship between a selected variable or assumption and a resulting single-point forecast. The results of sensitivity analysis are useful in (1) diagnosing backcasting errors, thus improving the explanatory power of the model, or in (2) forecasting for testing the reasonableness of individual assumptions. But these results, which reflect arbitrary and isolated perturbations, do not provide much assistance to planners.

Scenario forecasting, on the other hand, is specifically designed to support planning. A scenario is a complete story, a set of trends and assumptions that together describe a possible future state. To be informative, however, the scenarios must be plausible, comprehensive and internally consistent, and balanced.

Plausible

There is no purpose in posing a scenario that includes events or trends that are so unlikely that they would never be taken into consideration in a planning process. Particularly in the case of water facility planning, where assumptions pertain to long-term trends and there are opportunities for mid-course corrections, any scenario considered in planning should have a reasonable probability of occurrence.

Comprehensive and Consistent

In the course of designing a scenario, attention must be paid to interrelationships among key assumptions. For example, suppose a higher-than-baseline demographic projection is desired. It is

52 CDM, "Water Demand Forecast Scenarios," a presentation given on December 6, 2007.

necessary to make further assumptions as to where this increased growth would occur and within what socio-economic class. These assumptions may lead to changes in the forecasts of employment and median household income, so that future values of these variables are consistent with the larger number of households. Finally, if the higher demographic forecasts cause forecast water use to increase significantly, this may require utilities to seek higher cost sources, or to take other actions that increase the average cost of water and sewer. This may suggest modifying the projections of water and sewer price to be consistent with the demographic forecast.

Conversely, a lower-than-baseline demographic projection could, on examination and analysis, lead to lower rates of growth in employment and in water and sewer price. Slower growth may be associated with either lower or higher rates of growth of median household income, depending on what form the demographic changes take.

Some conservation assumptions (especially those that lower seasonal demands) may imply lower rates of growth of water and sewer prices. Some weather and climate assumptions, especially to the extent that they alter seasonal demands, might also affect projections of water and sewer prices.

Scenarios that ignore the interrelationships among the assumptions and trends do not provide useful information to planners. In fact, single-issue scenarios are nothing more than sensitivity analysis by a different name.

Balance

Scenario planning typically proceeds by comparison to a baseline scenario, which is sometimes also the most likely scenario. In order to properly consider the range of uncertainties, care should be taken to balance the scenarios; that is, to provide about the same number of scenarios that result in lower-than-baseline water forecasts as those that give higher-than-baseline forecasts. The scenarios should not give the impression that most alternative projections lead to more (or less) water demand in the future. The possibilities for deviations in either direction should be articulated in the scenarios.

CDM's Scenarios

- *Demographic assumptions.*--Two scenarios are provided that consider alternative demographic assumptions.[53] The Low Demographic Growth scenario incorporates a reduced growth rate for population which is translated into lower growth in households for each residential sector and for employment in the non-residential sector. The High Demographic Growth scenario assumes higher than baseline growth for these explanatory variables. However, no related changes are proposed for income growth or price growth. There is no indication that higher or lower demographic growth will affect seasonal water use, or that increases or decreases in the number of new households will affect the passive conservation assumptions.[54] Only total employment numbers for each sub-region are presented for these

53 Technical Appendix, pp. 5-6 through 5-13.

54 If fewer new households are added in the future, the fraction of households with water-efficient fixtures will be lower than it otherwise would be.

scenarios: it is not known whether or not changes are made within the non-residential sector, with associated changes in the adjustment factor, Δ.

- *Weather assumptions.*--Two scenarios consider deviations from historic weather patterns.[55] The Hot and Dry scenario uses average monthly maximum temperature of 5% above historical average (approximately the 90th percentile level) and total monthly precipitation of 30% below historical average. The Cool and Wet scenario lower historical average monthly maximum temperature by 5% (approximately the 10th percentile level) and increases precipitation by 30%. No changes are made in other explanatory variables, including price (which could be affected by the need to provide more or less peaking capacity).

- *Climate change assumptions.*--Possible future weather data were also obtained from three climate change models: GISS, ECHAM, and IPSL.[56] As in the case of the previous weather assumptions, no changes were made in other explanatory variables, including price.

The GISS climate change forecast predicted year 2060 water use at approximately the same level as the Hot and Dry scenario, but the other two climate change forecasts predicted significantly higher levels. All three climate change forecasts exhibited a "jumping off" problem, in that they produced year 2005 forecasts that were 10 to 14 MGD higher than baseline levels.[57] In presenting these results, CDM showed the forecasts net of the year 2005 discrepancy, as shown on Figure 7-5. This approach tends to minimize the impact of climate change on results early in the forecast period. Two alternative approaches that could be considered: (1) use the baseline 2005 result in combination with the 2010 and later climate change results, giving a 5-year change ranging from 5.4 to 11.6 MGD; or (2) merge the baseline forecast with the climate change forecast over the first 15 years.

With the exception of the baseline scenario, none of the alternative runs meet the definition of a scenario. In each case, two or three related explanatory variables are altered, with no consideration of the way in which the postulated future conditions could affect other variables. As sensitivity analyses, however, they do provide some helpful information.

CDM also suggests that scenarios may be constructed with various combinations of price and income growth rates.[58] This is a step in the direction of more attention to interactions among explanatory variables, but it suggests that growth in price will be generally greater when income grows faster. In fact, income growth is likely the result of growth in employment, while price growth is more strongly associated with increased water use and particularly increased seasonal water use.

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55 Technical Appendix, pp. 4-6 through 4-9.
56 Technical Appendix, pp. 4-9 through 4-19.
57 Technical Appendix, p. 7-15.
58 Technical Appendix, p. 3-9.

FINDINGS

The following section summarizes the more important findings of the independent review. Other observations and findings can be found in the text of this report, under the related headings.

None of the findings of this review suggest the presence of large errors or major biases in the forecasting model. The issues discussed below generally involve unknown bias or, at worst, relatively moderate biases. But even biases that appear small in the near term can grow over time and render long-term forecasts unreliable. For this reason, it is important that any forecasts generated by this model be revisited from time to time.

WATER USE MODEL

- The model chosen appears to be appropriate for the purposes of the study, given caveats mentioned below.

- The use of a disaggregated unit use approach, modified by the inclusion of several multiplicative factors (incorporating price, income, weather, etc.) is well established.

- The strengths of this model include:

  - The level of complexity is appropriate for a regional forecast covering the service areas of many purveyors.

  - The model is relatively transparent and easily implemented in a spreadsheet format, providing good accessibility.

  - The coefficients are readily updated in the future, with only modest data collection costs.

- The weaknesses of the model include:

  - Many significant explanatory variables are omitted, resulting in reduced explanatory power.

  - Elasticities transferred from other studies are potentially inappropriate for the study area.

- The disaggregation of residential users (SF vs. MF) is problematic for two reasons:

  - Water use factors for the multi-family sector appear to be computed by dividing utility-reported water use by PSRC data for number of housing units in multi-family structures. PSRC uses the U.S. Bureau of the Census definition for the multi-family sector: any structure with two or more households. There is no indication that all of the utilities in the region employ the same convention. Accordingly, it is likely that there is significant overlap between the two residential sectors, and possibly with the non-residential sector as well. This problem creates the potential for biased forecasts, as growth changes the relative size of these two sectors.

As a consequence of this computation, it is likely that the multi-family water use coefficient is too low and the single family water use coefficient is too high. The effect on forecasts depends on whether one sector grows faster than the other.

  - The U.S. Bureau of the Census definition of multi-family households is less than optimal for water use forecasting purposes. If the goal is to define sectors that distinguish between different patterns and levels of water use, and if the water use model is limited to two residential sectors, it would be preferable to define SF as all individually-metered households, regardless of building type, and to define MF as all master-metered units.

    Because individually metered and unmetered (master-metered) units are combined in the multi-family sector, the assumed price elasticity for this sector is necessarily a weighted average of the price elasticities for metered and unmetered units. If, in the future, the number of metered units grows faster than the number of unmetered units, and if real price rises over time, forecast water use for the multi-family sector will be biased upward.

- The introduction of an adjustment factor for the non-residential water use model provides some responsiveness to the changes in the structure of employment that are likely to occur in the future. CDM's approach to this problem makes good use of available disaggregate employment forecasts. A further improvement would be to utilize water use factors derived specifically for the Puget Sound region.

- The assumed rate of increase of real water and sewer marginal price appears reasonable, however it should be remembered that the model assumes the same rate of increase for all utilities in the region. Examination of actual base year prices might have identified some utilities that can be expected to have a higher rate of growth, at least in the near term, such as those with current prices that are unusually low for the size class. Since no price data were collected, this step was not possible.

    Depending on the number of utilities that will require higher-than-average price increases in the future, forecast water use for those utilities will be biased upward, and forecast water use for other utilities will be biased downward. It is unlikely that this has any significant effect on forecasts of aggregate regional water use.

- The weather elasticities used to adjust seasonal water use were derived from a mis-specified model and are therefore somewhat suspect.

  - The Weather-Production Model incorporates an employment term which would have, at best, a weak causal relationship to aggregate seasonal water use, yet it shows a strong correlation with the wrong sign (based on stated expectation). This suggests that the correlation is spurious and the weather elasticities may be biased.

From the information provided in the Technical Appendix, there is no way to tell how the weather coefficients may be biased, if at all. Accordingly, the impact of this issue on forecast water use cannot be predicted.

- ○ No price term is included in the Weather-Production Model or in the subsequent estimates of seasonal water use, despite the fact that seasonal water use is substantially more price-responsive that non-seasonal use.

  The omission of a price term in seasonal water use means that this sector of water use is assumed to respond to price in the same way as nonseasonal water use. The result is a water use forecast which is biased upward in the summer, but not affected in the winter. The forecast average annual water use is biased upward.

- ● The treatment of water conservation in the Technical Appendix contains errors and does not accurately describe the actual calculations performed in the spreadsheet model. Examination of the spreadsheet model revealed further errors.

  - ○ The adjustment factors used for all sectors are defined on the basis of total water use, rather than indoor water use.

    To the extent that seasonality is not identical for each sector, this method produces conservation adjustment factors that are biased upward, resulting in forecast water use that is biased downward.

  - ○ The subsequent computation of water savings from passive conservation is correctly based on indoor water use. However, the definition of indoor water use is inconsistent with conventional practice and with usage elsewhere in the forecasting study: it is taken to be equal to water use in March. This definition implies the existence of seasonal water use in 11 months of the year.

    Because March water use understates average nonseasonal use, the result of this computation is to understate conservation potential. Forecast water use is biased upward.

  - ○ Passive conservation for non-residential users utilizes the same adjustment factors calculated for residential users, even though they are applied to non-residential TSF uses which are 100% covered by water efficient fixtures. The adjustment factors are derived for residences where only a portion of water use is affected by water efficient fixtures.

    This results in understating conservation potential for non-residential users. The result is a forecast of water use which is biased upward.

  - ○ No assumptions are stated in the Technical Appendix regarding compliance with the Washington State Municipal Water Law. There is no finding as to whether the utilities in the study region are completely metered. If some are not they are required to fully meter by 2017; this would be accompanied by a significant and permanent drop in water use. CDM does not consider this possibility in the conservation projections.

To the extent that a significant number of presently unmetered users are metered during the forecast period, and to the extent that water use by those customers has been estimated with reasonable accuracy in the past, the installation of meters will result in a permanent drop in water use. Assuming that this occurs, forecast water use is biased upward.

DEMONSTRATING EXPLANATORY POWER

- There is no mention in the Technical Appendix of plans for verification or calibration of the water use model, or of using the model to backcast water use. These steps are necessary to demonstrate the ability of the model to explain water use.

WATER USE FORECAST

- The intention is to prepare a regional forecast as the aggregation of 16 sub-regional forecasts. Utility-level forecasts are not prepared, nor should they be. The modified unit use model selected by CDM, while appropriate for a regional forecast, is not generally suitable for utility-level forecasts.

- Eight scenarios are described, including a baseline forecast. Of these, only the baseline forecast can be called a true scenario. The others incorporate various demographic and weather assumptions, but without consideration of interrelationships among the key variables and assumptions. This results in single-issue scenarios; that is, little more than sensitivity analysis. These alternative forecasts provide some information about sensitivity of water use to specific variables, other things being equal, but since other things may not remain equal, they do not present a complete picture.

SPREADSHEET MODEL

- The scope of work for this independent technical review did not include an audit of the spreadsheet and none was performed. However, in some cases where the documentation raised questions as to how certain computations were made, relevant portions of the spreadsheet were examined. The results of these investigations are reported above, however three overall comments can be made.

  - In general, the spreadsheet is well organized and user-friendly. The overall design appears to be very well suited to the purpose.

  - Certain basic data and preliminary calculations do not appear in the spreadsheet. Specifically, actual base year water use data from the purveyors are not included and the calculation of the base year water use factors is not shown. This may not interfere with the intended use of the spreadsheet but, as noted in this report, it prevented the verification of certain questioned computations.

- There are a number of cases where the spreadsheet and the documentation do not match. This inconsistency was noted for the computation of passive conservation and for the definition of indoor (non-seasonal) water use.

RECOMMENDATIONS

Recommendations are presented here in three groups. The first concerns changes that should be made now. These issues have been singled out because they can be readily corrected without altering the structure of the existing model. In most cases, they involve minor adjustments to formulas or replacement of coefficients. The second group addresses changes that could be made now, but can also be made at any time in the next 5 or 10 years. The third group is intended as a list of things to keep in mind as the forecasting model is used, in the event that the opportunity to address these issues arises.

CHANGES THAT SHOULD BE MADE NOW

- **Passive Conservation.**--The computation of the effect of passive conservation should be corrected to eliminate the following problems:
    - The computation of the passive conservation adjustment factor is incorrectly based on total water use, not on indoor water use.[59]
    - Indoor water use should be equated to the average water use over the winter season (defined elsewhere in the model as October-April), not as the level for the minimum month. The current practice implies that weather-sensitive outdoor uses occur eleven months of the year.
    - Passive conservation for non-residential toilet-shower-faucet use, which is 100% impacted by water efficient fixtures, is calculated with the same adjustment factor used for residences, where only a portion of water use is impacted by efficient fixtures.
    - The rate of adoption of water-efficient fixtures (resulting from new or rehabilitated structures) is assumed to be the same for non-residential and residential units.
- **Passive Conservation Documentation.**--The description of the passive conservation adjustments in the Technical Appendix should be changed so that it accurately reflects the computations in the spreadsheet.
- **Municipal Water Law.**--The likely near-term effects of the Washington State Municipal Water Law should be investigated and incorporated into the forecasting model, where appropriate.
    - To the extent that some providers had unmetered connections in the base year, the effects of metering on overall water use, on sectoral water use estimates provided in the survey, and on non-revenue water should be determined, and the forecasting model parameters adjusted accordingly.

59 Note that changing the formula in the current spreadsheet will not alter the result, since all sectors (even non-revenue water) are assumed to have equal seasonality. A more realistic allocation of seasonality, as recommended here, will result in a more accurate passive conservation adjustment factor.

- CDM and the Forum should assess the likelihood of providers achieving the maximum 10% distribution system loss mandated by the Municipal Water Law. Assumed non-revenue water fractions should be adjusted as needed.[60]

- **Scenario Descriptions.**--The scenario specifications should be expanded to include related changes in other explanatory variables. For example, different demographic projections should be associated with different growth rates for income and possibly with different mixes for future employment. Weather-related scenarios that result in more or less seasonal water use should be associated with higher or lower growth rates for price, respectively.

- **Weather-Production Model.**--The Weather-Production Model should be re-estimated, eliminating the employment term. If a time trend--uncorrelated with weather variables--is still evident, it can be removed in various ways that do not introduce the likelihood of coefficient bias. However, due to the small amount of available data, this step should be approached cautiously.

- **Weather Adjustment of Seasonal Use.**--Once unbiased weather elasticities have been obtained from a revised Weather-Production Model, the weather adjustment to seasonal water use should be revised to include a price term. The price elasticity should be based on the consensus of the literature regarding the price elasticity of (specifically) seasonal use, minus the price elasticity of year-round use already incorporated in the model.

CHANGES THAT CAN BE MADE LATER

- **Verification and Backcasting.**--As per the present status of the forecasting study, there is no way to judge the explanatory power of the model. As noted elsewhere in this report and in the Task 1 Memorandum, verification and backcasting are the only available means of testing explanatory power at the time of model development. In this case, verification and backcasting have not been performed as of the date of this review. Although less satisfactory, the alternative would be to perform future year verifications. Sometime after the year 2010, for example, data could be collected on all the explanatory variables and used to calculate water use for 2010, as well as water use by sub-region.[61] A close examination of the results might suggest improvements and/or build confidence in the explanatory power of the model.

THINGS TO KEEP IN MIND

- **Omitted Variables.**--In the interest of transparency and usability, some known explanatory variables were omitted from the forecasting model. These include housing density, household size, housing type mix (e.g., rental apartments, condominium apartments, semi-detached units, etc.) and variables affecting non-residential uses. The effect of omitting these variables is to assume that they remain unchanged throughout the forecast period. If,

60 The definition of distribution losses in the Municipal Water Law excluded unmetered withdrawals which are tracked and accounted for, (such as main flushing, fire suppression, etc.) as well as losses from transmission mains.

61 This test can also be limited to selected sub-regions.

in the future, changes in these factors are noted, it is possible to correct the forecasting model by either (1) recalculating the affected water use factors or (2) revising the affected water use models.

- **Elasticities.**--The price and income elasticities were not empirically determined for the region, but were based on results from other studies as modified subjectively by local experience. If future demand studies in the region suggest different values for these elasticities, consideration should be given to replacing the values used in the forecasting model.

- **Price and Income Trends.**--The baseline forecasting assumptions include most likely long-term trends for real marginal water and sewer price and real median household income. If, after a number of years, it appears that the long-term trends have diverged from these assumed values, consideration should be given to altering the baseline forecast assumptions accordingly.

DOCUMENTS REVIEWED

SCOPE OF WORK

CDM Scope of Work (as conveyed via e-mail by Kyle Comanor on Nov. 19, 2007)

MEETING NOTES (APPROVED)

Jan. 11, 2007: Joint meeting-Municipal Water Demand Forecast & Municipal Water Supply Assessment Advisory Committees

Feb. 8, 2007: Joint meeting-Municipal Water Demand Forecast & Municipal Water Supply Assessment Advisory Committees

Mar. 1, 2007: Municipal Water Demand Forecast Advisory Committee

Mar. 15, 2007: Joint meeting-Municipal Water Demand Forecast & Municipal Water Supply Assessment Advisory Committees

Apr. 5, 2007: Municipal Water Demand Forecast Advisory Committee

Apr. 19, 2007: Joint meeting-Municipal Water Demand Forecast & Municipal Water Supply Assessment Advisory Committees

Jun. 7, 2007: Municipal Water Demand Forecast Advisory Committee

Jun. 21, 2007: Municipal Water Demand Forecast Advisory Committee

Jul. 19, 2007: Municipal Water Demand Forecast Advisory Committee

Aug. 16, 2007: Municipal Water Demand Forecast Advisory Committee

Sept. 20, 2007: Municipal Water Demand Forecast Advisory Committee

Oct. 18, 2007: Municipal Water Demand Forecast Advisory Committee (including two tables: (1) Central Puget Sound Percentage of Non-Revenue Water to Total Production (10-18-07), and (2) Puget Sound Draft Projections of Percent Served Using Available Data)

Nov. 8, 2007: Municipal Water Demand Forecast Advisory Committee

Dec. 6, 2007: Municipal Water Demand Forecast Advisory Committee

Jan. 17, 2008: Municipal Water Demand Forecast Advisory Committee

PRESENTATIONS

Jul. 6, 2006: Seattle Public Utilities Water Demand Forecast Model – Bruce Flory

No Date (possibly 2006?): City of Everett, Water Demand Projection Methodology – (No name)

Jun. 21, 2006: Puget Sound Regional Council (PSRC) Forecasts and Planning Data – Mike Simonson & Tim Michalowski

Mar. 1, 2007: Water Demand Forecasting Approach – Presented to the Water Demand Forecast Advisory Committee – CDM

Jun. 7, 2007: Water Demand Forecast Model: Technical Memorandum - Presented to the Water Demand Forecast Advisory Committee – CDM

Jul. 19, 2007: Water Demand Forecast Scenarios - Presented to the Water Demand Forecast Advisory Committee – CDM

Aug. 16, 2007: Data Collection and Water Demand Factors - Presented to the Water Demand Forecast Advisory Committee – CDM

Sept. 20, 2007: Re-Calculation of Unit Use Factors - Presented to the Water Demand Forecast Advisory Committee – CDM

Sept. 20, 2007: Analysis of Water Production - Presented to the Water Demand Forecast Advisory Committee – CDM

Oct. 18, 2007: Water Conservation Scenarios - Presented to the Water Demand Forecast Advisory Committee – CDM

Oct. 18, 2007: Water Production and Weather Model- Presented to the Water Demand Forecast Advisory Committee – CDM

Nov. 8, 2007: Preliminary Water Demand Forecast and Forecast Scenarios- Presented to the Water Demand Forecast Advisory Committee – CDM

Dec. 6, 2007: Water Demand Forecast Scenarios- Presented to the Water Demand Forecast Advisory Committee – CDM

Dec. 6, 2007: Comparison of Existing Water Supply and Demand Projections- Presented to the Water Supply Assessment Advisory Committee – CDM

Jan. 17, 2008: Water Demand Forecast Memo Update – Presented to the Water Demand Forecast Advisory Committee – CDM

Feb. 21, 2008: Water Demand Model Modification- Presented to the Water Demand Forecast Advisory Committee -- CDM

TECHNICAL MEMORANDA AND CORRESPONDENCE

Feb. 2007: Municipal Water Demand Forecast Advisory Committee- Background for the DCM Team, Demand Forecasting Model

Feb. 2007: Municipal Water Demand Forecast and Water Supply Assessment Advisory Committees- Background for the DCM Team, the Role of Conservation

May 22, 2007: (memo header date of May 10, 2007) Technical Memorandum Task 4.1 to Don Wright. Central Puget Sound Regional Water Supply Outlook: Water Demand Forecast Model, from Dan Rodrigo and Bill Davis

May 22, 2007: Ibid. Technical Memorandum Task 4.1. Central Puget Sound Regional Water Supplier's Forum Water Demand Forecast Model – Model Scenarios, from Dan Rodrigo and Bill Davis

Jun. 28, 2007: Correspondence from Richard Reich (e-mail) to Demand Forecast Advisory Committee members and CDM, posing questions Re the demand model structure proposed for discussion at the next advisory committee meeting

Jul. 02, 2007: Correspondence from Dan Rodrigo (e-mail) to Members of the Demand Forecast Advisory Committee and Don, in response to and regarding questions concerning the demand model structure proposed for discussion at the next advisory committee meeting posed by Richard Reich (e-mail) June 28, 2007.

Jul. 30, 2007: Technical Memorandum Task 2.4 to Don Wright. Central Puget Sound Regional Water Supply Outlook: Historical Curtailment Events, from Dan Rodrigo and Bill Davis

Jul. 30, 2007: Technical Memorandum Task 2.5 to Don Wright. Central Puget Sound Regional Water Supply Outlook: Self-Supplied and Large Water Users, from Dan Rodrigo and Scott Coffey

Aug. 9, 2007: Technical Memorandum Task 2.0 to Don Wright. Central Puget Sound Regional Water Supply Outlook: Data Collection and Processing, from Dan Rodrigo, Scott Coffey and Bill Davis

Aug. 9, 2007: Ibid. Attachment 1 – 11 X 17 Plots of Surveyed Water Purveyors and Planning Sub-Regions, Attachment 2 – Demographics by County

Oct. 23, 2007: Memorandum to Don Wright. Demand Forecast Scenarios (including table of "Assignment of Water Use Factors as of 11-2-07"), from Dan Rodrigo

Nov. 28, 2007: Memorandum to Don Wright. Revised Growth Rates and Elasticities for Price and Income, from Dan Rodrigo

Jan. 4, 2008: Memorandum to Don Wright. Central Puget Sound Regional Water Supply Outlook: Task 4.1: Water Demand Forecast Model – Updated, from Dan Rodrigo and Bill Davis

Jan. 18, 2008: Memorandum to Don Wright. Central Puget Sound Water Demand Forecast Task 3: Water Use Profile, from Dan Rodrigo and Bill Davis

Feb. 1, 2008: Memorandum to Don Wright. Central Puget Sound Regional Water Supply Outlook: Task 4.2: Weather-Production Analysis, from Dan Rodrigo and Bill Davis

REPORTS

CDM, 2008 Central Puget Sound Regional Water Supply Outlook: Water Demand Forecast Technical Appendix, (draft report), April 7, 2008.

SURVEY FORMS

Central Puget Sound Water Suppliers' Forum, 2008 Regional Water Supply Outlook, Water Utility Survey (one example of "Long Form," one example of "Short Form")

STATE OF WASHINGTON DOCUMENTS

House Bill 1338 (Second Engrossed Second Substitute), 58th Legislature, 2003 1st Special Session, "Municipal Water Supply – Efficiency Requirements Act of 2003," commonly known as the Municipal Water Law.

Office of Drinking Water, "Summary of the Water Use Efficiency Rule," Washington State Department of Health, Division of Environmental Health, DOH PUB. #331-302 (update), July 2007.

Office of Drinking Water, "Metering Requirements," Washington State Department of Health, Division of Environmental Health, DOH PUB. #331-306 (update), July 2007.

Office of Drinking Water, "Distribution Leakage Standard," Washington State Department of Health, Division of Environmental Health, DOH PUB. #331-304 (update), July 2007.

APPENDIX

Water Demand Forecast Review: Scope of Work and Schedule

Scope of Work

Work will be conducted in three tasks.

Task 1.--A Review of the Model Development Approach

This task will include examination of the forecasting model, data requirements and data collection protocols, and the suitability of the model for the Puget Sound application. Note, however, that this task will address only those questions that can be answered with the reports or other documentation available by mid-November 2007. Any of the following questions which cannot be answered in this task will be deferred to Task 2.

Among the questions to be asked about the model is whether it is sufficiently detailed but not overly complex; whether the degree of disaggregation produces reasonably homogeneous water use sectors; whether the model reflects current knowledge of the relationships between explanatory variables and water use but is still adequately transparent; and whether it imposes data requirements that can reasonably be met. The model design should reflect, as much as possible, consensus views of causal and other relationships. It should also minimize the role of judgment in producing a forecast.

Data requirements, data sources, and data specifications will also be examined in this task. Data should be fully documented and obtained from reliable sources. Where sampling or survey methods are used, the resulting estimates should be robust and statistically significant (where possible). Data gaps should be clearly identified and corrected by statistically sound and reproducible methods. Generally, the documentation of the data collection phase should be sufficient to allow another investigator to replicate the data set. In addition to a review of these issues, decisions regarding data specification (e.g., for the price variable) will be examined in this task.

A very important part of Task 1 is the determination of the suitability of the forecasting approach to the Puget Sound Region application. The model must include the relevant water use categories; incorporate variables which are capable of reflecting structural, economic, and demographic shifts; and must support the planned policy analyses. For example, the forecast should accurately reflect seasonality in water use, the effect of weather variation, the effect of climate change, future rate-making practices, and the effect of changes in water conservation policies.

The deliverable item for the first task will be a memorandum to the Independent Review Sub-Committee ("Sub-Committee") outlining the scope of the investigation, noting the limitations of the available information at this early stage, and summarizing the conclusions reached. The memorandum will also indicate which issues or questions are deferred to Task 2, due to lack of information. If weaknesses in CDM's approach have been identified, they will be described and, where possible, corrective actions proposed.

Task 2.--Review of the Final Model

This task covers the same topics addressed in Task 1, with the addition of a review of the application of the final model. The task will be based on whatever CDM reports or other materials have been completed by mid-December 2007.

To the extent that questions regarding the modeling approach, data collection, and model suitability could not be addressed in Task 1, they will be taken up again in Task 2.

Task 2 will also address some specific questions: If any changes have been made in the modeling approach, are those changes properly justified? Do any changes detract from the transparency, credibility, or other characteristic of the resulting forecast? Does the forecasting approach properly deal with sources of uncertainty or bias? Does the forecasting approach facilitate future updates? Will data collection for future updates be unnecessarily burdensome? Can the model be readily modified to reflect feedback from future forecasting applications?

If CDM has identified forecasting scenarios, this task will examine the way in which those scenarios were developed. Are the scenarios plausible? Is the set of scenarios balanced and bias-free? Are the scenario definitions appropriate to the decision/policy context?

Finally, this task will seek to determine if the final forecasts are likely to be fully supported by the methods and data and whether they are expected to be transparent, credible, persuasive, and useful.

The deliverable item for this task is a short draft report to the Subcommittee. After review by the Subcommittee and participating agencies, the report will be revised to reflect any questions or comments received. It is possible that the final, revised report will be submitted after the completion of Task 3.

Task 3.--Presentation of Review to Subcommittee

The Reviewer will provide a presentation of the results of this review to the Subcommittee, interested Forum members, and the model development team. In the course of a half-day workshop, the Reviewer's comments will be presented and questions and responses will be discussed. It is anticipated that the results of this workshop will be incorporated into the final report on Task 2.

Proposed Schedule

14 Nov 07	Notice to Proceed
16 Nov 07	Materials received from Subcommittee/CDM for review
19 Dec 07	Task 1 report submitted
30 Jan 08	Draft Task 2 report submitted*
Feb-Mar 08	Presentation of review to the Subcommittee at a time to be selected by the Subcommittee Final Task 2 report will be issued 14 days after receipt of Subcommittee comments on draft Task 2 report.**

* Schedule for Task 2 assumes that complete documentation of the Final Model will be available not later than 19 Dec 07. If documentation is not complete at this time, the completion of Task 2 may be delayed.

** Due to late completion of CDM materials, schedule dates were revised several times. The most recent dates for completion are:

5 May 08	Submission of draft final report
15 May 08	Presentation of review to Subcommittee
26 May 08	Submission of final report