

ADAPTING TO CLIMATE CHANGE: BRIDGING THE GAP BETWEEN GLOBAL
PROJECTIONS AND LOCAL PLANNING IN THE CHEHALIS BASIN

by

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ABSTRACT

Adapting to Climate Change: Bridging the Gap between Regional Projections and Local Planning in the Chehalis Basin

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The Pacific Northwest is on the forefront of the climate change issue and there has been a lot of legislative action related to climate change mitigation and to a lesser extent adaptation policy/planning. At the regional level, groups and agreements such as the Western Climate Initiative and the Climate Registry operate with a mitigation focus, working mainly to develop greenhouse gas inventories and greenhouse gas emissions reduction programs. On the State and local level in Washington legislation has also dealt mainly with mitigation but has acknowledged the need for adaptation. Due to lag times in our climate's forcing and feedback mechanisms (in particular the retention of heat in the ocean and the longevity of greenhouse gases in the atmosphere) even if atmospheric concentrations of greenhouse gases were stabilized today, the current warming trend would continue for decades (IPCC 2001; CIG 2005). It is no longer viable to conduct regional and local planning based on historic climate trends alone. The majority of scientists agree the change is coming, and it is time to adaptively plan with our eyes forward. Climate models have been established to produce climate projections which can aid in the planning process, though the majority of models in the current generation operate at a low resolution. Scientists have begun to develop downscaling techniques to correct this resolution deficiency and pave the way for the use of established hydrologic and ecosystem models to perform bottom up watershed planning to bridge the gap between the regional and local.

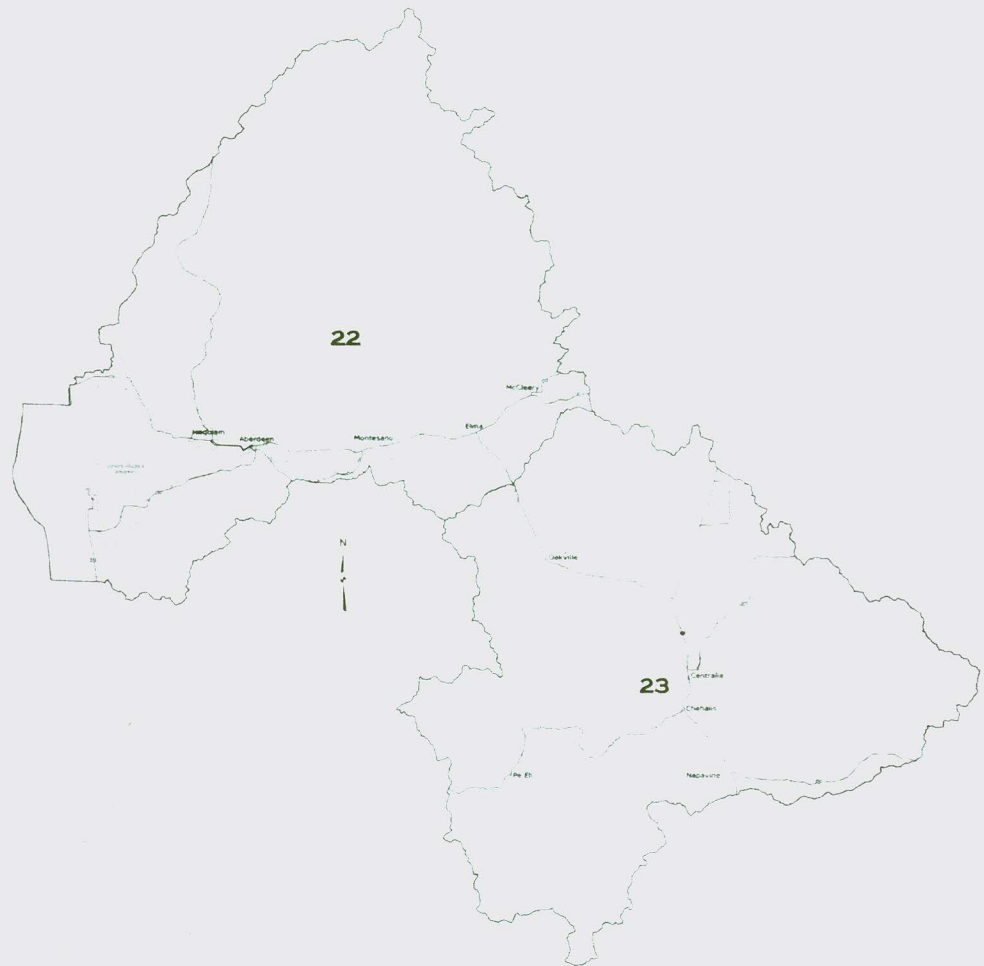
This thesis essay discusses advancements in adaptation planning and policy as they relate to Western Washington and specifically the Chehalis Basin. Using the processes laid forth in the 2007 University of Washington Climate Impact Group (CIG)/King County jointly authored document, "Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments", and other studies this thesis hopes to lay the groundwork for climate adaptation planning to begin in the Chehalis Basin. This involves performing initial scoping and vulnerability assessment based on the findings of the Chehalis Basin Partnership, the group currently performing watershed planning for the Upper and Lower Chehalis Watershed (Water Resource Inventory Areas (WRIA) 22 & 23 respectively) under the Watershed Planning Act of 1998.

*ADAPTING TO CLIMATE CHANGE: BRIDGING THE GAP BETWEEN REGIONAL
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CHAPTER 1.0 INTRODUCTION

The Chehalis Basin, Water Resource Inventory Areas (WRIA) 22&23, drains approximately 2600 square miles making it one of the largest basins in the state of Washington. The basin extends over eight counties but lies predominately in Grays Harbor Thurston and Lewis Counties. Uplands south and west (Willipa Hills) of Chehalis, Washington are the headwaters of the main stem of the Chehalis.



(CBP et al. 2004)

Major tributaries (headwater source) to the basin include the S. Fork Chehalis

(uplands south of Chehalis), Newaukum (Cascade foothills headwaters), Skookumchuck (Cascade foothills headwaters), Scatter Creek (headwaters in upland wetlands in S. Thurston Co.), Black River (headwaters in wetlands near Black Lake), Wynoochee River (Southern Olympic Mountain Range headwaters), Satsop River (Southern Olympic Mountain Range headwaters). The main stem of the Chehalis River is predominately fed by precipitation events, runoff, and groundwater, though the Humptulips, Wynoochee and Satsop Rivers do receive varying amounts of melt water from the snow pack on the southern portion of the Olympic Mountain Range. Annual precipitation varies from a minimum of 40 inches in the central portions of the basin (Chehalis/Centralia), to a high of 220 inches in the headwaters of the Wynoochee and Humptulips Rivers (Olympic Mountains). The seasonal hydrograph for the upper portion of the basin exhibits one peak in the winter months indicative of a system which receives the majority of its flow from seasonal precipitation by runoff or aquifer contribution (ie. not glacier or snow pack fed unlike many other basins in the region)(Envirovision Corporation 2000; Tetra-Tech/KCM 2003).

One of the biggest concerns arising from projected climate changes in the Pacific Northwest is that of the timing and availability of water resources with its implications for drinking water, irrigation, hydroelectric power, aquatic and terrestrial ecosystems, and coastal communities (Mote 2003; CIG 2005; IPCC 2007). It is logical that based on the varied range of potential impacts to water resources in the Pacific Northwest that beginning adaptive planning for climate change should begin on the watershed level (Whitely Binder 2006). There are numerous studies on the impacts of climate change on water resources and planning (Palmer et al. 2002; Werritty 2002; Casola et al. 2005;

Dessai et al. 2007).

In response to the Watershed Management Act of 1998, the Chehalis Basin Partnership (CBP) was formed to design and implement watershed planning for the Upper and Lower Chehalis Watershed (Water Resource Inventory Areas (WRIA) 22 & 23 respectively). The signed members of the CBP include: the cities of Aberdeen, Centralia, Chehalis, Hoquiam, McCleary, Montesano, Napavine, Ocean Shores, and Pe Ell; the counties of Grays Harbor, Lewis, Mason, and Thurston; the Confederated Tribes of the Chehalis; water suppliers including Grays Harbor Water District #2, the Boistfort Valley Water Company; the Ports of Centralia and Grays Harbor, the Chehalis Basin Fisheries Taskforce, the Washington Farm Bureau, the Washington State Departments of Fish and Wildlife, the Washington State Department of Ecology, the Washington State Department of Natural Resources, concerned citizens and the Weyerhaeuser Corporation. Current membership does not include an exhaustive group of stakeholders in the basin. There are many important issues facing the ecological and stakeholder interests in the basin however many of these issues either have their roots in or directly impact the management of the water resources of the Upper and Lower Chehalis Watershed.

Current issues identified in the Chehalis Basin Watershed Management Plan include:

- Water Quantity
 - Hydraulic Continuity
 - Water Rights
 - Exempt Wells
 - Water Conservation Strategies
- Water Quality
 - Point and nonpoint source pollution
- Habitat
 - Instream Flows

Based on global and regional climate projections for the Pacific Northwest all of the priorities of the Chehalis Basin Partnership identified in the basin management plan could potentially be impacted by future alterations of temperature and precipitation regimes (Mote 2003; CIG 2005; Schneider 2007). In this report priority management strategies identified in the plan will be discussed, data gaps impeding climate assessment will be isolated and recommendations will be made regarding both the need and the potential for incorporating climate variables into current management efforts.

1.1 BACKGROUND

One of the difficulties in preparing for climate change is the coarse resolution of the climate changes projections provided in climate model outputs (Dessai et al. 2005; Schneider 2007). On the federal level the United States government has been particularly slow in dealing with climate issues. This has not however stopped many state and local governments from adopting policies to reduce greenhouse gas emissions and develop adaptation strategies. There has been a great deal of research done at the global and regional level in predicting the probable impacts of anticipated climate changes (Adger 2007; Schneider 2007), but significant obstacles exist in developing efficient mechanisms for integrating climate data/projections into practical local concerns (Adger 2007). This has potentially large ramifications for flood plain management, recreation, land use planning, aquatic resource planning, and restoration and conservation projects (CIG 2005; Adger 2007; IPCC 2007).

Global and regional scale climate models project climate changes using major climate forcing and feedback features of the earth's atmospheric, oceanic, and terrestrial systems (IPCC 2007). The Climate Impacts Group of the University of Washington has

emerged as the scientific authority for interpreting climate impacts for the State of Washington. In 2007, as a result of Governor Christine Gregoire's Climate Change Challenge (Executive Order 07-02) the Washington State Departments of Ecology and Community Trade and Economic Development formed the Climate Advisory Team, a group made up of stakeholders and representatives from various private and public sectors anticipated to have a stake in climate change mitigation/adaptation policy and planning.

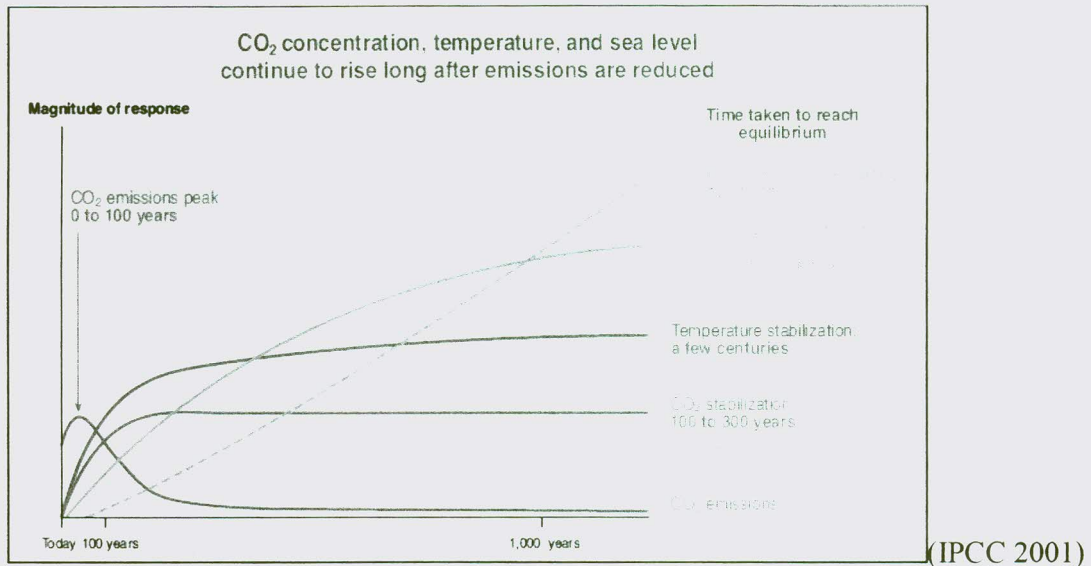
A large volume of work in western Washington has come from the Climate Impacts Group at the University of Washington and municipal partners including Seattle Public Utilities, King County, Seattle, Washington and Portland, Oregon. Several other cities and counties have implemented, or are in the process of developing climate change mitigation and adaptation planning documents (US-Government-Report 2007).

The purpose of this thesis essay is to discuss advancements in adaptation planning and policy as they relate to the Upper and Lower Chehalis Watershed, Water Resource Inventory Areas (WRIA) 22 & 23 respectively. Additional review presented in this thesis includes an assessment of climate data sources (proxy and observed), the use of climate models and the techniques utilized to downscale model projections. The substance of this investigation is synthesized into recommendations for future adaptation planning and policy.

The planning steps and methodology found in the literature will be applied to the Chehalis River Basin, an approximately 2700 square mile drainage fed almost exclusively by precipitation and groundwater, and dominated by forestry, agricultural, and rapidly developing urban and industrial land uses.

1.2 THE NEED FOR ADAPTATION PLANNING

Due to lag times in our climate's forcing and feedback mechanisms, even if atmospheric concentrations of greenhouse gases were stabilized today, the current warming trend would continue for centuries. (IPCC 2001; CIG 2005).



This is the challenge we are faced with, but how do we integrate climate change preparedness into plans and policies on a level that would truly permit strong climate adaptive actions to be taken on various scales of public and private entities?

Currently adaptation and mitigation based legislation are the primary ways in which policy affects Washington's treatment of climate change (CIG 2005; CAT 2007) (Executive Order 07-02, Senate Bill 6001, House Bill 2815, Global Warming Substitute Bill SSB6580, RCW 80.70, RCW 80.80). Mitigation or the reduction of greenhouse gas emissions, while very important in reducing the climate impacts of those emissions in the future, due to greenhouse gas atmospheric residency times, does little to protect our region from impacts related to predicted increases in temperature and variations in precipitation

(IPCC 2001). In 2007 as a result of Washington Governor Christine Gregoire's Executive Order 07-02 and Engrossed Senate Bill 6001 RCW Title 80 was amended and consequently became the first greenhouse gas mitigation law for Washington State. RCW 80.80.005 (Title 80 Public Utilities, Chapter 80.80 Greenhouse Gases Emissions, Section 80.80.005 Findings – Intent) states: “The legislature finds that: (a) Washington is especially vulnerable to climate change because of the state's dependence on snow pack for summer stream flows and because the expected rise in sea levels threatens our coastal communities. Extreme weather, a warming Pacific Northwest, reduced snow pack, and sea level rise are four major ways that climate change is disrupting Washington's economy, environment, and communities”.

Since 1987, the Intergovernmental Panel on Climate Change (IPCC) has been the global entity collecting and disseminating information on climate change scenarios, models, and mitigation and adaptation strategies. The IPCC is an international organization that amasses and disseminates credible and peer reviewed climate change research, outputs of various climate models, and strategies for both mitigation and adaptation. In the IPCC's 2007 Fourth Assessment Report (Adger 2007), Working Group II finds that adaptation to climate change is occurring, though on a limited basis; adaptation actions are rarely taken solely in response to projected climate changes; adaptation need not require large financial expenditures, though cost benefits have not been thoroughly examined; adaptation potential is unevenly distributed across societies; and there are barriers to making authoritative adaptation decisions.

The majority of adaptation planning in the Pacific Northwest has focused on high profile resources such as Puget Sound, Seattle/King County, and Portland with the

support of major stakeholders and technical expertise provided by academic/scientific organizations like the Climate Impacts Group at the University of Washington (Palmer et al. 2002; CIG 2005). Due to the high cost of developing stand alone climate action plans and the eminent need for adaptation based on observational and projected climate changes, it is important that procedures are developed for incorporating climate change planning into existing watershed planning efforts under the Watershed Planning Program (Whitely Binder 2006). The development of climate action plans need not involve the creation of new level of bureaucratic authority, fortunately many of the measures required for implementing an adaptation process capable of preparing Western Washington ecosystems and communities for the impacts of climate change are consistent with general precautionary planning in terms of the development near critical areas, construction and manipulation of floodplain areas, agricultural runoff, shoreline development, endangered species protection, etc. When even the most modestly projected climate changes predicted for our region are applied the complications related to these sectors will likely be exacerbated.

CHAPTER 2.0 SCIENTIFIC BASIS: PROXY DATA, OBSERVATIONAL EVIDENCE AND CLIMATE MODELS

There is general agreement amongst scientists that the principal driver of climate change on the Earth since its formation is differing amounts of insolation, short wave solar radiation, caused by cyclical variations of the Earth's orbit around the sun (Short et al. 1991). This is otherwise known as orbital forcing or Milankovitch cycles for the Serbian mathematician whose calculations helped to solidify the theory. These variations include: Eccentricity, the fluctuation of the Earth's orbit about the sun from more

elliptical to a more circular pattern (100k&400k year cycles), Obliquity, changes in the Earth's axial tilt (41k year cycle), and the Precession of the Seasons, the cyclical movement of the seasons relative to the earth's orbit (22k year cycle) (Short et al. 1991). The cycle of glaciations on the earth as revealed through paleoclimatology studies has shown a strong 100k year cycle for the past 400k plus years suggesting a predominate effect of eccentricity for these time periods (EPICA 2004). These variations in orbit result in increases and decreases in the amount of solar input received by the Earth (EPICA 2004)). Understanding just how these Milankovitch cycles effect the climate and feedback systems of the Earth remains the driving question for paleoclimatology (Petit 1999).

2.1 PALEOCLIMATE PROXY DATA

Since Louis Agassiz put forth his theory on the history of Earth's glacial advance and retreat in the mid 1800's, paleoclimatologists have been occupying themselves with the study of past global climates to analyze the fluctuations in atmospheric conditions that give way to the rise and fall of species, civilizations, and ice ages. Recently the focus in paleoclimatology has shifted towards comparing various natural indicators of past climate change, or "climate proxy data" (EPICA 2004; Pollack 2004; Cole 2005). The chronologies derived from these data sources aid researchers in understanding current climate changes (global warming) and the relative effects of anthropogenic forcing (greenhouse gas emissions) on the only superficially understood gaseous and temperature cycling of the planet (Petit 1999; EPICA 2004; Pollack 2004; Cole 2005).

Beyond the available direct instrumental data (climate records regionally limited in the last 150-300 yrs), the data sources in conducting paleoclimatology research generally

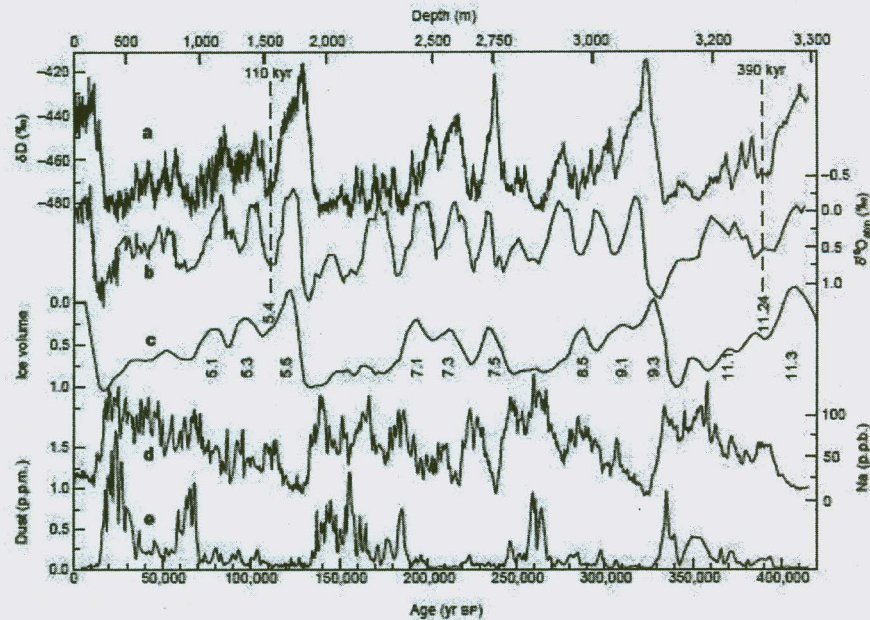
involve correlating known climatic events (volcanoes, drought, etc.) with data obtained from substrates that produce stratified layers originating through geologic, biologic, and/or atmospheric activity (Petit 1999; EPICA 2004; Pollack 2004; Cole 2005). The majority of these data fall into a category known in the research as proxy data. Proxy data are those data that have shown strong correlation with climate phenomenon and are, thus, thought to be indirect measures of climate change (e.g. tree rings, isotopes, etc.) (Jones 2004).

One of the major difficulties in utilizing proxy data is that they require calibration with the climatic parameter to establish the relative strength or quality of the climate signal within the proxy (Harris 2001) (Pollack 2004). This calibration is a result of spatial and/or temporal linear regression methods in comparison with other proxy data or known events (dated volcanic eruptions, modern instrumental climate data, or other predetermined proxy data) (Jones 2004). Other problems occur in proxy climate reconstructions in that the available methods can tend to simplify the proxy's relationship with climatic events and that proxies have varying temporal resolution (Pollack 2004).

Higher resolution proxy data are those data capable of expressing seasonal or annual variability within the climate signal of the proxy (Jones 2004). High resolution proxy data have been obtained from historical documents (human recorded climatic events), tree rings, corals, high accumulation or annually resolved ice cores, ocean and lake sediment cores, speleothems (cave formations: stalagmites, stalactites, and other forms that may be annually banded or contain compounds which can be radiometrically dated), and isotopes from mollusks (^{18}O as CaCO_3) (Jones 2004). An isotope is a variation in the number of neutrons (a particle composed of a proton and electron)

contained within the nucleus of an atom such that its atomic number remains the same but the mass number of the atom is varied. Paleoclimatologists utilize both stable and unstable isotopes as proxy data (Petit 1999; Jones 2004; Pollack 2004; Cole 2005). The isotopes studied in high resolution data are generally stable isotopes, as compared with the unstable isotopes used in radiometric dating (Jones 2004).

Lower resolution proxy data are those capable of providing general climatic trends over decadal, centennial, or more often greater periods of time due to nonspecific radiometric isotope dating or assumptions placed on stratigraphy rates (Jones 2004). With low resolution data it is not possible to discern linear temporal relationship between depositional layers, and the climate signal is often too weak to be correlated with known or measured climate shifts (Jones 2004). Radiometric dating often represents the best approximation available for determining an age reference for low resolution climate proxy data (Jones 2004). This method of dating relies on the decay rate of unstable isotopes, this occurs at constant, measurable rates called half-lives that can be used as dating references (Jones 2004). However, these unstable isotopes are generally unsuitable for studying climate under practical timescales, and their temporal accuracy may vary by a century or more (Jones 2004). Examples of low resolution climate data include most sediment cores, low accumulation ice cores (predominately temperate alpine glaciers), preserved pollen records, and macro-plant fossils within animal remains (eg. packrat middens) (Roucoux et al. 2001; Jones 2004; Pollack 2004; Cole 2005).



Selected Vostok Proxy Data vs Depth (top) and Time (bottom) in Years Before Present (bottom) (Petit 1999)

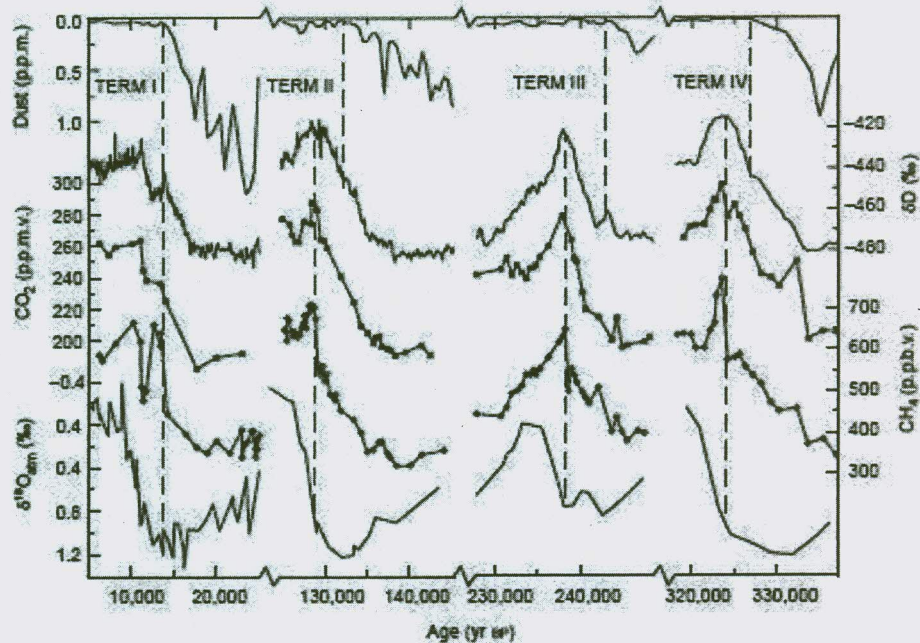
The data represented indicates 100k-year periodic peaks and valleys in temperature and dust abundance; yet another piece of data that suggests the influence of eccentricity, obliquity, and the precession of seasons have a direct influence on climate change as predicted by Milankovitch. As previously mentioned the cycle of glaciations on the earth as revealed through paleoclimatology studies has shown a strong 100k year cycle for the past 400k plus years suggesting a predominate effect of eccentricity for these time periods (EPICA 2004).

One of the important properties that make ice core data particularly interesting in determining the forcing and feedback mechanisms of Earth's atmosphere is achieved through the analysis of air bubbles locked within the ice (Petit 1999). It is commonly held that these air bubbles are representative of paleo-atmospheric gas concentrations (Petit 1999). Among the atmospheric gases well studied in the ice core air bubbles are

the concentrations of the “greenhouse gases” (primarily CO₂ and CH₄). Greenhouse gases are interesting in light of the correlation of their concentration timelines and those of temperature proxies (Petit 1999). Simple empirical explanations of the tandem changes in temperature and atmospheric composition are problematic due to uncertainty in the gas age-ice age difference (Caillon 2003). “The temporal relation between these two quantities is difficult to discern because air is trapped in ice at the base of the porous ice-precipitation interface layer, where, at low accumulation sites such as Vostok, ice may be 6000 years old” (Caillon 2003). Caillon et al. 2003 have suggested using an isotope of argon (⁴⁰Ar) as a gaseous temperature proxy to better correlate gas deposition (air bubble formation) with standard temperature proxy measurements (based on ice composition), though the relationship between ⁴⁰Ar and temperature is not fully understood. Their data suggest that atmospheric CO₂ increases lagged behind Antarctic post glacial warming by 800(+/- 200) years. Despite the work of Caillon et al. and others, the temperature/CO₂-CH₄ relationship remains somewhat of a “chicken or the egg” paradox. Data from the Antarctic ice core research can be added to modern measured gas concentrations to exhibit that CO₂ levels in our atmosphere today are the highest in the past several hundred thousand years or more (Petit 1999).

Greenhouse gas	Percent change 1750-2005	2005 atmospheric concentration	Historical perspective on current concentration	Major sources, human and natural
Carbon dioxide	+35 %	379 ppm	Higher than any in the past 650,000 years	Fossil fuel use, deforestation and land use changes, agriculture, cement production, decomposition of organic matter, oxidation of organic carbon in soils, oceans
Methane	+142%	1,774 ppb	Higher than any in at least 650,000 years	Agriculture, fossil fuel use, ruminants (e.g., cows) and manure management, landfills, wetlands, decomposition of organic matter
Nitrous oxide	+18%	319 ppb	Appears to be higher than any in the past 650,000 years	Agriculture, fossil fuel use, animal manure management, sewage treatment, nitric acid production, variety of biological sources in soil and water

Changes in GHG Concentrations (Snover 2007)



Vostok Antarctica Ice Core Data Surrounding the Past Four Glacial Terminations in Years Before Present (Petit 1999)

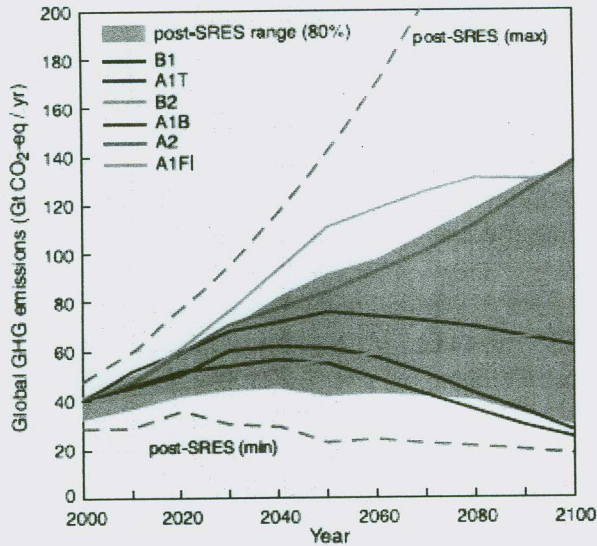
The graphical representation above depicts very similar climate responses for each glacial termination based on the Vostok data and correlates well with the orbital forcing theory (approximate 100k year frequency in the last 500k years). The graph shows that the terminations of the last four glacial periods (approximately 100k apart) proceed in a similar pattern of initial rapid warming followed by sharp peaks in greenhouse gas concentrations that are thought to provide important climate feedbacks that increase and sustain the warming trends. Petit et. al, 1999 have indicated that during each glacial termination there exists an approximate 2,000 year lag between the decrease of ¹⁸O composition in seawater and the following ¹⁸O increase in the atmosphere suggesting large ice-volume changes associated with deglaciation. The article further states that a

lag time exists between the deglaciation of the Southern Hemisphere (Antarctica data) and the Northern Hemisphere warming of approximately 4-6k years in the case of terminations I and III (first and third glacial periods back from present time), and approximately 9k years in the case of terminations II and IV (Petit 1999). Orbital forcing (increased insolation) followed by increases in greenhouse gases and subsequent ice-albedo feedback (ice melting and greenhouse effect) is the general pattern put forth by the Vostok data for the past four terminations, with deep ocean circulation and sea ice extent in the Southern Ocean playing a role in ocean CO₂ ventilation (Petit 1999).

2.2 CLIMATE MODEL PROJECTIONS

Climate models are computer derived representations of the Earth's climate system that are created by substituting mathematical equations as approximations for the chemical and physical processes of the atmosphere, ocean, cryosphere and land surface. General Circulation Models (GCM) are climate models that are used by scientists to study past climates and to make predictions about future changes in the Earth's climate system (Zhang 2005; IPCC 2007; Randall et al. 2007). In recognition of the strong and unpredictable influence of anthropogenic contribution to greenhouse gases in the atmosphere, when running the models, different scenarios of human development (CO₂ emissions, availability of technology etc.) are included in the inputs such that when analyzing the application of climate model outputs the research should be aware of both the climate model employed as well as the future "scenario" used to force the model. The scenarios outlined below vary in terms of homogeneity/heterogeneity of population growth, technological development, and economic disparities with implications for greenhouse gas emissions associated with each.

Scenarios for GHG emissions from 2000 to 2100 in the absence of additional climate policies



(IPCC 2007)

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) ^{a, d}		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations ^b	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

(IPCC 2007)

- *The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). (IPCC 2000)*
- *The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally*

oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. (IPCC 2000)

- *The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. (IPCC 2000)*

- *The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. (IPCC 2000)*

Scientists use Atmosphere GCMs (AGCM) to simulate atmospheric and land surface climate interactions and Ocean GCM (OGCM) to simulate the oceanic contribution to climate. In some models the outputs of these simulations are combined or coupled using “flux measurements” usually involving surface heat, water and momentum in order to obtain a stable base climate (Randall et al. 2007). Coupled models are called Atmosphere Ocean GCM or AOGCM. Models using flux measurements have been criticized due to the artificial flux inputs necessary to obtain the coupled result (Randall et al. 2007). Though flux adjusted models are able to simulate the Earth’s climate system effectively, many models used in the IPCC’s Fourth Annual Report no longer rely on flux measurements which further increases the confidence in the outputs of these models (Randall et al. 2007). Other approximations used in AOGCM in parameterizations which are inputs used to simulate otherwise omitted small scale or complex local influences on climate variability (Randall et al. 2007).

Many of the AOGCM in the current generation of climate models are highly

complex and better able to make climate predictions on a regional basis but it is important to note that different climate models are better at representing different features of the climate system so selection of the appropriate model should be application based (Randall et al. 2007).

The IPCC fourth annual report was released in 2007. The report evaluates 23 different climate models and states that there is considerable confidence, especially at larger scales of resolution, in the ability of Atmosphere-Ocean General Circulation Models (AOGCM) to accurately predict future changes in the climate system (Randall et al. 2007). Climate models are evaluated based on their ability to reproduce observed and approximated past climate changes. GCM still show significant errors particularly as models are applied at smaller “more resolved” scales (IPCC 2007). Particular deficiencies are related to:

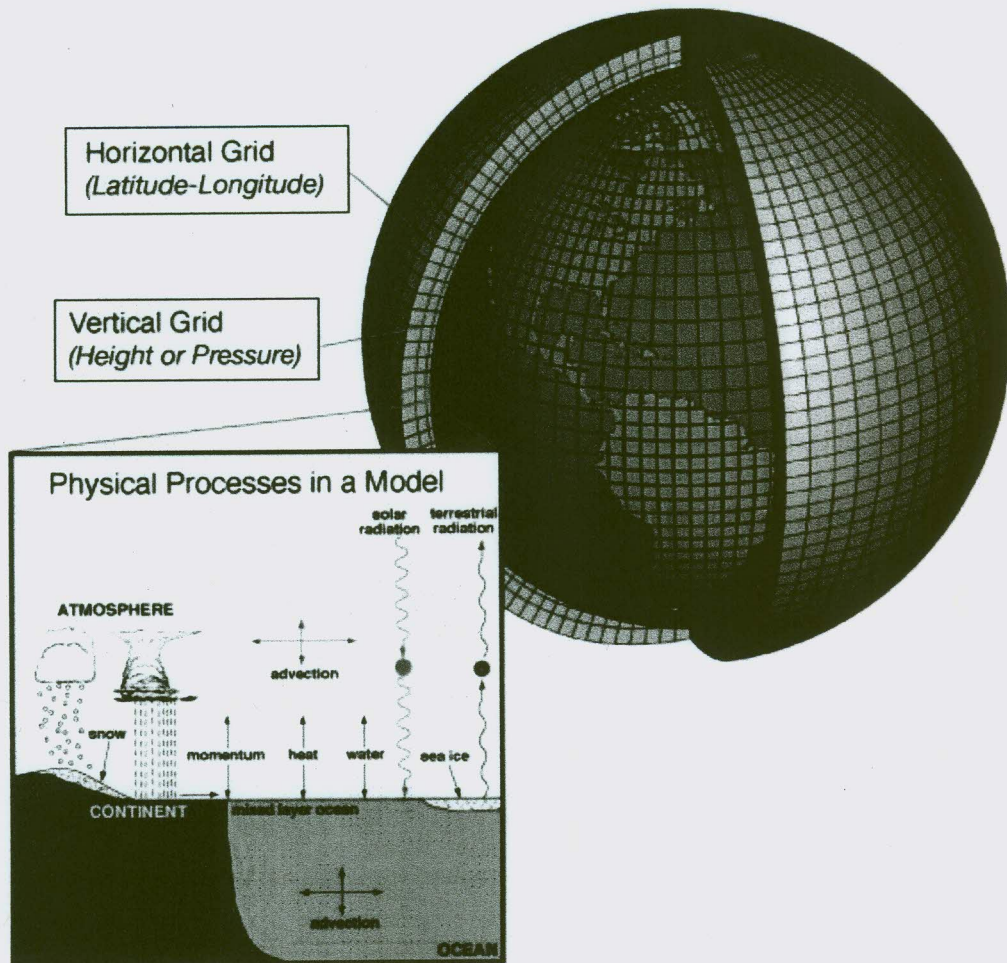
- The simulation of large scale climate cycles such as the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and others
- Local or regional mesoscale and micro-climate zones related to topography, water bodies and other surface features
- Model representation of clouds, and in the resulting cloud responses to climate change

The source of these uncertainties has its roots in limitations in computing power required to run climate model simulations and a lack of scientific understanding or sufficient observations of certain aspects of the global and regional climate systems (IPCC 2007). Due to the uncertainties in the various components of the climate system, different GCM outputs project different levels of climate change under future

anthropogenic forcing scenarios depending on the amount and accuracy of the inputs to the models (IPCC 2007). Models are unanimous in their prediction of warming as a result of increased greenhouse gas emissions, which also corresponds to observed trends in temperature and greenhouse gas increases.

To supplement small scale resolution weaknesses in the current generation of climate models scientists have employed other techniques including regional climate models, or downscaling methods to study climate projections and impacts at regional and local scales (Christensen 2007; IPCC 2007). As computing power and understanding of climate variables continues to improve future generations of GCM will likely become more and more accurate. Many models now include plant responses, ocean biological and chemical interactions, and ice sheet dynamics (IPCC 2007). These uncertainties should not however be used as an excuse for inaction (Markoff et al. 2008). Due to the magnitude of the threat, if regional adaptation strategies are to be effective decision making will need to move forward in spite of inherent uncertainties in climate predictions (Markoff et al. 2008). Uncertainties in modeling of climate are typically dealt with by using a range of various climate models and presenting projected future climate changes as a range of values based on the various models and development scenarios selected for the analysis (Christensen 2007).

GCMs function by dividing the ocean and atmosphere into horizontal grids (cells) comprised of varying numbers of vertical layers, and assessing the climate system on a cell by cell basis while incorporating exchanges between neighboring cells (Randall et al. 2007). Therefore the resolution of climate models is limited, which is one of the complicating factors in identifying specific climate impacts on a local basis.



Atmospheric Model Schematic (NOAA 2008)

The global AOGCMs with the finest resolution are several degrees of latitude and longitude per cell and include varying numbers of layers of atmosphere and ocean (Randall et al. 2007). Typical AOGCMs are too coarse to pick up influences of topography and other microclimate forming conditions such as the rain shadows produced on the back side of mountainous areas (Christensen 2007). In order for projections to be more locally accurate and thus more useful in adaptation planning, scientists have developed methods for downscaling or resolving regionally and locally

important climate altering features (Christensen 2007). There are two main approaches to downscaling GCM information discussed in the IPCC Fourth Annual Report released in 2007: Dynamical and Statistical Downscaling (Christensen 2007).

Dynamical downscaling employs high resolution regional climate models (RCM), bound by GCM ranges, to portray mesoscale (2-2000km (Orlanski 1975)) atmospheric phenomenon (Christensen 2007). These high resolution models are made using physical principals and their wide geographic applicability increases confidence in the technique, though the computational cost and scale limitations are obstacles to their wide use (Christensen 2007). Statistical downscaling techniques on the other hand are relatively computationally inexpensive, capable of operating at smaller scales, and are able to account for parameters that cannot be derived from RCM (Christensen 2007). The weaknesses of the statistical downscaling technique relate to an inability to handle feedback interactions between macro-scale and mesoscale climate feedbacks, they require long and comprehensive observational climate records (Christensen 2007).

One of the ways climate models are evaluated for the accuracy of their predictions is by applying them to historic conditions and comparing the model output to the observed climate record.

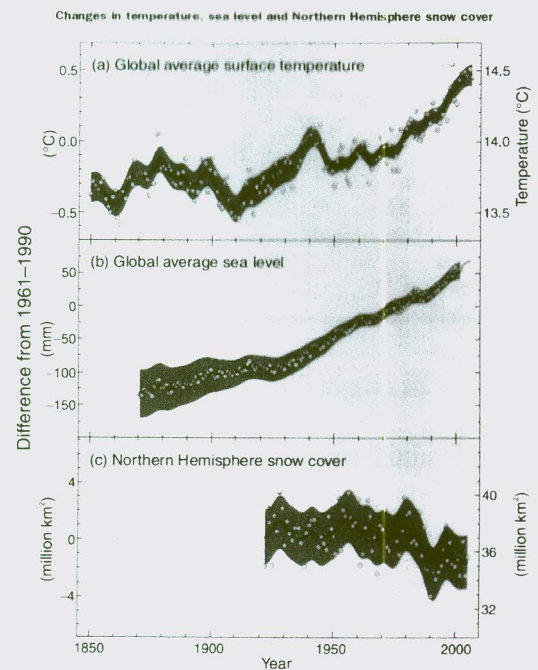
2.3 THE USE OF EMPIRICAL DATA AND CLIMATE SENSITIVITY

Observational data serve many functions in the application of traditional forms of resource management, but they also serve to ground studies of the implications of climate change. On large scales observational data provided the obvious benefit of providing measurable direct evidence that surface temperatures of land and ocean are increasing, that CO₂ levels are increasing at unprecedented rates compared with the paleoclimate

record, that sea levels are rising and that glacier and ice sheets are receding (IPCC 2007). These data are used by climate scientists to study the interplay of the major forces in the climate system in order to reinforce theoretical understanding of system processes (Randall et al. 2007).

As reported in the 2007 IPCC Fourth Annual Report on Climate Change observational data of the climate system have yielded the following (IPCC 2007).

- *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC 2007).*
- *Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increase (IPCC 2007).*
- *There is medium confidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers (IPCC 2007).*

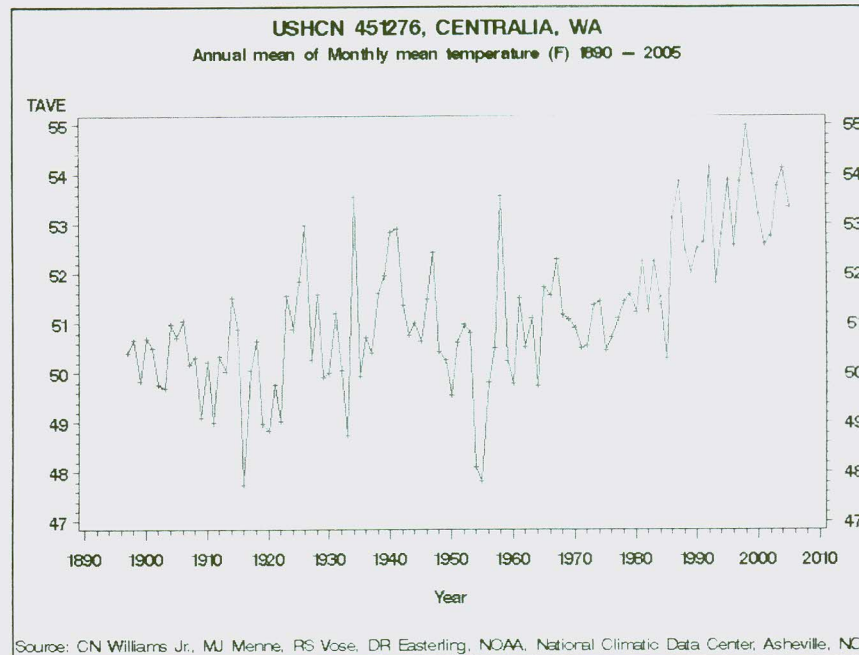


Empirical evidence from the Pacific Northwest illustrates similar trends to those seen on the global scale. In the figures below, provided by the Climate Impacts Group (University of Washington), 20th century trends in average annual precipitation and temperature (1920-2000) are depicted as increases (decreases) represented blue (red) dots for precipitation, and increases (decreases) in temperature are indicated with red (blue) dots. The size of the dot corresponds to the magnitude of change. (CIG 2005)



(CIG 2005)

The graph of mean monthly temperature data below from Centralia, Washington in the Chehalis basin depicts a similar progression of temperature increases over the 20th century and to a lesser extent precipitation, as is evident from the figures below.

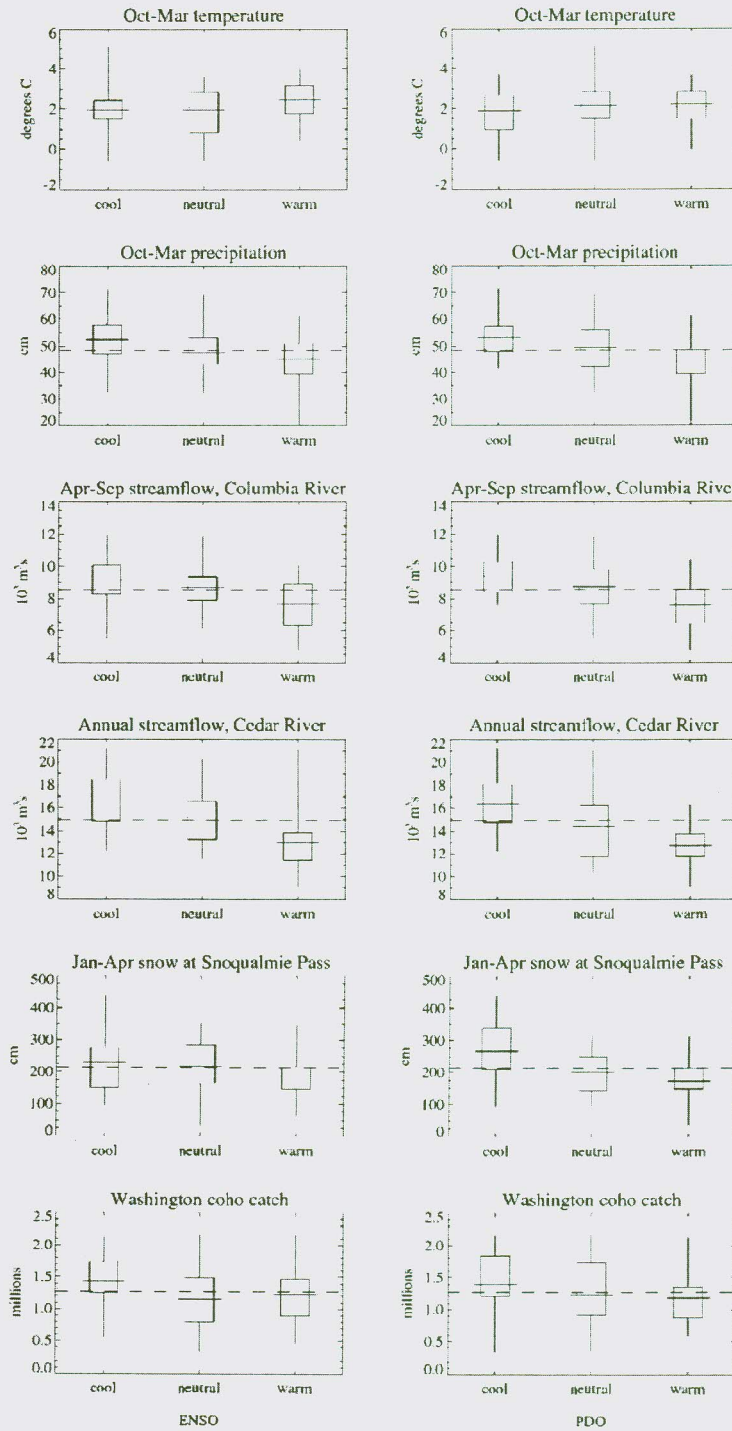


In the Pacific Northwest our weather is strongly influenced by the large scale climate phenomenon of the Pacific Decadal Oscillation (PDO) and El Niño-Southern Oscillation (ENSO). Both the PDO and ENSO represent large scale seesaw patterns of climate variability facilitated by changes in sea surface temperatures and sea pressure (Mantua 1997; Trenberth 1997). Trenberth defined ENSO quantitatively based on observations since 1950 as "...5-month running means of sea surface temperature (SST) anomalies in the Niño 3.4 region (5°N–5°S, 120°–170°W) exceed 0.4°C for 6 months or more. With this definition, El Niños (warm phase) occur 31% of the time and La Niñas (cool phase with an equivalent definition) occur 23% of the time" (Trenberth 1997). El Niños occur with a varying frequency of 3-5 years. The PDO is a similar phenomenon also marked by sea surface temperatures in the northeast and tropical Pacific Ocean and oscillating between warm or cool phases.

ENSO, PDO and other large scale climate patterns have been shown to have

impacts on air temperatures, terrestrial vegetation, herbivore and carnivore relationships, precipitation (ie stream flows) and marine biology and fish stocks (Mantua 1997; Mote 2003; Stenseth 2003) One place to begin assessing the vulnerabilities of a system to climate change is by assessing the sensitivity of past fluctuations in climate or paleoclimate to variations in system (water, species ranges, etc.) behavior (Mote 2003). The following observations were made in the Mote 2003 study of the potential impacts of climate change on the water, salmon and forest of the Pacific Northwest.

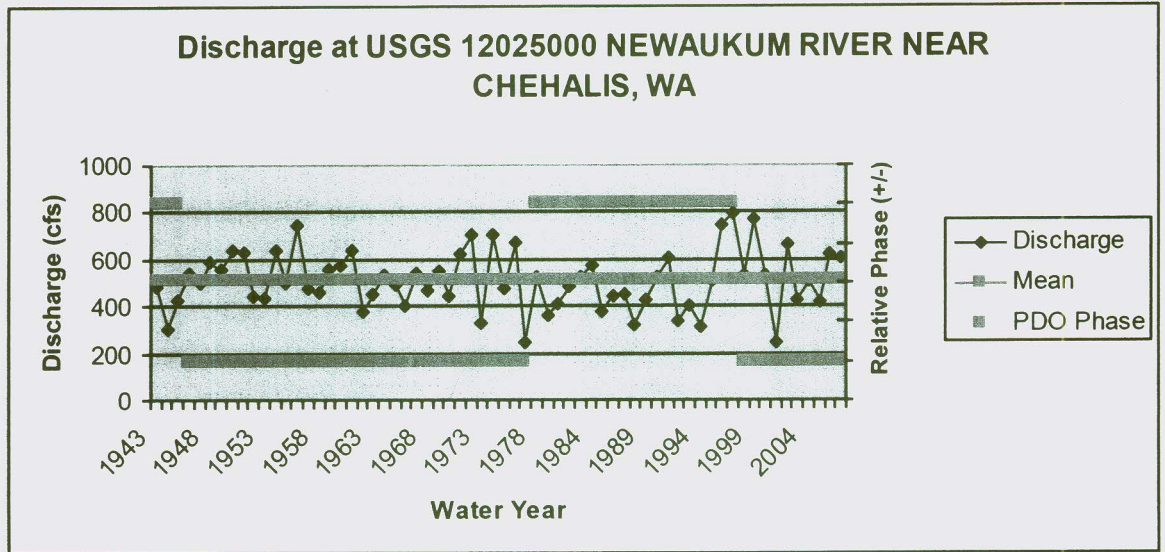
- Warm phases of ENSO and PDO tend to result warmer and drier winter and spring weather in the PNW, and cool phases tend to result in cooler wetter weather
- The difference between warm and cool phases is approximately +/-1 degree Celsius and +/-20% for precipitation.
- The multi decadal persistence of PDO phases may provide a tool for assessing system responses to projected climate changes.



(Mote 2003)

These bar and whisker plots (Mote 2003) illustrate the relationship of warm and cool ENSO and PDO phases on temperature precipitation, stream flow in the Columbia River and Cedar Rivers, January to April snow at Snoqualmie Pass, and the Washington

coho salmon catch(Mote 2003). Observing how ENSO and PDO phases impact important or sensitive resources may be a valuable tool in identifying sectors sensitive to future warming or alterations in precipitation regimes from a resource management perspective.



The graph above depicts the discharge in the Newaukum River recorded at a USGS station located near Chehalis, WA near the confluence with the Chehalis River. The orange bars represent the dominate PDO phase for years since 1943 (Mantua 1997; Mote 2003). Positive (or warm) phases are shown above the mean discharge for all years (pink) and negative (or cool) phases are shown below the mean discharge line. The Newaukum River discharge volume appears to be sensitive to warm phases (positive) of PDO with above average discharge from 1945 to 1977 and lower than average discharge recorded for the period from 1977 to 1998. Long-term trends in climate and stream flow in the Chehalis Basin closely correspond to trends across the Pacific Northwest. (Envirovision Corporation 2000; CBP et al. 2004).

Observed/Empirical Data Uses in Climate Impact Studies

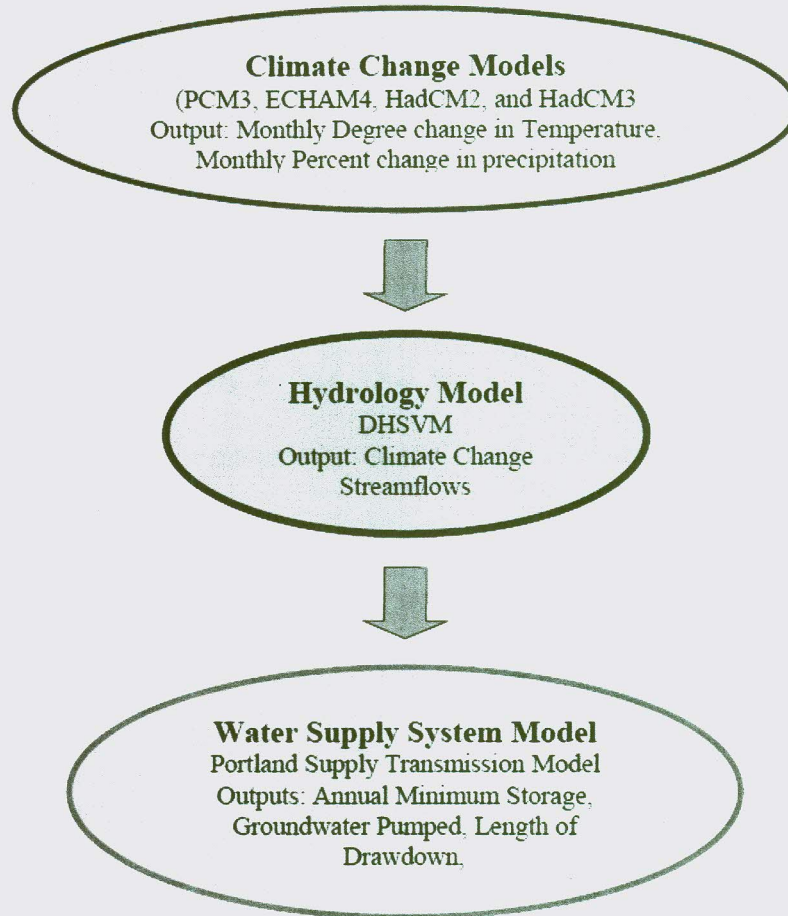
- Basis for traditional resource management (i.e. the future will resemble the past)
- Allow scientists to test the accuracy of climate models by applying the models to previously observed climate/forcing conditions
- Provide a means of assessing the historic and possibly the future vulnerability of key sectors in a planning area to variations in temperature, precipitation, and extreme events
- Provide a sense of the adaptability of planning area sectors to projected conditions

In the following sections, examples of vulnerability assessments will show how scientists have combined downscaled GCM outputs with observations and resource management models into a series of successive models to perform assessments with implications regarding resource management.

2.4 PUTTING THE TOOLS TOGETHER: CLIMATE VULNERABILITY ASSESSMENTS

In a study commissioned by the Portland Water Bureau (Oregon) on water resources under the influence of projected climate change, the Climate Impacts Group found average increases in demand related to climate change by 2040 would approximate 50% of the total increase expected from population growth alone in that same period (Palmer et al. 2002). The study of the Bull Run Watershed for the Portland Water Bureau was conducted using a series of linked models simulating the climate system, hydrologic processes and water supply management (Palmer et al. 2002). The output from the climate models are used in conjunction with recorded weather data to aid in the simulation of natural climate variability (Palmer et al. 2002). This altered climate data was then used as input for the hydrologic model to simulate stream flows under projected climate scenarios, and these flows were ultimately applied to water supply system models to assess the potential vulnerability of the Bull Run watershed (Palmer et al. 2002). The

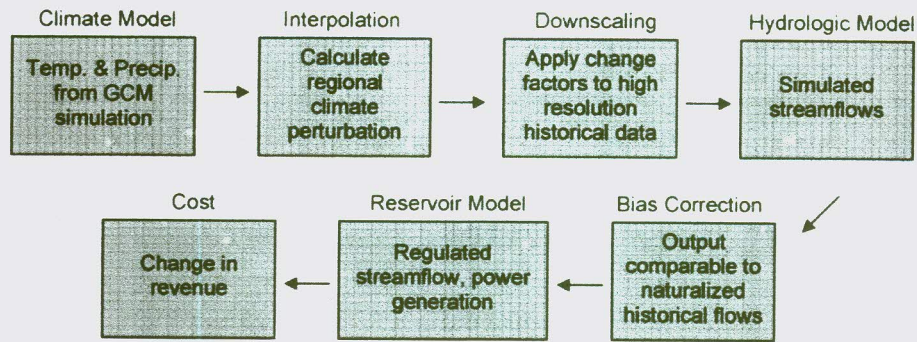
vulnerability assessment can then be used by policy makers to create more sustainable management strategies. The following figure illustrates the linked model approach used in this study, similar to other climate vulnerability studies discussed in this report.



(Palmer et al. 2002)

Unlike many areas of the county, power consumption in the Pacific Northwest is historically at its highest in winter due to heating and lighting during the shortened days. There is a possibility that demand under the projected temperature increases in the Pacific Northwest will alter this trend towards generally decreased power demand in the winter and increased demand in the summer (Casola et al. 2005; NWPCC et al. 2005). In a study produced by Markoff and Cullen on the impacts of climate change on Pacific

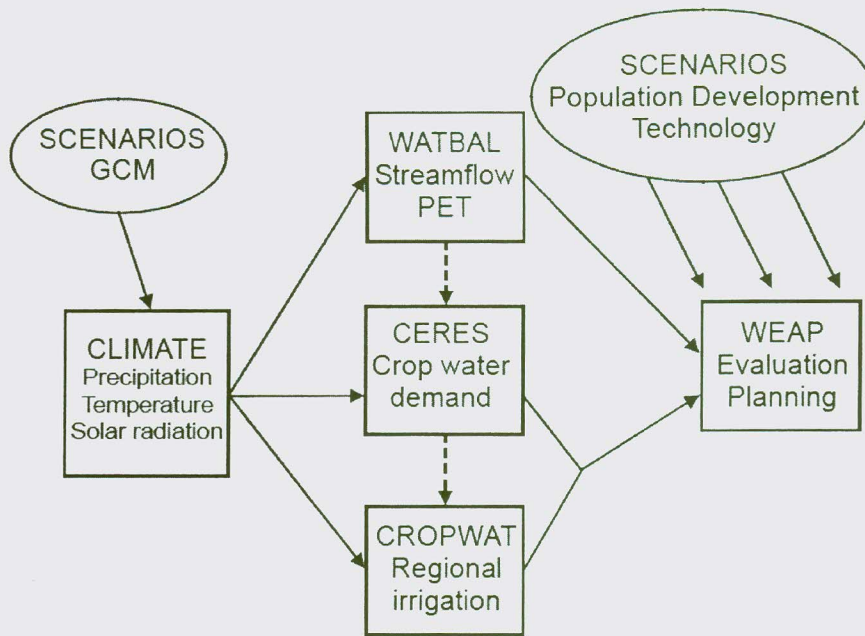
Northwest hydropower production the methodology is similar to that of the Portland Study. The study points out deficiencies in the Northwest Power and Conservation Council's (NWPCC) treatment of climate change impacts in the organization's Fifth Northwest Electric Power and Conservation Plan (2005). Though the NWPCC does explore potential climate change impacts in a section of the report, the report does not incorporate climate change data into the power projections (NWPCC et al. 2005; Markoff et al. 2008). Using a series of models and analytical methods chained end to end, Markoff and Cullen are able to demonstrate that power production prognosis in the Columbia River Basin may be more negatively impacted by climate change complications than realized in the NWPCC document. To assess regional scale climate projections this study utilizes temperature and precipitation changes from the outputs of widely employed GCMs and then interpolates the gridded global predictions to regional level. The climate variations are then applied to high resolution measured meteorological data for the Columbia River Basin to produce a detailed time series that captures local variability which can then serve as the input for a macro-scale hydrologic model of the basin to simulate stream flows. These modeled stream flows are then applied to a reservoir operations model that allows for speculation of future power efficiency and potential revenue fluctuations as a result of climate change impacts. The figure below illustrates the chain of actions described above.



al. 2008)

(Markoff et

Climate impacts to agricultural production within a basin have been studied in a similar fashion as those methods described above for municipal water use and hydropower generation. Depending on the region and on the crop, agricultural demand for water resources increases with increased temperature, though there have been studies that suggest crop water demand to decrease in the presence of elevated carbon dioxide (Shaw et al. 2002; Gleick et al. 2004). There are a variety of agricultural models that can be used in conjunction with climate model outputs to form a range of potential outcomes. The use of high and low ranges to encompass the maximum potential for change allows for adaptive management of resources as scenarios of climate change and land use play out (Rosenzweig et al. 2004). The following model represents one possible way of integrating various models in order to assess water demand forecasting and planning for the agricultural component of a watershed.



(Rosenzweig et al.

2004)

In this example, GCMs are used to establish ranges of monthly mean temperature, precipitation and solar radiation changes are obtained for the area of study. These are in turn used to create various scenarios of future climate conditions that can be used in the previously developed water and crop modeling techniques (Rosenzweig et al. 2004). Rather than applying these management models using climate conditions of historic averages, a range of future climate is applied. A goal of this type of modeling is to create contrasting future circumstances with and without climate change using scenarios established by the IPCC for both optimistic and pessimistic outcomes of technological and population growth (Rosenzweig et al. 2004). Climate change adaptation studies which lead to policy require an ongoing and adaptive approach to managing basin resources.

Annual and seasonal climate changes predicted for the global agriculture calls for the need to develop qualitative and quantitative guidelines for cultivars adaptation

implying changes in planting schedules, adaptation of crop genetic characteristics, maturity class, heat tolerance, duration of growth stages, photoperiod sensitivity, vulnerability to pests, and sensitivities to pesticides (Rosenzweig et al. 2004).

In a future wrought with climate changes such as those projected for the Pacific Northwest, the range and distribution of many species of plants and animals may be altered. As previously stated, salmon have shown a strong response to long term variations in temperature and precipitation regimes brought about by climate patterns such as the PDO (Mote 2003). The ability of a species to migrate may largely be determined by the individual characteristics of the species as well as the geographic area including natural and man-made obstructions (Pearson 2003). In relating the impact of climate on species, early ecological studies have focused on local weather patterns, thus omitting the holistic nature of the climate system (Stenseth 2003). There is a recognized need for interdisciplinary studies in solving the ways in which large scale climate fluctuation shape species population dynamics (Stenseth 2003). One way of examining the impact of climate changes on species presented in the literature are through the use of Bioclimate envelope models (Pearson 2003). Bioclimate models rely heavily on mapping of potential species ranges based on climate tolerances, and have proven useful in predicting species ranges on large spatial scales where climate variations appear to be the prevailing influence (Pearson 2003). While climate appears to drive species ranges at large scales, smaller scale range variations are likely more influenced by species interactions, land use, and topography (Pearson 2003).

The studies above represent pieces of what may be accomplished in a watershed level climate impact study. Municipal water use, reservoir operations, agriculture and

rural water use, and in-stream flows for aquatic species are all inseparably intertwined therefore individual studies such as those presented could be combined within the scope of watershed planning and characterization to facilitate informed decisions on water resource management on this level.

CHAPTER 3.0 PNW CLIMATE ACTION ORGANIZATIONS AND PLANS

In 2007 as a result of Washington Governor Christine Gregoire's Executive Order 07-02 and Engrossed Senate Bill 6001 RCW Title 80 was amended and consequently became the first greenhouse gas mitigation law for Washington State. RCW 80.80.005(Title 80 Public Utilities, Chapter 80.80 Greenhouse Gases Emissions, Section 80.80.005 Findings – Intent) states: "The legislature finds that: (a) Washington is especially vulnerable to climate change because of the state's dependence on snow pack for summer stream flows and because the expected rise in sea levels threatens our coastal communities. Extreme weather, a warming Pacific Northwest, reduced snow pack, and sea level rise are four major ways that climate change is disrupting Washington's economy, environment, and communities".

In the Pacific Northwest there has been abundant legislative action related to climate change mitigation, but adaptation has been left almost entirely in the hands of local, county, and multi-jurisdictional partnerships. At the regional level, groups and agreements such as the Western Climate Initiative and the Climate Registry operate with a mitigation focus, working mainly to develop greenhouse gas inventories and greenhouse gas emission standards. On the State and local level in Washington, legislation has dealt mainly with mitigation but has also acknowledged the need for

adaptation.

In recent years in the Pacific Northwest there has been a lot of legislative action related to climate change mitigation and adaptation policy. At the regional level, groups and agreements such as the Western Climate Initiative and the Climate Registry operate with a mitigation focus, working mainly to develop greenhouse gas inventories and greenhouse gas emission standards. On the State and local level in Washington, legislation has dealt mainly with mitigation but has also acknowledged the need for adaptation.

3.1 PUGET SOUND PARTNERSHIP (PSP)

The Puget Sound Partnership is responsible for developing policies and coordinating various state agencies in the protection and restoration of the Puget Sound by a target date in the year 2020. Climate change, as an important component of Puget Sound restoration/policy, has only very recently been observed in the plan/strategy documentation of the restoration effort. Most of the previous work has been related to the Clear Air Act (vehicle and industrial emissions, etc).

The Puget Sound Partnership assumed control of the restoration effort from the Puget Sound Action Team in July 2007. The immediate tasks of the Partnership are to implement the 2007-2009 Puget Sound Conservation and Recovery Plan, and develop the 2020 Action Agenda for Puget Sound. 2020 Action Agenda will be released in September 2008 and will operate under following objectives: protect habitat, restore habitat, reduce toxic pollution, reduce human/animal waste, better manage stormwater, assure adequate water supply for people and wildlife, preserve biodiversity and recover imperiled species (including salmon), and build and sustain the capacity for action.

In Washington State the Puget Sound Partnership (PSP, under various names and forms historically i.e. Water Quality Authority, Action Team/Council, etc) is responsible for developing policies and coordinating various state agencies in the protection and restoration of the Puget Sound by a target date in the year 2020.

In 2005, the Puget Sound Action Team commissioned a report from the University of Washington's Climate Impacts Group (CIG) titled "Uncertain Future: Climate Change and its Effects on Puget Sound". The report details specific climate model outputs for the Puget Sound region including temperature and precipitation forecasts, and the implications for the region in terms of loss of snow pack, flooding, water quality and ecosystem alterations. Prior to the release of the CIG report, climate change and its implications were not addressed in the 2005-2007 Puget Sound Conservation and Recovery Plan, a plan revised on a biannual basis by the former Puget Sound Action Team. (PSAT 2007).

According to the report the average of climate model outlooks for the Puget Sound region call for a 0.34°C (0.6°F)/decade warming rate for the Pacific Northwest between 1990 and 2040s. There is less certainty when climate models are used to predict variations in precipitation largely due to the quantity of unaccounted for local and regional influences on precipitation trends; however most of the model outputs observed by the CIG suggest a 0-20% increase in winter precipitation. Summer precipitation forecasts tend to be negative. A human influence in precipitation trends has yet to be observed. Precipitation is suspected to be less directly impacted by human influence, or the impacts of anthropogenic climate forcing on precipitation may lag those impacts on temperature(CIG 2005). Snow pack is measured in terms of snow water equivalent

(SWE), which is the amount of water contained in the snow pack (if melted). SWE measurements in the Pacific Northwest since 1916 have shown declines particularly at lower elevations. This has been attributed to temperature and precipitation changes (CIG 2005).

The CIG foundation report forecasts the observed warming trend to continue with possible increases in precipitation leading to variations in precipitation type (more precipitation falling as rain particularly at lower elevations), increased winter stream flows, decreased summer stream flows, earlier snow melt, variations in salinity, and various other hydrology changes to the Puget Sound basin(CIG 2005). Further, “such stresses, coupled with ongoing habitat losses, could effect unprecedented changes in the population dynamics and geographic distributions of species and communities” (Halpin 1997).

There is an important warning in the CIG report that solidifies the need to integrate adaptation strategies to climate change into all facets of Puget Sound restoration; “...note that because of lags in the climate system (for instance, ocean uptake of heat), if concentrations of greenhouse gases in the atmosphere were stabilized, warming would still continue for decades. Sea level rise would continue for centuries as the warming ocean continued to expand” (CIG 2005).

Climate change, as an important component of Puget Sound restoration/policy, has only very recently been observed in the plan/strategy documentation of the restoration effort. The 2007-2009 Puget Sound Conservation and Recovery Plan adopts preparing for and adapting Puget Sound efforts to a changing climate as its eighth priority (of eight) for Puget Sound recovery. The plan includes broad strategies to prepare and adapt

restoration efforts in the Sound to a changing climate, and then details specific results expected.

The Puget Sound Conservation and Recovery Plan 2007-2009 speaks strongly about the need to integrate climate change concerns into all facets of the Puget Sound restoration effort. The robust plan seems to fall short on funding by allocating only \$124,000 of the \$352,794,611 budget towards its stated climate change preparedness goals.

The plan establishes the following strategies to “prepare and adapt” all other efforts undertaken by the PSP.

- “Support, track and report on science related to the effects of climate change on the Puget Sound ecosystem” (PSAT 2007).
- “Provide risk-assessment models to help identify vulnerabilities to existing infrastructure and work with affected entities to prepare for or respond to potential impacts” (PSAT 2007).
- “Review state, federal and local activities and expenditures on conservation and recovery in the Puget Sound basin in light of climate change impacts, and make specific recommendations for changes, if necessary” (PSAT 2007).
- “Make specific recommendations on management and planning adaptations in response to climate change for all levels of government in Puget Sound.” (PSAT 2007)

Expected results following the implementation of these strategies are also documented in the current recovery plan, and include the entity responsible for producing the result in parenthesis (). The expected results are as follows, taken directly from the 2007-2009 Conservation and Recovery Plan (PSAT 2007):

- Support, track and report on science related to the effects of climate change on the Puget Sound ecosystem.
- 2 reports are provided annually on the most recent scientific studies relating to climate change and its impact on marine systems. (Partnership)

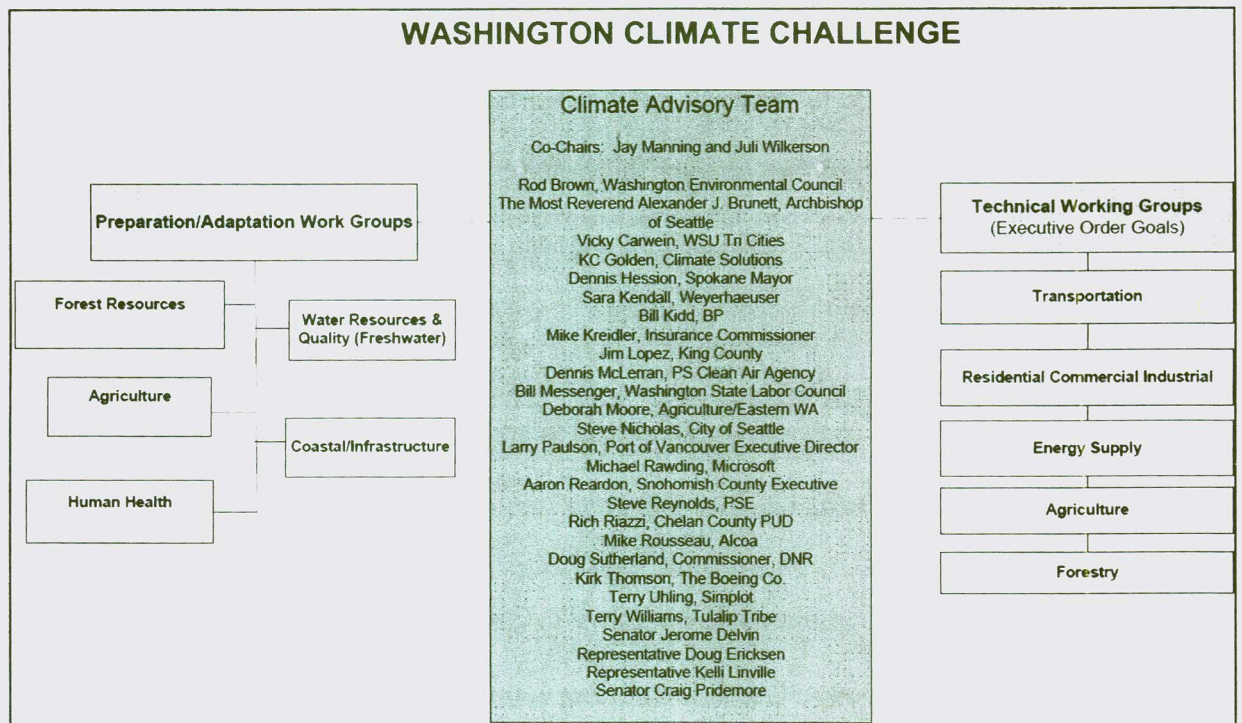
- A workshop is held for regional scientists and resource managers to exchange research findings on the implications of climate change to the Puget Sound region. (Partnership)
- Provide risk-assessment models to help identify vulnerabilities to existing infrastructure and work with affected agencies to prepare for or respond to impacts.
- A risk-assessment model applicable to Puget Sound is provided to state, local and tribal government agencies. (Partnership)
- Key individuals in federal, state, local and tribal agencies identify how a risk assessment model meets their needs and 20 percent apply the model to drafting risk-assessment plans for their areas of responsibility. (Partnership)
- Review state, federal and local activities and expenditures on conservation and recovery in the Puget Sound basin in light of climate change impacts, and make recommendations for changes, if necessary.
- A report is produced to address the most recent research relating to implications to conservation and recovery activities, with recommendations for changes to these activities. (Partnership)
- Regional leaders working on conservation and recovery projects incorporate the recommendations on possible climate change impacts into conservation and recovery plans. (Partnership)
- Make recommendations on management and planning adaptations in response to climate change for all levels of government in Puget Sound.
- A strategy for state agencies is developed to examine how resource management policies would perform in the future if various elements of climate were altered. (Partnership)
- A system to monitor and report on regional climate and ecosystems for ongoing changes is developed with an adaptive management loop to incorporate monitoring findings into management and planning decisions. (Partnership)

It remains to be seen how the 2020 Action Agenda will address climate change concerns in the action plan due for release in September 2008, but the hope for successful restoration of the Sound by 2020 may depend on it.

3.2 CLIMATE ADVISORY TEAM (CAT)

Governor Christine Gregoire's Executive Order 07-02 (Washington Climate Challenge) called upon the Department of Ecology and the Department of Community

Trade and Economic Development (CTED) to jointly form the Climate Advisory Team (CAT) to address mitigation and adaptation strategies in Washington State. The CAT is composed of stakeholders from various public and private sectors with an interest in climate change policy (see organizational detail below). The stated goals are generally related to emissions reductions, clean energy inputs, and coordinating with local governments to maximize local and state climate initiatives. Notably absent is any mention of implementing the Puget Sound Partnership's policies in regard to climate change adaptation policy.



- **Technical Working Groups (TWGs)**

- Agriculture - biofuels, waste reduction, recycling and energy recovery, solid waste management
- Energy Supply - heat and power generation, electrical generation, transmission
- Forestry - forest restoration, sustainable forest management, wood energy and sequestration

- Residential, Commercial & Industrial - energy efficiency and conservation, industrial process, "customer side" of the meter
- Transportation - including vehicle efficiency, alternative fuels and demand reduction programs

- **Preparation/Adaptation Working Groups (PAWGs)**

- A set of fundamental issues/vulnerabilities for further examination
- Specific adaptation approaches and expectations for these issues/vulnerabilities:
- Draft a report of suggested recommendations that identifies opportunity areas and additional preparation/adaptation strategies WA can pursue as well as critical research needs and approaches for filling information gaps
- Participate in a cross-sector dialog to identify additional strategies that are broad and cross-cutting
- PAWG recommendations will focus on strategies that can most effectively and immediately move the state (at all levels) forward in integrating climate impacts into future decision-making in straightforward and meaningful ways.

In the PAWG document "Preparing for the Impacts of Climate Change in Washington: Draft Recommendations", preliminary impacts and implications of Pacific Northwest resources to projected climate changes are listed (CAT 2007) below.

Water Supply and Demand

- Changes in the seasonality of water supply (e.g. reductions in summer)
- Changes in water demand (e.g. potentially increasing evaporation)
- Changes in drought stress
- Increasing conflicts between water supply and other uses and users of water

Energy Supply and Demand

- Changes in the seasonality and quantity of hydropower resources
- Changes in energy demand
- Increasing conflicts between hydropower and other uses and users of water

Instream Flow Augmentation

- Changes in low-flow risks
- Changes in the need for releases from storage to reproduce existing streamflow regime.
- Changes in water resources management related to water quality (e.g., to provide dilution flow or to control temperature)

Flood Control and Land Use Planning

- Changes in flood risks
- Changes in flood control evacuation and timing
- Changes in design standards and land use planning
- Dam safety procedures

Estuaries

- Changing flood risk in low lying areas
- Impacts to ecosystem function as a result of changes in the timing and volume of freshwater inflows (e.g., increased winter peak flows, reduced summer low flows)
- Changes in land use policy and insurance as a result of changes in flood risk (e.g., coastal armoring, land ownership, FEMA maps)

Ecosystem Function

- Impacts to fish and aquatic ecosystems related to changes in the seasonality and intensity of flows (e.g., increased winter peak flows, reduced summer low flows)
- Changes in watershed function due to large-scale vegetation changes (e.g., fire, insect damage)
- Changes in aquatic ecosystem function related to changes in water quality (e.g., changes in water temperature, sediment transport)

Long-Term Planning, Water Resources Agreements, Water Law and Policy

- Water allocation agreements in a non-stationary climate (e.g., water permitting) Preparation and Adaptation Draft Recommendations – Dec. 2007 72
- Appropriateness of the historic streamflow record as a legal definition of climate variability or water availability
- Need for new water planning and management frameworks in a non-stationary climate
- Transboundary implications (e.g., Columbia Basin, Snake River, Spokane Aquifer)

3.3 CLIMATE IMPACTS GROUP/KING COUNTY ADAPTATION MANUAL

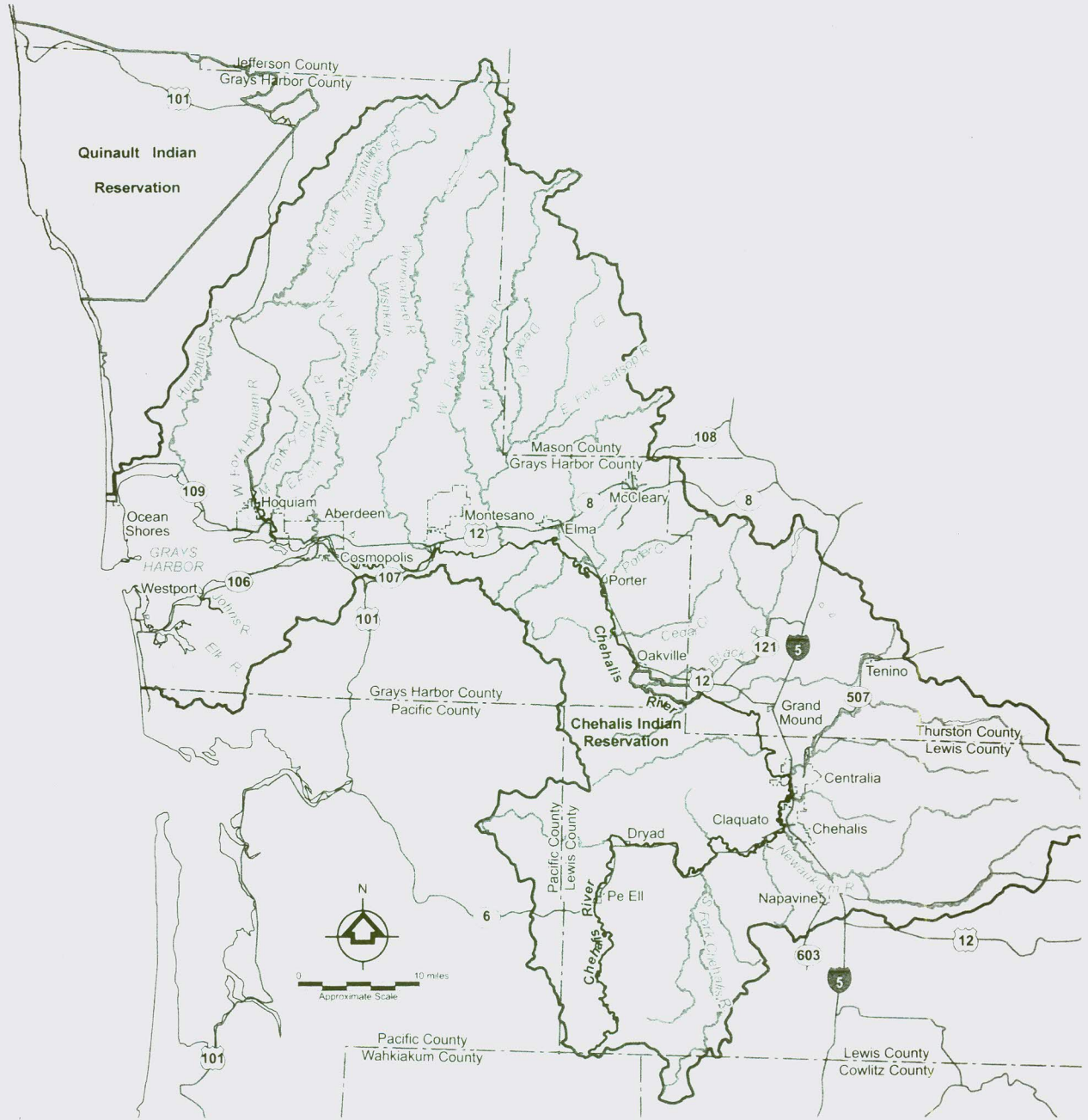
The process of adaptation recommended by the King County/CIG co-authored guidance document (Snover 2007) proceeds on a step by step basis in order as follows:

- 1) Estimate future atmospheric greenhouse gas concentrations and other climate drivers
- 2) Use climate models to project future climate at a global scale
- 3) Downscale climate model results to project future climate at a regional scale
- 4) Use regional models and observed relationships to project impacts on natural resources
- 5) Use resource management models or empirical relationships to understand implications for resource decisions

The remainder of this report will specifically focus on identifying potential

vulnerabilities in WRIAs 22 and 23 using the Chehalis Basin Partnership professional reports combined with regional temperature and precipitation projections of the CIG (Mote 2005) and sea level rise reported by the IPCC (IPCC 2007).

CHAPTER 4.0 CHEHALIS BASIN CLIMATE CHANGE SCOPING



Map of WRIs 22 and 23 (Grays Harbor County, 2008)

The Chehalis Basin, Water Resource Inventory Areas (WRIA) 22&23, drains approximately 2700 square miles making it the second largest basin in the state of Washington. The basin extends over eight counties but lies predominately in Grays

Harbor, Lewis, Thurston and Mason Counties. Uplands south and west (Willipa Hills) of Chehalis, Washington are the headwaters of the main stem of the Chehalis.

Major tributaries (headwater source) to the basin include the S. Fork Chehalis (uplands south of Chehalis), Newaukum (Cascade foothills), Skookumchuck (Cascade foothills), Scatter Creek (upland wetlands in S. Thurston Co.), Black River (wetlands near Black Lake), Wynoochee River (Southern Olympic Mountain Range), Satsop River (Southern Olympic Mountain Range). The main stem of the Chehalis River is predominately fed by precipitation events, runoff, and groundwater, though the Humptulips, Wynoochee and Satsop Rivers do receive varying amounts of melt water from the snow pack on the southern portion of the Olympic Mountain Range. Annual precipitation varies from a minimum of 40 inches in the central portions of the basin (Chehalis/Centralia), to a high of 220 inches in the headwaters of the Wynoochee and Humptulips Rivers (Olympic Mountains). The seasonal hydrograph for the upper portion of the basin exhibits one peak in the winter months indicative of a system which receives the majority of its flow from seasonal precipitation (ie. not glacier or snow pack fed unlike many other watershed areas in the region).

There are as many as 70 dams known to exist within the Chehalis Basin with approximately 54 dams in the upper basin, whose effect on downstream flows has not been analyzed (Tetra-Tech/KCM 2003). The largest of these dams are on the Skookumchuck and Wynoochee Rivers. The Wynoochee River dam is in the foothills of the Olympic Mountains in Grays Harbor County (TPU 2008). The dam was built in 1972 to provide flood control, industrial water storage for the City of Aberdeen and water for irrigation and to support the river's fishery (TPU 2008). The dam is owned by the City of

Aberdeen (TPU 2008). In 1993 Tacoma Power built a powerhouse about one-quarter mile downstream from the dam and began generating electricity in 1994 producing about 30 million kilowatt-hours of electricity each year, enough to serve 2,100 Northwest homes (TPU 2008). The Wynoochee drains approximate 41 square miles and has an average discharge of 534 cfs (TPU 2008). The Skookumchuck dam was constructed in 1970 and TransAlta, a private corporation, currently owns and operates the dam to provide water supply for the 1400-megawatt Centralia Steam Electric Plant and to supplement flows for fish resources. Skookumchuck Dam is an un-gated structure with a capacity of 28,000 cfs at its spillway crest elevation of 477 feet (USACE 2002) and a 35,000 acre-feet capacity at the full pool elevation which occurs in winter, usually not before December, indicating that additional storage may be possible.

In response to the Watershed Management Act of 1998, the Chehalis Basin Partnership (CBP) was formed to design and implement watershed planning for the Upper and Lower Chehalis Watershed (Water Resource Inventory Areas (WRIA) 22 & 23 respectively). The signed members of the CBP include: the cities of Aberdeen, Centralia, Chehalis, Hoquiam, McCleary, Montesano, Napavine, Ocean Shores, and PeEll; the counties of Grays Harbor, Lewis, Mason, and Thurston; the Confederated Tribes of the Chehalis; water suppliers including Grays Harbor Water District #2, the Boistfort Valley Water Company; the Ports of Centralia and Grays Harbor, the Chehalis Basin Fisheries Taskforce, the Washington Farm Bureau, the Washington State Departments of Fish and Wildlife, the Washington State Department of Ecology, the Washington State Department of Natural Resources, concerned citizens and the Weyerhaeuser Corporation (CBP et al. 2004). Current membership does not include an

exhaustive group of stakeholders in the basin. There are many important issues facing the ecological and stakeholder interests in the basin however many of these issues either have their roots in or directly impact the management of the water resources of the Upper and Lower Chehalis Watershed.

Water quantity, water quality, and habitat are the overriding concerns listed in the Chehalis Basin Watershed Management Plan (CBP et al. 2004). To assess these concerns the Chehalis Basin Partnership initiated a series of studies to evaluate consumptive water use in the basin, major sources of water quality concern in the basin, the potential for additional storage (CBP et al. 2004). The Chehalis Basin Partnership has completed the following tasks, and based on the findings of this report and the wealth of scientific literature available on interlinking resource and climate models, each item could benefit from the incorporation of climate projections to achieve more successful, more adaptable planning and resource management.

Watershed Management Plan (2004) – The Partnership provides a current vision and framework for water resource management in the Chehalis Basin. The Plan calls out 56 priority actions that we believe are essential to understand the water resources and management in the basin.

Multi-Purpose Water Storage Assessment of Basin (2003) – The Partnership conducted a survey-level study to identify potential projects to store excess wintertime runoff for use in the drier months to increase flows.

Chehalis Basin Instream Flow Study (2003) – The Partnership assessed habitat and hydrologic conditions in the basin.

Detailed Implementation Plan (2007) – The Partnership outlined a comprehensive approach for retaining sufficient water in the Basin for production agriculture, commercial, industrial and residential uses, and instream.

GIS Clearinghouse (ongoing) – The Partnership compiled GIS data of the Chehalis Basin area. The GIS data is detailed in 29 layers.

Ecosystem Diagnostic Treatment (EDT) – The Partnership in collaboration with Grays Harbor College and the US Army Corps of Engineers are working to acquire the computer model EDT built for the Chehalis watershed. The model is for salmon

management while looking at the entire ecosystem and designed to provide a practical, science-based approach for developing and implementing watershed plans.

Characterization of the water resources of the Chehalis Basin through a partnership with USGS – The Partnership intends to submit a request for financial assistance to initiate this project with USGS. Once funded the project includes compiling and evaluating information needed to characterize a hydrogeologic setting and ground-water flow system in the basin and its interaction with associated surface-water features which will be used in the construction of a conceptual model.

The Chehalis Basin Salmon Habitat Restoration and Preservation Work Plan 2007 – This document provides the goals of salmonid habitat restoration in the Chehalis Basin along with profiles of current salmonid stocks and important sub-basins

4.1 CLIMATE, POPULATION AND LAND USE CHANGES

Western Washington shows a high degree of climate correlation across the region, meaning that warm and cold years are uniformly expressed across the region (Mote 2003), this trend is also observed in the Chehalis Basin (Envirovision Corporation 2000). Since basin specific modeling has not occurred on the Chehalis Basin, and doing so is not a part of this thesis essay, regional modeling conducted by the Climate Impacts Group and the IPCC will be used to begin to assess potential impacts on natural resources, and specifically water resources in the context of the Chehalis Basin Management Plan.

In the absence of downscaled regional climate projections specific for the Chehalis Basin the Pacific Northwest projections detailed in the preceding section can be utilized in conjunction with available studies of water quantity, quality, and habitat within the Chehalis Basin to allow for scoping of the potential impacts, adaptation and planning sensitivity in the watershed (Rosenzweig et al. 2004; Snover 2007). The implication is that comprehensive interdisciplinary studies are required to assess the bio-geophysical and socioeconomic processes resulting from climate change impacts to watersheds, ecosystems, and human populations (Huang et al. 1998; Rosenzweig et al. 2004;

Schneider 2007).

Ten climate models were utilized in a Mote et al 2005 study of climate scenarios for the Pacific Northwest: PCM1, GISS-ER, CSIRO-MK3, CGCM3.1, CCSM3, HadCM3, CNRM_CM3, MIROC_3.2, IPSL_CM4, and ECHAM5. The conditions in 2020 were reported based on the average projected change from 2010 to 2040 minus the average temperature and precipitation for the period from 1970 to 2000 (Mote 2005). The changes projected for the 2040 and 2080 temperature and precipitation values were determined in the same fashion.

Temperature- IPCC Emissions Scenario A2 (IPCC 2000)

Temperature increases are the climate variable for which climate models depict with the largest degree of certainty, both globally and in the Pacific Northwest (CIG 2005; Mote 2005; IPCC 2007; US-Government-Report 2007). The following represent projected mean temperature increases for the given period.

2020: 0.4°C (0.7°F) to 1.8°C (3.2°F) (Mote 2005)

2040: 0.8°C (1.4°F) to 2.6°C (4.6°F) (Mote 2005)

2080: 1.6°C (2.9°F) to 4.9°C (8.8°F) (Mote 2005)

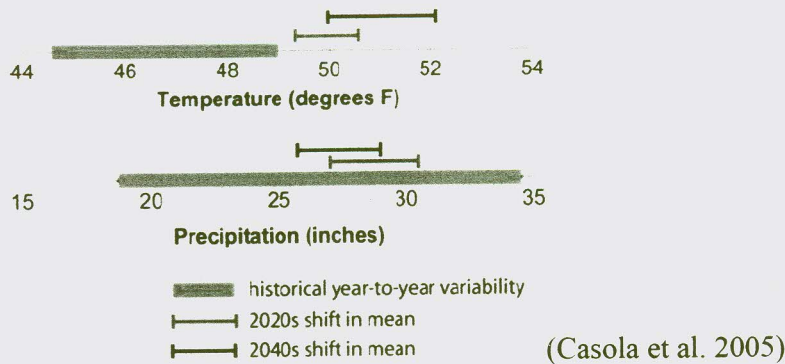
Precipitation IPCC Emissions Scenario A2 (IPCC 2000)

Models have generally predicted an increase in winter precipitation and a decrease in summer precipitation.

2020: -4% to +6% (Mote 2005)

2040: -4% to +9% (Mote 2005)

2080: -2% to +18% (Mote 2005)



Produced by the Climate Impacts Group for the PNW, this graphical representation depicts changes in mean temperature and precipitation in the region. Note that the mean shifts in temperature for the 2020 and 2040 projections are beyond the scale of historically observed year to year variability, while the mean shift in precipitation, though reflecting an increase in mean precipitation, still lies within the historic range of year to year variability.

Sea Level Rise IPCC Emissions Scenario A2 (IPCC 2000)

2090-2099: 0.23 – 0.51m (IPCC 2007)

Because scientists have limited understanding of some important effects driving sea level rise, for example the potential for rapid melting of the Greenland or Antarctic ice shelves, the IPCC does not assess the likelihood or upper limit of the sea level rise currently being observed (IPCC 2007).

Extreme Events and Flooding

Globally a general increase in the variability and severity of extreme weather events has been predicted (IPCC 2007).

Population and Land Use

Traditional water resource planning takes into account service area through assessments of historic variations in water system performance and climate variables, as

well as population and land use. Climate change will exacerbate the existing pressures on the Chehalis system caused by increased population and land use changes. In the Level 1 study of WRIA 22 and 23 conducted by the Envirovision Corporation in 2000 projected population increases for the basin are as follows:

WRIA	2000	2005	2010	2020
22	64,109	66,032	68,673	76,914
23	94,000	103,400	110,640	122,810

(Envirovision

Corporation 2000)

By 2030 the Washington State Office of Financial Management estimates the populations in the major counties in the basin, including Thurston, Grays Harbor and Lewis Counties, is projected to increase by a combined 77% (WOFM 2008).

TABLE 1-2.
LAND USE/LAND COVER BY SUBBASIN

Subbasin	Portion of Total Area by Land Use/Land Cover					
	Forest	Agriculture/ Field	Urban	Water	Bare	
WRIA 23 - Upper Chehalis						
1	Chehalis River Headwaters	96%	3%	1%	0%	0%
2	Elk Creek	99%	1%	0%	0%	0%
3	South Fork Chehalis River	90%	10%	0%	0%	0%
4	Upper Chehalis River	82%	17%	1%	0%	0%
5	South Fork Newaukum River	93%	7%	0%	0%	0%
6	North Fork Newaukum River	95%	5%	0%	0%	0%
7	Newaukum River	70%	28%	2%	0%	0%
8	Salzer Creek	84%	13%	3%	0%	0%
9	Skookumchuck River	88%	8%	2%	0%	2%
10	Middle Chehalis River #1	69%	21%	10%	0%	0%
11	Black River	76%	20%	3%	1%	0%
12	Cedar Creek	96%	2%	2%	0%	0%
13	Middle Chehalis River #2	78%	16%	6%	0%	0%
	WRIA-wide Average¹	83%	13%	3%	<1%	<1%
WRIA 22 - Lower Chehalis						
14	Cloquallum Creek	92%	4%	4%	0%	0%
15	East Fork Satsop River	98%	0%	1%	1%	0%
16	Decker Creek	96%	4%	0%	0%	0%
17	Middle Fork Satsop River	100%	0%	0%	0%	0%
18	Satsop River	95%	3%	2%	0%	0%
19	Lower Chehalis River #1	79%	6%	15%	0%	0%
20	Wynoochee River	96%	3%	0%	1%	0%
21	Wishkah River	96%	2%	2%	0%	0%
22	Hoquiam River	95%	0%	5%	0%	0%
23	Middle Fork Hoquiam River	100%	0%	0%	0%	0%
24	East Fork Hoquiam River	98%	1%	1%	0%	0%
25	Humtulsips River	98%	2%	0%	0%	0%
26	Elk River	99%	1%	0%	0%	0%
27	Johns River	98%	2%	0%	0%	0%
28	Newskah Creek	98%	2%	0%	0%	0%
29	Charley Creek	95%	5%	0%	0%	0%
30	Lower Chehalis River #2	66%	6%	25%	3%	0%
31	Grays Harbor	75%	9%	12%	3%	1%
	WRIA-wide Average¹	92%	3%	4%	<1%	<1%
	Basinwide Average¹	88%	8%	3%	<1%	<1%

¹ Basin averages are area weighted percentages.

(Tetra-Tech/KCM 2003)

The chart above shows the approximate percentage of land covers for major sub basins in WRIs 22&23. Approximately 88 percent of the Chehalis Basin is forest land, much of it corporate/private owned; 8% of the land use is agriculture/fields, 3% is urban and less than 1% is covered by water and bare earth. Although only 11 percent of the basin, as a whole, is in agriculture, urban, or industrial uses, this figure climbs to 42

percent in those areas within one mile of the major Chehalis Basin.

4.2 CURRENT AND FUTURE ISSUES IN THE CHEHALIS BASIN

Observing existing sensitive areas of the basin and those aspects of the basin observed to be most impacted by climate fluctuations in the past provides a meaningful starting point for vulnerability assessment and later adaptation studies. Similar to other basins in Western Washington State, the Chehalis Basin receives the majority of its water input through winter precipitation, and during the winter the abundance of water provides for both in-stream flows and consumptive uses without issue (Tetra-Tech/KCM 2003). During the summer months however, competition for resources exist as precipitation is at a minimum. This problem is emphasized on the Chehalis River due to its condition of being almost exclusively fed by precipitation and groundwater with little or no stream flow in the spring and summer months coming from snow pack or glacial melt waters.

In the Chehalis Basin, a comprehensive watershed model has yet to be developed, though the Chehalis Basin Partnership has indicated the development of such a model as a priority to ensure effective management (CBP et al. 2004). In lieu of a more comprehensive hydrologic model of the basin, Tetra-Tech's 2003 Water Quantity study of the Chehalis Basin (Tetra-Tech/KCM 2003) created a simplified water balance for the Chehalis Basin depicting estimated rates for precipitation, runoff, evapotranspiration, and water use which will serve as a surrogate for an examination of climate impacts on the water resources of the basin.

$$\text{Precipitation} = \text{Runoff} + \text{Evapotranspiration} + \text{Water Use} + \text{Change in Groundwater Storage}$$

TABLE 2-8.
ESTIMATED WATER BALANCE, LOW FLOW AND WATER RIGHTS

Volume (acre-feet, rounded figures)									
Month	Precipitation	Runoff (50% exceedance flow)	Et	Use (C)	R + C + Et	Balance	Runoff (90% exceedance flow)	Total Rights (with Volume Limits) ¹	Total Rights (Year-Round Continuous Withdrawal) ¹
October	760,000	138,000	192,000	1,000	331,000	429,000	55,000	18,500	161,000
November	1,193,000	535,000	110,000	1,000	646,000	547,000	156,000	18,500	161,000
December	1,342,000	875,000	58,000	1,000	934,000	408,000	373,000	18,500	161,000
January	1,241,000	895,000	56,000	1,000	952,000	289,000	334,000	18,500	161,000
February	994,000	788,000	84,000	1,000	873,000	121,000	366,000	18,500	161,000
March	876,000	683,000	145,000	2,000	830,000	46,000	336,000	18,500	161,000
April	568,000	442,000	215,000	3,000	660,000	-92,000	247,000	18,500	161,000
May	347,000	250,000	334,000	4,000	588,000	-241,000	156,000	18,500	161,000
June	263,000	137,000	406,000	9,000	552,000	-289,000	93,000	18,500	161,000
July	140,000	89,000	435,000	8,000	532,000	-392,000	59,000	18,500	161,000
August	179,000	61,000	373,000	7,000	441,000	-262,000	41,000	18,500	161,000
September	346,000	63,000	309,000	3,000	375,000	-29,000	40,000	18,500	161,000
Total	8,249,000	4,956,000	2,717,000	41,000	7,714,000	535,000	2,256,000	222,000	1,932,000
% of Precip.	100%	60.1%	32.9%	0.5%	93.5%	6.5%		2.7%	23.4%

1 - See pages 2-7 to 2-9 for discussion of methodology. Monthly average water right estimates are unadjusted for seasonal differences. Without seasonal adjustment, the allocations greatly exceed the estimated 90 percent exceedance flow of the Chehalis from May through November.

(Tetra-Tech/KCM 2003)

Based on the simplistic water balance model depicted above the observation can be made that runoff and evapotranspiration are the major ways that water leaves the Chehalis Basin, with runoff at approximately 60 percent of estimated annual precipitation, and combined evapotranspiration at approximately 33 percent, together totaling 93 percent of precipitation (Tetra-Tech/KCM 2003). Although only 11 percent of the basin, as a whole, is in agriculture, urban, or industrial uses, this figure climbs to 42 percent in those areas within one mile of the major Chehalis Basin Rivers (Tetra-Tech/KCM 2003). Drawdown from wells in this 1 mile buffer and the cumulative effects on the hydraulic continuity of the groundwater and surface waters of the Chehalis were not assessed in the water quantity report. This could be a valuable area of study for

future modeling endeavors and could have ramifications given projected temperature changes and the increased demand for water resources in the dry season that may follow.

As with many river basins in Western Washington, water use in the Chehalis Basin is divided between municipal, domestic, irrigation, power generation (non-consumptive), industrial uses. Irrigation and domestic use are reported as the primary purpose for the largest number of different water rights, while power generation and domestic uses account for the water rights with the highest total instantaneous withdraw rates, and municipal and irrigation are the primary purpose with the highest total annual limit (Tetra-Tech/KCM 2003). The Level I Assessment (Envirovision Corporation 2000) and subsequent Tetra-Tech water quantity (Tetra-Tech/KCM 2003) and storage (Tetra-Tech/KCM 2003) reports initiated by the Chehalis Basin Partnership as part of Phase II of watershed planning under the Watershed Planning Act states that groundwater discharges to the Chehalis River along most of the river's length making hydraulic continuity an issue everywhere in the watershed, this is supported by the preliminary findings of a USGS "gaining" and "losing" reach study initiated in September 2007. (Envirovision Corporation 2000; Tetra-Tech/KCM 2003; USGS 2007).

Precipitation and temperature changes projected for the Pacific Northwest can have implications for water quantity, water temperature, consumptive and nonconsumptive use, habitat availability, and evapotranspiration (Palmer et al. 2002; Mote 2003). This suite of implications can be further exacerbated by current and future land use choices in the Chehalis Basin.

Identified vulnerable sectors can be further assessed using hydrologic models, empirical relationships and resource management models to begin to quantify impacts

and facilitate adaptive measures.

Non agricultural consumptive/nonconsumptive use of water resources drawn from surface water, private/exempt wells and municipal wells represents a small proportion of the overall water budget in the Chehalis Basin, but in a future with increases in temperature those uses are likely to increase, particularly in the warm summer months when domestic irrigation, recreation, and potentially hydroelectric power generation (under increased summer temperatures and milder winters) are at their peak. The Level I Assessment of the Chehalis Basin did not take into account the potential increases in the water demand due to the effects of climate changes in the following estimates of future water use.

WRIA	Average Per Capita Water Demand (gcd)	Average Day Water Demand (cfs)			
		2000	2005	2010	2020
22	123	12	12.5	13	15
23	144	21	23	25	27
TOTAL		33	33.5	38	42

(Envirovision Corporation 2000)

As water supplies become more developed, utilized and therefore managed, the total cost of further use and development increases at a nonlinear rate (Rosenzweig et al. 2004). The Portland water resources study described in section 2.4 of this report found that by 2040 average increases in water demand related to climate change would approach 50% of the total increase expected from population growth alone (Palmer et al. 2002). The implications of this study suggest that taking a second look at projected water demand for all consumptive water use in the Chehalis Basin will be important to managing the resource.

One of the problems identified in the Chehalis Basin Partnership documents is that

of exempt wells. In an article by Robert N. Caldwell, "Six-Packs for Subdivisions: The Cumulative Effects of Washington's Domestic Well Exemption", Caldwell states there are hundreds of thousands of exempt wells in Washington, and thousands of new wells constructed every year with unquantified withdraw on aquifers with unknown impacts on streamflows in areas hydraulically connected to groundwater aquifers" (Caldwell 1998). The exempt well statute in Washington providing for these exempt wells under the Water Code is RCW 90.44.050, states

After June 6, 1945, no withdrawal of public ground waters of the state shall be begun ... unless an application to appropriate such waters has been made to the department and a permit has been granted by it as herein provided: Except, however, that any withdrawal of public ground waters for stock watering purposes, or for the watering of a lawn or of a noncommercial garden not exceeding one-half acre in area, or for single or group domestic uses in an amount not exceeding five thousand gallons a day, or for an industrial purpose in an amount not exceeding five thousand gallons a day, is and shall be exempt from the provisions of this section, but, to the extent that it is regularly used beneficially, shall be entitled to a right equal to that established by a permit issued under the provisions of this chapter...

While this law may have made sense at the time it was enacted, the recently observed explosion of development and the current interest in establishing proper resource management may prove the exception outdated. By 2030 the Washington State Office of Financial Management estimates the populations in the major counties in the basin, including Thurston Grays Harbor and Lewis Counties, is projected to increase by 77% combined (WOFM 2008). As cities increase to capacity more and more of this development will likely occur outside of municipal water service areas compounding water management issues further. The Chehalis Basin Partnership has recommended pursuing the issue of impacts of exempt wells (CBP et al. 2004).

The majority of the rivers in the Chehalis Basin have state water quality

classifications of A, excellent (CBP et al. 2004). Although water quality in these rivers is on the average pretty good, during the more dry summer months many rivers in the basin exhibit low dissolved oxygen level, excessive temperatures and sediment loads (Envirovision Corporation 2000; Smith et al. 2001) and failure to meet instream flow protection of aquatic species is common in some reaches. The dissolved oxygen problems have been attributed mainly to agricultural runoff, livestock operation and urban stormwater influx, and temperature changes attributed to loss of riparian vegetation and sedimentation alterations of depth to width ratios (Smith et al. 2001). Although the waters basin-wide generally attain water quality standards when data are averaged over the long term, individual measurements have failed to meet the standards often enough that 24 water bodies or stream segments in the basin are considered to be impaired and are included on the state's 303(d) listing of impaired water bodies (CBP et al. 2004).

Legally set month to month in-stream flows, those flows determined to be protective of in-stream resources and values (fish, wildlife and recreation) were established on the Chehalis Basin in under Washington State Law in 1976 as defined under Washington Administrative Code (WAC) Chapter 173-522. Of 32 identified salmonid stocks in the basin, 21 are considered healthy, three are considered depressed, seven have a condition that is unknown, and one has a condition that is disputed (Envirovision Corporation 2000; CBP et al. 2004). Stream channels throughout the Chehalis Basin have been observed to have undergone losses of riparian vegetation likely for farming and logging which leads to shade reduction and reduced stream bank stability, high levels of sediment in the water and increased water temperatures all of which can be detrimental fish stocks. Increased temperatures, water demand, and land

use pressures in the Pacific Northwest will likely increase the frequency and severity of currently experienced water quality and habitat issues making it increasingly difficult for salmonid species to thrive in the dry summer months.

Sea level rise may lead to increased salinisation/salt water intrusion of irrigation water, estuaries, and fresh water systems; increased costs associated with the protection of coastal lands and/or limitations on the cost/benefit of certain coastal land use (IPCC 2007).

CHAPTER 5.0 DISCUSSION AND CONCLUSIONS

Climate change adaptation need not involve colossal spending or the establishment of new levels of bureaucratic authority to make land and water use decisions. The study of climate change impacts on complex and uncertain features of economic and environmental systems lends itself to integrated research involving multiple disciplines (Huang et al. 1998; Stenseth 2003). It does require a systematic process that is facilitated by the participation or accounting of all stakeholders in a watershed; examines current use and deficiencies in the watershed; then looks for vulnerabilities based on the highest resolution climate projection data available and finally facilitates adaptive action plans.

Different aspects of the climate impact study area will be impacted by projected changes at different temporal scales, therefore reflection of temporal variation is important for effective assessment and adaptation (Huang et al. 1998). It has been suggested that adaptation would best be performed through actions based on a “no regrets policy” or actions that a resource manager might perform with or without the impacts

associated with climate change (Risbey 1998; Gleick et al. 2004; Adger 2007).

	Get history scenario (normal streamflow)	Get GCM scenario (earlier runoff)	Get anti-GCM scenario (moderate streamflow dec.)	Get big dry scenario (large streamflow dec.)
Use history to plan (BAU)	successful planning; no new infrastructure required; small cost; conventional payback	will operations management suffice?; infrastructure may be needed to catch earlier runoff; may be decades delay before this is in place, so defer costs til then, but get some water shortages as extra precipitation runs out of the basin	get chronic water shortage due to precipitation decrease; new storage no help; need to develop moderate amount of alternative supply	new storage little help; large chronic water deficit; need to find substantial alternative sources; continued losses while implementing these
Use GCM to plan (protect runoff)	may have incurred infrastructure costs that are largely unnecessary, since original system would have sufficed	must cope with uncertainty on sufficiency of operations management (o/m) to protect runoff; broad savings if o/m used and sufficient; water shortages if not sufficient; if opt to develop infrastructure then costs in development, but payback in protecting supply	may incur unnecessary infrastructure costs and have water shortages to boot	may incur unnecessary infrastructure costs and face chronic water shortages
Use anti-GCM to plan (develop supply)	moderate amount of alternative supply developed unnecessarily	development of alternative supply perhaps suboptimal to using basin resources, but since no new storage built, can use this to make up for any runoff losses	some investment in alternative supply needed and carried out; supply successfully maintained in the face of moderate ongoing basin shortages	under-investment in alternative supply, but better than no investment; some amelioration of chronic shortages
Use big dry to plan (develop alternative supply)	unnecessarily spent large sums on developing alternative supply	need not have invested in costly new supplies, but can use them to offset streamflow losses possibly incurred from earlier runoff with no new infrastructure in place	need not have invested so much in costly new supplies, but can use them to offset water shortages due to precipitation decreases	developed alternative supply at large cost, but maintaining supply in the face of a dry climate; worst case ameliorated

(Risbey 1998)

A planning sensitivity matrix such as that provided by Risbey (Risbey 1998) above can provide useful insights into water resource management in the Chehalis Basin. In the matrix the subtleties of projected climate changes are dissolved to allow for a coarse assessment of a range of potential future climates and the potential consequences of planning decisions associated with each. Planning drivers are located along the left hand side and resultant climate scenarios are located across the top. The business as usual strategies involves planning based on current management strategies; the GCM scenario is planning for a future with increased temperature, earlier runoff, increased winter precipitation and drier summers; the anti GCM scenario is planning for a future

with a cooler temperature and decreased winter precipitation; and the “Big Dry” scenario involves more extreme drought and major decreases in stream flows (Risbey 1998). By assessing management in this way, a more complete assessment of future scenarios can be considered, and the selection of adaptive measures based the necessary level of response and the economic inputs can begin to be assessed. In the Chehalis Basin, if the recommendations of the CBP are not implemented, the business as usual strategy will very likely lead to more of the same water quantity and quality that the basin is currently experiencing to the detriment of water users and aquatic species. The CBP has recommended establishing basin wide hydrologic models, increasing storage capacity in the basin, and restoring riparian/stream function. These recommendations are not inconsistent with planning that could conceivably occur under the GCM scenario in the planning sensitivity matrix. Fortunately for Chehalis basin residents the adaptation planning methods that may need to be employed are related to current problems, ie. building in the flood plain, industrial/individual air pollution, water resources disputes between fish, recreation, power generation, habitat vs development (responsible development), and drinking water. It is possible that existing strategies in the Chehalis Basin for coping with current natural fluctuations in climate may be sufficient for dealing with the potential climate changes predicted for the Pacific Northwest, however the impact and adaptation research must be done to ensure existing strategies can handle the potential changes likely to occur and at what economic and ecological cost (Gleick et al. 2004).

Given the projected increases in temperature and possibly winter precipitation, the most affordable adaptation strategies to water stress are the same as they have always

been; conservation. Other strategies to could be to augmented storage capacity through gray-water reuse and aquifer recharge, wetland restoration, and possibly increased reservoir capacity.

Recommendations for the Chehalis Basin Partnership to begin adaptation

planning:

- Incorporate regional climate project and impact language/information into planning and management documents of the CBP.
- Establish high quality hydrologic models of the basin through comprehensive groundwater characterization (underway as part of the CBP Management Plan)
 - Quantify water use in the basin assessing exempt water withdrawal
- Increase high resolution meteorological data throughout the basin
- Produce downscaled climate projections specific to the Chehalis Basin
- Integrate climate project derived agricultural and reservoir management models with overall basin hydrologic model, thereby developing a model chain relating various water and land use practices throughout the basin

Watershed management in the past has been based largely on the assumption of fluctuating, but not necessarily changing natural systems. Instead of looking back in time to determine how to best meet the needs of both the developed and natural world, climate adaptation planning is about looking forward.

We are just beginning to understand the dynamics of the climate system, but scientists are far from a comprehensive understanding, which leads to uncertainties in climate projections and therefore adaptation strategies. As model resolution and our understanding of climate forcing and feedbacks increases adaptation policies integrated into management plans should be fluid, limit regrettable decisions, and ever developing.

There is unlikely to be end policies or concrete laws that can be established to ensure effective adaptation. The implications of climate change suggests that intensely managed areas will become even more managed and areas already under water/climate duress could be faced with an inability to expand water use in the future (Rosenzweig et al. 2004).

The response of the Washington State Departments of Ecology and Community Trade and Economic Development, King County/Seattle, and the City of Portland in collaborating on climate impact assessments with academic institutions such as the Climate Impacts Group of the University of Washington could serve as a positive example to other regional planning groups, such as the Chehalis Basin Partnership, and may provide a platform for further use of local academic resources such as the CIG, Grays Harbor Community College, or the Evergreen State College.

Other avenues for incorporating climate change language in planning efforts not discussed here might include:

- *Watershed Planning Act*
- *Floodplain Management*
- *DOT Watershed Characterization Plans*
- *Forest Practices Watershed Analysis*
- *Growth Management Act Implications*
- *Washington State Environmental Policy Act*
- *Hydroelectric Power and Dam Re-licensing*
- *Local County and Municipal Codes and Ordinances*

Perhaps ironically, given the abundance of water resources in Washington State, climate adaptation has nearly everything to do with water.

“Do not let your chances, like sunbeams pass you by, For you never miss the water till the well runs dry” musician Rowland Howard 1867

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