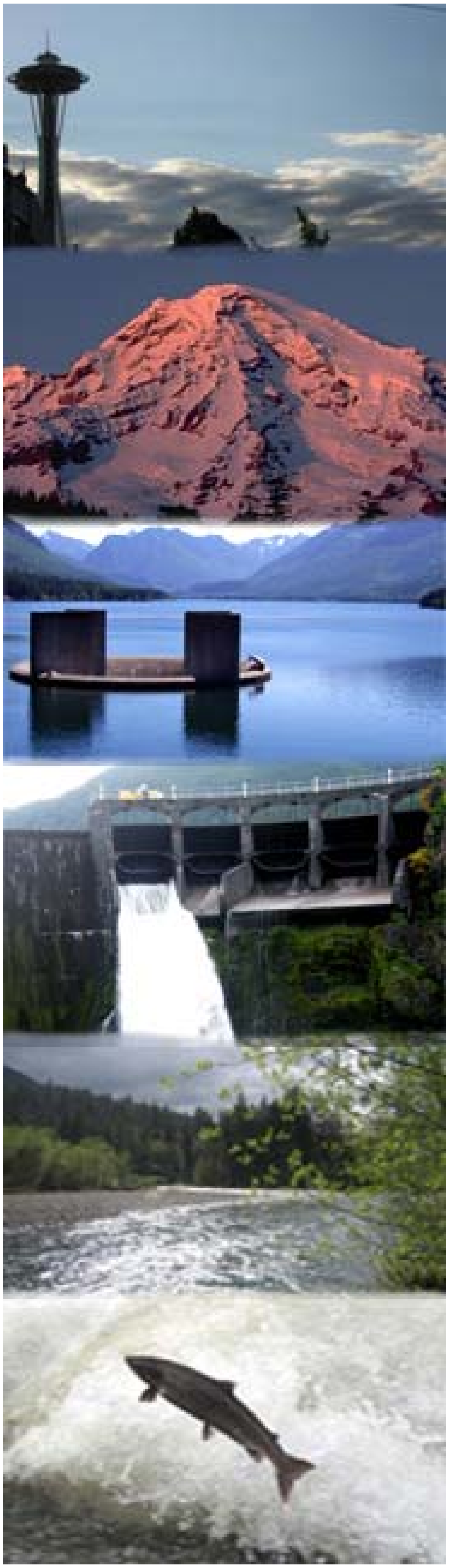

Final Report of the Climate Change Technical Committee

Prepared for:

Climate Change Technical Committee

12/10/07

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Executive Summary

The Climate Change Technical Committee (the Committee) was formed in the spring of 2006 as part of several technical committees proposed in a regional water planning framework adopted by multiple stakeholders in October 2005. The Committee's goals were to: 1) Identify the basic building blocks of our understanding of climate change, 2) Identify what is known about climate change in the Puget Sound region and its potential impacts, 3) Identify where more information would be useful, 4) Communicate what is known to other committees in this process, and 5) Document the Committee's findings.

The Committee authored ten reports. These reports were drafted by a support staff from the University of Washington and reviewed by the Committee members. The reports established a scientific basis for understanding the impacts of climate change and reviewed studies of the impacts of climate change on water resources. The reports also developed techniques for incorporating General Circulation Models (GCMs) outputs into forecasts of changes of regional meteorology. The meteorological impacts were then used to evaluate the hydrological impacts in the major watersheds that provide drinking water for King, Pierce, and Snohomish counties.

The first report, Climate Change Building Blocks (Palmer et al., 2007), summarized 13 accepted facts based on peer reviewed literature of changes in regional meteorology and hydrology during the 20th century and forecasts of future changes. The next report, Technical Memorandum #1 (Alexander et al., 2007), summarized the peer reviewed literature on the impacts of climate change on water resources, illustrating the extensive literature on the subject dating back to the mid-1980s and noting that snow-melt derived water supplies have been identified as candidates for significant climate change impacts.

The process of converting output from GCMs to regional information (downscaling) is summarized in Technical Memorandum #2 (Polebitski et al., 2007(a)). This statistical downscaling technique is used in Technical Memorandum #4 (Polebitski et al., 2007(b))to create climate-impacted meteorological data at key weather stations for five water supply basins. Three different GCMs/emission scenarios pairs (ECHAM-A2, IPSL-A2, and GISS-B1) were applied in decades surrounding the years 2000, 2025, 2050, and 2075. Individual model forecasts of average daily air temperature for 2075 produced increases above the 1928-2004 historic period that range from 3.8°F to 9.0°F (2.1°C to 5.0°C) for summer and from 1.4°F to 8.1°F (0.8°C to 4.5°C) for winter, when averaged across the stations. The ensemble average of all three GCMs shows future temperature increases of 6.8°F and 5.4°F (3.8°C and 3.0°C) by 2075 for the summer and winter seasons, respectively. Precipitation changes were less consistent for each model and between models, with changes in seasonal precipitation in 2075 relative to the historic period ranging from -29% to +11% in summer and -6% to +48% in winter. The ensemble average for seasonal precipitation shows a trend of drier summers and wetter winters. The ensemble average of annual precipitation for the 14 sites increases 12% by 2075 relative to the historic period.

Technical Memorandum #5 (Polebitski et al., 2007(c)) presents the results of using the climate impacted meteorology in hydrology models for the five major water supply drainage basins (the Sultan, South Fork Tolt, Cedar, Green and White rivers) in the study area. Climate impacts to streamflow were found to be substantial in each of the five basins, with the magnitude differing across basins. In all basins, earlier snowmelt caused the spring peak in the hydrograph to occur earlier. This

leads to lower early summer flows at each location investigated. The least amount of change occurs in the GISS-B1 model, where, despite being drier than the other models, warming is substantially lower than in other GCMs. Relatively large changes in early summer flows are seen in the IPSL-A2 and ECHAM-A2 models as median summer flows become increasingly reduced in the projected future. Basins where precipitation falls predominantly as rain (Green River) were less affected in spring shifts than those in which snow has been more dominant in the past. For the primary sites used to characterize inflows into the reservoirs , by 2075 the ensemble averages across all five basins compared to historic flows decrease by 37% during the summer and increase by 48% during the winter. The climate impacted meteorological and hydrological data from the study are available from an on-line database[1], which is described in Technical Memorandum #3 (O'Neill and Palmer, 2007).

Technical Memorandum #6 (Palmer, 2007(a)) provides guidance on approaches to including climate change in evaluations of water demand and water supply. The suggested approach uses well-accepted GCM outputs, transforms these outputs to reflect regional characteristics, and generates streamflows with this climate impacted meteorology for a range of climate change scenarios. Recommendations are provided for how to use the data created by the Committee to evaluate impacts to municipal water demand and supply, as well as other water resources and ecosystem issues. Other recommendations include clearly identifying the user's needs for climate impacted data, keeping the evaluation appropriately simple, framing the problem in familiar terms, and emphasizing relative uncertainties.

Technical Memorandum #7 (Alemu and Palmer, 2007) summarizes an investigation of the regional relationship between cloud cover and other climatic variables and their implication on future climate change. Current data do not support the hypothesis that warming inland temperatures will increase cloudy days in the Puget Sound region. This suggests that other larger-scale climatic factors influence cloudiness in Western Washington.

Technical Memorandum #8 (Alexander and Palmer, 2007) is a literature review of the impacts of climate change on groundwater, focusing on studies that may be relevant to the Puget Sound lowlands region. The report notes that no single groundwater model has emerged as appropriate for evaluating the impacts of climate change for all watersheds. The studies reviewed suggest substantial differences in the estimates of potential impacts of climate change on groundwater. This is due to the importance of site specific effects, such as groundwater pumping, rates of recharge, and arid versus humid environments.

The impacts of climate change should be considered in evaluating future water supplies and water demands for the region. Review of the literature and results of recent modeling efforts indicate that climate change has impacted and will continue to impact the meteorology and hydrology of the five basins. In contrast, our understanding of the impacts of climate change on groundwater in the region is limited at this time. The datasets generated by the Committee's work are available to others to evaluate water supply and related water resource issues in the region. Because of the importance of climate change and its impacts on water resources, this topic should be revisited as advances are made in our understanding of climate science.

[1] www.climate.tag.washington.edu

Final Report of the Climate Change Technical Committee

Introduction

In February 2005, King County and the Cascade Water Alliance (Cascade) signed an agreement that set into motion a collaborative planning process for water supply and water resource management planning. The agreement noted the need for a public process that included elected officials and other interested parties. The agreement also recognized the role of the Tribes as sovereign governments and co-managers of fisheries resources. The activities identified in the agreement included comprehensive water resources and supply planning, a coordinated water supply plan, and a study of the Cascade Transmission and Supply Plan. In July 2005, a more regionally inclusive planning process was initiated to engage the participation of City of Seattle; City of Auburn; King County Council; Muckleshoot Indian Tribe; Washington Environmental Council; Shared Strategy for Puget Sound; three state agencies (the Departments of Ecology, Health, and Fish and Wildlife); Tacoma Public Utilities; Lakehaven Utility District; Woodinville Water District; Cedar River Water and Sewer District; Seattle-King County Public Health; and King County Department of Natural Resources and Parks (DNRP). By October 2005, these entities agreed to a water supply "Planning Framework" for themselves and additional interested parties.

Under this more inclusive process, seven working groups were established in early 2006 to generate information for regional water planning. Participation was voluntary. These initial working groups developed planning-level technical information regarding: a) Regional demand forecast, b) Supply alternatives analysis for King, Pierce, and Snohomish counties, c) Climate change analysis, d) Reclaimed water, e) Source exchange strategies, f) Prioritization of flow-impaired tributaries, and g) Small water systems. The Demand and Supply working groups were formed and funded by the Central Puget Sound Water Suppliers' Forum. An eighth proposed technical committee on implementation of the Municipal Water Law was never formed.

The working group that addressed the potential impacts of climate change on the region's water resources is called the Climate Change Technical Committee (Committee). Committee members are listed in Appendix A

Table 1. As indicated in the table, the Committee is composed of representatives from a wide range of agencies, including local utilities, resource agencies, the Muckleshoot Tribe, and city, county, state, and federal governments. The Committee met 17 times from March 2006 through December 2007. Dr. Richard Palmer led researchers at the University of Washington who provided technical support to the Committee.

The Committee drafted and agreed upon a charter in April 2006, which described the initial goals of the Committee as: 1) Identify the basic building blocks of our understanding of climate change, 2) Identify what is known about climate change in the Puget Sound region and its potential impacts, 3) Identify where more information would be useful, 4) Communicate what is known to other committees in this process, and 5) Develop a report documenting the information developed by the Committee.

One of the primary goals of the planning process was to develop the best available data, information, and pragmatic tools that the participants could use, at their discretion, to assist in the management of their respective water systems and resources, and in their water supply planning activities. The information developed by the technical committees was to be shared, but each of the participants would be free to accept or reject the results of this process.

This report summarizes the efforts of the Committee. The Committee produced ten reports, including this summary (Table 2). The Committee began its work by creating a document that summarized the Committee's understanding of climate change in the region. Once a common vocabulary was established, the Committee shifted its emphasis to quantifying the projected impacts of climate change on regional meteorology and hydrology in the major watersheds that provide drinking water for the region.

Throughout the Committee's tenure, the research team at the University of Washington provided technical documents that the Committee thoroughly reviewed before making them publicly available. All reports, technical memoranda, and data generated are now accessible via the Committee's webpage[2].

The remainder of this report summarizes the overall results of the Committee's work. The sections that follow highlight the Committee's reports and their major findings. The intended audience of this report includes water resource planners and managers, elected officials, and stakeholders interested in the possible impacts of climate change on regional water supply. This report's goal is to summarize the Committee's efforts and to provide readers access to the information available in the other Committee reports.

Climate Change Building Blocks

The Climate Change Building Blocks (Palmer et al., 2007) is the first report produced by the Committee. There were several goals associated with this report. The creation of the Building Blocks served as an opportunity for the Committee to identify the global, national, and local impacts of climate change. This process helped familiarize the Committee with the literature on climate change and recent technical papers on the subject. Early in the process the Committee identified the value of using, to the extent possible, only peer-reviewed literature in its deliberations. Completing the Building Blocks required more than six months. There was active debate among the Committee members in creating the specific building blocks, but all of the building blocks were developed by a consensus process.

The Committee also sought to create a document that would have a general readership and that could be used as an educational tool for a wider audience. The Building Blocks were designed to clearly state a series of well-documented facts concerning changing climate that were copiously

[2] The final products of the Climate Change Technical Committee can be downloaded from its webpage: http://www.govlink.org/regional-water-planning/index.htm

documented by the peer-reviewed literature. This process also was designed to inform decision making in King, Pierce, and Snohomish counties relative to water supply planning.

When the Building Blocks were completed, they were distributed to interested parties in the region. The 13 building blocks listed in the report are presented in Figure 1. The full report includes supporting citations for each of the Building Blocks and is available from the Committee's website.

Technical Memorandum #1 - Literature Review of Research Incorporating Climate Change into Water Resources Planning

Technical Memorandum #1 (Alexander et al., 2007) reviews the early peer-reviewed research associated with incorporating climate change into water resources planning. The review begins by describing reasons for concern over climate change, and then focuses on the research of three innovators in the water resources/climate impacts field. The second half of Technical Memorandum #1 focuses on the key issues in evaluating the impacts of climate change. Specifically the report gives detailed description of General Circulation Models (GCMs), the process of downscaling and why it is used, an in-depth discussion of hydrologic modeling, and a brief discussion on evaluating uncertainty. The literature review notes that climate change is a real and pressing concern. This is based on the recent Intergovernmental Panel on Climate Change Report and many other peer-reviewed studies. Among the impacts associated with climate change scenarios for King, Pierce, and Snohomish Counties are warmer air temperatures, warmer stream temperatures, higher winter streamflows, lower spring and summer streamflows, and negative impacts to salmonid habitat.

The first innovator discussed in the report is Peter Gleick and his role in developing an evaluation paradigm (Gleick 1986; Gleick 1987; Frederick and Gleick, 1999; Chalecki and Gleick, 1999). Gleick's emphasis has been in snow-melt dominated systems and he has compiled a list of 900 bibliographic references analyzing and evaluating the impacts of climate change and variability on water resources in the United States. Dennis Lettenmaier and others at the University of Washington in the Climate Impacts Group (CIG) also published widely on climate change research in the 1990's, with emphasis on Washington, California, and the Columbia and Colorado River systems (Lettenmaier and Gan, 1990; Lettenmaier and Sheer, 1991; Hamlet and Lettenmaier, 1999; Lettenmaier et al., 1999). The work of Paul Kirshen is also noted, particularly his research related to the Boston water supply. The body of work of these researchers and their colleagues has provided useful insight into potential impacts of climate change.

The second half of Technical Memorandum #1 describes several key issues in evaluating the impacts of climate change. The report provides a detailed description of GCMs, the downscaling of the data from GCMs to a scale appropriate for regional climate assessment, hydrologic modeling and uncertainty in evaluating climate change impacts. The literature review establishes that impacts of climate change on water resources have been studied for over 20 years, and that these impacts are noted as some of the most significant impacts related to climate change, and that methodologies for evaluating these impacts have been formulated. The review also notes that because of varying assumptions and modeling approaches, GCMs produce varying forecasts of the future. Because of this, care must be taken in applying their outputs to regional studies. It is recommended to use multiple GCMs to cover the range of projected climate scenarios.

Technical Memorandum #2 - Methodology for Downscaling Meteorological Data for Evaluating Climate Change

Technical Memorandum #2 (Polebitski et al., 2007(a)) details the downscaling methodology used in this study and presents a summary document describing the statistical downscaling process through use of flow charts and graphics. The basis for the downscaling method originates from Wood et al. (2002) for long range hydrological forecasting, and has since been modified for use in climate studies (Wiley et al., 2006).

The study area includes five river basins in four Watershed Resource Inventory Areas (Figure 2). The Washington State Climatologist, Dr. Phillip Mote, selected the GCMs and emission scenarios used in this study. His selection is based upon the GCM's ability to recreate 20th century Washington climate and the breadth of the forecasts they provide. Figure 3 indicates that these models provide a range of forecasts that span from small increases in temperature and decreases in precipitation to large increases in temperatures and increases in precipitation.

The general method for making the outputs from the GCMs appropriate for use at a watershed level has three steps: First, monthly output from a GCM is downscaled to a regional grid of 1/8° resolution. (For this region, 1/8° is approximately 8.65 miles in longitude and 3.45 miles in latitude.) This process creates transfer functions that bias-correct the output from the GCMs, making the variables more representative of regional climate. Second, the bias-corrected output is downscaled to regional meteorological stations. The bias-correction in this process is typically minimal compared to the first step, as the regional grid has similar meteorological characteristics as the station located within its boundaries. Lastly, an expanded time series of a climate impacted variable is generated. This is based on observed weather at a meteorological station, the use of transfer functions developed in the first and second steps, and the simulated future output from the GCMs. The last stage produces a time series of climate variables that has the length of the historic record and its associated variability and time series properties (pattern or sequence of climatic events), but is scaled or shifted by GCM output to represent projected future conditions. The meteorological time series are generated for each GCM and emission scenario pair using thirty-one years of the GCM output surrounding 2000, 2025, 2050, and 2075 to rescale the historic meteorology. Each created time series is seventy-seven years in length and contains the minimum and maximum daily temperature and total daily precipitation.

Technical Memorandum #3 - Online Database Functionality and Design for Climate Impacted Data

Technical Memorandum #3 (O'Neill and Palmer, 2007) documents the creation and use of a web-accessible database, denoted as the Online Climate Variables Database (www.climate.tag.washington.edu). This database provides access to meteorological and hydrological forecasts of the impacts of climate change and the climate change forecasts that were produced as part of the Regional Water Supply Planning Process. Technical Memorandum #3 also describes the data in the website and details the website functions, design and organization. The memorandum provides guidance on accessing and using the climate variables database.

Technical Memorandum #4 – Development of Climate Impacted Meteorological Data and its Quality Assurance/Quality Control

Technical Memorandum #4 (Polebitski et al., 2007(b)) details the results of the downscaling process used to generate climate impacted meteorological variables. The data source used for this analysis included fourteen weather stations either in or very close to the four Water Resources Inventory Areas (WRIAs) covered in this study. The climate impacted meteorological data are examined for consistency by comparing the downscaled output for the simulated year 2000 to observed data within that period. Next, projected changes in temperature and precipitation are discussed. Comparison between the simulated year 2000 and historic observations confirm that the downscaling method performed well in removing GCM bias while maintaining natural climatic variability.

Future changes for temperature and precipitation vary between GCMs. This is typical and emphasizes the value of using several GCMs in evaluating potential climate impacts. The three GCMs are used (the ECHAM-A2 Model and Scenario couple – from the Max Planck Institute for Meteorology, the GISS-B1 Model and Scenario couple – from the Goddard Institute for Space Studies, and the IPSL-A2 Model and Scenario couple – from Institute Pierre Simon Laplace). Table 3 presents the seasonal change in temperatures for the three models from the historic averages for fall, winter, spring, and summer. Individual model forecasts of average daily air temperature for 2075 produced increases above the 1928-2004 historic period that range from 3.8°F to 9.0°F (2.1°C to 5.0°C) for summer and from 1.4°F to 8.1°F (0.8°C to 4.5°C) for winter, when averaged across the 14 sites (not including Stamped Pass). The ensemble average of future temperature increases by 6.8°F and 5.4°F (3.8°C and 3.0°C) by 2075 for the summer and winter seasons, respectively. Figure 4 presents the changes in temperature by month for the three GCMs in the future. Figure 4 demonstrates clearly a warming trend, particularly during the summer.

The change in temperature for summer months in 2075 is displayed spatially in Figure 5. The three maps in the upper portion of the figure contain the average temperature in 2000 for the winter months and the three maps in the lower portion contain the average temperature for 2075 for their respective GCMs. The ECHAM-A2 and IPSL-A2 GCMs indicate the largest changes, particularly in the Cascade Mountains and around Mount Rainier. The GISS-B1 model indicates smaller but similar warming in the winter.

As shown in Table 4, precipitation changes were less consistent for each model and between models than temperature. Changes in seasonal precipitation in 2075 relative to the historic period range from -29% to +11% in summer and from -6% to +48% in winter. However, the ensemble average for seasonal precipitation shows an apparent trend of drier summers and wetter winters. The ensemble average of annual precipitation for the 14 sites increases by 12% for

2075 relative to the historic period. Annually, total precipitation remains similar to the past, though due to the temperature increases, more precipitation will fall as rain rather than snow at higher elevations. Figure 6 presents changes in precipitation relative to historic for the periods of 2000, 2025, 2050, and 2075.

Technical Memorandum #5 – Development of Climate Impacted Streamflow Data and its Quality Assurance/Quality Control

Technical Memorandum #5 (Polebitski et al., 2007(c)) describes the development of climate impacted streamflows in the for the major water supply drainage basins in the study area. These streamflows represent unregulated inflows into reaches of the Sultan, South Fork Tolt, Cedar, Green, and White Rivers important for water supply. The memorandum consists of two sections; the first is a comprehensive review of the performance of the Distributed Hydrology, Soil, and Vegetation Model (DHSVM) in replicating historic streamflows in the five basins when forced with observed climate data. The second section discusses the changes in streamflow exhibited when DHSVM is forced with the climate impacted variables described earlier.

In general, replication of historic streamflow at reservoir locations in the five study basins was successful. Minor corrections were needed at locations where the model physics, the meteorological dataset, or routing network presented issues with simulating historic streamflow.

Climate impacts to streamflow were found to be substantial in each basin, with the magnitude differing across basins. In all basins, earlier snowmelt caused the spring peak in the hydrograph to occur earlier. This, in turn, leads to lower early summer flows at each location investigated. As an example, Figure 7, Figure 8, and Figure 9 display changes in streamflow exhibited under a warming climate in the Sultan River. Decreases in early summer flows occur for each GCM and period investigated in the future. Table 5 presents the changes in streamflow for the GCM ensemble average at the major inflow points for each of the major water supply basins in the region. The least amount of change occurs in the GISS-B1, where, despite being drier, warming is substantially lower than in other GCMs. Relatively large changes in early summer flows are seen within the IPSL-A2 and the ECHAM-A2 model and scenario pair, with median summer flows becoming increasingly reduced in the projected future. Basins with precipitation falling predominantly as rain were less affected in spring shifts than those in which snow has been more dominant in the past. This is particularly noticeable in the Green River system (Table 5), in which changes in average summer flow are less than exhibited in other basins.

Table 5 illustrates that there is a wider range of variability among the seasons across the five watersheds. Changes in the average winter streamflow for the 2075 period range for the five watersheds in the ensemble average range from 41% to 57% increases relative to the simulated historic period. This is a result of precipitation falling as rain rather than snow over a larger portion of the watersheds. There is relatively little overall annual change (less than 10% increase in flow for the ensemble average). The shift in the hydrograph could pose challenges in meeting municipal demands and environmental requirements during summer periods, where decreases in the ensemble average between 27% and 42% in summer flow will strain existing storages under current operational strategies (Figure 7).

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

Technical Memorandum #6 (Palmer 2007) provides guidance to those in the region charged with incorporating the results from the Committee into evaluations of the impacts of climate change on water demand and water supply. The report begins with a justification of incorporating climate change into a regional water analysis. It identifies the potential impacts of climate change on the region, specifically those noted in other Committee reports. A summary of the impacts of climate change on the three-county region relative to meteorology and streamflows is presented to motivate a discussion on how best to incorporate these results into analysis of water supply and water demand. Next the approach suggested by Frederick and Gleick (1999) is presented which includes the following steps:

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, and
5. Assess the impacts on the users of water resource systems, including potential changes in demand and demographics under climate change scenarios.

A series of general principles is presented for using climate change data in evaluations. These include: 1) Address the needs of the user, 2) Keep the evaluation as simple as possible, 3) Frame the problem in familiar terms, and 4) Emphasize relative uncertainties. Suggestions are made specifically about including the data created by the Committee into evaluations of municipal and industrial water supply, municipal and industrial water demands, and instream habitat. The report concludes with comments on educating potential users of climate change information.

Technical Memorandum #7: Impacts of Climate Change on Cloud Cover in the Puget Sound Region

Technical Memorandum #7 (Alemu and Palmer, 2007) investigates the regional relationship between cloud cover and other climatic variables and their implication on future climate change. The research explores the hypothesis that cloudiness in Western Washington is strongly impacted by inland temperatures. This memorandum presents the results of a retrospective statistical analysis of historical cloud cover observations and temperature observations as the drivers of cloudiness in Western Washington.

Two hypotheses are tested to address the question of whether future warming in Central Washington would result in increased cloudiness in Western Washington. The first hypothesis tested an inland heating theory that assumed that Central Washington warming would draw colder air from the coast, which would mean more cloudiness in Western Washington. This premise was tested by relating standard variables of cloudiness in Western Washington to the average maximum temperature variables in Central Washington. The second hypothesis tested the air-conditioning effect of warming Central Washington climate, which can be described as consecutive warm days in Central Washington followed by cool and cloudy days in Western

Washington. This premise was tested by looking for patterns in the hottest summer months in the cross-covariance coefficients of Western Washington cloudiness and average Central Washington maximum temperatures. Available data do not support the hypotheses that warming inland temperatures will result in increased cloudy days in the Puget Sound region. This suggests that larger climatic factors drive cloudiness in Western Washington.

Technical Memorandum #8: Impacts of Climate Change on Groundwater Resources: A Literature Review

Technical Memorandum #8 (Alexander and Palmer, 2007) summarizes research of the impacts of climate change on groundwater that may be relevant the Puget Sound region. The report overviews groundwater processes, groundwater in the Puget Sound, and the eight most relevant studies completed in the United States and Canada investigating the impacts of climate change on groundwater resources. The review is followed by a list of recommendations and "next steps" that can be taken in the region. These recommendations provide guidelines and suggestions for how to effectively evaluate potential climate change impacts on groundwater resources in the Puget Sound region.

The report notes that no universally accepted study approach or groundwater model has emerged as the protocol for investigating climate change impacts on groundwater resources. For some regions, it appears the effects of population growth and increased groundwater pumping often dominate the predicted impacts of climate change on groundwater. Some studies indicate decreasing groundwater recharge from climate change, while other studies indicate increases. Local conditions (such as evapotranspiration, surface water exchanges, and changes to groundwater pumping among others) often dominate groundwater levels. Because of the unique nature of the Puget Sound Lowlands aquifer system, there are no published results directly applicable to the Puget Sound region. Furthermore, the majority of the studies cited in this report were completed in semi-arid climates not similar to the Puget Sound region.

Three basic approaches for evaluation of the effects of climate change on groundwater are reviewed: a detailed study approach, a general overview study approach, and semi-detailed study approach. Finally, it is recommended that incorporation of output from GCMs into regional groundwater impact studies should follow the methodology created by the Committee and make use of referenced literature to ensure proper treatment of model uncertainty and climate impacts.

Conclusions

The conclusions of the Climate Change Technical Committee are as follows:

- Climate change is impacting and will continue to impact the meteorology and hydrology of Water Resource Inventory Areas 7, 8, 9 and 10, which are the watersheds that contain the Sultan, South Fork Tolt, Cedar, Green, and White rivers.
    - The research of the Committee (as summarized in the Climate Change Building Blocks and in Technical Memoranda #1, #4, #5 and #6) indicated that temperatures in the region have warmed and are projected to warm further. In addition, the timing and characteristics of seasonal hydrology has shifted to higher runoff in the winter and early spring and less runoff in the summer.

- Climate change should be considered in evaluating future water supplies and water demands for the region.
    - Because of the shifts in the hydrographs and the limited storage capacity in the region, changes in streamflow could impact the ability to meet municipal water demands. In addition, climate change will impact summer flows and stream temperatures regionally, placing more stress on freshwater aquatic ecosystems (Climate Change Building Blocks and in Technical Memoranda #4, #5 and #6).

- A web-accessible database of forecasted meteorology and hydrology change has been created for periods associated with the decades surrounding the years 2000, 2025, 2050, and 2075 for three GCM/emission scenario pairs.
    - Using a series of models, climate impacted meteorology and hydrology data have been created for three GCM/emission scenario pairs (Technical Memoranda #4 and #5). The meteorology data have been downscaled at key meteorological stations across the WRIAs and the hydrology data have been generated for sites associated with the operations of municipal water supplies. For each of these sites, 77 years of generated data is available at daily time steps for time periods associated with the decades surrounding the years 2000, 2025, 2050 and 2075.

- The database can now be used to evaluate future water supply and demand as outlined by the Committee.
    - Significant effort and resources have been used to arrive at a consensus on the potential impacts of climate change on the region and to create data representing potential futures. These data, based on the 2007 IPCC report, can be used when appropriate to evaluate future water supply and demand, adaptation strategies, ongoing efforts to ecosystem sustainability, and other water resource issues.

- Our understanding of the impacts of climate change on groundwater is limited at this time.
    - The literature review conducted illustrated the lack of detailed knowledge available regionally concerning groundwater and potential impacts of climate change. This is one area, among many others, where further research might be fruitful.

- Because of the importance of climate change and its impacts on water resources, this topic should be revisited at regular intervals to incorporate advances in our understanding.
    - Climate science and climate impact assessment are relatively new fields of science. Significant strides in climate science have occurred and additional progress is expected. Because of these advances, assessments of the impacts of climate change should be made at regular intervals. An appropriate interval would coincide with the release of updated Intergovernmental Panel on Climate Change reports which are produced every 6 years.

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Appendix A

Table 1: Members of Climate Change Technical Committee. 2006-2007

Member	**Affiliation**
Jane Lamensdorf-Bucher	King County Department of Natural Resources and Parks – Committee Chair
James Battin	NOAA
Geoff Clayton	Woodinville Water District Commissioner, Position 4
Holly Coccoli	Muckleshoot Tribe
Jefferson Davis	City of Kent
Paul Fleming	Seattle Public Utilities
Paul Hickey	Tacoma Water
Joan Kersnar	Seattle Public Utilities
Erin Leonhart	City of Kirkland
Maher Maher	Steward and Associates
Bruce Meaker	Snohomish PUD
Jim Miller	City of Everett
Phil Mote	University of Washington, Speaker
Steve Nelson	RH2 Engineering
Kelly Peterson	City of Kent
Jim Simmonds	King County Department of Natural Resources and Parks
Amy Snover	University of Washington, Principal, Climate Impacts Group
Chris Thorn	City of Auburn
Kurt Unger	Washington State Department of Ecology
Seshu Vaddey	US Army Corps of Engineers
Lara Whitely Binder	University of Washington, Climate Impacts Group
Facilitator and Technical Support Staff	
Tamie Kellogg	Committee Facilitator – Kellogg Consulting
Richard Palmer	Technical Lead, University of Washington, Principal Climate Impacts Group
Eset Alemu	Technical Support Staff, University of Washington
Donee Alexander	Technical Support Staff, University of Washington
Ben Enfield	Technical Support Staff, University of Washington
Kathleen King	Technical Support Staff, University of Washington
Courtney O'Neill	Technical Support Staff, University of Washington
Austin Polebitski	Technical Support Staff, University of Washington
Lee Traynham	Technical Support Staff, University of Washington
Matthew Wiley	Technical Support Staff, University of Washington

Table 2: Work Products from the Climate Change Technical Committee

Technical Memorandum Title	**Memo #**
Literature Review of Research Incorporating Climate Change into Water Resources Planning	1
Methodology for Downscaling Meteorological Data for Evaluating Climate Change	2
Online Database Functionality and Design for Climate Impacted Data	3
Development of Climate Impacted Meteorological Data and its Quality Assurance/Quality Control	4
Development of Climate Impacted Streamflow Data and its Quality Assurance/Quality Control	5
Framework for Incorporating Climate Changes into Water Resources Planning	6
Investigation of the Relationship between Temperature and Cloud Cover in Puget Sound Region	7
Impacts of Climate Change on Groundwater Resources: A Literature Review	8
Climate Change Building Blocks	Building Blocks
Final Report from the Technical Committee on Climate Change	Final Report

Impacts of Climate Change on Temperature

Building Block 1 – The global average temperature has increased during the 20th century and is forecasted to increase in the 21st century.

Building Block 2 – Warming in the Puget Sound Region has increased at a faster rate during the 20th century than the global average and increases in temperature are forecasted to continue.

Building Block 3 – Increased surface temperatures in the Pacific Northwest will increase the rates of evaporation and transpiration (evapotranspiration).

Impacts of Climate Change on Precipitation

Building Block 4 – Global precipitation is projected to increase in the future, although there is less certainty in predicting changes in precipitation than in temperature.

Building Block 5 – The occurrence of heavy precipitation events has increased over the U.S. during the 20th century. This trend is projected to continue during the 21st century.

Impacts of Climate Change on Snowpack and Glaciers

Building Block 6 – The loss of snowpack and glaciers in the Pacific Northwest mountains has been due to increased temperatures in the 20th century.

Building Block 7 – Forecasted increases in temperatures associated with climate change will further reduce snowpack and glaciers in the Pacific Northwest mountains.

Impacts of Climate Change on Streamflows

Building Block 8 – Climate change is projected to increase winter flows and decrease summer flows in snowmelt influenced river systems of the Pacific Northwest, particularly transient watersheds.

Building Block 9 – Climate change is projected to increase the frequency of flood events in most western Washington river basins.

Building Block 10 – Climate change is projected to increase the frequency of drought events in the Pacific Northwest.

Impacts of Climate Change on Sea Level Rise

Building Block 11 – Climate change is forecasted to raise global mean sea level in the 21st century.

Impacts of Climate Change on Salmonid Habitat

Building Block 12 – Climate change is forecasted to increase temperatures of rivers, streams, lakes, and river mouth estuaries in the Puget Sound region.

Building Block 13 –Climate change, as described in Building Blocks 1-12, is forecasted to contribute toward stream flow and temperature conditions that have been shown to negatively impact freshwater and estuarine habitat of most species of salmonids in the Puget Sound watersheds.

Figure 1: Climate Change Building Blocks

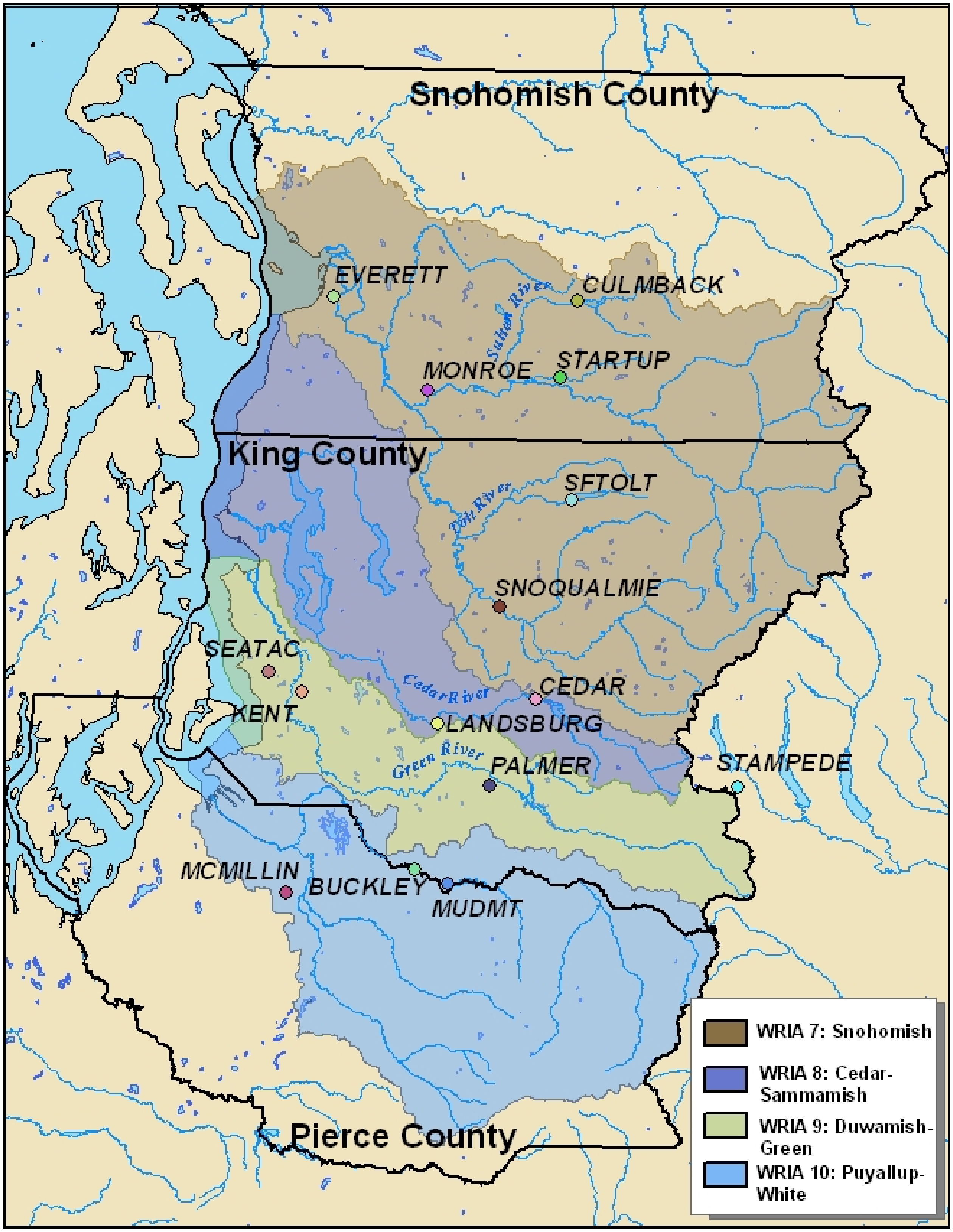

Figure 2: Study Area

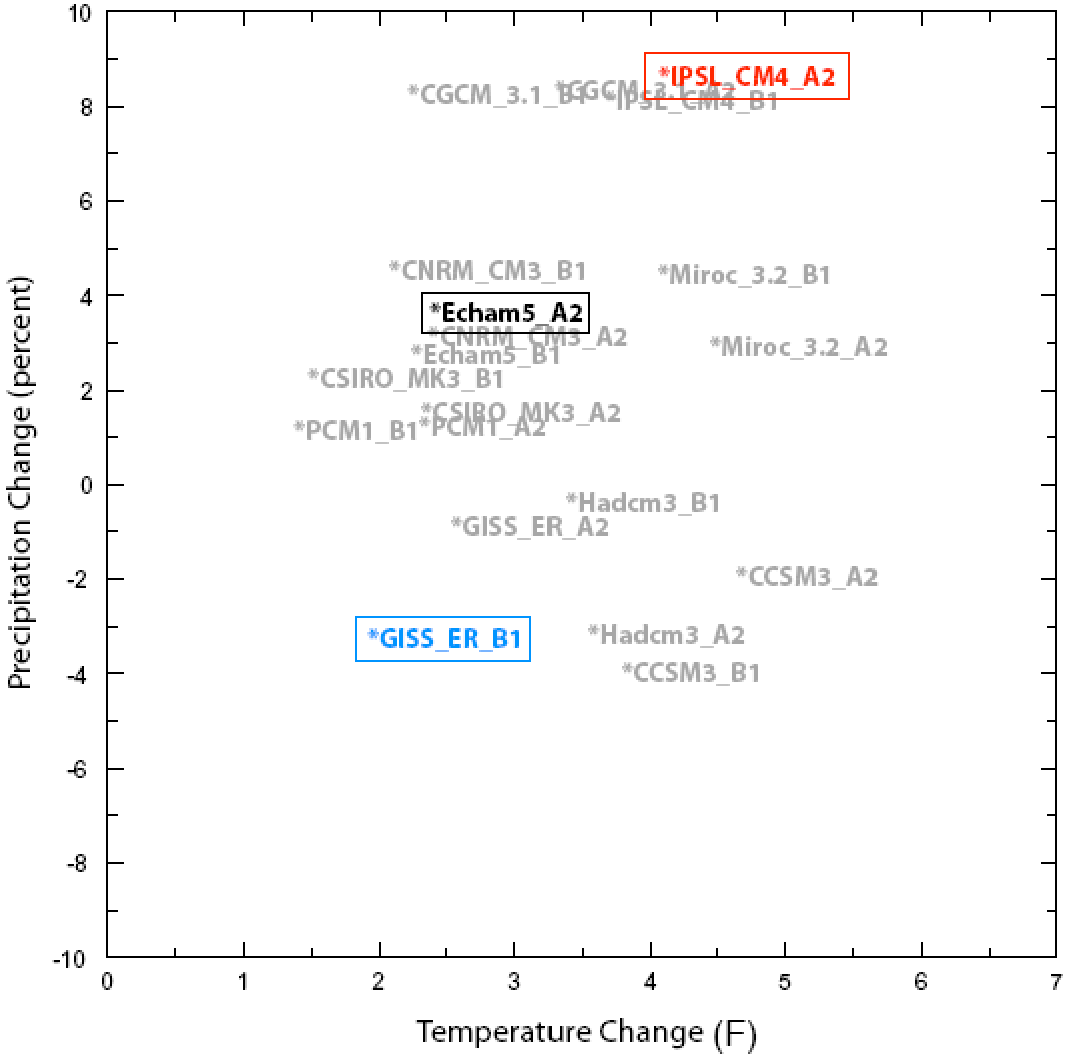

Figure 3: Comparison of the General Circulation Models and Emission Scenarios Pairs[3].

[3] Figure shows changes in annually averaged temperature and precipitation for the 2040s relative to historic (i.e., 2030-2059 model results minus 1970-1999 observations) for the Pacific Northwest regions (Mote et al, 2005)

Table 3: Projected Average Seasonal Temperature Changes Relative to Historic[4]
(Degrees Fahrenheit, Degrees Celsius in parentheses)

ECHAM_A2	Spring	Summer	Fall	Winter	Annual
2000	0.5 (0.3)	1.6 (0.9)	0.9 (0.5)	0.2 (0.1)	0.9 (0.5)
2025	1.6 (0.9)	2.2 (1.2)	2.2 (1.2)	2.5 (1.4)	2.2 (1.2)
2050	2.2 (1.2)	4.7 (2.6)	2.9 (1.6)	3.4 (1.9)	3.2 (1.8)
2075	4.7 (2.6)	7.9 (4.4)	5.8 (3.2)	8.1 (4.5)	6.7 (3.7)

GISS_B1	Spring	Summer	Fall	Winter	Annual
2000	0.9 (0.5)	1.6 (0.9)	-0.7 (-0.4)	0.5 (0.3)	0.5 (0.3)
2025	0.5 (0.3)	2.2 (1.2)	0.4 (0.2)	1.4 (0.8)	1.1 (0.6)
2050	0.9 (0.5)	2.9 (1.6)	0.7 (0.4)	0.9 (0.5)	1.3 (0.7)
2075	0.5 (0.3)	3.8 (2.1)	1.3 (0.7)	1.4 (0.8)	1.8 (1)

IPSL_A2	Spring	Summer	Fall	Winter	Annual
2000	1.1 (0.6)	1.4 (0.8)	1.8 (1)	0.5 (0.3)	1.3 (0.7)
2025	2 (1.1)	3.1 (1.7)	2.5 (1.4)	2.3 (1.3)	2.5 (1.4)
2050	3.6 (2)	5.8 (3.2)	4.5 (2.5)	3.6 (2)	4.3 (2.4)
2075	6.1 (3.4)	9 (5)	7.6 (4.2)	6.8 (3.8)	7.4 (4.1)

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

[4] The historic period is 1928-2004. The average is across 14 meteorological stations. 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 4: Projected Seasonal Precipitation Changes (Average Total Inches) Relative to Historic[5]
(Projected Percent Seasonal Precipitation Changes Relative to Historic in parentheses)

ECHAM_A2	Spring	Summer	Fall	Winter	Annual
2000	1.2 (11%)	-0.4 (-9%)	1.5 (12%)	2.4 (16%)	4.8 (11%)
2025	0.4 (3%)	1.0 (22%)	2.7 (21%)	0.5 (4%)	4.6 (11%)
2050	1.8 (16%)	0.3 (7%)	2.1 (16%)	1.2 (9%)	5.4 (13%)
2075	1.0 (9%)	0.5 (11%)	1.9 (15%)	2.5 (17%)	5.9 (14%)

GISS_B1	Spring	Summer	Fall	Winter	Annual
2000	0.5 (5%)	0.0 (0%)	3.9 (31%)	0.5 (3%)	4.9 (11%)
2025	1.4 (13%)	-0.2 (-5%)	3.1 (24%)	-0.8 (-6%)	3.5 (8%)
2050	0.3 (3%)	-1.1 (-24%)	2.8 (22%)	-2.4 (-16%)	-0.3 (-1%)
2075	1.6 (14%)	-1.3 (-29%)	0.7 (5%)	-0.9 (-6%)	0.0 (0%)

IPSL_A2	Spring	Summer	Fall	Winter	Annual
2000	1.2 (11%)	0.8 (17%)	0.8 (6%)	1.9 (13%)	4.7 (11%)
2025	0.5 (4%)	0.9 (20%)	1.9 (15%)	3.2 (22%)	6.4 (15%)
2050	1.6 (14%)	-0.7 (-16%)	2.1 (16%)	4.4 (30%)	7.4 (17%)
2075	2.3 (21%)	-1.1 (-25%)	1.8 (14%)	7.0 (48%)	10.0 (23%)

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

[5] The historic period is 1928-2004. The average is across 14 meteorological stations. 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)

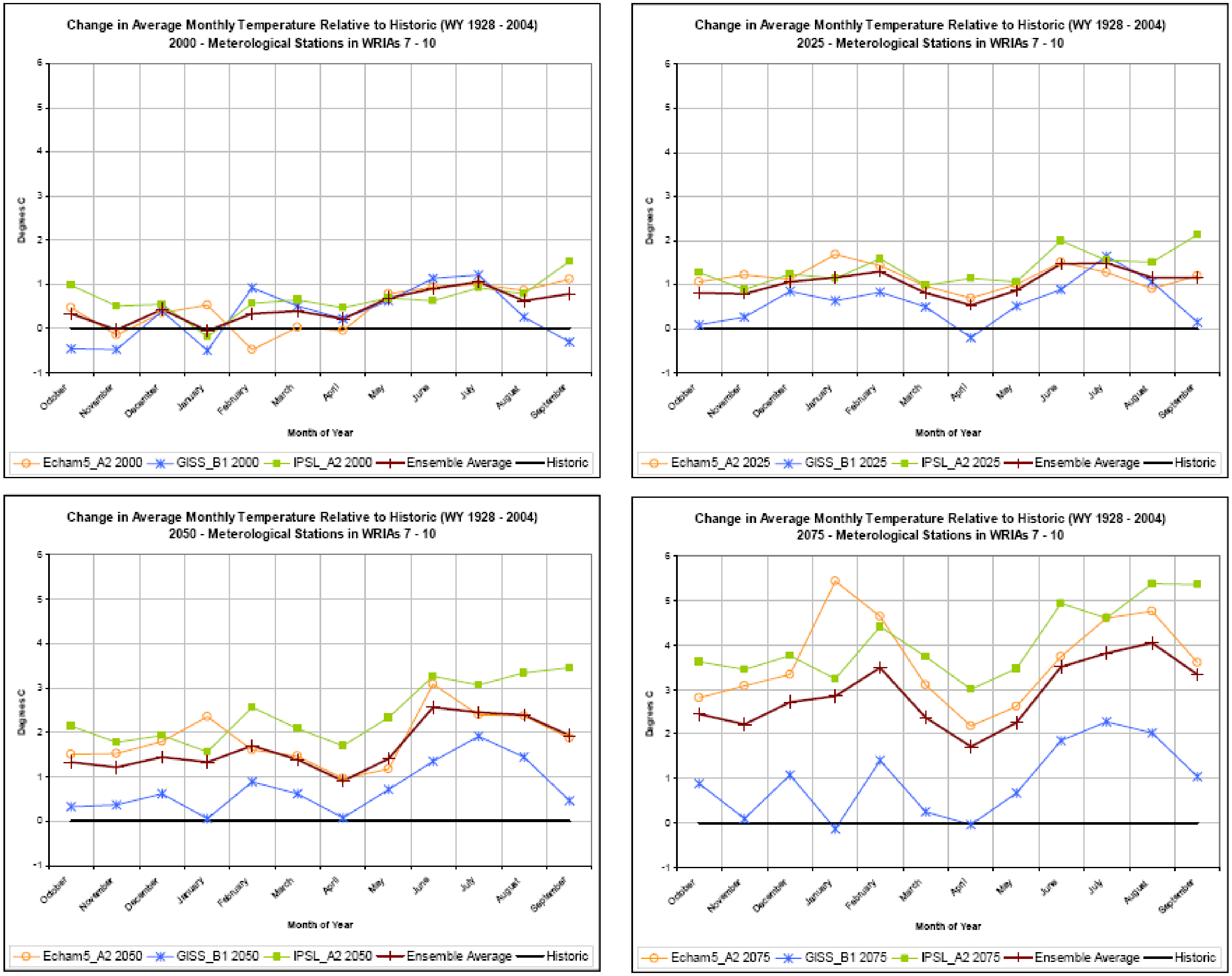

Figure 4: Projected Changes in Average Monthly Temperature Relative to Historic (1928-2004) Climate for 14 Meteorological Sites in Western Washington

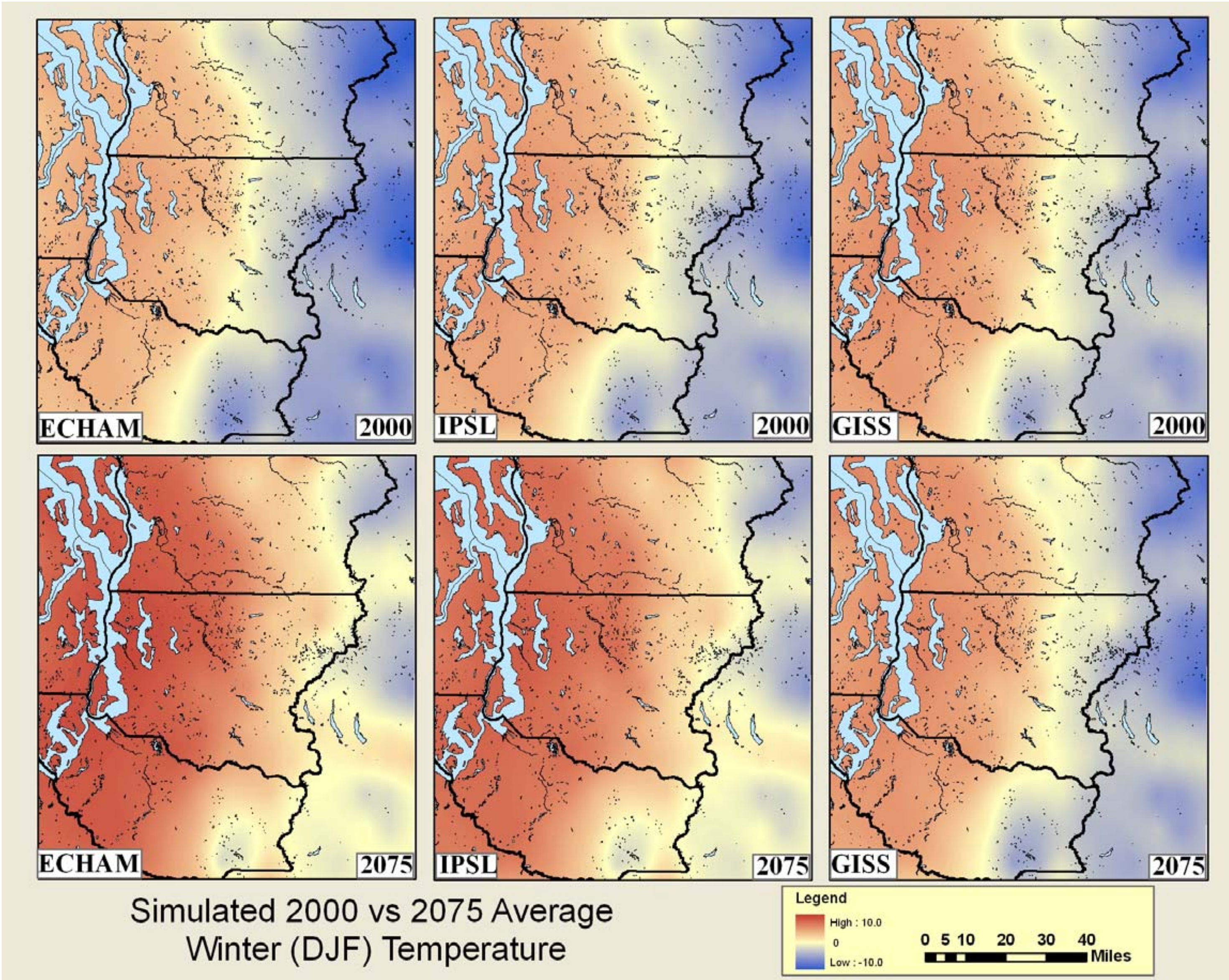

Figure 5: Simulated 2000 vs. 2075 Average Winter Temperature for three GCMs

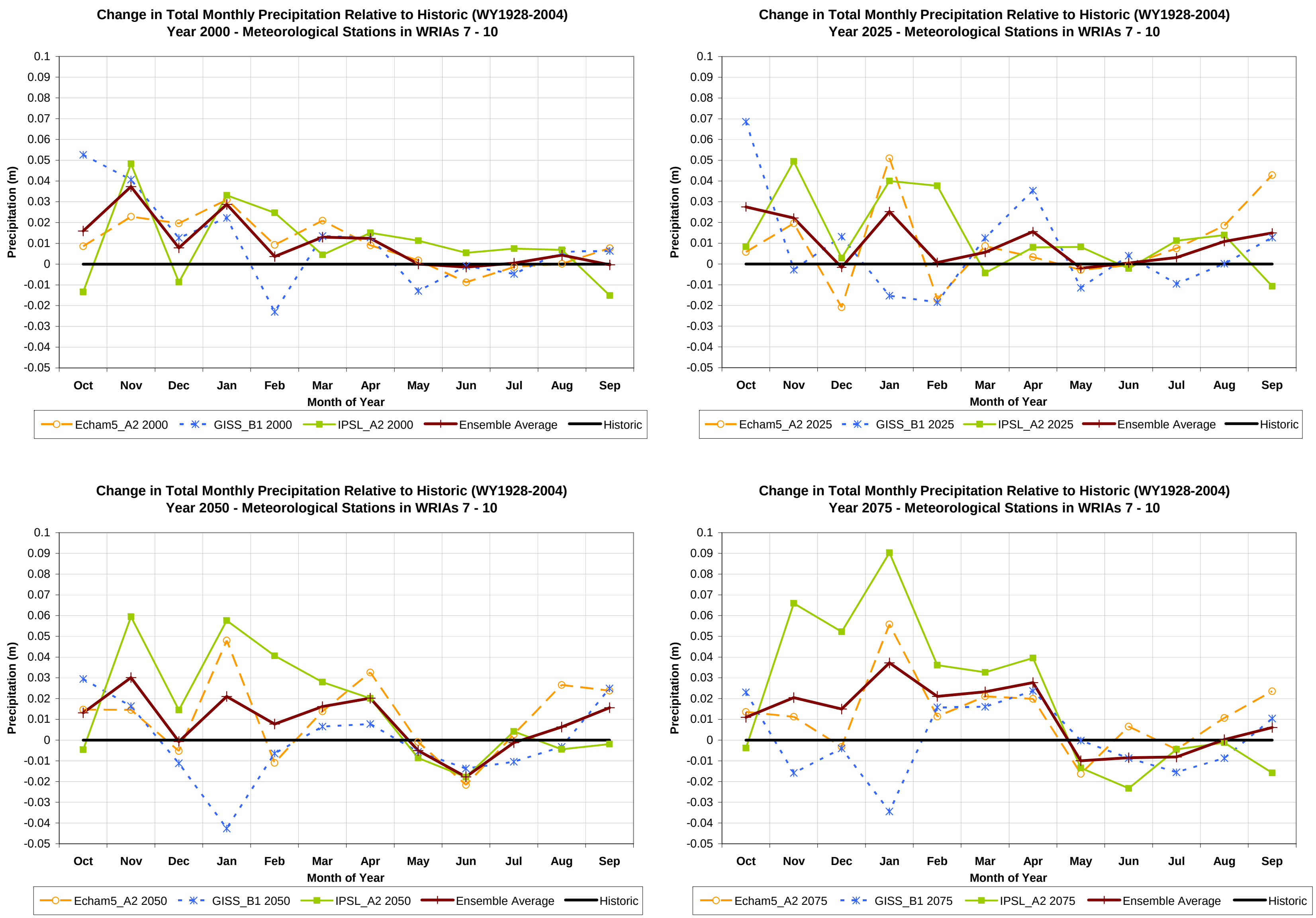

Figure 6: Projected Changes in Precipitation Relative to Historic (1928-2004) Climate for 14 Meteorological Sites in Western Washington

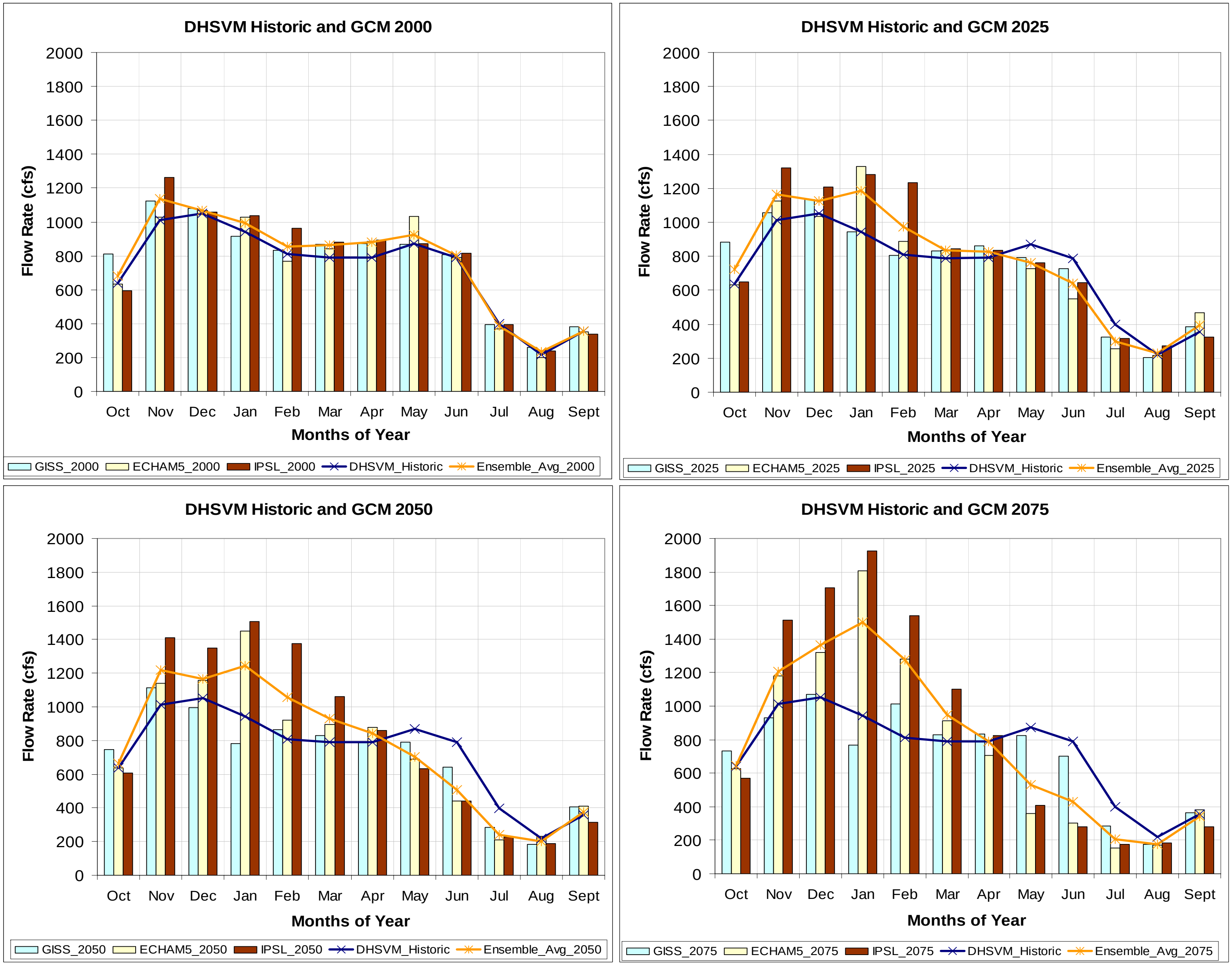

Figure 7: Hydrograph of Sultan Reservoir Inflows for the 2000, 2025, 2050, and 2075 periods. (Inflows into Spada Lake (Q1))

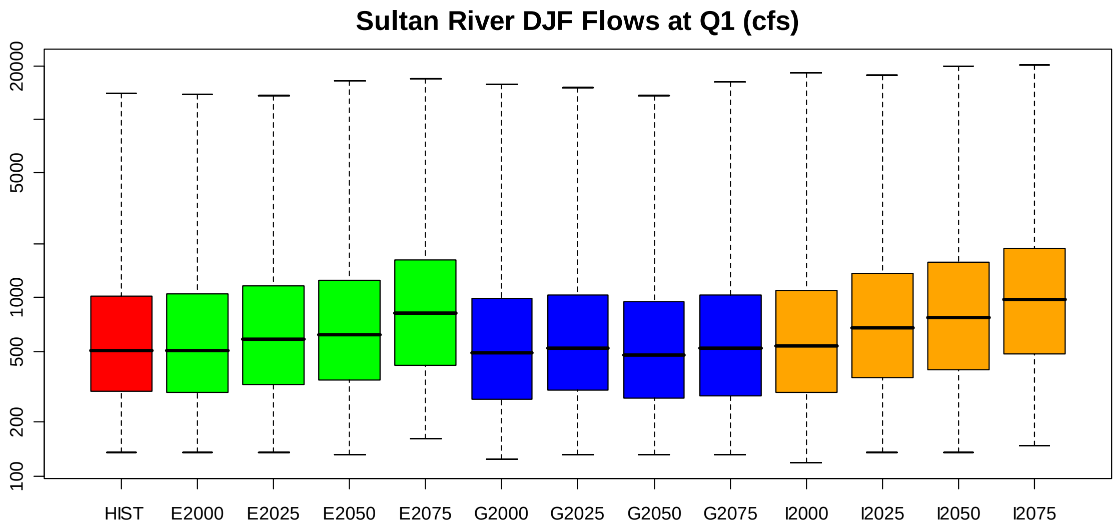

Figure 8: Boxplots of Projected Winter Streamflows at Sultan Reservoir[6]

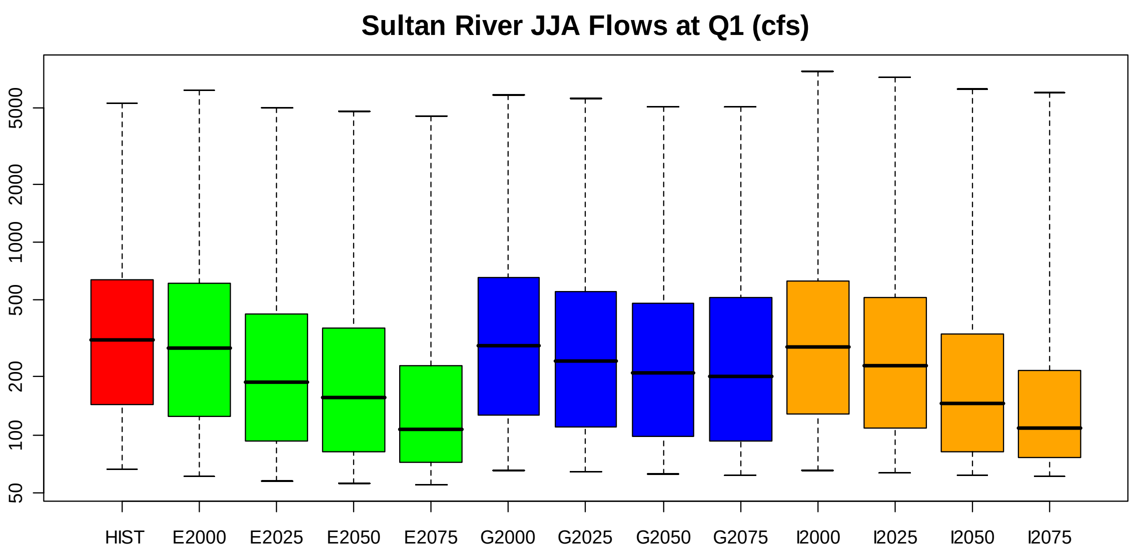

Figure 9: Boxplots of Projected Summer Streamflows at Sultan Reservoir

[6] A boxplot displays the distribution of a range of data. A boxplot in this figure represents the median value of the data as the black line in middle of the box, the 25th and 75th percentiles as the extents of the box, and the 5th and 95th percentiles as the whiskers extending from the box.

Table 5: Projected Seasonal Changes in Ensemble Average Streamflow Relative to Simulated Historic[7]
(Projected Percent Seasonal Minimum and Maximum Average Streamflows Relative to Simulated Historic in parentheses)

		Spring	Summer	Fall	Winter	Annual
Cedar	2000	10% (8%, 12%)	11% (7%, 13%)	10% (6%, 16%)	8% (6%, 12%)	9% (9%, 10%)
	2025	-2% (-6%, 1%)	-11% (-19%, -1%)	19% (15%, 22%)	22% (9%, 33%)	8% (7%, 11%)
	2050	-3% (-5%, -2%)	-28% (-38%, -15%)	19% (16%, 21%)	29% (1%, 52%)	8% (1%, 14%)
	2075	-12% (-23%, 0%)	-37% (-52%, -12%)	17% (4%, 25%)	48% (8%, 80%)	9% (2%, 17%)
Sultan	2000	9% (6%, 13%)	1% (-4%, 4%)	8% (0%, 16%)	4% (1%, 9%)	6% (4%, 8%)
	2025	-1% (-4%, 1%)	-17% (-27%, -11%)	14% (11%, 16%)	17% (3%, 32%)	6% (2%, 11%)
	2050	1% (-2%, 4%)	-33% (-39%, -21%)	13% (9%, 16%)	24% (-6%, 51%)	5% (-3%, 15%)
	2075	-8% (-19%, 1%)	-42% (-55%, -18%)	9% (1%, 18%)	47% (1%, 84%)	8% (-2%, 21%)
South Fork Tolt	2000	8% (6%, 9%)	3% (2%, 3%)	8% (4%, 16%)	6% (0%, 10%)	6% (6%, 7%)
	2025	-3% (-7%, 0%)	-16% (-20%, -12%)	16% (10%, 21%)	20% (4%, 35%)	6% (3%, 10%)
	2050	-2% (-3%, 0%)	-34% (-41%, -25%)	15% (12%, 17%)	27% (-5%, 55%)	5% (-3%, 12%)
	2075	-8% (-19%, 2%)	-41% (-53%, -23%)	10% (0%, 18%)	48% (3%, 85%)	7% (-3%, 17%)
Green	2000	10% (8%, 13%)	7% (5%, 9%)	12% (8%, 19%)	9% (7%, 11%)	10% (9%, 10%)
	2025	-3% (-8%, 1%)	-4% (-8%, 0%)	23% (18%, 30%)	23% (8%, 34%)	11% (8%, 14%)
	2050	-5% (-7%, -3%)	-23% (-29%, -17%)	23% (20%, 27%)	28% (0%, 49%)	10% (1%, 16%)
	2075	-13% (-25%, 1%)	-27% (-39%, -14%)	18% (5%, 28%)	41% (5%, 71%)	10% (2%, 19%)
White	2000	9% (7%, 10%)	-5% (-7%, -3%)	14% (11%, 20%)	20% (16%, 23%)	9% (9%, 9%)
	2025	3% (1%, 5%)	-18% (-23%, -13%)	20% (17%, 22%)	31% (19%, 43%)	8% (6%, 11%)
	2050	6% (0%, 13%)	-28% (-33%, -22%)	16% (16%, 18%)	36% (9%, 59%)	7% (-1%, 14%)
	2075	4% (-4%, 11%)	-38% (-48%, -18%)	12% (4%, 16%)	57% (14%, 89%)	9% (1%, 18%)

[7] 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 USGS stream gauge sites used to measure inflows into reservoirs, except on the Green and the Sultan, where total inflows were used.