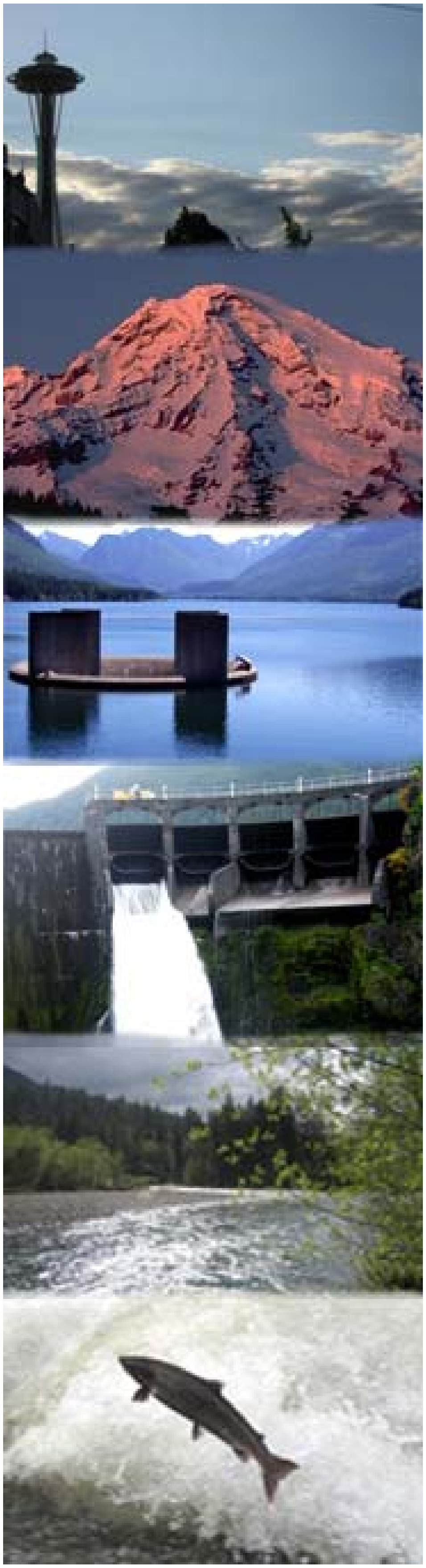

Technical Memorandum #6:

Framework for Incorporating Climate Changes into Water Resources Planning

Prepared for:

Climate Change Technical Committee

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Technical Memorandum #6
Framework for Incorporating Climate Changes into Water Resources Planning

Why Incorporate Climate Change into Regional Water Resources Planning?

The ability of many municipal water supply systems to provide ample and reliable water is influenced by both climate and weather[1]. The variability of weather from year to year determines if a particular year is unusually warm or cool, wet or dry. A region's climate defines the average conditions over several decades, thus providing insight into what is most likely to reoccur. In the past, water resources engineers and hydrologists incorporated the variability of a region's weather in evaluating water supplies. In general, a region's climate was considered stationary; that is, climate was assumed to be constant over time.

The opinion that only weather variability needs to be considered in water resources planning is changing dramatically. The Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) (2007) concludes climate change is real, that it has occurred and that it will continue in the future. In the four IPCC reports that have been issued thus far (1990, 1995, 2001, and 2007), the authors state that climate change will significantly impact water resources. In these reports, changes in water resources have been consistently listed as one of the most important global impacts of climate change. These reports represent the most comprehensive and thoroughly reviewed documents on the subject of climate change. In addition to the four IPCC reports (the assessment reports are actually a series of multiple reports plus extensive supplemental material), other peer reviewed literature and general studies have been published on the impacts of climate change on water resources.

In addition to international reports, the Regional Integrated Sciences and Assessments (RISA) Program of the Climate Program Office in the National Oceanic and Atmospheric Administration (NOAA) has established regional centers for climate impacts research throughout the US. One of the RISAs deals specifically with climate change in the Pacific Northwest. This center is located at the University of Washington and is called the Climate Impacts Group (CIG). CIG has produced regional and national climate science research for over a decade (Battin et al., 2007; Hamlet et al., 2005; Hamlet et al., 2007; Mote, 2003; Mote, 2006; Mote et al., 2005a; Snover et al., 2003; Van Rheenen et al., 2003; Van Rheenen et al., 2004; Whitely-Binder, 2006). Northwest regional studies performed by CIG, and by other researchers, have indicated that this region, with its reliance on snowpack and high utilization of its rivers and streams for hydropower, water supply, irrigation, and fish habitat will be particularly impacted by climate change. Impacts clearly identified are a shift in the hydrologic cycle, increasing temperatures and evapotranspiration, increasing streamflows in the late fall and winter, decreasing inflows in the late spring and summer, decreases in average snowpack in April, and potentially increasing

[1] Weather is the mix of events that happen each day in our atmosphere including temperature, rainfall and humidity. Climate is the average weather pattern in a location over many years. Climate at a location controls the weather. The climate of Dallas is different from that of the Puget Sound, but both can experience hot days and cold days. Abstracted from the National Center for Atmospheric Research (NCAR) website, http://www.eo.ucar.edu/basics/ .

storm intensities and extreme streamflows for the winter months. With expected changes in peak streamflow timing, municipal water supplies throughout the West are facing increased competition for water and potential water shortages during peak water demand seasons. Moreover, the projected impacts to salmon and other fish listed under the Endangered Species Act (ESA) indicate that lower summer flows, higher summer water temperatures and increased winter flows will all have negative impacts on fish populations throughout the West and specifically in the Pacific Northwest (Battin et al., 2007).

Because of the growing scientific consensus that our climate is changing and because of the mounting research that suggests these change will have significant impacts, it is important that climate change be evaluated in future estimates of water demand and supply. This fact has been clearly recognized in the Puget Sound Region. Many agencies and organizations in the Puget Sound Region are voluntarily participating in a Regional Water Supply Planning Process (http://www.govlink.org/regional-water-planning/index.htm). The purpose of the Regional Water Supply Planning Process (RWSPP) is to identify, compile information on, and discuss many of the key issues that relate to or may affect water resources in the region. The goal is to develop the best available data, information, and pragmatic tools that the participants may use, at their discretion, to assist in the management of their respective water systems and resources, and in their water supply planning activities. To address the issue of climate change and other key issues that relate to or may affect water resources in the region, the Scoping Committee of the RWSPP created the Climate Change Technical Committee (the Committee) to develop preliminary information as to what we know and can use as planning scenarios and recommend ways that this information can be integrated into the water planning processes. This technical memorandum describes a framework developed by the Committee for estimating the impacts that future climate change may have on municipal water demand and water supply.

What are the Potential Impacts of Climate Change?

Water resources planning traditionally assumes that past events are useful indicators of the future. Planners are well aware that the past will not repeat itself, but water resources planners typically use history to characterize the past and use it as an indicator of future variability. Rippl (1883) developed the, now famous, Rippl diagram to incorporate past streamflows to estimate the required storage in a reservoir to meet water demands. Hurst (1950) in his groundbreaking studies of the Nile River developed estimates of the needed storage on the Nile River to meet future needs based upon the statistics of streamflows in the past.

In the future, climate change will make those past approaches less appropriate. Climate change will recast the manner in which engineers and scientist can extrapolate past conditions as oracles of the future. Past events will remain reminders of what can and has occurred, but the extent to which past events can serve as design elements of the future will diminish. This will require a significant shift in our planning paradigm, and such shifts are often challenging to implement.

In the Puget Sound region, climate change will have many impacts. Among the most important are changes in: 1) Temperature, 2) Precipitation, 3) Snow/Snowpack, 4) Storm Events, 5) Wastewater Flows, 6) Ability to meet instream flow requirements, and 7) Water Quality. Climate change impacts on temperature are well documented and are addressed in the other

Technical Memorandums produced by the Committee. As noted in those reports, temperatures in the Puget Sound Region have increased during the past 50 years by more than twice the average for the US as a whole. Increased temperatures are forecasted to continue in the 21st century. Table 1 presents the results of evaluating three GCM models for the King, Pierce, and Snohomish Counties. The three General Circulation Models (GCMs) model/scenario couples (ECHAM5_A2, GISS_B1, and IPSL_A2) selected for this study provide a broad range of future scenarios for investigation. Details can be found in Technical Memorandum #4 (Polebitski et al., 2007) and the Final Report. As indicated in the table, annual average temperatures are forecasted to increase by 5.2 °F by 2075.

Table 1: Projected Ensemble Average Seasonal Temperature Changes Relative to Historic[2]
(Degrees Fahrenheit, Degrees Celsius in parentheses)

	Spring (MAM)	Summer (JJA)	Fall (SON)	Winter (DJF)	Annual
Ensemble-2000	0.7 (0.4)	1.6 (0.9)	0.7 (0.4)	0.4 (0.2)	0.9 (0.5)
Ensemble-2025	1.3 (0.7)	2.5 (1.4)	1.6 (0.9)	2.2 (1.2)	2 (1.1)
Ensemble-2050	2.2 (1.2)	4.5 (2.5)	2.7 (1.5)	2.7 (1.5)	3.1 (1.7)
Ensemble-2075	3.8 (2.1)	6.8 (3.8)	4.9 (2.7)	5.4 (3)	5.2 (2.9)

Precipitation will also be impacted by climate change (Table 2). Some GCMs forecast increasing precipitation for the Puget Sound during the fall and winter and decreasing precipitation during the summer.

Table 2: Projected Ensemble Seasonal Precipitation Changes (Average Total Inches) Relative to Historic [2]
(Projected Percent Seasonal Precipitation Changes Relative to Historic in parentheses)

	Spring (MAM)	Summer (JJA)	Fall (SON)	Winter (DJF)	Annual
Ensemble-2000	1.0 (9%)	0.1 (3%)	2.1 (16%)	1.6 (11%)	4.8 (11%)
Ensemble-2025	0.8 (7%)	0.6 (13%)	2.5 (20%)	1.0 (7%)	4.8 (11%)
Ensemble-2050	1.2 (11%)	-0.5 (-11%)	2.3 (18%)	1.1 (8%)	4.2 (10%)
Ensemble-2075	1.6 (15%)	-0.6 (-14%)	1.5 (12%)	2.9 (20%)	5.3 (12%)

Snow events and snowpack will also change, primarily due to increasing temperatures. Because much of the surface area in local watersheds that provide municipal drinking water lie in transient regions (those that have historically received precipitation during the late Fall, Winter, and early Spring as both rainfall and snow fall), small increases in temperature will result in shifts from snow events to rain events. These changes will result in significantly less snowpack in the spring on average. This will decrease the naturally occurring storage of the snowpack available in the watershed and place increased stress on the man-made storage of the reservoirs. Impacts on streamflows will be significant, as indicated in Table 3.

[2] The historic period is 1928-2004. The average is across 14 meteorological stations (excluding Stampede Pass). The seasonal periods are: Spring (March, April and May); Summer (June, July, and August); Fall (September, October, and November); and Winter (December, January, and February)

Table 3: Projected Ensemble Average Streamflow Changes Relative to Simulated Historic[3]

Average for All Basins	Spring	Summer	Fall	Winter	Annual
Ensemble-2000	9%	4%	10%	10%	8%
Ensemble-2025	-1%	-13%	18%	23%	8%
Ensemble-2050	-1%	-29%	17%	29%	7%
Ensemble-2075	-7%	-37%	13%	48%	9%

Other changes are also expected to occur on water resources in the region due to climate change. Increases in temperatures and shifts in the timing of rainfall will also result in increased high flow events, again, primarily in the fall and winter (Salathé, 2006; Salathé et al., 2007). These changes will also impact regional infrastructure, such as the conveyance of wastewater. Because a significant portion of the sewage drainage system is either combined systems or has infiltration, wastewater runoff peaks may increase. Changes in the natural hydrograph will increase the difficulty in maintaining the instream flow requirements for fish. This will be due to smaller amount of runoff that will be available in the spring and early summer, and generally drier watershed conditions in the summer due to increased evapotranspiration. Finally, water quality will be impacted. These impacts will include streams warming in the summer due both to lower streamflows and higher ambient temperatures and increasing peak flows in the winter, increasing scour.

Creating a Framework for Evaluation: Data Streams for Climate Impacted Meteorology and Hydrology

There are a number of approaches for creating a framework to evaluate the impacts of climate change on water resources. Frederick and Gleick (1999) developed a five-step framework that can be summarized as:

1. Use GCMs to simulate future climate conditions on a global scale,
2. Re-scale of global climate data down to a river basin scale,
3. Downscale GCM data to simulate streamflows under altered climate conditions using hydrologic modeling
4. Assess the effects of altered streamflows on water resource systems using systems simulation model.
5. Assess the impacts on the users of water resource systems, including potential changes in demand and demographics under climate change scenarios.

Following on the approach outlined by Frederick and Gleick (1999) and Gleick (2000), Miller and Yates (2006) recommend techniques that can be used to evaluate climate change and note that:

> "Scenarios based on climate model output are a tool that utilities can use for these assessments, but it is important to understand that no single climate

[3] The historic period is 1928-2004. The seasonal periods are: Spring (March, April and May); Summer (June, July, and August); Fall (September, October, and November); and Winter (December, January, and February). Flow points are at the primary stream gage sites used to measure inflows into reservoirs on each river system, except for the Sultan and Green rivers, where total inflows are used.. The five basins are the Sultan, South Fork Tolt, Cedar, Green, and White.

> model can yield a reliable projection of future climatic conditions. If climate model output is used, it must be appropriately downscaled to the relevant watershed level, and any analysis should use projections from several models to generate a range of physically plausible scenarios of the impacts of climate change on the utility's water resources. The utility can then use the resulting hydrologic projections to evaluate the robustness of alternative response strategies given the unavoidable uncertainties arising from climate change."

Using a series of examples throughout the US, Miller and Yates (2006) conclude that "water utilities should not ignore this risk *(from climate change)*, because this new source of uncertainty is significant for long-term planning." They suggest that,

> "To plan effectively for the future, utilities should assess the potential impacts of a range of plausible climate change scenarios on their ability to meet customer needs and comply with quality standards and environmental objectives in a cost-effective manner. This requires rethinking traditional approaches to the planning process that rely on assumptions such as climate stationarity."

Based on their review of the literature, much of which was directly related to the Pacific Northwest, Miller and Yates concluded that climate change impacts to water supplies could be significant and that estimation techniques exist. They also note that, "this new source of uncertainty is significant for long-term planning."

The Committee developed a framework that builds on that of Frederick and Gleick, and broadens the types of water resources issues that can be evaluated using the data streams generated in this study under a range of climate change scenarios as recommended by Miller and Yates. These data have been made available through the website and database developed by the Committee's technical support staff. Figure 1 presents a schematic depicting the development of the data within the Frederick and Gleick framework and indicates some of the potential analyses the data might support beyond system simulation models. This framework is used here to summarize the development of the data, followed by descriptions of how to use the data and general principles for incorporating climate change into water system evaluations. It should be noted that there are many other potential uses for these data and many other models within the region for which the data could serve as input.

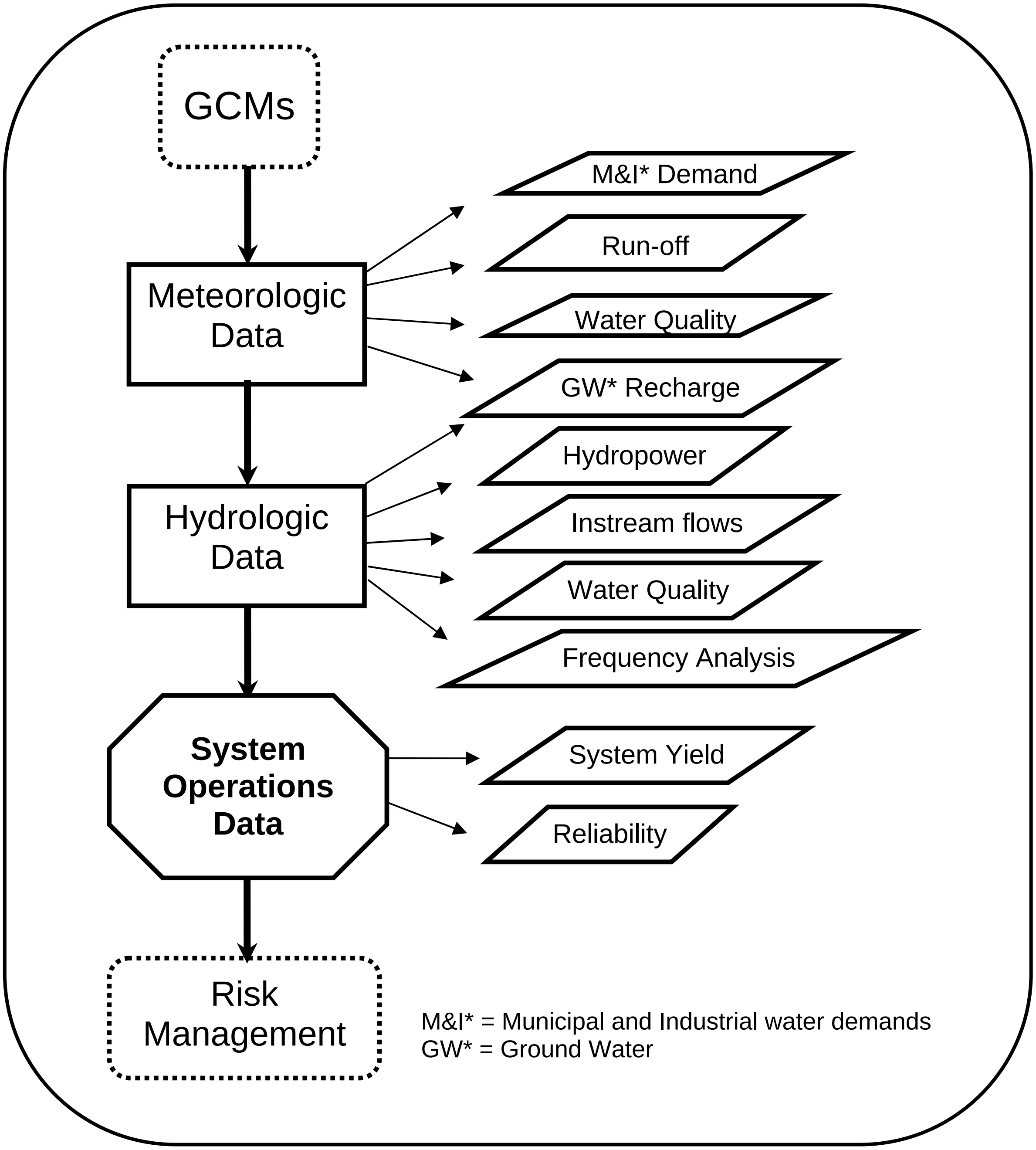

Figure 1: Data Flow from Models of Climate Change

Development of the Meteorologic and Hydrologic Data Sets

Development of the meteorologic and hydrologic datasets is described in Technical Memorandums #2 (Polebitski et al., 2007(a)), #4 (Polebitski et al., 2007(b)) and #5 (Polebitski et al., 2007(c)), and is summarized here. These datasets are available to others through an on-line database described in Technical Memorandum #3 (O'Neill and Palmer, 2007).

Use of GCMs to Simulate Future Climate Conditions on a Global Scale

The first box in Figure 1 indicates the use of GCMs to forecast future climate conditions based upon assumptions concerning anticipated levels of greenhouse gases. In this effort, two basic decisions were made by the Committee: what GCMs are to be used and what emission scenarios are the most appropriate. In addition, decades in the future had to be selected to summarize periods to investigate. Others researchers, using this work as a template, will need to make similar decisions.

Selection of the most appropriate GCMs is based on several issues. Because GCMs do not represent a uniform future, it was determined that a range of GCMs be used in evaluations of regional streams and water supplies. The IPCC provides access to the results of all of the most prominent GCMs. These models have typically gained their prominence due to the level of resources that have been devoted to their construction and their ability to recreate past climate trends accurately. In the selection of GCMs to use in a study, it is important to include those whose outputs are characteristic of other model outputs and to include models that do represent ranges of the potential future.

In addition to using a range of climate models, a range of greenhouse gas emission scenarios are also recommended. These emission scenarios represent different futures associated with how the global economy develops and different energy consumption patterns. For the work performed by the Committee, three GCMs and two emissions scenarios were chosen as pairs from ten models that were possible contenders (Figure 2). These are:

1. **GISS_ER SRES B1** as the *"warm" regional change* scenario (nearly the smallest increase in temperature, nearly the largest decrease in precipitation)
2. **ECHAM5 SRES A2** simulation of the *"warmer" regional change* scenario (mid-range increases in temperature and precipitation)
3. **IPSL_CM4 SRES A2** simulation of the "*warmest" regional change* scenario (large increase in temperature, nearly the largest increase in precipitation)

These scenario pairs were recommended by the Washington State Climatologist, Dr. Phil Mote (Mote et al., 2005b). As indicated in Figure 2, these three models provide a range of values for both precipitation and temperature. None of the GCMs selected demonstrate the most extreme changes in temperature, with the GISS_ER SRES B1 and ECHAM5 SRES A2 showing below average increases in temperatures relative to the other family of models, and the IPSL_CM4 SRES A2 changes in temperature above average relative to the other models. For changes in precipitation, the IPSL_CM4 SRES A2 is at the upper extreme of increases, while the ECHAM5 SRES A2 has modest increases and GISS_ER SRES B1 has one of the largest decreases. Monthly meteorological data from these three models are obtained for transient model runs from 2000 to 2100 for the prescribed SRES emission scenarios. The choice of scenario pairs is an important step in the process and reasons for selection should be clearly articulated.

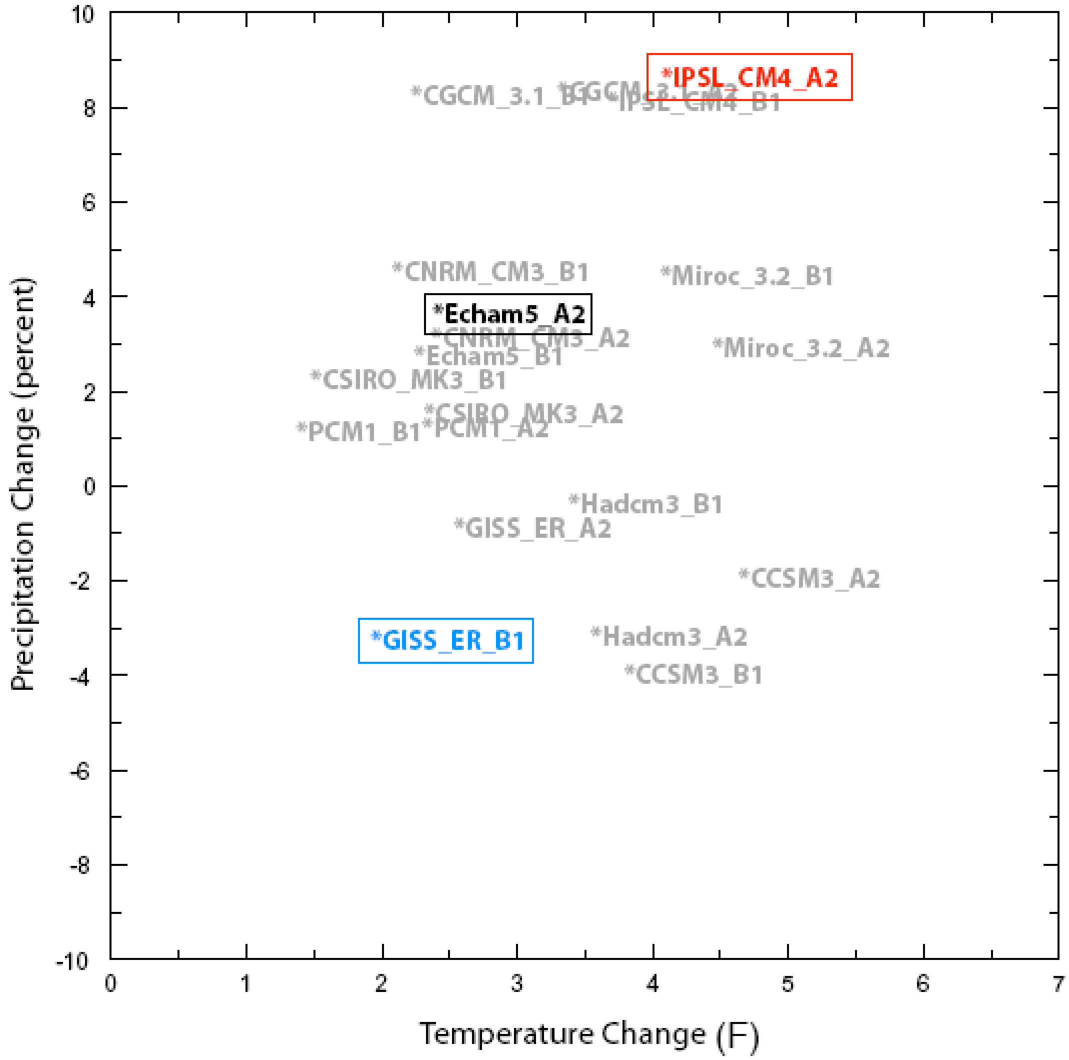

Figure 2: Comparison of General Circulation Model's Temperature and Precipitation (Mote et al., 2005b)

Re-scale of Global Metrological Data to a River Basin Scale

The process used to re-scale the global climate data to a river basin scale is the second major decision that must be made. The process used in this study is described in full in Technical Memoranda #2 (Polebitski et al., 2007(a)) and #4 (Polebitski et al., 2007(b)). Essentially this process involves bias-correction of the GCMs' recreation of 20th century climate to make it representative of local/regional meteorological statistics. This process is accomplished by comparing the statistics (specifically the monthly cumulative distribution function) of each GCM's 20th century re-creation to observed data. This comparison of cumulative distribution function is then used to bias-correct estimates of future climate change. This translates the transient[4] runs of the GCMs into a series of meteorological outputs associated with the decades related to the years 2000, 2025, 2050, and 2075.

[4] Transient is defined here as a single trace from a GCM that typically ranges from 1900- 2100.

As noted previously, the data originated from three GCMs and emission scenarios for four periods (2000, 2025, 2050, and 2075) are available from the IPCC. These monthly data were used as inputs in a process that resulted in daily climate impacted, gridded (at 1/8 degree) meteorological data for the study region. These data were also used to generate 77 years of daily minimum and maximum temperature and total precipitation data at 15 meteorological stations in the region for the four future time periods for each of the GCM/emission scenario pairs (Figure 3). The climate-impacted meteorological station data were then used as inputs into the hydrology model that resulted in a set of climate impacted streamflows for the major water supply systems in the Puget Sound.

Downscale GCM Data to Simulate Streamflows for Altered Climate Conditions Using Hydrologic Modeling

The climate impacted meteorological station data created in this process is used as input in a distributed hydrology model to estimate streamflows in the future. This process is described in detail in the Committee's Technical Memorandum #5 (Polebitski et al., 2007(c)). The model chosen for this process is the Distributed Hydrology Soil Vegetation Model (DHSVM). This model runs at a three-hour time step and divides each of the watersheds into a 150 meter by 150 meter grids. Streamflows are generated for a 77 year period for multiple sites in the watersheds. The three-hour time-step data is aggregated into daily streamflow estimates.

Use of Climate Impacted Meteorology and Hydrology Data Streams in Water Supply Evaluations

Figure 1 presents potential uses of the climate impacted meteorological and hydrologic data in evaluating water supply and other related water resource issues. This section describes how to use the datasets generated through this work for these evaluations.

How to Use the Meteorological Data in Water Resource Evaluations

Uses of the meteorological data include evaluations of the impacts of climate change on future water demands, irrigation needs, groundwater resources, runoff, and water quality. The list could easily be extended to any study or modeling activity that currently is driven by past meteorological data and for which the impacts of climate change are to be evaluated. Care should be taken to ensure that the analysis appropriately considers the timescale of the generated data and its reliance on the historic time series. The following sections elaborate on use of the meteorological data in forecasting municipal water demands, evaluating changes to groundwater recharge, and generating climate-impacted streamflow data.

Evaluating the Impacts of Climate Change on Municipal Water Demand

The climatology of King, Pierce, and Snohomish Counties consists of wet, overcast and cool winters and relatively warm, clear and dry summers. Water demand in the summer, which is largely for landscape irrigation, is influenced by the weather. Because of the consistently dry summer months and the correlation between precipitation and temperature, relative changes in summer precipitation have less of an effect on overall water demand, leaving temperature as the main driver for seasonal oscillations in water consumption.

Temperature and precipitation variables are important when investigating the variation in demand within a year, and departures from average temperature on an annual level may be an important factor for investigating yearly water consumption. Municipal water demand models typically use a seasonal climate variable to represent temperature and precipitation effects on annual consumption. Climate variables can be represented as a function, as anomalies or departures from mean, or as elasticities in a water demand model. Within a year, water demand is primarily driven by climatic variables. For longer time horizons (i.e. projections of water use for a 25-year planning period) population is typically the major driver.

When considering a changing climate, it is important to use a suite of climates and associated variables for demand estimates. The uncertainties associated with the inputs to demand forecasts become larger the further into the future the forecast is made, and these uncertainties can be quantified using ranges for the input variables. The climate-impacted temperature and precipitation data generated for meteorological stations in the region are available to evaluate a range of possible scenarios and their impact on future municipal water demands. These can be used to evaluate the impact on peak season and annual demands. The resulting climate-impacted demands can also be used in water system evaluations, as well as to explore possible demand management approaches and strategies that can be used in the future.

The meteorological database developed by the Committee can be used to help forecast changes in future water demand. Temperature changes have been forecasted for each of the model scenarios for the decades associated with the years 2000, 2025, 2050, and 2075. The Demand Forecast Advisory Committee to the Central Puget Sound Water Suppliers' Forum is in the process of developing regional temperature and rainfall elasticities (the % change in water demand for a % change in temperature and the % change in water demand for a % change in precipitation) for each summer month. The forecasted changes in temperature can be used to calculate the differences in future demand that would result from climate change, independent of, or in addition to, changes in future population.

Evaluating the Impacts of Climate Change on Groundwater Resources

The climate impacted meteorological station data created by the Committee can be used as input into both types of groundwater models, groundwater recharge models and groundwater flow models, suggested in Technical Memorandum #8 (Alexander and Palmer, 2007). This data can be used to project changes in groundwater recharge and groundwater flow conditions due to climate change for the years 2025, 2050, and 2075.

Evaluating the Impacts of Climate Change on Runoff and Streamflow

The climate impacted meteorological station data created in this process can be used as input into hydrology models to estimate streamflows in the future. While the work of this Committee made use of the Distributed Hydrology Soil Vegetation Model (DHSVM), other models may also be used. The selection of the type of hydrology model to be used should be based on the intended use of the streamflows that are generated. Hydrology models that do not adequately model snowpack and energy balances would not be appropriate for studies in the Pacific Northwest, although they might be appropriate for studies in the Southwest. A particular challenge is the modeling of peak flood flows, particularly in smaller basins. Often such models must operate on very short time-steps – shorter than the daily meteorological data available – to capture the impacts of high flows.

How to Use the Hydrological Data in Water Supply Evaluations

Figure 1 also presents four potential uses of the climate impacted hydrological data. Those indicated on the figure include evaluations of potential changes in water supply, hydropower generation, streamflow characteristics, frequency analysis, and water quality. Again, the figure only depicts a small number of activities for which the data would be appropriate. The following sections expand on uses of the hydrology data for water supply and instream flow analyses.

Evaluating the Impacts of Climate Change on Municipal and Industrial Water Supply

To evaluate the impacts of climate change on municipal water supply in the region, the climate impacted streamflow data can be used as inputs in each utility's water supply model to determine the potential impact on water supply availability. It is appropriate that the "change" in system yield be evaluated against a consistent base period for each of the three climate models. For instance, the yield of a water supply system could be evaluated for the Year 2000 GISS_ER SRES B1 streamflow data, then this result would be compared to the yields of that same scenario in Year 2025, 2050, and 2075. A similar analysis should be done for the ECHAM5_A2 and IPSL_A2 models. Alternatively, the historic period can be used for the base period. These differences will indicate a general trend, and the extremes can be used to indicate our current understanding of the range of uncertainty that is associated with the estimate of the yield in a given year.

Because the water supply models include system-specific operational rules developed under historic hydrological conditions, it may be possible to offset some losses in available supply due to climate change by modifying system operations. The climate change scenarios and water supply models can be used by each utility to explore different operational strategies to adapt to climate change. Such analyses would allow each utility to better understand its vulnerability to climate change and develop plans for adaptation, which could include additional conservation programs and new sources of supply.

Evaluating the Impacts of Climate Change on Instream Habitat

The Puget Sound area's commitment to salmon restoration is well recognized. This commitment reflects both the law of the land and the priority that is placed on the region's natural resources. The climate altered streamflows generated by the Committee can be used to determine our future ability to meet streamflows in regulated streams as well as evaluating the likelihood of there being sufficient flows in streams in the future to maintain a healthy habitat. Past studies (such as Battin et al., 2007) indicate that climate change could have a significantly negative impact on salmon production, due to higher winter flows, lower summer flows, and higher stream temperatures.

The climate altered streamflows generated by the Committee can be used to evaluate the degree to which sufficient streamflows can be maintained in regulated streams. For regulated streams, this can be accomplished once again by using the utility's water supply models and exploring the effects that the climate impacted flows have on the system's ability to maintain mandated or agreed upon instream flow requirements. As before, each of the climate change scenarios should be evaluated and the changes in instream flows' reliability by climate model investigated.

The climate-altered streamflows generated by the Committee also can be used to investigate the impacts of climate change on unregulated streams. The Tributary Streamflow Committee, one of the committees established in the Regional Water Supply Planning Process, has identified a series of flow-impaired tributary streams. The changes in the climate altered streamflows for the year 2000 to the year 2075 can be used to illustrate the likely changes in streamflow that can be expected in many streams in the region. For some streams not included in the work of this Committee, climate altered streamflows may be generated using statistical correlations with one of the streams analyzed in this study if it is appropriate to assume that the relationship will remain the same under the climate change scenarios.

General Principles for Incorporating Climate Change into Water System Evaluations

The framework suggested by Frederick and Gleick (1999) and the framework presented in this report represent potential frameworks for incorporating climate change into system evaluation. In Technical Memorandum #1 (Alexander et al., 2007), there is a comprehensive review of a variety of approaches. As described in that memorandum, the two basic approaches can be characterized as: 1) Use the outputs of General Circulation Models to create climate impacted hydrology to be used in water supply models, or 2) Assume specific ranges of climate change that will occur in the future (like a 5° F increase in temperature or a 20% decrease in precipitation) to create climate impacted hydrology to be used in water supply models. In addition to such frameworks, general principles for incorporating climate change into evaluations that facilitate their success are listed below.

Address the Needs of the User

Because the field of climate impacts on water resources is relatively new, precise answers to potential impacts are difficult and, in fact, can be misleading. Rather, most users benefit from an indication of the relative impact that climate change might have on the management of a water resource. Climate impact studies should appropriately address the type of questions that can help the user make more informed decisions. This suggests that climate impacts studies should not be viewed as supplemental to system evaluation but as an integral part of the scenario planning and evaluation process. Evaluation of climate impacts will be especially appropriate as demand for water approaches the existing availability of water and changes in system infrastructure or operation are being carefully studied.

Keep the Evaluation Simple

As an emerging field, there is still much to be learned in the arena of climate impact assessment and evaluation. This includes our understanding of the meteorological sciences that influence climate assessment, the mechanism in which impacts are manifested, and in the management response. The simple notion of Occum's Razor ("all things being equal, the simplest solution tends to be the right one") should be followed. This idea suggests that the explanation of any phenomenon should make as few assumptions as possible, eliminating those that make no difference in the predictions. The inputs to climate impact assessments that arise from the most complex models are those associated with the GCMs and the sociological forecasts of future emissions. It is very unlikely in a typical water resource climate study that the basic assumptions of these models will be challenged. Given that, it is appropriate to recognize the uncertainties of these inputs and to keep the remainder of the analysis as simple as is appropriate.

Frame the Problem in Familiar Terms

Climate change studies should attempt to use techniques and present results in a manner that is consistent with past evaluations, to the extent possible. This provides a sense of familiarity to those using the results and engenders confidence in the analysis. The impacts that climate change will have on a water supply system can be viewed simply as one more component of "risk management."

Water supply evaluations typically look at extreme events and the impacts these events have on estimation of system yield. The same approach should be taken with climate change information. For instance, if a region has 80 years of historic data upon which they evaluate their system reliability, it would be ideal for the projections of the climate impacted hydrology to also be 80 years in length for simple comparisons.

Typically, water resource engineers wish to determine the "safe" or "firm" yield of a system and this idea is based on the concept of a historical record with a consistent mean and standard deviation. Since the turn of the century, engineers have applied the concepts of Rippl (1883) which are based upon the fact that streamflows are statistically stationary (their mean and standard deviation are not changing over time). Techniques described in Technical Memorandums #2 (Polebitski et al., 2007(a)) and #5 (Polebitski et al., 2007(c)) address how the climate impacted streamflows have been generated to make it directly applicable to the region's estimates of yield.

Emphasize Relative Uncertainties

As has been stated and implied, the outputs from climate change studies should be presented as possible futures, and a variety of scenarios should be included to help bracket both the average future condition and its extremes. Because there are uncertainties, climate impact studies have been described as having "cascades of uncertainties." These uncertainties are not dissimilar to the uncertainties associated with much of scientific study and engineering design. They should not be used to discourage the use of climate studies but rather to ensure that the results of these studies always be viewed as possible future outcomes about which there is uncertainty.

Ranking relative uncertainties is important. Relative to climate change, scientific consensus is much more unified on the degree to which the planet has warmed and will warm in the future, than in the precise changes that will occur to precipitation at specific locations. It is important to acknowledge this uncertainty and to make sure that it is understood. In the Puget Sound region, for instance, it is important to note that changes in snowpack are due primarily to changes in temperature (for which there is strong scientific consensus) and less to do which changes in rainfall (for which there is less scientific consensus).

Engage and Educate a Large Audience

Effectively providing consumers with climate change information is a key component in the Regional Water Supply Planning Process. The audience for this information includes technical staff and decision-makers of local, state, and federal governments; local utilities; tribal nations; and resource agencies, and in some instances the general public. A goal is to provide stakeholders with information that can be used to better inform decision making. The Regional Water Supply Planning Process has illustrated the challenges in improving the link between climate sciences and water resources stakeholders.

One of the goals of the Committee is to provide decision makers with accurate information about the ways in which water resources in the Puget Sound region are vulnerable to changes in climate. In future work, these vulnerabilities should be directly linked to a risk assessment.

The Committee has attempted to promote application of climate change information through the development of an online database and a series of technical memoranda. These data and information are publicly available from the Online Variables Database website (www.climate.tag.washington.edu). Through the online database and technical memoranda, the Committee has provided a necessary link in disseminating valuable information to stakeholders. Others pursuing this type effort should carefully consider how best to engage and educate as large an audience as possible.

Conclusions

Climate change represents a significant challenge to water managers. The American Water Works Association (AWWA) Research Foundation is encouraging the nation's water suppliers to carefully investigate the potential impacts of climate change on their systems (Miller and Yates, 2006). Such investigations require a departure from traditional approaches for evaluating system yields and an understanding of how to best incorporate the advances being made in the new science of climate change. This report and the other Technical Memoranda provided by the Climate Committee provide a framework for both creating the data needed and how this data can be applied. Altering the paradigm to include climate change in evaluations of water supply reliability and performance will not be simple, since existing methods have been in place for over a century. However, this change is necessary if we are to accurately assess our water resources and plan according for the future.

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Appendix A

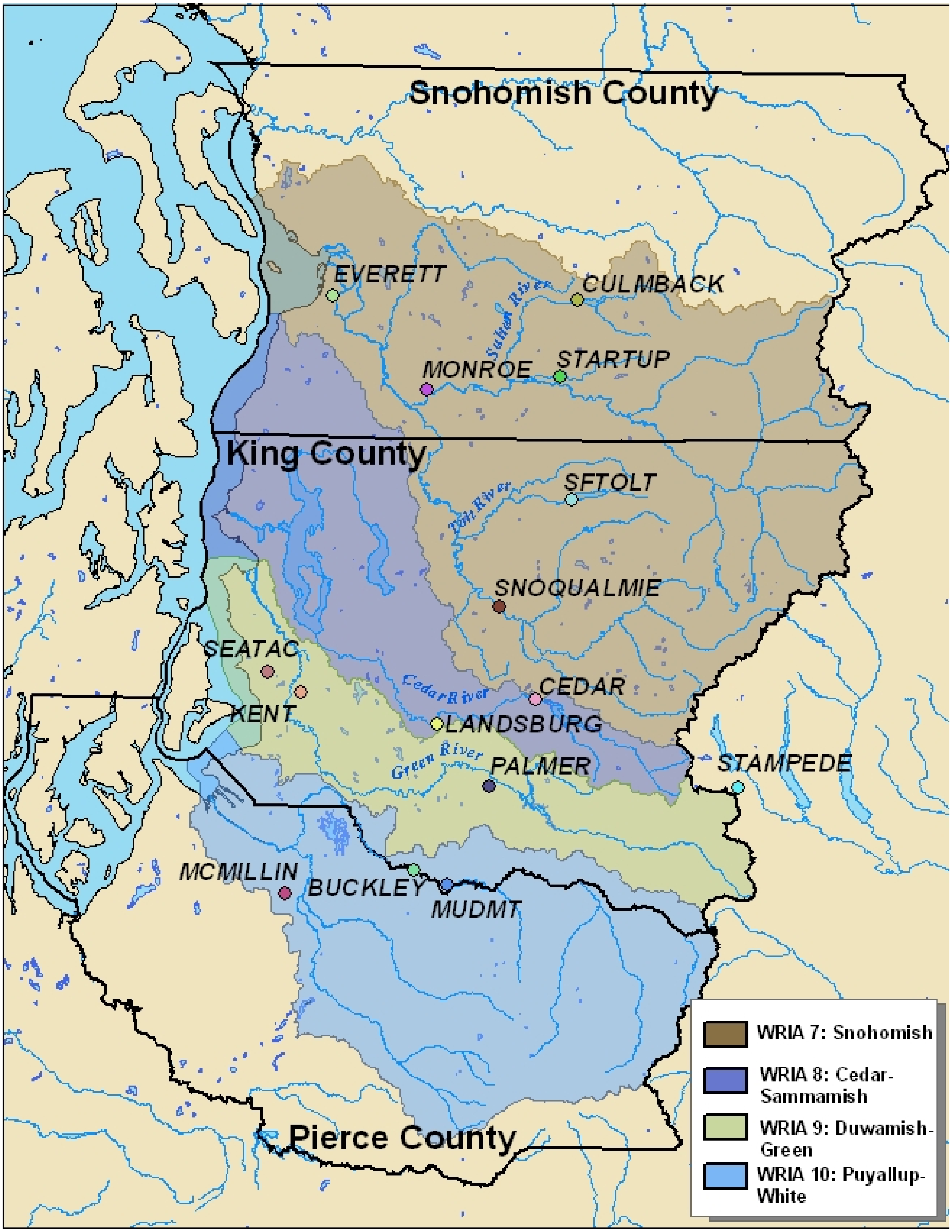

Figure 3: 15 meteorological stations and the four WRIAs evaluated in this study