Implications of 2005 Climate Change Scenarios for Pacific Northwest Hydrologic Studies

a report by

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In preparation for the Fourth Assessment by the Intergovernmental Panel on Climate Change (http://www.ipcc.ch; due out in 2007), modeling centers around the world have prepared new simulations of future climate change, using updated global climate models and greenhouse gas emission scenarios. The Climate Impacts Group has recently acquired and downscaled this output to the Pacific Northwest using recently developed downscaling techniques.

Overall, the new projections for PNW climate change ("2005 scenarios") show smaller temperature increases than scenarios used in previous studies, but similar precipitation changes. These differences are primarily due to the examination of a much larger set of global climate models and a new and improved standardization method (for establishing the baseline to which future changes are compared). The new baseline for all model projections is the 1970-2000 mean climate. For more information about the models used, evaluation of model skill at simulating 20th century PNW climate, and projections for 21st century PNW climate, see Mote et al. (2005).

The general implication of the 2005 scenarios is that temperature increases will occur at a slower rate, with changes previously projected for the 2020s and 2040s occurring a decade or more later in the century than previously projected. As a result, climate impacts that depend on these temperature changes (such as reductions in snowpack) would also occur later in the century.

In this document we discuss the implications of the 2005 climate change scenarios for previously reported hydrologic studies for the Columbia River basin (using the Variable Infiltration Capacity model, VIC) and the Puget Sound basin (using the Distributed Hydrology Soil Vegetation Model, DHSVM).

I. Implications for Columbia River basin hydrologic studies (VIC)

Summary of Changes: Climate Change Scenarios

As compared with earlier studies, there has been a general progression toward lower (temperature) sensitivities of global climate models (GCMs) with time (Table 1).

- In the 1992 Lettenmaier et al. study, temperature changes were prescribed (fixed throughout the year) at 2 and 4°C, which more or less corresponds to the range across different models in the CO_2 doubling scenarios that were used in most studies in the early 1990s. Doubling of atmospheric levels (compared to pre-industrial values) is now estimated to occur around 2050-2070.
- The Lettenmaier et al (1999) paper summarizes a set of six studies for water resource systems across the U.S. that was conducted from 1993 to 1996. Two of these studies (Green River and Columbia River) were in the PNW. These six studies used some of the first transient climate change scenarios available (from three different models), in addition to CO_2 doubling scenarios. Because transient scenarios are now the norm for most climate change studies, we report the results for the transient scenarios only.
- Hamlet and Lettenmaier (1999) and Miles et al. (2000), which reported on the Climate Impact Group's contribution to the U.S. National Assessment, used transient scenarios from two GCMs, temperature and precipitation changes for which are reported.
- Snover et al. (2003), reporting on climate change-adjusted streamflow scenarios for water resources planning, used two additional transient scenarios, as well as a "composite" scenario, which was selected to be more or less mid-range with respect to the various models. We report here only the composite.

- Payne et al. (2004) report results of the Accelerated Climate Prediction Initiative (ACPI) demonstration study for the Columbia River basin. This study used multiple ensembles from a single GCM, NCAR/DOE PCM.

Table 1. Comparison of climate change scenarios used in previous studies with 2005 climate change scenarios

STUDY & CLIMATE SCENARIO	TEMPERATURE INCREASE (°C)	PRECIPITATION CHANGE (%)
PREVIOUS STUDIES		
Lettenmaier et al (1992)		
Prescribed annual changes for CO_2 doubling		
	2.0	0
	4.0	0
Lettenmaier et al (1999)		
Green River basin 2040s annual changes		
GFTR	3.3	+7
HCTR	2.5	+2
MPTR	1.8	-2
Lettenmaier et al (1999)		
Columbia River basin 2040s annual changes		
GFTR	3.4	+5
HCTR	3.0	~0
MPTR	2.6	-9
Hamlet and Lettenmaier (1999), Miles et al. (2000)		
Columbia River basin 2040s winter changes		
HadCM2	3.0	+9
MPI	2.7	-1.2
Snover et al. (2003)		
Columbia River basin 2040s winter changes		
"composite" scenario	2.3	+6.8
Payne et al. (2004)		
Columbia River basin ~ 2055 (2040-2069) annual changes		
PCM	1.2	~0
2005 IPCC SCENARIOS		
Mote et al. (2005)		
Pacific Northwest 2040s annual changes		
GISS-B1	1.1	-3.3
ECHAM-A2	1.3	+4.0
IPSL-A2	2.3	+8.7

There are slight differences among the various studies in terms of the averaging period for precipitation and temperature changes (some values are reported as annual averages, others as winter averages). For precipitation, annual and winter averages are likely to be quite similar, since precipitation in the Pacific Northwest is strongly winter dominant. For temperature however, winter and annual values can differ substantially, although there usually is a strong relationship between a model's winter and annual average changes.

The studies also differ in terms of the spatial domain over which the climate changes refer to. For Hamlet & Lettenmaier (1999) and Miles et al. (2000), for example, the spatial domain is the Columbia basin. The 2005 scenarios were calculated over the "Pacific Northwest", i.e., the region between 124° and 111° west longitude, 42° to 49° north latitude: Washington, Oregon, Idaho, and western Montana. This difference would probably have a small, but perhaps noticeable, impact on the reported climate changes.

All of the above studies assess hydrologic, and, in most cases, water resources implications of the climate scenarios summarized in the table. The earlier studies mostly use what is termed the delta method of downscaling – specifically, the hydrologic model forcings (historical observations) are adjusted, on a monthly basis, by the given amount of change in temperature or precipitation. In the case of temperature, both the daily maximum and minimum are adjusted by the amount of change for the given month. For precipitation, all (daily) values in a given month are scaled by the amount indicated. In the case of Lettenmaier et al (1999) for instance, all temperature values in every month are adjusted upward by either 2 or 4°C, whereas precipitation is unchanged.

This method, while simple, has fallen out of favor because it utilizes only the most basic information from the GCM. Because all values are adjusted by the same amount, for instance, the method does not incorporate information about changes in, say, extreme precipitation, except as it is reflected in changes in the mean. Payne et al. (2004) and Mote et al. (2005) utilize more sophisticated statistical downscaling methods. Nonetheless, the summary statistics included in the table give a general idea of the magnitude of changes in precipitation and temperature reflected in the various climate scenarios.

Summary of Changes: Hydrologic Impacts

Temperature changes are by far the most important factor determining climate change impacts on snow-melt and transient river basins, due to their influence on winter precipitation type, snowpack accumulation, timing of snow melt and peak flows, and summer low flows. In non-snowmelt dominant watersheds, precipitation changes (which are less certain) may be important. However detailed studies of such streams (e.g. the Chehalis), which are less numerous across the PNW, have not been conducted. In general, the 2005 scenarios would affect previous projections of hydrologic impacts as follows:

- Under the 2005 climate change scenarios, because of the slower rate of warming, temperature related effects (including decreases in snowpack, increases in April soil moisture, streamflow timing shifts from summer to winter, and water resources impacts associated with earlier peak flow and decreased summer water availability) that were previously projected for the 2020s and 2040s would occur later in the century.
- Increases in annual streamflow volume (which are controlled primarily by winter precipitation changes) previously projected for the 2020s are probably overestimated, given the drier projections of the 2005 scenarios.

Below we summarize briefly how the different temperature and precipitation changes resulting from the 2005 scenarios might be reflected in specific published studies, if the original methods were used, but with the current (2005) climate change scenarios. Because only some studies have looked at the 2020s, while all looked at the 2040s, we use the latter period as the basis for comparison.

- *Lettenmaier et al (1992).* As noted above, the temperature changes for this study were prescribed, and precipitation was assumed to be unchanged. The +4°C scenario is warmer than any of the 2005 scenarios; however the +2°C scenario is close to the 2005 "high" scenario (+2.3°C temperature change). The 2005 high scenario is accompanied by a +8.7 percent precipitation change, however insofar as the Lettenmaier et al study results were dominated by hydrograph timing shifts, rather than volume, the +2°C temperature change in that study can be roughly interpreted as equivalent to the 2005 "high" scenario.
- *Lettenmaier et al (1999).* For the Green River study, the GFTR scenario (+3.3°C temperature change) is larger than any of the 2005 scenarios. However, HCTR (+2.5°C) and MPTR (+1.8°C) lie roughly in the range of the 2005 "high" scenario (HCTR) and between "high" and "medium" (MPTR). Both of these scenarios had modest precipitation changes; however the results were dominated by hydrograph shifts which are linked primarily to temperature changes. Therefore, the HCTR and MPTR scenarios can reasonably be interpreted in terms of 2005 scenarios. For the Columbia basin study, both GFTR (+3.4) and HCTR (+3.0) scenarios have temperature changes that are warmer than the 2005 "high" scenario. MPTR, with +2.6°C temperature change, is roughly equivalent to the 2005 "high" scenario.
- *Hamlet and Lettenmaier (1999) and Miles et al. (2000).* In these U.S. National Assessment studies, two scenarios were used, HadCM2 and MPI. The HadCM2 temperature change of +3.0°C and precipitation change of +9 percent are quite close to the 2005 "high" scenario, and those results can therefore be linked quite closely to the 2005 scenarios. The MPI scenario had +2.7°C temperature change, and -1.2 percent precipitation change. As for other studies in the PNW, the hydrograph shifts, linked mostly to temperature, are probably more important than annual streamflow volume changes, which are more related to precipitation. In any event, given that the two scenarios used in the Hamlet and Lettenmaier study have quite similar temperature changes, the differences in the scenarios can be interpreted in terms of sensitivity to precipitation changes, at roughly the temperature change levels of the 2005 "high" climate scenario.
- *Snover et al. (2003).* The composite climate scenario used in this study is quite similar to the 2005 "high" scenario (+2.3°C and +6.8 percent vs. +2.3°C and +8.7 percent, respectively) and the results are best interpreted as representative of this 2005 scenario.
- *Payne et al (2004).* This paper used a scenario with the lowest temperature change (+1.2°C) of any of the studies. The precipitation change was close to zero. This scenario is quite close to the 2005 "medium" scenario (+1.3°C and +4 percent precipitation change), notwithstanding the difference in the precipitation change. (For the reasons noted above, precipitation changes are generally less important than temperature changes given the small size of the reservoirs in the region).

II. Implications for Puget Sound basin hydrologic studies (DHSVM)

The impacts of climate change for the Wiley (2004) study of climate change impacts on Seattle Public Utilities water supply were assessed not only using an earlier set of climate change scenarios, but also a different method of downscaling the global climate model output than was used for the most current (2005) climate scenarios.

In general the 2005 scenarios are largely similar to those used in Wiley (2004), with the exception of the presence of one notably cooler scenario in the 2005 set.

In terms of temperature, three of the four scenarios used in the Seattle study (ECHAM4_A2, HadCM3_A2, and GFDLR30_A2) are close to the warmer 2005 scenarios (ECHAM5-A2 and IPSL-A2) for the analysis decades of the 2020s. The fourth SPU scenario (PCM1_A2) is comparable to the coolest 2005 scenario (GISS_B1) for the 2020s. For the 2040s analysis period the first three SPU scenarios are approximately mid-way between the middle and the warmest of the 2005 scenarios while the PCM1_A2 scenario falls between the middle and coolest 2005 scenarios. The precipitation changes shown in the 2005 scenarios are generally similar to that for the models used in the SPU study. As a result, it is expected that the main differences in the hydrologic impacts associated with the new (2005) and old scenarios will result from the differences in projected temperature changes.

Under the 2005 climate change scenarios, the climate impacts on streamflows will be largely similar to those assessed previously by Wiley (2004). The notable exception to this is the presence of the cooler GISS_B1 scenario, which is expected to expand the range of potential impacts to include a future in which the warming occurs less quickly, effectively pushing the timeline of impacts previously associated with the 2020s and 2040s back ten to twenty years.

III. References

Hamlet, A. F., and D. P. Lettenmaier. 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. *Journal of the American Water Resources Association* 35(6):1597-1623.

Lettenmaier, D.P., K.L., Brettman, L.W. Vail, S.B. Yabusaki, and M.J. Scott. 1992. Sensitivity of Pacific Northwest Water Resources to Global Warming. *The Northwest Environmental Journal* 8:265-283.

Lettenmaier, D.P., A.W. Wood, R.N. Palmer, E.F. Wood, and E.Z. Stakhiv.1999. Water resources implications of global warming: A U.S. regional perspective. *Climatic Change* 43(3):537-79.

Miles, E. L., A. K. Snover, A. F. Hamlet, B. M. Callahan, and D. L. Fluharty. 2000. Pacific Northwest regional assessment: The impacts of climate variability and climate change on the water resources of the Columbia River Basin. *Journal of the American Water Resources Association* 36(2):399-420.

Mote, P., E. Salathé and C. Peacock. 2005. *Scenarios of future climate for the Pacific Northwest.* Report prepared for King County (Washington) by the Climate Impacts Group (Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle).

Payne, J.T., A.W. Wood, A.F. Hamlet, R.N. Palmer, and D.P. Lettenmaier. 2004., Mitigating the effects of climate change on the water resources of the Columbia River basin. *Climatic Change* 62(1-3): 233-256.

Snover, A. K., A. F. Hamlet, and D. P. Lettenmaier. 2003. Climate change scenarios for water planning studies: Pilot applications in the Pacific Northwest. *Bulletin of the American Meteorological Society* 84(11):1513-1518.

Wiley, M.W. 2004. *Analysis techniques to incorporate climate change information into Seattle's long range water supply planning*. M.S.C.E. thesis, Department of Civil and Environmental Engineering, University of Washington, Seattle.