Proposal to NOAA OGP
CDEP and RISA Programs

from

THE CENTER FOR SCIENCE IN THE EARTH SYSTEM

JISAO, University of Washington

E.L. Miles & E.S. Sarachik, PIs
N. Mantua, co-I

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Abstract

This is a five year proposal from the Center for Science in the Earth System (CSES) to the NOAA Regional Integrated Sciences and Assessment (RISA) and Climate Dynamics/Experimental Prediction (CDEP) programs. The purpose of CSES is to research (by analysis and by doing) the use of climate information for the benefit of the people of the PNW and the nation. The Center does this through a program of applied research, case studies, development, outreach and education. It is a unique center in its end-to-end orientation, having climate dynamics, climate impacts, and climate applications aspects, and draws on the resources of major universities in the region to complement its own activities. It is composed of leaders in the fields of climate dynamics and diagnostics, hydrology, forestry, water resources, economics, marine ecology, and institutional and policy analysis, all working together toward the common goal of enhancing regional and national resilience to climate variability and change.

The Center's work responds directly to three of the four goals in NOAA's *Strategic Plan for FY 2003-2008 and Beyond*:

> 1. Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management
>
> 2. Understand climate variability and change to enhance society's ability to plan and respond
>
> 3. Serve society's needs for weather, climate, and water information,

directly to four of the five goals of the Climate Change Science Program (CCSP):

> Goal 1: Extend knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed changes
>
> Goal 3: Reduce uncertainty in projections of how the Earth's climate and environmental systems may change in the future
>
> Goal 4: Understand the sensitivity and adaptability of different natural and managed systems to climate and associated global changes
>
> Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change,

and indirectly to the other goal:

> Goal 2: Improve understanding of the forces bringing about changes in the Earth's climate and related systems,

directly to the goal of the NOAA Intraseasonal to Interannual Prediction Program:

> Provide the Nation with a seamless suite of climate forecasts and application products to manage risks and opportunities of climate impacts due to intra-seasonal to interannual climate variations,

directly to one of the two goals of the CDEP program:

> Contributing to enhanced NOAA climate products and services,

directly to the goal of the RISA Program:

> The RISA program supports research that addresses complex climate sensitive issues of concern to decision-makers and policy planners at a regional level,

and generally to the goal of the NOAA Climate and Global Change Program to design and implement climate services in the US.

Members of the Center participate in the formulation of global and regional climate programs within NOAA and throughout the nation through membership on committees and through participation in major climate programs and assessments. The Center interacts with, and services, a wide variety of public and private stakeholders in the PNW and also houses the Office of the State Climatologist of Washington. It interacts with and advises the International Research Institute for Climate Prediction (IRI), an institution having similar goals as CSES but designed to bring the benefits of climate information primarily to developing countries. It also interacts with other RISA teams, with other Applied Research Centers, and with the National Center for Environmental Prediction.

This proposal indicates what the CSES has done over the last five years, and what it will do in the next five years. Because the range of activities is so great, this proposal is necessarily long—a historical background (Sec. 1a) and an overview (Sec. 1c) is included to give an idea of the CSES, its activities, and this proposal.

CONTENTS

Acronyms

ACPI	Accelerated Climate Prediction Initiative (DOE)
ARC	Applied Research Center
BOR	Bureau of Reclamation (Department of the Interior)
CCRI	Climate Change Research Initiative
CCSP	Climate Change Science program (successor to USGCRP)
CDG	Climate Dynamics Group
CDEP	Climate Dynamics and Experimental Prediction (NOAA Program)
CIG	Climate Impacts Group
CSES	Center for Science in the Earth System
DHSVM	Digital Hydrology, Soil, and Vegetation Model
DOE	Department of Energy
ECHAM	European Center for Medium Range Weather Forecasting-Hamburg (refers to a particular climate models built by these institutions jointly)
ECPC	Experimental Climate Prediction Center (Scripps Inst. of Oceanography)
ENSO	El Niño/Southern Oscillation
EPA	Environmental Protection Agency
ESA	Endangered Species Act
GEOSS	Global Earth Observing System of Systems
IPCC	Intergovernmental Panel on Climate Change
GCOS	Global Climate Observing System
GLOBEC	Global Ocean Ecosystem Dynamics (International Geosphere Biosphere Pro-gram)
GOOS	Global Ocean Observing System
HADCM	Hadley Centre (British Met. Office) Climate Model
IDWR	Idaho Department of Water Resources
IRI	International Research Institute (for Climate Prediction)
JISAO	Joint Institute for the Study of Atmospheres and Oceans
MM5	Mesoscale Model 5
MJO	Madden-Julian Oscillation
NCC	North California Current
NCAR	National Center for Atmospheric Research (NSF)
NCTP	NOAA Climate Transition Program
NCEP	National Center for Environmental Prediction
NRCS	Natural Resources Conservation Service (part of USDA)
NSF	National Science Foundation
OCI	Oyster Condition Index
OGP	Office of Global Programs (NOAA)
OSU	Oregon State University
OOPC	Ocean Observing Panel for Climate (A GOOS/GCOS Panel)
PCM	Parallel Climate Model (Built by DOE and NCAR)
PDO	Pacific Decadal Oscillation
PDV	Pacific Decadal Variability

PICES	North Pacific Marine Science Organization
PNNL	Pacific Northwest National Laboratory
PNW	Pacific Northwest
RISA	Regional integrated Scientific Assessment (NOAA Program)
SFM	Seasonal Forecast Model
SMA	(UW) School for Marine Affairs
TAO	Tropical Atmosphere-Ocean (Array in Equatorial Pacific)
UCAR	University Corporation for Atmospheric Research
UNFCC	United Nations Framework Convention on Climate Change
USDA	US Department of Agriculture
USGCRP	US Global Change Research Program
UW	University of Washington
VIC	Variable Infiltration Capacity (Soil Wetness Model)
WDOE	Washington (state) Department of Ecology
WRIA	Water Resource Inventory Area

1. Background to this Proposal

This is a proposal from the Center for Science in the Earth System (CSES) within the Joint Institute for the Study of Atmosphere and Ocean (JISAO) at the University of Washington to the NOAA Regional Integrated Sciences and Assessment (RISA) and Climate Dynamics and Experimental Prediction (CDEP) programs.

a. Overview of this Proposal

The CSES:

According to its Charter, the Center for Science in the Earth System (CSES) conducts integrated research on the impacts of climate variability and change on the U.S. Pacific Northwest (PNW). It does this by combining and integrating expertise in climate dynamics, ecological dynamics, hydrologic dynamics, and institutional and policy analysis for the study of PNW climate dynamics, impacts, and decision support. The CSES also researches the methodologies for accomplishing climate research, and researches the application of climate information in regional decision-making processes in support of the regional aspects of an eventual Climate Service. Outreach and education are important elements in making contact with, understanding, and working with our stakeholders.

The overall strategy for accomplishing its mission is presented in Sec. 2 and is summarized in Fig. 1.

The known climate drivers of the PNW are the El Niño/Southern Oscillation (ENSO) on seasonal-to-interannual scales, the Pacific Decadal Oscillation (PDO) on decadal scales (both acting on the atmospheric Pacific North American Pattern), and the slower global climate change. The expression of these climate drivers in the PNW is a problem of downscaling and is one of the keystones of the climate effort. Other possible climate drivers yet to be fully elucidated are the intraseasonal Madden-Julian Oscillation and the long term effect of changes in the magnitude and distribution of global sea surface temperature (SST) which have been recently implicated in western droughts.

The Center concentrates on understanding the climate impacts and developing the use of climate information in four sectors of special interest to the PNW: hydrology and water resources, marine ecology (especially salmon), forest ecology, and coastal environments. The CSES would extend its concentration to two additional sectors, health and agriculture, but funding limitations have, up to now, prevented this extension. It should be noted that the importance of climate in a number of health problems in the PNW (e.g. seasonal affective disorder) and in the major agricultural industries in the region (apples, grapes, etc.) require that these additional sectors eventually be included.

In addition to researching and understanding climate drivers and climate impacts in the four sectors, the Center assesses, in as integrated a way as possible, the combined effects of climate variability and change on the ecology, people, and people's institutions. Because resource decisions made for economic reasons affect regional water and ecology, efforts to bring the benefits of climate information to decision making for water and ecological resource management *must* include the combined effects on all sectors in isolation and in combination. The CSES also examines the institutional and policy basis for using climate information since information that is incompatible with the way people think and with people's existing institutions will simply not be used and enormous effort could be expended with little resulting effect.

The Center also reaches out, educates, interacts, and partners with the people and decision makers of the PNW by means of educational programs, interactive workshops, the development and distribution of useful decision support tools, by surveys and other modes of information gathering, and by a number of other mechanisms. The educational and outreach aspects of the Center's work is an absolutely essential aspect of its mission.

<u>This Proposal:</u>

This proposal describes the work of the last five years in all the areas in which the CSES works (Sec. 3) and describes the work intended in the next five years (Sec. 4).

In the area of climate, the last five years have primarily concentrated on those large scales aspects of the climate that are known to affect the PNW. Major advances were made in the understanding of the mechanisms of ENSO; in the relationship between these mechanisms and the predictability of ENSO; in the relationship between interannual ENSO and its longer period manifestations which closely resemble (and may be the same as) the Pacific Decadal Oscillation); in the atmospheric forcing that arises from the SST variations characteristic of ENSO; in the design of the observing system deployed to measure ENSO; in the nature of long period variability in the atmosphere, especially the Pacific North American and the Arctic Oscillation; in the processes that affect the strength and stability of the thermohaline circulation under anthropogenic climate change and its effect on the equatorial Pacific thermocline and therefore on ENSO; on the trends in regional climate and especially mountain snow and ice relevant for streamflow and water resources; and on developing both statistical and dynamical techniques for downscaling the large scale climate information for use in the PNW region. Additional advances were made in paleoclimatology in building an additional 185-year record of Columbia River streamflow, thereby pushing the instrumental record back from 1930 to 1750; and in using geoducks to reconstruct a record of Puget Sound/Strait of Juan de Fuca SST's from 1844 to 1920.

The next five years will show a very different orientation for the climate work. While yet unknown aspects of the Pacific Decadal Oscillation most relevant for the PNW still need to be clarified, especially the need for a nowcast of the PDO, the climate work will shift to a much more regional focus with regional climate products being the dominant emphasis. In particular, regional products arising from future predictions of ENSO and from projections of long term change in response to the anthropogenic addition of radiatively active constituents to the atmosphere. These products are needed for use in resource predictions for our stakeholders so that resource models and resource simulations can be made to aid resource and infrastructure decisions in the PNW on both short (seasonal) and long (decades) lead times. Effort will also be expended in designing a regional observing system appropriate to the problems in the PNW and in implementing a climate data and information distribution system so that our stakeholders can have access to the latest authoritative climate information for their own best use.

In the area of hydrology and water resources, the last five years have seen a concentration on the river basin scale and in particular, the Columbia and Snake Rivers. A major highlight during this time was the development of an experimental seasonal streamflow forecasting system for the Columbia River Basin which has now become quasi-operational. Additional products of the hydrological work have been the ColSim and SnakeSim reservoir simulation models which have been linked to the seasonal streamflow forecasts to produce truly useful reservoir storage forecasts for decision support for water agencies in the PNW. Work has also started on rivers on the west side of the Cascades, in particular involving water resources for Seattle, Portland, and Tualatin. The next five years will see the solidification of these products and the continued attempt to transition these products to appropriate agencies in the PNW.

A major thrust in the next five years for the hydrology and water resources sector (indeed for all the other sectors) will be the extension of the work to those smaller space scales that our stakeholders have told us is more useful: the watershed scale. Additional work will involve understanding and providing decision support for the conflict between instream flows and the flow needs of salmon. We have also proposed work on the hydrology of irrigated agriculture.

In the area of marine ecosystems, work over the last five years has concentrated on understanding the life cycle effects on salmon in the PNW, from coastal ocean to stream conditions. Climate has different effects at different stages of the life cycle: in the coastal ocean, climatic conditions are controlled by the state of the PDO and ENSO; in rivers and streams by the precipitation additions and withdrawals for agriculture, municipal water, and hydropower production. Additional work has dealt with the development of a fisheries ecosystem model for decision support of fisheries management in the California Current along the west coast of the U.S. The next five years will see an expansion and development of the marine ecosystems models for coastal species so that marine fishery managers will have a firm scientific basis for policy decisions on fish stocks and its changes under climatic variability and change.

In the area of forest ecology, the previous five years have examined the effects of climate variability, especially the PDO, on forest growth and productivity and on forest disturbances, especially wildfire regimes. Tree ring analysis has also been conducted to give a history of drought in the PNW since 1750. This is especially important since the PNW was settled only in the late 19^{th} century and the normal drought climatology can only be obtained via paleoclimatic reconstructions. The next five years will continue these studies and integrate them at the watershed level with hydrological models to be able to examine the effects of present and future forest management practices on the hydrology of the region.

In the area of coastal environments, the previous five years mostly dealt with the issue of coastal hazards due to climatic influences and the ability of government to use climate information to ameliorate coastal hazards. The next five years envisions a major expansion and integrations of the coastal environments sector. The overall goal of the larger, integrated project is to examine the multiple pathway linkages between anthropogenic activities at the watershed scale (e.g. land development and land use practices, including forestry) and stream flows and habitats, and the effects of those influences on salmon productivity and general estuarine ecology, both of which are also affected by coastal ocean conditions.

All these impacts of climate on the sectors and resources of the PNW are tied together by an integrated assessment activity. The previous five years has examined the effects of climate on each sector separately and how climate information can be used for better decision support in the various sectors. This work has been a prominent part of the National Assessment and has culminated in a major book, *Rhythms of Change*, slowly working its way through the publication process. Over the next five years, the assessment work will involve a much more horizontally integrated view of resource management in the PNW and arises from the interactions of salmon recovery, water management practices, the Endangered Species Act, and the stresses due to much increased population pressure and urbanization. The basic idea is to provide decision support for resource decisions in the PNW taking into account these complex and largely unknown interactions between the various sectors. This is a major expansion (both qualitatively and quantitatively) in our view of assessment in the PNW.

Finally, the human dimensions aspects of the Center asks basic questions about the ability of the PNW to use and plan for present and future climate variability and change. The past five years have examined the current ability of human institutions to use climate information and have identified institutional barriers to such use in each sector separately and identified options for overcoming these barriers. The next five years will extend the work to understanding the ability of institutions to deal with intersectoral knowledge and whether or not (and how) this can lead to better decision and management practices. The issue of how to best adapt to climate change over the next fifty or so years, will also be a major focus of the human dimensions work.

The education and outreach programs will see the continued development of additional tools, and outreach material to make better contact with our stakeholders. These are elaborated in detail in the body of the proposal.

The proposal closes with a set of questions that the Center was specifically asked to respond to by the program mangers of the RISA and CDEP program (Sec. 5). While they are answered implicitly in the body of the proposal, we thought it would be clearer to break out the answers explicitly.

The proposal concludes with a budget request (Sec. 7) for next year and the four years after that. It should be clear that this proposal is for everything the CSES wants to do not all of which will be supported by NOAA. The budget request is the NOAA part only—the CSES will attempt to fund other parts of this proposal through other sponsors if possible.

b. People and Places

The CSES arose out of a merger of the Climate Dynamics Group (CDG) and the Climate Impacts Group (CIG) in 2000. The Center is co-Directed by Ed Miles and Ed Sarachik with Nate Mantua as Assistant Director. Administration is provided by Adrienne Karpov and Mary Smith and their colleagues.

The CDG consists of David Battisti, Ed Harrison, Igor Kamenkovich, Nate Mantua, Todd Mitchell, Phil Mote, Eric Salathé, Ed Sarachik, and Mike Wallace.

The CIG consists of Ed Miles, Nate Mantua (Marine Ecosystems), Doug Canning (Coastal Resources and Management), David Fluharty (Human Dimensions), Bob Francis (Marine Ecosystems), Alan Hamlet (Hydrology), Dennis Lettenmaier (Hydrology), Ed Miles (Policy and Human Dimensions)), Phil Mote (Outreach and Washington State Climatologist), Robert Nordheim (Geographic Information Systems), Richard Palmer (Water Management), David Peterson (Forestry), Don Reading (Economics and Water Policy), Eric Salathé (Downscaling), Richard Slaughter (Economics and Water Policy) (Amy Snover (Integrated Assessment and Outreach), Lara Whitely Binder (Water Resources and Outreach).

In addition to the above there are a number of graduate students whose work will be mentioned in the rest of the proposal. Clearly there is much overlap between the CDG and CIG: this is a legacy of history. As time goes on, we intend for the distinctions between the two groups to be erased.

CSES Central is housed in the JISAO building with some of the senior people and graduate students in residence at their home departments. It makes use of shared space, computer resources, and administrative resources with JISAO.

2. The CSES Vision and Strategies

According to its Charter "The CSES researches the impacts of climate on the PNW in as integrated a sense as possible. It does this by combining and integrating expertise in climate dynamics, ecological dynamics, hydrologic dynamics and institutional and policy analysis, all concentrated on climate variability and change in the PNW. The CSES also researches the methodologies for accomplishing the above. It also researches the applications of climate information by servicing stakeholders in the PNW in support of the regional aspects of an eventual Climate Service."

CSES has been working since 1995 to increase the resilience of the PNW to fluctuations in climate, i.e., to provide resource managers and policy makers with the information and tools they need to improve their adaptability, and therefore decrease their vulnerability, to climate fluctuations and change. To this end, the Center performs interdisciplinary research aimed at understanding the regional consequences of natural climate variability and anthropogenic climate change and works with PNW planners and policy makers to bring this information into regional decision making processes. In effect, Center functions as a "pipe fitter", doing the work necessary to fit the outputs of climate research efforts (e.g., innovations in climate forecasting or advances in climate change projections) with the information needs and technological and institutional capacities of regional natural resource management entities (Figure 1), thereby connecting two otherwise mostly independent (and often mismatched) institutions.

Making innovations in climate research relevant to regional stakeholders requires basic and applied research on the linkages between changes in climate and changes in natural resources. The CSES strategy is to develop an assessment of the implications of past climate variability for natural resources as a basis for projecting impacts and proposing adaptation strategies for future climate variability and change. Our research focuses on identifying the environmental parameters to which each natural resource system is sensitive and delineating the links between (a) regional climate and key environmental parameters (e.g., changes in snowpack due to changes in winter temperature), (b) environmental parameters and natural resources (e.g., changes in summer streamflow as a result of changes in snowpack), and (c) planetary and regional scale climate (e.g., changes in PNW winter climate associated with El Niño conditions). This work draws on process-based quantitative models (as in the case of climate impacts on water resources), empirical models (drawing on observed historic patterns of climate and resource variation), and conceptual models (based on hypothesized connections between climate and impacts) at a variety of timescales. Center research also includes an analysis of the characteristics and adaptive capacity of human institutions involved in natural resource management.

The CSES conducted a second quinquennial survey in 2003 of all stakeholders in the four sectors in which we work to assess the extent to which they use climate forecasts and other information in planning and operations and to get a clearer and more systematic idea of their needs and desires. On the basis of that survey the executive group defined our future course for the period 2005-2010 in terms of the strategic questions listed in Appendix A. These questions are suffused throughout the programmatic design for the next phase of our work.

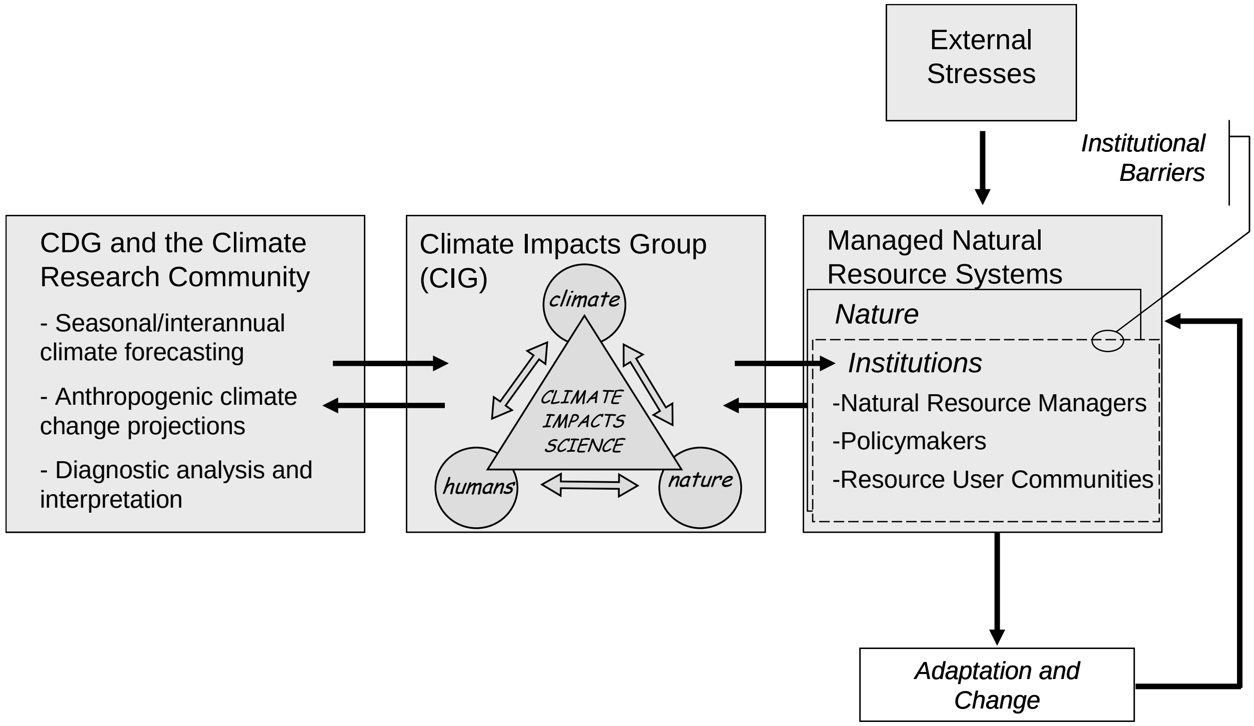


Figure 1. The CSES translates climate information about natural climate variability and human-caused climate change into regionally-specific natural resource forecasts/projections for stakeholders in the Pacific Northwest (PNW). This translation is made possible by climate impacts research, a study of how climate, natural systems, and human socioeconomic systems and institutions interact to determine a region's sensitivity, adaptability, and vulnerability to climate fluctuations. Through outreach activities, such as specialized resource forecasting workshops, one-on-one consultancies, and high level policy and planning meetings, CSES works to tailor and provide this climate information to regional decision makers, with the aim of improving regional resilience to climate fluctuations. The institutional adaptation and change that could result in improved resilience is often impeded, however, by institutional barriers, which may also filter incoming information. (Note that institutional adaptation and change can also result from other external stresses on the management system.)

3. Accomplishments over the Last Five Years

a. Climate Variability and Climate Change

The work of the CDG has looked at large scale climate variability and change and its climatic expression in the PNW.

ENSO:

Over the last five years significant work on the mechanisms of El Niño/Southern Oscillation (ENSO), its predictability, and the best way to monitor it has been accomplished.

- A new stable mechanism for ENSO has been proposed based on the idea that non-normal disturbances are excited by random noise. The mechanism shows the same predictability as unstable mechanisms and can be very simply formulated (Thompson & Battisti 2000, 2001).

- The stable mechanism for ENSO has such a simple form that predictions can easily be made. The TAO array was tested in this simple model and it was concluded that the array can be meridionally sparser (Morss and Battisti 2004) without sacrificing much prediction skill.

- Various reviews and assessments of ENSO were made for specialized and general audiences (Wallace et al. 1998; Harrison and Larkin 1998; Sarachik 1999, 2001).

- Mechanisms for the termination of warm and cold phases of ENSO have been proposed (Harrison and Vecchi 1999; Vecchi and Harrison 2003)

- Statistical methods for ENSO prediction were developed (Johnson et al. 2000) and ongoing predictions are available at:
  http://www.atmos.washington.edu/~wroberts/ENSO/forecasts.html

- Current capabilities for seasonal prediction, due to ENSO and other possibilities, was reviewed (Mote, Sarachik & Dequé 2000).

Pacific Decadal Climate Variability:

- A solid connection between interdecadal variations in North Pacific climate and the abundance of salmon and other marine species in the PNW and Alaska was demonstrated, and in so doing named and defined the "Pacific Decadal Oscillation" (PDO) (Mantua et al. 1997). The PDO is now recognized internationally as a major climate driver with wide-scale impacts on natural resources in the western U.S., Canada, and eastern Russia.

- Investigated the interdecadal modulation of interannual climate variability in the North

Pacific (Minobe and Mantua 1999).

- Carefully analyzed the mechanisms for a PDO in a coupled numerical model of the climate (Vimont et al. 2001, 2003).
- Showed that the "footprinting" mechanism characteristic of mid-latitude Pacific decadal variability could have an effect on ENSO (Vimont, Wallace, and Battisti 2003).
- Showed, on the basis of NCEP Reanalysis, that the decadal ENSO-like mode is symmetric with respect to the equator (Garreaud and Battisti 1999).
- Published PDV review articles for peer-reviewed professional journals (Mantua 2001; Mantua and Hare 2002) and for the Climate Risk Solutions industry newsletter (Mantua 1999) and as a book chapter (Sarachik and Vimont 2003).
- Convened two sessions on PDV at national professional meetings (AGU/ASLO Ocean Sciences, Fall 2002, Mantua) AGU Annual Meeting, Spring 2002 (Mantua and Sarachik)
- Convened a NOAA/NASA/NSF sponsored workshop on PDV to draft a PDV prospectus in Arlington, VA (February 2003) (Mantua and Sarachik).

Other Climate Variability:

- The Arctic Oscillation (AO) was named here (Thompson and Wallace 2000), and was shown to be useful for climate prediction (Thompson et al. 2002; Wallace and Thompson 2002) and especially for extreme events in the U.S. including the PNW (Thompson and Wallace 2001).
- Significant work has been done on the factors that weaken the thermohaline circulation of the world's ocean as global warming sets on (Kamenkovich et al. 2003; Kamenkovich and Sarachik 2004.) The thermohaline circulation not only affects the global climate, but essentially determines the nature of ENSO by affecting the mean depth of the Pacific equatorial thermocline (Huang et al. 2000; Goodman and Sarachik, in review).
- Established that sub-seasonal variability in the tropics can affect higher latitudes and may be predictable, thereby extending the range of deterministic predictability (Bond and Vecchi 2003; Vecchi and Bond, in press).

Large Scale Influences on Pacific Northwest Climate Variability:

- Work on La Niña impacts on PNW climate (Mantua 2002; Harrison and Larkin 2002) and on effects of ENSO on higher latitudes (Harrison and Larkin 1998; Bond and Harrison, in review) has allowed the characterization of PNW climate variability and trends, noting, for example, (1) the association of warm-dry and cool-wet winters with warm and cool phases of ENSO and PDO, and (2) the links between several other large-scale climate modes (e.g., Pacific North America pattern and the Artic Oscillation) and extreme weather events such as windstorms, cold air outbreaks, and snow.

- Developed a set of web-pages for linking 2-week lead-time forecasts of dominant atmospheric circulation patterns (the PNA, AO, and NAO) to extreme weather events in North America (http://www.cses.washington.edu/cig/fpt/extreme.shtml; also see Brown 2002).

Identifying 20th Century Trends:

20th century trends in temperature, precipitation, and snow water equivalent (an important indicator for predicting summer water supplies) have been analyzed using data from the U.S. Historical Climate Network for the PNW. The research finds that annually averaged PNW temperature and precipitation increased more than the global average during the 20th century. The research also identified significant decreases - up to 60% at some locations - in PNW snow water equivalent over the second half of the 20th century (Mote 2003, 2004). Decadal-scale variability in the North Pacific, as represented by the North Pacific Index, accounts for about one-third of the warming trends during the winter in the region west of the Cascades, slightly less farther east and in spring, and not at all during other seasons. These trends are consistent with projected climate change impacts for the PNW and, as such, have generated significant interest among water resources managers throughout the PNW.

Identifying Climate Impacts on Key Pacific Northwest Resources:

CSES has demonstrated how ENSO, PDO, and other aspects of climate influence key natural resources in the PNW, including: snowpack, streamflow, flooding, and droughts; forest productivity and risk of forest fire); salmon returns; and quality of coastal and near-shore habitat. Warm phases of ENSO and/or PDO, for example:

- increase the probability for reduced snowpack, streamflow, flooding, salmon returns (PDO only), and coastal and near-shore habitat quality (Hamlet et al. in press),

- increase the probability for drought and forest fires (Hessl et al. 2004), and

- contribute to increased tree growth and ecosystem productivity at higher elevations (with the opposite effect at lower elevations) (Gedalof et al. 2002) .

Cool phases of ENSO and PDO increase the probability for the opposite effects.

Paleoclimate Reconstruction:

The frequency and intensity of phases of the Pacific Decadal oscillation and of ENSO are crucial determinants of the climate of the PNW and probes of its vulnerability. Since the instrumental record is so short and the characteristic periods of the PDO so long, the only way to get a handle on these characteristics is through paleoclimate reconstructions.

- Demonstrated the utility of using geoduck clam growth rings for paleo-environmental reconstructions with a 160 year SST and PDV reconstruction (Strom et al. 2004).

- Demonstrated the utility of using a multi-proxy approach for PDV climate reconstructions, and produced a new PDO climate reconstruction back to 1750 (Gedalof et al. 2002)

- Developed a paleo-reconstruction for Columbia Basin runoff and drought since 1750 (Gedalof et al. 2004).

As a result of this research, we have been able to conclude, for example, that:

- The 1930s drought in the Columbia Basin was probably the second worst in the last 250 years (after the 1840s). This finding is important for water resource managers using the 1930s drought for "worst case scenario" planning.

- Innovative use of geoduck shells to reveal climate signals since the mid-1840s places the 1990s as the warmest decade of the last 154 years for March through October sea surface temperatures in the Strait of Juan de Fuca. Other warm periods occurred during 1870s, the 1900s, and the years from 1926 to 1934.

- The variability of the PDO over the past several hundred years has fluctuated, with the period of 1800 to 1920 (roughly) having lower interdecadal variance than other times.

The extension of the PNW's climatological record provides valuable insight into the potential range of climate variability in the PNW, potentially allowing for more complete evaluation of infrastructure planning needs and future climate impacts

<u>Downscaling:</u>

We have focused on two approaches to simulating the regional climate: statistical downscaling and regional climate modeling.

Statistical Downscaling

We have developed statistical downscaling methods tailored to the PNW (Salathé 2003, 2004a; Widmann et al. 2003) and have applied these to downscale several of the global climate change simulations distributed by the Intergovernmental Panel on Climate Change (IPCC) (Salathé 2004a). The downscaling methods apply to both monthly-mean temperature and precipitation and a method for disaggregating monthly means to daily values has been developed. The downscaled data have been applied to hydrologic modeling.

The precipitation downscaling methods and streamflow simulations using the downscaled data have been validated using NCEP reanalyses as the large-scale fields (Salathé 2003). These results show that the downscaling method captures both interannual and decadal variability in precipitation. The ability to capture natural climate variability suggest the downscaling methods are appropriate for downscaling climate change simulations. Climate-change simulations from the ECHAM4, HADCM3, and NCAR-PCM models (Salathé 2004a, b) have also been downscaled over the Columbia Basin at 1/8-degree daily resolution. Comparisons of streamflow simulations from these downscaled data help illustrate important differences among the ability of global models to simulate large-scale patterns that control the PNW climate.

Regional Climate Modeling

We have developed a high-resolution climate model of the PNW based upon the MM5 mesoscale weather model. A graduate student, Patrick Zahn, is supported by CSES and is undertaking much of the model development and validation. Prof. Clifford Mass in the Atmospheric Sciences department is participating in this effort and brings expertise in mesoscale meteorology and numerical forecasting for the region.

We are currently using this model to downscale simulations from the National Center for Atmospheric Research-Department of Energy (NCAR-DOE) Parallel Climate Model (PCM). To match the climate model grid spacing of approximately 300 km, we use nested grids of 135, 45, and 15 km resolution.

The use of nudging in this model is an important distinction to other approaches. Nudging preserves the large-scale state provided by the global model. Thus, the downscaling provides the regional meteorological details consistent with that large-scale state without attempting to improve the large-scale state, which is assumed to be well resolved by the global model. We have also made improvements in how the land-surface is treated in the model to better account for the seasonal cycle in soil properties.

<u>Support for Climate Impacts Applications:</u>

We are collaborating with an EPA STAR project on the effects of climate change on air quality. For this project, we are providing regional climate simulations using the MM5 regional model to downscale Parallel Climate Model (PCM) simulations of present-day and climate-change conditions. Preliminary results for this study were presented at the American Meteorological Society meeting (Chen et al. 2004). Global warming, population growth, and land use change are closely interrelated forces that may cause significant changes in air quality and human health within the U.S. Assessing the potential impact of global change requires a comprehensive numerical modeling approach that explicitly incorporates the effects of global change.

<u>Evaluating the Impacts of Global Climate Change:</u>

The CIG has taken a lead role in researching the regional impacts of climate change on the PNW, conducting the nation's first comprehensive examination of climate change impacts on the PNW and using the results of that work as a foundation for outreach and continued research. The CIG's research projects significant challenges in the decades ahead for the region's water resources, salmon, forests, and coasts as a result of human caused global warming. These challenges include:

- an increased risk of winter flooding and summer drought;

- an increased risk of salmon mortality in freshwater habitats as a result of warmer water temperatures, winter flooding, reduced summer flows, and summer drought;

- an increased risk of forest fires and changes in forest growth and regeneration at the high elevation forest/alpine meadow interface (increased growth) and low elevation forest reaches (decreased growth, particularly in drier forests east of the Cascade mountains); and

- an increased risk of coastal erosion and flooding as a result of sea level rise.

Continued research on climate change impacts and the integration of this research into PNW resource management is a major focus of the CIG.

b. Hydrology and Water Resources

Research in the hydrology and water resources sector of the Climate Impacts Group has focused over the last five years on:

- Understanding the effects of climate variability and climate change on hydrologic variability in the PNW and assessing the impacts to water resources systems,

- Developing experimental streamflow forecasting systems linked to climate forecasts at a variety of timescales (seasonal to interannual and long-range climate change scenarios),

- Developing specific water resources planning and management applications to make use of these experimental forecasting products, and assessing the skill, error characteristics, and value of experimental forecasts to particular users,

- Education, outreach, and partnerships designed to share information and experimental products and to develop ongoing relationships with the evolving user community and operational forecasting agencies.

Much of the research that forms the foundation for the CIG's continuing research efforts in hydrology and water resources was conducted from 1996-1999. From 2000-2004 continued research on these topics has extended the scope, breadth, and depth of these research topics.

<u>Impacts of Climate Variability and Change in the Columbia River Basin:</u>

A series of linked hydrologic and water resources models for the Columbia River Basin (with additional linkages to global and meso-scale climate models) were developed and refined from 1996-1998, and various climatic and hydrologic data sets were assembled. These tools were extensively exercised in 1998-1999 in support of the CIG's contribution to the US National Assessment of Climate Variability and Change (Gleick 2000; Hamlet and Lettenmaier 1999b; Mote et al. 1999). The research findings for the National Assessment were also updated and published as a separate journal article (Mote et al. 2003). Additional integrated studies on climate and water management in the Columbia River basin were conducted in 1999-2003 using these models (Cohen et al. 2000; Miles et al. 2000; Hamlet 2003). Many of these findings are also discussed in several chapters of *Rhythms of Change*, which is currently under review (Miles and Snover (eds) 2004).

In 2003-2004, extended gridded precipitation and temperature data sets at 1/8 degree from 1915-2003 have been developed (Hamlet and Lettenmaier 2004), which have so far been used to study the effects of climate variability and change on snowpack in the Western U.S. from 1916-2003 (Hamlet et al. 2004; Mote et al. 2004).

Seasonal-to-Interannual Streamflow Forecasts:

In 1998-1999, a suite of hydrologic simulation tools for long-range streamflow forecasting were constructed using the previously developed Variable Infiltration Capacity (VIC) hydrologic model (Liang et al. 1994) for the Columbia River basin and linkages to various kinds of climate forecast information (for an overview see Hamlet and Lettemaier 2000; Lettenmaier 2003). Streamflow forecasts using resampling techniques based on forecasts of the PDO and ENSO were first developed (Hamlet and Lettenmaier, 1999a) and the evaluation of techniques using meso-scale and global climate models followed (Leung et al. 1999).

Starting in 1998, long-range forecasts (i.e. up to one year lead times) for the Columbia River at The Dalles were produced each year in June (http://www.ce.washington.edu/~hamleaf/DallesForecast.html). These forecasts were typically updated in September in preparation for the CIG fall water workshops (see section on outreach below). The VIC hydrologic model has been continuously updated from 1998-2004. The first versions used for CIG streamflow forecasting were implemented at 1 degree resolution over the Columbia basin, with the latest versions running at 1/8 degree resolution over the Columbia basin and coastal areas. Long-range forecasts for The Dalles continue to be produced once a year in mid-summer. The forecasting methods developed under CIG funding in the past five years have also been transferred to a quasi-operational forecasting system (developed and supported under separate funding) for the western US (http://www.hydro.washington.edu/Lettenmaier/Projects/fcst/). Experimental streamflow forecasting applications for the Seattle Water Supply system using similar techniques developed for the Columbia basin are currently being produced under separate funding (http://www.tag.washington.edu/projects/midrangefore.html).

An evaluation of the retrospective skill and error of long-range streamflow forecasting techniques for the Columbia basin using resampling methods is currently in progress with a paper anticipated this fall.

Climate Change Scenarios for Water Planning Studies:

In addition to the climate change research conducted for the National Assessment (described above), additional research has focused on the development of streamflow scenarios to support long-range water planning by specific water management agencies in the PNW (Snover et al. 2003). These scenarios are made available on the web (http://www.ce.washington.edu/~hamleaf/climate_change_streamflows/CR_cc.htm), and currently support the GENESYS model used by the Northwest Power and Conservation Council, and the ColSim and SnakeSim reservoir models (described below) developed by the CIG researchers. These scenario generation efforts are associated with several ongoing partnerships described below. Similar techniques have also been applied (with additional funding from the Portland Water Bureau and Seattle Public Utilities) to produce climate change scenarios for smaller watersheds in the Cascades (Hahn and Palmer 2003; Wiley 2004), and in the Tualatin basin in Oregon (primary funding for this project was provided by the City of Tualatin, OR)

Water Resources Research and Applications:

Several water management models have been developed for use in CIG research. The **ColSim** reservoir model (Hamlet and Lettenmaier, 1999b) simulates the reservoir operations in the Columbia River basin. **SnakeSim**, a more detailed model of the Snake River basin (a major tributary of the Columbia) is currently nearing completion, and encompasses the complex ground water and surface water management issues in the basin. This model will be used in ongoing research to conduct integrated assessments of the Snake River basin in the context of climate variability and climate change.

Previously developed water management models of smaller water supply systems have been used in CIG studies of the Portland Water Supply system (Palmer and Hahn 2002 (http://www.tag.washington.edu/publications/papers/PortlandClimateReportFinal.pdf) and for the Seattle Water Supply system (Wiley 2004).

An application of the CIG's long-range streamflow forecasts to the operation of the Columbia River hydro system has been developed, and the economic value of these forecasts for non-firm hydropower in the Columbia River basin was assessed by Hamlet et al. 2002. Economic benefits were shown to be on the order of $150 million per year.

The ColSim and SnakeSim reservoir models have also been linked to experimental streamflow forecasts to produce experimental ensemble forecasts of reservoir storage. These experimental products are currently presented at the CIG's fall water workshops.

In addition to the climate change research described above, a study on water management adaptation to climate change in the Columbia River basin (primarily funded by DOE under the Accelerated Climate Prediction Initiative) was conducted by Payne et al. (2004) using the ColSim model.

Current research by CIG members Richard Slaughter and Don Reading on evolving water allocation in the Snake River basin will ultimately be linked (via water allocation scenarios) to the SnakeSim water resources model. This research will facilitate an integrated assessment of water markets as an adaptation strategy to population growth, changing socio-economic conditions, and climate change.

The CIG's Role in the Adoption of Climate Information and Forecasts by Decision Makers:

Many social, professional, institutional, and economic obstacles in the water management and operational forecasting communities constitute barriers to the adoption of new sources of climate forecasts and information. The CIG outreach strategy has been to prepare the water resources user community to interpret and make use of new forecasting systems that incorporate climate information (via education, workshops, and pilot forecasting and decision support applications) while simultaneously developing and evaluating experimental forecasting systems to help promote fully operational forecasting applications in agencies like the Pacific Northwest River Forecast Center and the Natural Resources Conservation Service.

Early adopters of experimental streamflow forecasting systems using PDO and ENSO forecasts have been small hydropower companies (e.g. Seattle City Light and PacificCorp via streamflow forecasts provided by 3-Tier Environmental Forecast Group) and small, innovative water management agencies such as Seattle Public Utilities. The US Army Corps of Engineers has also recently produced new statistical forecasts based on the CIG's method for November 1 and December 1 at Libby Dam using the Southern Oscillation Index (a simple ENSO forecast) as an explanatory variable. The Portland Water Bureau, Seattle Public Utilities, the Northwest Power and Conservation Council, and the Idaho Department of Water Resources have (in partnership with the CIG) taken a leadership role in incorporating climate change scenarios into long-range planning. These early adopters are helping to place the use of climate forecasts in the context of professional practice and to provide a "road map" for other water management agencies who may be interested in using climate information in their decision support systems.

One important aspect of the problem that has been a significant obstacle to producing fully operational products from official sources has been the lack of funding and personnel to move academically developed forecasting technology into the operational agencies. The CIG's experience in its outreach program, and specific recommendations from CIG researchers has been instrumental in developing sources of funding for this purpose via the NOAA Climate Transition Program. Several proposals to this program associated with CIG partnerships within the management community are anticipated this year.

<u>Honors and Awards in the Hydrology Sector:</u>

2001 AWRA Boggess Award, Best Paper in 2000. Journal of the American Water Resources Association. (Miles, E.L., A.K. Snover, A. Hamlet, B. Callahan, and D. Fluharty, 2000. Pacific Northwest regional assessment: The impacts of climate variability and climate change on the water resources of the Columbia River Basin. *Journal of the American Water Resources Association* 36(2): 399-420)

Best Practice Oriented Paper in 2002. Am. Society of Civil Engineers Journal of Water Resources Planning and Management. (Hamlet, A.F., Huppert, D., Lettenmaier, D.P., 2002. Economic value of long-lead streamflow forecasts for Columbia River hydropower. ASCE *Journal of Water Resource Planning and Management* 128(2): 91-101)

c. Marine Ecosystems

<u>Climate and PNW Coastal Coho Salmon – A Look at the Ocean:</u>

This research is a collaboration between the CIG and NOAA's National Marine Fisheries Service (Northwest Fisheries Science Center and Alaska Fisheries Science Center) to study physical processes that affect marine productivity in the PNW coastal ocean, with a particular focus on Oregon coastal coho salmon.

This research breaks new ground on a number of fronts. Most important we posit that it is the sequencing of events in the PNW coastal ocean that affects marine survival of maturing coho salmon. This sequencing starts in the winter before ocean entry – what we call winter preconditioning set by the intensity of the winter Aleutian Low and the state of the tropical ENSO process. It then continues into the spring of ocean entry with the timing of the transition in prevailing coastal wind from southwest to northwest, the density structure of the upper ocean, and the intensity and variability of the coastal upwelling process. Finally ocean conditions during the first and only winter most coho spend in the ocean ends the sequence. In particular we point out that while this sequence seems to be what is important to coho productivity, the individual processes that make up the sequence are not necessarily correlated. This research resulted in the publication Logerwell et al (2003).

PNW Climate Reconstructions using Geoduck Shells:

Understanding the interannual to interdecadal climate variability of the North Pacific Ocean requires longer historical climate records than those currently available. To extend ocean temperature records we have developed a new tool for paleo-climate reconstruction using growth rings in geoduck clams. We demonstrate that the shells of these long-lived clams, when collected from appropriate sites, can provide high quality proxy records of past ocean temperatures. The highest rates of shell accretion in the 154-year chronology occurred during the 1990s. This is consistent with climate data indicating that the 1990s was the warmest decade on record in the PNW. The results of this work are Are Strom's MS thesis and Strom et al (2004).

Climate, Habitat and Productivity of Sardine and Hake in the California Current:

CIG-support Ph.D. research focuses on how the relationship between climate and ocean habitat for Pacific sardine and Pacific hake, throughout their life histories, affect manifestly different patterns in their population dynamics. Sardine is notorious for its outbreaks of high abundance followed by large crashes in the population – patterns that have temporal coherence throughout the North Pacific Hake, on the other hand, has shown high frequency spikes in production in alternation with periods of low abundance. Both species seem to have close temporal and spatial overlaps in terms of their spawning off Mexico and southern California and seasonal feeding migrations to the PNW. Both species are the sources of major fisheries in the PNW coastal marine ecosystem as well as major ecological components. The most important findings of this study are the characterizations of hake and sardine habitat on both the southern spawning grounds and the northern summer feeding and fishing grounds.

- Localized physical variability in the California Current System provides an explanation for the amount of energy coastal pelagics in this system expend in migration.

- Pacific hake and sardine appear to have evolved to use space to compensate for variability in their environment. They migrate long distances within the California Current. This allows them to take advantage of locally favorable conditions in a dynamic environment.

- Hake spawning habitat occurs below the mixed layer and is influenced most strongly by ENSO scale variability. Their migratory extent in the northern feeding grounds is influenced by the intensity of the subsurface Davidson Current which in turn varies at the PDO (interdecadal) scale.

- Sardine spawning habitat occurs in the mixed layer and is influenced most strongly by PDO scale variability. The strength of sardine recruitment seems to be independent of available food during the early life history phase. The population seems to explode with a series of very strong year-classes when surface ocean temperatures warm, expanding the winter spawning habitat into California and the summer feeding habitat as far north as the British Columbia coast.

<u>Toward a Fisheries Ecosystem Plan for the Northern California Current:</u>

This project (partially supported by Washington Sea Grant) focuses on developing an ecosystem perspective for managing fisheries in the Northern California Current (NCC), and has resulted in the first climate driven ecosystem scale model the PNW coastal ocean. The model is forced by climate from both the bottom up (primary production) and top down (predation). Major findings so far include:

- A picture of how climate structures NCC production is that in years with a weak winter Aleutian Low (PDO-), strong southward advection of cold subarctic water and strong upwelling winds in spring and summer, primary production is high and the zooplankton community comprises large subarctic copepods and abundant euphausiids. Such years tend to be associated with significantly greater success for juvenile salmon, rockfish, sablefish, shrimp and other residents. In other years, particularly strong Aleutian Low (PDO+) winters and/or El Nino (or El Nino north) years, the surface of the ocean is warm, the mixed layer is deep and strongly stratified at the bottom, primary production tends to be much lower, the zooplankton community tends to be subtropical and have much lower production, and there is less forage for resident herrings, anchovies, smelts and other forage fish. In addition, sardine, hake, mackerel and other migrants from the south flood further north during these warm years, bringing ravenous appetites, and perhaps outcompeting (or simply eating) the juveniles of the resident species of salmon, rockfish, sablefish, and shrimp that tend to do poorly in such years. Life blooms but not as brightly as when things are cooler.

- Developing and balancing a static ecosystem model have shown how important migratory coastal pelagics (hake, sardine) are predators, competitors and prey for other elements in the ecosystem.

- Fitting the dynamic version of the model to data on abundance and fishery harvests have shown how important climate is in structuring the system both from the bottom up and top down. Bottom-up forcing was drawn from the analysis of Logerwell et al (2004).

- Among the management recommendations are the need to appoint a regional fisheries oceanographer to advise the Pacific Fishery Management Council. This person's main role would be to act as a conduit between the climate research community and the fisheries management community by synthesizing climate (atmospheric and oceanic) information and findings, in particular how they affect the structure, dynamics and fishery production of the PNW coastal marine ecosystem.

This project has resulted in the Ph.D. dissertation of John Field, now employed by National Marine Fisheries Service, Santa Cruz, CA.

Climate Impacts on Marine Ecosystems:

- Identified a climatically-driven inverse production pattern in Pacific salmon (Hare, Mantua and Francis 1999).

- Identified empirical evidence for climate and marine ecosystem regime shifts in the North Pacific (Hare and Mantua 2000).

- Described methods for linking large scale climate to local scale marine ecosystem dynamics (Mantua et al. 2002).

- Examined the potential impacts of anthropogenic climate change on coastal upwelling from the outputs generated by state of the art climate models (Mote and Mantua 2002).

- Described the uncertainties associated with greenhouse warming for fishery scientists (Mantua and Mote 2002).
- Developed a model for understanding and predicting Oregon coho marine survival based on coastal ocean processes (Logerwell et al 2003).

- Wrote a review paper on methods for detecting regime shifts in large marine ecosystems (Mantua 2004).

- Contributed to a review of evidence for regime shifts in marine ecosystems (de Young et al. 2004).

- Developed a model for linking climate to stream impacts on Oregon coho salmon productivity (Lawson et al 2004).

Application of Climate Information in Resource Management:

- Examined climate and extinction risk for Pacific salmon (Francis and Mantua 2003).

- Described approaches for bringing climate information into salmon fisheries management for short-term harvest and long-term restoration planning (Mantua and Francis, in press).

- On the basis of the new knowledge generated and in response to the stated desire of fisheries managers to be informed about the role of climate variability in explaining the observed underlying variation in the resources they manage, planned and designed a series of workshops to focus on salmon management and recovery in the Columbia Basin in Portland, OR. For September 21, 2004 and, for West side streams, in Seattle for late January/early February 2005. Transitioning the use of this new knowledge will be facilitated by our now close relationships with NMFS Northwest and Alaska Science Centers and our proposed Sea Grant extension links.

d. Forests

Research Focus:

- Forests encompass the primary source of productivity and carbon storage in the terrestrial biosphere. The response of specific forest ecosystems and individual species to climatic variability and change has been poorly described.

- Growth rates of dominant tree species are relevant for managing ecosystems for ecological benefits and economic outputs. Responses to climatic variability need to be quantified, so public lands can be managed more effectively in a changing climate.

- Better understanding of the effects of climatic variability on ecological disturbance, especially fire, is needed in order to incorporate climatically controlled disturbance regimes in management strategies.

- Better understanding of linkages between forests and the hydrological cycle is needed in order to accurately quantify the effects of climatic variability and change on mountain ecosystems.

Overall Strategy:

Representative watersheds (west side and east side) have been identified in the Olympic (Hoh, Dungness), North Cascade (Thunder Creek, Stehekin), and Northern Rocky Mountains (Lake McDonald, St. Mary's). These watersheds are the focus of empirical data collection in forest ecosystems, from low elevation to tree line. This approach facilitates multi-scale analysis of data with respect to the effects of climatic variability on forest resources over time (local [plot] → watershed → mountain range → region). Paleoecological studies, contemporary data, and modeling allow us to use climatic conditions of the past as a window into potential scenarios of the effects of future climatic change.

We addressed the response of forest ecosystems to climatic variability and change within the strategic framework of Climate-Landscape Interactions on a Mountain Ecosystem Transect (CLIMET, http://www.cfr.washington.edu/research.fme/climet).

Specifically we accomplished the following:

- Documented the effects of climatic variability (specifically the Pacific Decadal Oscillation) on growth and productivity of forest ecosystems at the regional scale (Peterson and Peterson, 2001, Peterson et al., 2002).

- Documented fine-scale effects of climatic variability on growth of mountain hemlock, subalpine fir, Douglas-fir, and Sitka spruce (Nakawatase, 2003, Holman, 2004).

- Quantified the relationship between the Pacific Decadal Oscillation and fire occurrence in eastern Washington since 1650 (Hessl et al., 2003).

- Quantified how synoptic climatology affected wildfire patterns in PNW forests during the 20th century (Gedalof et al., 2004a).

- Documented fire occurrence and fire effects on vegetation for montane forests of the Cascade Range for the past 10,000 years (Prichard, 2003).

- Reconstructed drought patterns for the Columbia River basin since 1750 (Gedalof et al., 2004b).

- Used tree-ring chronologies and coral data to provide a more accurate reconstruction of the Pacific Decadal Oscillation (Gedalof et al., 2002).

e. Coastal Environments

<u>Coastal Hazards:</u>

In Year 1 of the project [1995-1996] (Hershman and Waldeck 1996) we were able to do a literature review and to identify the major climate related impacts on coastal resources in the PNW. This led to the selection of three case studies for Year 2 work – South Puget Sound, the Southwest Washington and Oregon Coast, and Willapa Bay.

In Year 2 (Field and Hershman 1997) we studied the three case areas in detail to outline the impacts that could be related to five climate signals: Sea Level Rise, ENSO, PDO, GCM-Regional, Monotonic. In addition to impacts we identified anthropogenic changes and public decision processes that respond to and at times increase hazards stemming from climate related forces. This work set the stage for the institutional analysis in Year 3. In Year 2 (Johnson et al., 1998) the relevant decision processes for selected climate impacts problems were described and key officials in government interviewed to determine the degree to which climate related information is used, or perceived to be relevant to decisions. This was done for Washington and Oregon. Preliminary findings are that most officials are only comfortable using available historic data and probabilities derived from them and that they think the tools for forecasts and trends analysis are not precise enough for use in their work. At this point the work was terminated for lack of funding. Work was resumed in 2003-2005 but by then we had shifted the focus from coastal hazards to coastal watershed management.

f. Human Dimensions

1999 – 2001

By 1999 the Human Dimensions Sub-group had answered three specific questions directly:

1) What shortcomings in the design of institutional arrangements relative to climate variability and change can be identified and how can they be remedied?

2) What planning, adaptation, and mitigation policies vis-à-vis climate variability and change in the PNW currently exist? What shortcomings are evident? How can performance be improved?

3) Is it possible to integrate the capacities of the various management systems to make use of and respond to climate forecasts, climate variability, and climate change at the regional spatial scale?

The major failures in institutional design all sum up to a single result: the inability of the region as a whole to optimize water supply in the face of declining supply relative to demand and a significant additional shortfall in supply predicted as a result of climate change on the order of 2ºC by the year 2050. The second major shortcoming is that there do not yet exist policies at the regional level in the region to respond to current climate variability and future climate change, except for the single case of flood control. However, it should be noted that Idaho has been significantly innovative in responding to higher levels of water scarcity since 1919 than has either Washington or Oregon. These measures include the Committee of Nine, for direct allocation between natural flow and stored water (1919-26, continuing to today); water sharing and rental (c. 1935); changes in the definition of "beneficial use," the state water bank (1979); several water district-run rental pools; suspension of prior appropriation requirements during declared droughts; and conjunctive management, *inter alia*.

With respect to climate forecasts, the group concluded that:

1) The value of climate forecasts in an economic sense, as opposed to their potential operational utility, is highly variable, e.g., low for fisheries as presently managed but potentially quite high for hydropower(Kaje,1998; Hamlet, Huppert, and Lettenmaier 2002).

2) At present, climate forecasts are not generally seen to be useful by a clear majority of managers in all four sectors (Callahan, Miles, and Fluharty 1998).

3) To increase the utility of climate forecasts a great deal of reciprocal education is necessary between climate diagnosticians and the user community *(ibid)*.

4) Much greater specificity is required in the forecasts, along with a significant increase in skill. It is necessary to marry the forecast with a substantial amount of interpretation about impacts. And impacts interpretation must be targeted to different categories of management responsibilities *(ibid).*

5) Where anthropogenic effects dwarf the climate signal, managers are reluctant to invest much time or resources to understand the climate signal in their areas of responsibility *(ibid)*.

6) There was a universal mismatch (prior to the CIG's existence) between the attempt to inject climate variability and change considerations into operational management and the structure and dynamics of the institutional arrangements which define the management system *(ibid)*.

7) There is a clear need to create an iterative process between forecast producers, potential users, and regional researchers on impacts to facilitate understanding and interpretation on an ongoing basis *(ibid.)*.

As we considered how to proceed from 2005-2010, two requirements appeared to be high priority. First, several managers in outreach meetings had indicated quite strongly to us that the regional focus was not relevant to them. Unless we could talk directly to their *watershed level concerns,* they implied that our information was not really useful to them. Taking their challenge seriously, we proposed to explore what we could do with at least the largest watersheds, i.e. the Snake and Yakima Basins. We chose to begin with the Snake River and entered into a collaboration with three economists from Idaho: Professor Joel Hamilton on water markets, Professor Richard Slaughter (now in private practice with Richard Slaughter and Associates) on institutional adaptation to climate variability and demand change in the Snake River Basin, 1950-2000, and Dr. Don Reading, in private practice with Johnson and Associates, on the impacts of climate variability and change on development and non-development values of the Hell's Canyon complex. Because the institutional hurdles we had encountered relative to the use of climate forecasts in planning and operations appeared to be very severe, we chose to investigate water markets as an initial potential policy option to decision-makers facing increasing regional vulnerability to climate change

Later, Slaughter and Reading (Hamilton had retired) expanded the research agenda beyond water markets by adding "Incorporation of Climate Change Impacts into ROI Calculations Relative to Public/Private Investments: A Case Study of Ski Areas in Idaho." This work examines ways in which climate change information can enter into public policy decisions. Ski areas are a natural choice, because they involve long-term investment, are subject to climate conditions for a period that exceeds the forecast interval, and involve both public land and impacts on surrounding communities.

At the same time, we took the watershed challenge seriously and decided to invest in building a regional physical template because integrated assessments needed to develop the capacity to measure impacts, sensitivity, and vulnerability across all policy-relevant spatial scales and some managers were demanding a watershed focus.

By 2005 our goal was to have developed a physical regional model to assess quantitatively climate impacts on each sector via both direct and indirect interactive pathways. This physical template will be used to facilitate teaching of professionals and students with respect to the regional impacts of climate variability and climate change, and will serve as a useful tool for evaluation alternative policy response strategies. The goal as we phrased it in 1999 was as follows:

> "Develop a socio-economic database on time and space scales which are comparable to the physical and biological dimensions of our climate impacts model. Scale impact assessments and management responses to model parameters. Examine mitigation strategies in depth, beginning with an evaluation of the potential consequences of introducing water markets (i.e., pricing strategies) into the region as a mechanism for increasing both efficiency of use and organizational flexibility in the management system."

Significant Research Findings:

1) Ski area viability after 2020 will depend increasingly not only on altitude but also on availability of water for snowmaking. Many ski areas do not have access to sufficient, or inexpensive, water supplies to support snowmaking (Reading: "Global warming and ski area economics in the northwest" (submitted Spring 2004)).

2) Water marketing is becoming an increasingly viable means of adapting to climate stress, primarily drought. Water is being transferred between users and uses at an increasing rate in Idaho, though less so in Washington and Oregon. Markets are developing partly in response to moratoria on new water appropriations, and are supported by techniques that enable quantification of injury from water transfers, as well as by policies that support and regulate mitigation. A state water bank and rental pools are also assisting short term transfers as well as preservation of rights long term. Both innovations result in increased streamflow and increased willingness to adopt water saving technology (Slaughter: "Water Allocation Under Stress: ... "; Reading: "The many water markets ...").

3) Most water markets will operate under government regulation due to the specificity, in time and place, of water assets. Thus, a single market-wide price for water should not be expected, nor will transactions costs decline to levels seen in competitive markets (Slaughter: "Water allocation under stress ... ")

4) Water markets are based in techniques and policies that protect and define property rights in water, e.g., water banks, rental pools, water adjudications, limitation of transfers to consumptive use, injury measurement and mitigation (Slaughter: Institutional history of the Snake River; "Water allocation under stress ...").

5) Water allocation based on administrative processes, in the absence of market mechanisms, may become highly politicized when allocation outcomes change (Slaughter: Water allocation under stress ... ").

6) Markets are supporting changes of use from irrigation to instream municipal/industrial uses. Some of these transfers allow for interstate transfer as well as in-state. (Reading: "The many water markets ...")

7) Riparian and community allocation systems appear to be incapable of supporting water markets. (Reading: "The many water markets ...")

Other Human Dimensions Work

Watershed Spatial Scale Investigations:

CIG-supported graduate work led to a first effort at developing vulnerability indicators vis-à-vis climate variability and change for watershed planning in Washington and examination of factors influencing the inclusion of climate information in Washington State watershed planning. The focus was on the Water Resource Inventory Areas (WRIAs) of the state. The study was entitled: "Watershed Planning, Climate Variability, and Climate Change: Bringing a Global Scale Issue to the Local Level" (Whitely Binder 2002). This MPA degree project has resulted in the following paper currently in review at the *Journal of the American Water Resources Association*:

> "Factors Influencing the Integration of Climate Change into Long-range Watershed Planning," submitted to the Journal of the American Water Resources Association, August 2003 (accepted for second review, July 2004).

This project, and the paper which has resulted from it, examines issues related to integrating climate impacts into long-range watershed plans being developed under Washington State's Watershed Planning Program (ESHB 2514). A second component of the research involves identifying factors at the watershed level which may affect watershed vulnerability to the hydrologic impacts of climate variability and climate change. Identified vulnerability indicators include watershed type (rain, transient, snow dominant), watershed size, water use by source (groundwater versus surface water), major water uses, and water quality problems. Indicators are ranked by level of influence; assumptions regarding how the indicator affects vulnerability are also identified. The purpose of the vulnerability indicator research is to facilitate assessment of general vulnerabilities to climate impacts at the watershed level.

Miles and Doug Canning of Washington Department of Ecology (WDOE), leader of the CIG's Coastal Zone Sub-group, decided to shift the focus of the group from coastal hazards to watershed management and thereby to integrate the work of the group much more tightly into the mosaic formed by the other sectors. This decision was pursuant to a strategic planning exercise referred to earlier, the results of which are reported in Appendix A. The research question of highest priority was defined as follows:

> What are the critical interactions among resources (and resource management) that will shape regional impacts of climate variability and change, and how could cross-sectoral management improve adaptive capacity by exploiting those interactions?

As we considered our unfunded priorities in 2002, we decided that coastal watershed management was our highest priority for two major reasons. First, it would respond to acute needs of the watershed and coastal management community at state and local government levels in Washington and Oregon and provide the opportunity of continuing and deepening our collaboration with them at a time when they were (and still are) losing additional capacity as a result of budgetary reductions. Secondly, it would be a powerful aid to facilitating horizontal integration across all four sectors within the CIG, i.e. coastal zone, aquatic ecosystems, hydrology, and forest ecosystems. In our view, the coastal watersheds phase is a necessary step along the way to developing an understanding of estuarine ecology under climate variability and change regimes. Ultimately, we seek development of an integrated watershed-estuary-coastal ocean model.

Planning and Conducting a Second Survey of Stakeholders, 2002-2003:

In 1996-1997, we conducted our initial survey of stakeholders across the four sectors. However, a single survey is but a snapshot. In order to stay abreast of a changing environment, and as a means of assessing the effects the CIG might be having on the community, we decided to conduct these surveys every 5 to 6 years. Accordingly, our second survey involving 56 respondents from four sectors was completed during winter, spring, and summer of 2003.

All interviews have been completed and coded. Detailed analysis and one draft paper were completed in summer 2004. One paper has already been completed and accepted for publication:

> Andersen, M.S., E. L. Miles, and D. L. Fluharty. 2004. A comparison of the incorporation of climate forecasts and other climate information by coastal managers in the Pacific Northwest between 1996 and 2003. In conference proceedings for The Coastal Society 19th International Conference, Alexandria, Virginia: The Coastal Society.

g. Integrated Assessment

Integration and Assessments Research:

- ***Approaches to Integrated Assessment.*** Developing methodological approaches to regional integrated climate impacts assessment and stakeholder involvement, e.g., Climate Impacts Group (2000) [Climate Impacts Group 2000. *Climate Impacts Research at the University of Washington, 1995-2005*. Climate Impacts Group, University of Washington, Seattle.], Snover et al. (NOAA) (2003), Gamble et al. (2003), Snover and Miles (in prep) [*Rhythms of Change*, Chapter 2], Miles and Snover (in prep) [*Rhythms of Change*, Chapter 11].

- ***Characteristics of Adaptive Systems.*** Researching root causes and characteristics of adaptability in natural resource management (e.g., Snover et al. (NOAA) 2003, Snover et al. (BAMS) 2003).

- ***Pacific Northwest Assessment.*** We reviewed key results from the ongoing NOAA-funded *Integrated assessment of climate impacts on the Pacific Northwest.* Written for a variety of audiences (climate impacts scientists, more general biological scientists, and the general public), these highlight the region's sensitivity and vulnerability to temperature changes as they propagate through the hydrologic cycle to impact ecosystems and water resources in the region (Mote et al. 1999a,b 2003; Parson et al. 2000; Peterson et al., in prep). Applying the IPCC analytical framework of sensitivity, adaptability, and vulnerability to climate impacts on water resources in the Columbia River basin, Miles et al. (2000) won the American Water Resources 2001 Boggess Award for the best paper published in 2000. These results have also been presented at innumerable academic and public talks.

- ***Rhythms of Change.*** The CIG is nearing completion of the substantial revision of a book length manuscript prepared for MIT Press. The book is now in eleven rather than nine chapters. *Rhythms* presents a comprehensive treatment of the CIG's integrated assessment of climate impacts across all sectors of the PNW on the basis of work completed up to 2002. We have added a new chapter on the human rhythms of the PNW and integrated human dimensions more completely in each sectoral chapter as recommended by the reviewers. We have expanded our discussion of methods and approaches to integrated assessment, revised the analysis of patterns in the use of climate forecasts to take account of recent trends and re-written the concluding chapters putting heavier emphasis on horizontal connections across sectors. The manuscript will be resubmitted in 2004.

h. Service, Products, and Outreach, 1998-2004

The basic service the CIG provides has been described in the opening section of this proposal, i.e., we perform interdisciplinary research to understand the basic patterns of regional climate variability, to understand the ways in which those patterns generate typical impacts in the ecosystems and human social systems of four sectors of regional activity, and to share that understanding with regional planners, managers, and policy makers as they go about their jobs. Sharing the understanding is based on introducing products and engaging in an extensive outreach program. Sharing is also bi-directional since close and repeated interactions with stakeholders educate the CIG in considerable detail about their situations and needs. The CIG's outreach program and the role of specific partnerships within the developing user community are described in more detail by Gamble et al. (2004) and Snover et al. (2003: ftp://ftp.hydro.washington.edu/pub/hamleaf/papers/Snover_final.pdf). The full list of CIG outreach efforts from 1998-2004 can be found in Appendix C.

Contributions to Decision Support: Tools and Resource Forecasts:

A list of CSES decision support products is provided below. Where items have been described earlier in the paper, no commentary is provided.

- *Translating ENSO forecasts for use in resource management.* The CIG translates long-range ENSO forecasts into regional climate and water resource forecasts and works closely with agencies in applying these forecasts to resource management.

- *Climate-based long-lead (seasonal-to-interannual) streamflow forecasts.*

- *Seasonal forecasts for coho salmon survival.* The CIG has developed a new method for predicting marine survival for Oregon coastal coho salmon. These forecasts, made in collaboration with NOAA Fisheries, provide coho program managers at Washington and Oregon Departments of Fish and Wildlife with additional, independent, and likely improved run-size estimates early enough to be considered in annual harvest decisions.

- *Forecasting fire season severity in the PNW.* Using 47 years of wildfire data on U.S. National Forest land in the PNW, the CIG has identified several key atmospheric patterns that can potentially be used to develop risk-based forecasts for fire-season severity.

- *Forecasting extreme weather events up to two weeks in advance.*

- *Climate change streamflow scenarios for planning.*

- *Climate change impacts on municipal water supplies.*

- *Climate change impacts on the Pacific Northwest ski industry*.

- *Technology transfers to the stakeholder community.*

- *Office of the State Climatologist.* The CIG, in partnership with the Washington State Department of Ecology, has reinstituted the Office of the State Climatologist for Washington State. The State Climatologist provides valuable support to public and private entities through the collection and distribution of climate data, forecasts, and other information. Philip Mote, a CIG researcher and outreach specialist, is now serving as State Climatologist in addition to his general research responsibilities at the CIG.

- *Streamflow data server*.

In development:

- *GIS Decision Support Tool for the Pacific Northwest.* The CIG has hired a GIS-specialist with a M.S. in GIS and six years of experience to develop the GIS relational databases and relevant meta-data to support research on integrated assessment, aid communication within CIG, enhance external communication, and undergird decision-support tools for regional stakeholders. We are currently constructing the "physical template," a GIS-based quantitative virtual reality of the PNW to combine fine-scale information not only about climate impacts, but the regulatory, socioeconomic, and ecological environments in which they will occur. The initial phase of work has been completed; we have assembled the base layers of geospatial information necessary for a physical template of the PNW and the Columbia River basin, developed fine-scale boundary of the Columbia River Basin as a geospatial data layer, developed procedures for easy production of maps and animations of historical and forecast climate and for extracting output from the VIC hydrology model, and begun to develop maps of regional climate variability for an online climate information service. This work will continue into the next 5 years to support provision of fine-scale climate information to regional stakeholders.

Influencing Operations and Policy:

- *Increased agency interest in planning for climate change.* In 1997, policymakers and other stakeholders saw little need to plan for climate change. By 2002, partly in response to outreach efforts and media coverage of the CIG's work, many agencies and planning efforts are beginning to take climate change into account.

  Private sector:

  - On February 11, 2004, a group of middle to upper management of the Cascade Natural Gas Co. in Seattle sought the CIG's advice on how they should account for climate change in projecting natural gas demands on a timescale of 1-10 years into the future. Philip Mote represented the CIG.

  - On July 13, 2004 Philip Mote was invited by David Mills, Director of Power and Gas Supply Operations at Puget Sound Energy Co. to brief the executives on the CIG's findings and current state of research on climate change impacts on the PNW and then to meet with senior staff after the briefing to discuss the same issues. Puget Sound Energy is particularly concerned about the hydrological impacts of our climate change scenarios as they would relate to hydropower production and meeting their customers' future needs.

  Federal:

  - During the week of April 26, Philip Mote was invited to testify at the Hearings scheduled by Sen. John McCain, Chairman of the Senate Committee on Commerce, Science, and Transportation concerning a recent CIG paper analyzing snowpack trends in the Western U.S. as evidence of a changing climate. While in Washington, Mote was also invited to meet with a selection of staff members from the PNW Delegation to the U.S. House of Representatives concerning the CIG's efforts to prod the PNW to begin taking adaptive measures for climate change. Members of Congress from both Houses are now looking seriously at the question of what legislation would be appropriate in facilitating adaptive capacity.

  Regional:

  - The Columbia River Intertribal Fisheries Commission has developed an alternative operating plan for the Columbia River water resources management system for use in a future world affected by climate change based on the CIG's streamflow projections.

- In November 2003, the Governors of Washington, Oregon, and Idaho launched a Tri-State Initiative on mitigating western regional emissions of CO_2 into the atmosphere. By June 2004 all states had become interested in the issue of impacts and adaptation as well and the CIG was much in demand. Information has been provided to the California Energy Commission, the Governor of Oregon's Advisory Committee on Climate Change, the House Interim Subcommittee on Water of the Oregon Legislature, and the Governor's Office, State of Washington.

<u>State:</u>

- At the urging of, and in partnership with the CIG, the Idaho Department of Water Resources and the Northwest Power and Conservation Council plan to incorporate streamflows from future climate scenarios in their hydrological planning tools.

- The Future Water Needs Task Force for the Washington State Governor's Central Puget Sound Water Initiative recognized the potential impacts of climate change on PNW snowpack and run-off, recommending "that the State initiate a targeted research effort to evaluate the potential impacts to water supplies in the region. Academic institutions in partnership with the State and local governments and utilities in the region should conduct this effort" (Future Water Needs Task Group Report, 2002, p.6)

- Washington's Water Storage Task Force referenced the CIG and climate change impacts in its 2002 discussion of future water storage needs.

- In mid-May, 2004 the CIG was invited by the special Legislative Interim Committee on Natural Resources, through Mr. Karl Dreher, the Director of the Idaho Department of Water Resources, to give a presentation before the Committee on June 3, 2004, concerning our observations and projections for climate change in the PNW. The Committee is working to resolve water allocation issues involving surface and groundwater rights during drought and as a result of the adoption of irrigation efficiency measures in the 1980s which reduced aquifer recharge. The issue's priority has risen due to a water "call" that nearly, and may yet, result in curtailment of over 150 groundwater rights.

<u>Sub-regional</u>:

- With the CIG's assistance, several watersheds participating in Washington State's Watershed Planning Program have begun to incorporate climate variability and change into long-range plans.

<u>Municipal</u>:

- As a result of a briefing by the CIG, the City of Seattle's Office of Sustainability is working with Seattle City Light to consider use of the CIG's climate change information in projecting electricity supply and demand.

Education on Methods and Applications of Climate Impacts Research:

- *International Workshops on Regional Integrated Assessment of Climate Impacts.* The CIG convened the first and second International Conferences on Integrated Climate Impacts Assessment: Castelvecchio Pascoli, Italy (September 2002) and Grainau, Germany (June-July 2004). These 5-day workshops brought together practitioners and theorists of regional assessment to discuss methods and approaches, to share successes and failures, and to discuss the blending of academic research with policy influence. Each workshop was attended by ~45 attendees from more than 20 countries, including 15 people from 12 developing countries, many of whom were provided with fellowships to support their attendance. http://www.cses.washington.edu/Workshops/SICCIA/

- *Course on Climate and Natural Resource Management.* CIG team members developed and teach (yearly, since 2001) a University of Washington graduate course on "The Role of Climate Information in Natural Resource Management." This course examines current and future patterns of PNW climate and their impacts on regional natural resources and ways in which this information could be used to improve regional natural resource management. Reflecting its interdisciplinary nature, this course is cross-listed by the following units at the University of Washington: School of Marine Affairs, Atmospheric Sciences, Program on the Environment, Earth and Space System Science. http://www.cses.washington.edu/cig/outreach/classes/585/

- *Course on Science and Decision* Making. In collaboration with the University of Washington's Evans School of Public Affairs, the CIG developed and taught a new University of Washington graduate course on "The Role of Science in Environmental Decisions." This course examines how science contributes to decisions that involve the natural environment: how science and scientists help frame debates and decisions; how scientific findings are incorporated into decision-making processes; and how scientists and nonscientists deal with uncertainty about scientific questions. This course is listed as a core quantitative course in the Evans School of Public Affairs and is the core science-based course for the University of Washington graduate certificate program in Environmental Management.
http://www.cses.washington.edu/cig/outreach/classes/RoleofScienceS2004.pdf

- *Seminar Series on Decision Making.* In collaboration with the University of Washington Evans School of Public Affairs, CIG team members developed and organized a new university-wide seminar on risk-based decision-making in public sector natural resources management entitled "Decision Making in the Face of Uncertainty: Practitioner Views on Environmental Resource Management Challenges." Speakers from a variety of natural resource sectors discussed how their agencies approach decisions affected by uncertainty.
http://www.cses.washington.edu/cig/outreach/classes/uncertaintysem03/index.html

- *Seminar on* ***Consequences of Climate Change and Climate Variability for Pacific Northwest Forests.*** CIG researchers developed and ran a University of Washington graduate seminar to build on previous reviews of climate change and climate variability impacts on forest ecosystems. Seminar participants surveyed the rapidly growing body of recent regional, national, and international research to examine the roles of variability, uncertainty, complexity, and vulnerability of forest ecosystems adapting to environmental change within the construct of human natural resources management efforts and policy. Each participant developed a fact sheet focusing on a specific aspect of climate impacts on forest ecosystems for use by the CIG outreach team. http://www.cses.washington.edu/cig/outreach/classes/521A_Forests.pdf

- *Course on Global Climate Change and Regional Impacts.* The CIG developed and taught a new Oregon State University graduate course on "The Science and Policy of Global Climate Change."

Infrastructure Development:

- *CSES Website.* The CIG managed the design and development of a new CSES website oriented towards the needs and interests of stakeholders, the media, academia, and interested members of the public. The new site provides greatly streamlined access to information about CSES, our products and forecasts, outreach events, research results and current projects, datasets, and publications. It demonstrates how CSES is creating the foundation for a regional climate service: http://www.cses.washington.edu.

Web Sites Maintained:

- CLIMET: Mountain Ecology: http://www.cfr.washington.edu/research.fme/climet
- Western Mountain Initiative: http://www.cfr.washington.edu/research.fme/wmi
- Experimental Streamflow Forecasts: http://www.ce.washington.edu/~hamleaf/DallesForecast.html
- Mid-Range Hydrologic Forecast Tool: http://www.tag.washington.edu/projects/midrangefore.html
- Climate Change Streamflow Scenarios for Water Planning Studies: http://www.ce.washington.edu/~hamleaf/climate_change_streamflows/CR_cc.htm
- Land Surface Hydrology Group Publications: http://www.hydro.washington.edu/Lettenmaier/Presentations.html
- CIG Meeting and Workshops: http://www.cses.washington.edu/cig/outreach/workshops.shtml
- ENSO Prediction Papers and Site: http://www.atmos.washington.edu/tpop/pop.htm
- Pacific Decadal Oscillation: http://www.jisao.washington.edu/pdo/
- ENSO Statistical Predictions: http://www.atmos.washington.edu/~wroberts/ENSO/forecasts.html
- Pacific Northwest Extreme Weather Event Forecasts: http://www.cses.washington.edu/cig/fpt/extreme.shtml

4. Proposed Work for 2005-2010

During 2005-2010, CSES will expand on the work of the previous five years in each sectoral area with the aim of developing increasingly integrative assessments of climate impacts and of potential climate response strategies. This work will focus on those smaller space scales that our stakeholders have told us are more useful – the watershed scale – and on important resource issues currently facing the region. In addition, the Center will significantly expand its horizontal (across sector) integrated assessment capacity in order to assess the complex and largely unknown interactions among individual resource sectors, regulations affecting regional resources, and other anthropogenic stresses. This assessment will undergird the development of decision support tools for PNW natural resource managers and other stakeholders of the Center. Finally, the Center plans to significantly expand its education, service, and outreach efforts providing decision support to the region's natural resource managers.

a. Climate

During 2005-2010, climate research will focus on (1) developing regional climate products (stemming from ENSO predictions and anthropogenic climate change projections) to support forecasts and projections of future regional natural resource conditions undertaken elsewhere in the Center, (2) designing a regional observing system appropriate to the most pressing natural resource issues in the PNW, and (3) implementing a climate data and information distribution system to facilitate transfer of the latest authoritative climate information to the Center's regional stakeholders. In addition, the Center continues to provide climate advice to the nation and world.

<u>Support for Climate Impacts Studies:</u>

Regional Climate Modeling And Downscaling

The principal objective of mesoscale climate research conducted within the CSES is to provide data products to support climate impacts studies. The statistical downscaling method developed previously has been well validated for hydrologic studies. The downscaling has been applied to a variety of global climate change simulations and streamflow results have been computed for sub basins of the Columbia (Salathé 2003, 2004a). We will expand our application of this method, producing a comprehensive set of downscaled climate model results and corresponding streamflow simulations based on this method to be distributed by the CSES live access server (see Outreach: Infrastructure Development, below).

The development of a regional numerical climate model permits broader application of climate simulations to climate impacts studies. While statistical methods are adequate for downscaling precipitation and temperature for studies on the scale of the Columbia River Basin, studies in smaller regions or studies that need additional parameters are not well served by the statistical model. The regional numerical model will provide the full suite of meteorological and land-surface parameters required by a broad range of applications, such air quality projections or ecological modeling. Furthermore, the numerical model will more adequately simulate processes critical to small regions, such as basins used in municipal water supply in Western Washington.

Future work on downscaling will concentrate on the following topics:

Meteorological Processes and Regional Climate Impacts

The statistical downscaling methods applied in the PNW assume that the trends in precipitation and temperature associated with climate change and the anomalies associated with seasonal variability are well represented by global models. However, there are a number of mesoscale meteorological processes, which interact with the large-scale climate state, that may produce local trends that do not match those represented in global models. For example, global models do not resolve the local topography and cannot represent orographic precipitation processes that are critical to PNW rainfall.

Climate scenarios and regional climate model simulation experiments will be designed to study the relationship of orographic and convective precipitation, ENSO teleconnections, marine influences, and snow and soil-moisture feedbacks to climate change and variability. Understanding changes in mesoscale meteorology is critical to predicting the vulnerabilities of regional natural resources (e.g. water, fisheries, forests) to climate change and variability, and the project will coordinate with regional projects applying climate results to impacts studies.

Realistic simulations of the sensitivity of the local climate to changes in global patterns is essential to applications research in the Climate Impacts Group and will be critical to developing adaptation strategies for resource managers and stakeholders. High-resolution output from the regional model will be linked to hydrological and air-quality applications for climate impacts studies and freely distributed via the Internet. Through collaboration and interactions with ongoing climate impacts research both in the Center and elsewhere, we shall tailor the regional simulations to the needs of the research and stakeholder communities.

Downscaling Seasonal NOAA Forecast Products

To improve seasonal forecasts of the PNW regional climate and streamflow we plan to use coupled mesoscale meteorological and hydrological models to downscale global seasonal forecasts. This project builds upon NCEP global ensemble forecast products. In this work, we will interact with researchers performing global climate forecasts at NOAA/NCEP (Dr. Arun Kumar) and at the Scripps Experimental Climate Prediction Center (Drs. Kanamitsu and Roads).

The regional seasonal forecasts will consist of an ensemble of simulations, each downscaled from a member of a global forecast ensemble. The global simulations will be from the updated NOAA Seasonal Forecast Model (SFM). A new version of the NCEP forecast system will become available in the next year, and we plan to base our regional forecasts on that product when it becomes available. The new forecast system is a 1-tier coupled model, as opposed to the previous two-tiered system wherein the high latitude effects were communicated by atmosphere-only system underlain by the predicted sea surface temperature. We have discussed obtaining simulation output with Dr. Arun Kumar at NOAA/NCEP.

This project will also coordinate with activities at the Experimental Climate Prediction

Center (ECPC) at Scripps Institution of Oceanography (Dr. John Roads and Dr. Matsao Kanamitsu). We shall obtain seasonal prediction products from ECPC simulated from their global and regional models. Global simulation data will be used to drive our regional model. The ECPC regional model domain approximately corresponds to an intermediate nest of our model, and we shall make direct comparisons between the two approaches. Our project is distinct from ECPC work in that we will produce simulations at higher spatial resolution in order to reveal specific mesoscale meteorological processes and our emphasis is on coupling the regional atmospheric model to hydrologic models and on the PNW region.

This research will focus on how several mesoscale processes and feedbacks affect the regional seasonal atmospheric forecasts downscaled from global ensemble simulations and how these differences in turn affect the streamflow forecast. Specific processes to be considered include orographic precipitation, snow-albedo feedbacks, soil-moisture feedbacks, and ENSO teleconnections. The influence of these mechanisms on the PNW regional hydrometeorology is likely to be substantial given the complex topography, which includes the Olympic, Cascade, and Rocky Mountain ranges. The use of a high-resolution (under 20-km grid spacing) mesoscale model is critical to simulating these effects over complex terrain, and the MM5 real-time forecasting system upon which our model is based, has been extensively validated at this spatial resolution.

The regional climate model will be coupled to the Variable Infiltration Capacity (VIC) and Distributed Hydrology Soil Vegetation Model (DHSVM) hydrologic models. Coupling will be performed both one-way, with the simulated meteorological parameters forcing a separate hydrologic simulation, and two-way, with the hydrologic model used as the land surface scheme in the mesoscale simulation. The VIC-based simulations will be directly comparable to output from the University of Washington West-wide Seasonal Streamflow Forecasting Project (developed under separate funding), which uses statistical downscaling instead of a mesoscale climate model. Comparisons between these two products will help establish whether – and under what conditions – the regional climate model approach improves hydrometeorological forecasts.

<u>Precipitation Forecasts Using PNA Forecasts:</u>

We have identified relationships between the frequency of extreme weather events at stations across North America and daily values of circulation indices tracking the state of the Pacific North America (PNA), Arctic Oscillation (AO), and North Atlantic Oscillation (NAO) patterns. We are now in a position to explore the utility of extending NOAA/CPC 2-week lead-time forecasts for these major teleconnection indices into 2-week lead-time forecasts for useful regional applications. The first regional application will link the NOAA/CPC teleconnection index forecasts (available at http://www.cpc.ncep.noaa.gov/products/precip/CWlink/all_index.html) to 2-week lead-time stream flow forecasts. To date, we have not developed forecast systems that systematically exploit the skill in the NOAA/CPC ensemble forecasts to improve 2-week lead-time stream flow forecasts. Ultimately, we will combine these 2-week lead-time forecasts with our seasonal-interannual timescale stream flow forecasting systems that are already in place. Because the PNA pattern is strongly associated with PNW precipitation variability at these time scales, and the PNA pattern is the most predictable large scale circulation pattern at lead times of 5 to 14 days, we expect that this effort will improve stream flow forecast accuracy at both intraseasonal and seasonal-interannual lead times. Using long retrospective indices associated with the PNA (e.g. the North Pacific Index, http://www.cgd.ucar.edu/~jhurrell/np.html) historical climatic data sets from 1916-2003, simple resampling techniques can be used to create ensemble precipitation forecasts for use in experimental streamflow forecasting applications. These techniques also permit an analysis of the skill and error characteristics of these forecasts using retrospective forecasts.

Predictability and Forecasts of Hydrologic Extremes:

Current streamflow forecasting techniques have been able to narrow the conditional probability distributions of future streamflows associated with particular climate conditions. While these forecasts have been shown to have value to water management, many water management systems are most vulnerable to hydrologic extremes (droughts and floods), and skillful forecasts of these kinds of events would be very valuable. The potential to provide forecasts of extreme events, however, has only very recently begun to develop. Some of the most promising work to date on drought has shown that certain sea surface temperature patterns are strongly associated with persistent droughts such as those experienced, at continental scales, across the West over the last five years and during the Dust Bowl years of the 30's and 40's (Hoerling and Kumar 2003; Schubert et al. 2004). These studies have demonstrated drought predictability at very large spatial scales, but predictability at regional spatial scales has not been adequately explored. We propose to evaluate the usefulness of these very large scale drought forecasts for the PNW and to understand their error characteristics.

Forecasts of very wet years are also of great interest to water management. ENSO and PDO forecasts have been shown to influence the likelihood of flows above the mean annual flood, but the risk of more extreme conditions does not seem to be well related directly to ENSO and PDO in the current winter. Preliminary research, however, suggests that certain ENSO transition states (e.g. a transition from warm ENSO to cool ENSO in a single year) are frequently associated with extremely wet winter conditions in the PNW. We propose to identify a physical mechanism for this apparent relationship, and to understand the skill and error characteristics of these kinds of forecasts.

Decadal Climate Variability and Global Warming:

The persistence of the PDO index on an interannual basis and the relationship with in-year ENSO variability has been shown to be predictable using simple regression techniques (Newman et al. 2003), and seasonal to interannual streamflow forecasts based on these simple climate forecasts have also been shown in retrospective studies to be about as skillful as having perfect foreknowledge of decadal climate "regimes". However, a limited understanding of decadal climate variability on longer time scales has proven to be a serious drawback in terms of producing long range hydrologic forecasts associated with climate change. Recent research using long climate records has demonstrated that decadal climate variability probably plays a dominant role in determining regional scale precipitation variability. This explains, for example, why different global climate models give very different projections of changes in precipitation at the regional scale. Inability to project decadal precipitation variability with confidence presents water resources planners with large uncertainties. We will utilize a variety of approaches to examine decadal precipitation processes at longer time scales to provide more information about whether and how they are projected to change:

1) *Increase the sample size.* Several research groups are currently producing very long (5000 years) climate simulations at a fixed greenhouse gas concentration. Having a very long run allows systematic changes in precipitation to be more robustly identified using statistical techniques. In addition, the uncertainty in relationships between large scale circulation indices (such as Nino3.4 or the PNA index) and precipitation variability can be assessed.

2) *Exploit the relationships between large scale climate phenomena such as the PNA pattern and the ENSO and regional precipitation variability.* If reasonably robust relationships between large-scale climate circulation indices and regional scale precipitation in particular months of the year can be established, then this suggests a potential bridge to assess the frequency of anomalously wet or dry winters in a smaller number of transient climate change scenarios. Such an approach would potentially avoid limitations in the ability of climate models to directly simulate regional scale precipitation variability by substituting indices based on large scale circulation patterns (which climate models simulate well) as proxies for precipitation.

Regional Observing System and Integrated Data Sets for the Pacific Northwest:

Data and analyses of data are the foundation for identifying climate variability and trends, from which all climate impact analysis comes. Present sources of data for the PNW come in two forms: time series of data from particular stations and gridded data sets. [It should be noted that there are only two upper-air stations in the State of Washington: Quiliute and Spokane]. Only the station records are pure observational records; gridded data involve observations and analyses which may involve data assimilation systems. Increasingly we depend upon data from reanalyses of various sorts because they provide better regional coverage than does the station network. Unfortunately even the highest spatial resolution reanalyses do not resolve the watershed level scales that are important for regional climate impact identification. Thus we are constantly faced with the challenges of 'downscaling' the larger scale information in order to address variability on the true scales of local concern. Downscaling can be done statistically, using historical relationships between station observations and larger scale data, or dynamically, by forcing high resolution models with boundary information from larger scale data. The utility of dynamically downscaled results can only be assessed by comparison against station observations.

We will examine and propose a design for observing systems for specific problems in the PNW. For specific problems (e.g. hydrology) the intrinsic variables (e.g. streamflow), the associated meteorological variables and any associated variables needed to interpret the intrinsic variables will be identified. Correlation scales will be identified, area by area, to the extent possible from existing stations. The minimum station array that should be maintained is the one that has minimum spatial redundancy. That is, it should be able to continue to resolve the energetic scales of climate concern even if a neighbor station does not report observations. Even an array of this density may not be able to provide accurate area integrals of, for example, precipitation, but it is the smallest network that might provide a foundation for regional climate analyses. We anticipate that the density of the needed network will be driven by either wind or precipitation scales rather than by surface pressure or by air temperature.

A minimum observing system for the PNW is one that adequately allows us to monitor the most pressing problems in the PNW. Over the course of the next year, we will design specific observing systems for several of the sectors and see if any additional cross-sectoral integration of the separate observing systems is possible. Once designed, we will try to encourage our partners and stakeholders to urge the state government to institute pieces of the system – this is a long term process, but one that is essential to improving the decision support systems of the PNW.

<u>Climate Data and Information Distribution System:</u>

This effort is described below (see Outreach: Infrastructure Development).

<u>Climate Advice to the Nation and World:</u>

ENSO Book

Ed Sarachik will be on sabbatical leave during the academic year 2004-2005 for the purpose of writing a book (many years in gestation) with Mark Cane of Columbia University called "The El Niño-Southern Oscillation Phenomenon**:** Mechanisms, Predictability, Impacts," with the following chapter structure:

0. Introduction; a historical overview of ideas about ENSO

1. Observations of mean and annually varying state of the atmosphere-ocean system over the tropical Pacific. Observations of the ENSO phenomenon as anomalies from the mean and annually varying state.

2. Tropical ocean wave dynamics and thermocline adjustment. What determines tropical sea surface temperature and its changes.

3. Tropical atmospheric thermodynamics and dynamics--the mean state. Convection over warmest water. Thermal forcing. Hadley and Walker circulations.

4. ENSO mechanisms

5. Numerical models of ENSO

6. ENSO predictability and predictions.

7. ENSO impacts and applications of ENSO predictions

8. ENSO in a wider context: decadal variability, paleoclimate, and global warming.

9. The present situation--what we know and what we still don't know.

10. Technical Appendices

A full set of lecture notes has been produced as a result of sets of lectures given at least four times by Cane and Sarachik in Fortaleza, Brazil and Trieste, Italy. A contract has been signed with Cambridge University Press for the manuscript to be delivered on Jan, 1, 2006.

IPCC

Phil Mote has been appointed lead author on the 4th Assessment Report Chapter 4: Observations: Changes in Snow, Ice and Frozen Ground. This will involve writing, coordination meetings, and response to reviews until the publication of the Report in 2007.

GCOS

Having finished the *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCC*, Ed Harrison, as Chair of the OOPC, is participating in the writing of the *Implementation Plan for the Global observing Systems for Climate in Support of the UNFCC.* The report is available in draft form at www.wmo.ch/web/gcos/gcoshome.html.

b. Hydrology and Water Resources

During 2005-2010, hydrology and water resources research at CSES will continue supporting the translation of climate information (provided by the Center's climate researchers and others) into hydrology and water resources forecast products of use to regional planners and decision makers. This research will focus on (1) developing streamflow and reservoir seasonal forecasts and decadal projections for the watershed scale of PNW water management, (2) understanding and providing decision support for the conflict between instream flows and the flow needs of salmon, and (3) the hydrology of irrigated agriculture. In addition to developing the products and services detailed below, CSES hydrology and water resources researchers continue to provide information, forecasts, data, and other support to individual water management stakeholders and operational agencies interested in developing water resources planning and management applications incorporating climate information.

Hydrology Research:

A number of specific research opportunities have recently emerged in the context of improving streamflow forecasts. We propose research on the following topics:

Trends in Runoff and Soil Moisture Over the West from 1916-2003

A proposed companion paper to the papers on 20th century snowpack trends described previously (Hamlet et al. 2004, Mote et al. 2004) will examine trends in simulated runoff, baseflow, and soil moisture associated with changes in precipitation and temperature over the 20th century. A parallel analysis of snow accumulation and melt statistics from NRCS SNOTEL point source observations will be used to broadly validate the VIC hydrology model simulations in terms of the spatial and temporal variations in runoff from snowmelt, and the model simulations will then be used to extend the record to the full 88 years of record with full spatial coverage. The model simulations should corroborate the streamflow timing shifts observed in western North America during the later part of the 20th century (Stewart et al. 2004) and will also provide the full spatial coverage needed to assess hydrologic changes at the basin scale over the longer historic record. These analyses have great utility in the context of diagnosing and evaluating potential losses of summer water availability that have presumably occurred in sensitive areas as a result of the loss of snowpack. The separate role of temperature and precipitation variability in the observed changes will be explicitly evaluated in a similar manner to that used in Hamlet et al. (2004).

Trends and Predictability of Flood Risks in the Western US, 1916-2003

This project will focus on an analysis of evolving flood risks and their predictability. Several analyses of precipitation and streamflow observations in small, unregulated watersheds in the US have concluded that, while annual precipitation has apparently been increasing over time, flood risks have not changed enough to be detectable using conventional statistical tests (see, e.g., Lins and Slack 1999). Changes in flood risks can be due to changes in precipitation intensity and duration, time between major storm events (systematic differences in initial soil state at the beginning of storms), changes in temperature that effectively increase the basin area when the largest storms typically occur, changes in land use, etc. Because many of these physical changes are gradual and continuous in an observed data set, sample size problems prevent a clear diagnosis using statistical methods. By using a longer data set from 1916-2003 and a hydrologic model, many of these separate influences can be isolated and evaluated in an explicit manner. For example, by detrending the temperature time series in the VIC hydrology model forcing data set, 88 years of precipitation variability can be used to identify a systematic change in flood risk associated with warmer temperatures and increased effective basin area during winter storms. Changes in natural flow in basins of larger size (which are typically regulated by dam operations) can also be evaluated in a more consistent manner.

Some questions that will be addressed in the research are:

- Have increasing temperatures in transient snow basins systematically increased flood risks in early winter as climate change scenarios suggest they should?

- Have changes in temperature and precipitation in snowmelt dominant basins increased or reduced spring flood risks? What is the relative role of winter temperature (loss of snow) and spring precipitation in these changes?

- How have flood risks changed in rain dominant basins? What aspects of evolving precipitation variability are most important in these basins and what is the role of climate and topography?

- What role have observed changes in ENSO frequency and decadal variability associated with the PDO played in observed changes in flood risk? Have the influence of PDO and

ENSO remained constant over time? What are the implications for forecasting of flood risks?

Forest Hydrology

Research examining the influence of land use change on forest hydrologic processes is also proposed, and is described under forest ecosystem research, below (see Forests: Forest Hydrology).

Gridded Data Sets for Climatic and Hydrologic Research and the General Public

High-quality and easily accessible model-derived hydrological data bases are frequently requested by members of the academic community and would be welcomed by watershed planners and other Center stakeholders. Simulations of hydrologic variables from 1915-2003 from the VIC hydrologic model can be used to produce the primary data needed to create these data bases. This work will involve:

- Producing updated VIC model simulations to archive a full range of hydrologic variables.
- Reformatting the data to accommodate access via web based data analysis tools (e.g. Live Access Server, see Outreach: Infrastructure Development, below)
- Developing and maintaining web server applications

Hydrologic Data Bases for Small Scale Water Planning Studies in Washington

The Washington Department of Ecology's (WDOE) Watershed Planning Program provides the framework and funding for voluntary development of watershed management plans in Washington State. Plans are developed by locally-based stakeholder groups for state-delineated Water Resource Inventory Areas (WRIAs). Forty-three (43) of 62 WRIAs are currently participating in the Watershed Planning Program.

The Watershed Planning Program provides CSES an opportunity to efficiently and directly encourage incorporation of climate change information into a large number of watershed scale planning studies in Washington. However, few watershed planning units have the resources to produce hydrologic climate change scenarios and some have very limited access to hydrologic information of any kind.

The CIG has been working to provide basic information on expected hydrologic changes associated with global warming and to set up a web based archive of basic hydrologic data for each WRIA based on VIC hydrology model simulations. The anticipated final product will archive hydrologic data such as snowpack, runoff and potential evapotranspiration for the current climate, and for simple climate change scenarios assuming set amounts of warming (i.e. +0.5 C, +1.0 C, and so forth). These data are intended primarily to assist the watershed planning units in understanding the potential vulnerability of their WRIA to global warming. This information can be used, for example, to assess the need for more sophisticated planning tools to better quantify global warming impacts. In cases where vulnerability to global warming impacts is expected to be relatively low, financial resources can be directed to other planning needs. In cases where vulnerability is expected to be high, WRIAs will know they should undertake further analysis. This project is considered a pilot project with the potential to expand the database to Oregon and Idaho watersheds.

This work will involve:

- Producing updated VIC model simulations to archive a full range of hydrologic variables (in conjunction with the previous project).

- Developing automated software to extract data from VIC hydrologic simulations and produce a group of standardized figures and html files.

- Web site development and maintenance.

<u>Water Resources Research:</u>

Water Resources, Climate and Management Alternatives in the Snake River Basin

CIG researchers have created simulation and optimization models to evaluate conjunctive water resource management (groundwater and surface water). These models incorporate and respond to climate variability, climate change, reservoir operation policies, fish flow requirements, agricultural needs, water rights, and economic considerations. These models are linked to the VIC hydrology model derived streamflow scenarios described previously. Research on the Snake River basin will continue in 2005 and will produce several papers that describe the tools and the management alternatives investigated.

In a parallel and complimentary effort, CIG is developing tools to quantify changes in water allocation resulting from socio-economic drivers and alternative water allocation policies such as water markets. These tools will produce scenarios of changing water allocation for the Snake River basin, but have broad application in other areas of the PNW where irrigated agriculture dominates consumptive water use.

Continued research in the Snake River basin will use the tools discussed above to evaluate the following:

1) Use of long-range streamflow forecasts for improving water management. This research will focus on both seasonal and inter-annual time scales. The goal is to create more effective management policies that balance irrigated agriculture needs, instream flow for fish, and hydropower.

2) Managing the Snake River to complement other Columbia River operational objectives. Currently, the sub-basins of the Columbia River are not operated as an integrated system but as unique sub-basins. Because of its size, the Snake River operations have a profound effect on the lower basin. One of the most interesting aspects of this problem in-

volves flood control policy. Many existing dams within the Columbia basin are not used for flood control because of conflicts with irrigation needs, and the burden of flood mitigation falls on a relatively small number of federally owned projects on the main stem and major tributaries. In expected wet years (which can be forecast with long lead times), flood space in more dams could be utilized to reduce the evacuation requirements on the main stem projects. These operational alternatives can best be evaluated using an integrated model.

3) The hydrological investigations detailed above will be fully integrated with research on water markets to be elaborated in sub-section f which describes the human dimensions work to be undertaken.

Reservoir Storage Forecasts Linked to Long-Range Operational and Quasi-Operational Streamflow Forecasts

Ensemble streamflow forecasts are available from a number of sources on an operational and quasi-operational basis. To support the CIG outreach effort we have produced long-range reservoir storage forecasts once a year using the ColSim and SnakeSim reservoir models. A quasi-operational forecast of reservoir conditions has been requested by and would be a very valuable decision support tool for water resource managers (and energy traders) in the PNW. We propose to produce quasi-operational ensemble predictions of aggregate reservoir storage for particular sub-basins of the Columbia and Snake River basins. This project will involve:

- Development of a UNIX-based reservoir modeling system to replace the current STELLA environment. (This is required to facilitate the full automation of the forecasting process).

- Linkage to existing experimental and operational streamflow forecasts for the PNW.

- Data assimilation software to update reservoir storage in real time.

- Web site development and maintenance

Salmon protection vs. Hydropower production in the Columbia River Basin

Endangered Species Act listings of Columbia River basin fish species have intensified ongoing conflicts in the Columbia River basin between operations for hydropower and flood control and operations to maintain and enhance instream flow for fish. Preliminary research has demonstrated that changing the seasonality of hydropower production in the Columbia River basin has the potential to dramatically improve the reliability of fish flows in summer while incurring relatively modest energy replacement costs of about $250 million per year in winter. We propose to extend these preliminary studies with the objective of evaluating these experimental reservoir operating policies in an operational context in combination with seasonal streamflow forecasts and climate change scenarios. In particular the ability to use forecasts to better optimize how much additional water to release for fish flows in summer on the basis of seasonal forecasts would be explored. In addition we would explore this alternative policy as an adaptive response to the altered streamflow timing expected under climate change. This is an extension of research reported by Hamlet and Lettenmaier, 2002, and Payne et al. 2004.

c. Marine Ecosystems

The first mission goal of the most recent NOAA Strategic Plan (New Priorities for the 21st Century) is:

> *Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.*

This goal is echoed by the U.S. marine fisheries community, both inside (U.S. Commission on Ocean Policy 2004) and outside of government (Pew Oceans Commission 2003). As fisheries crises continue to attract the attention of the general public, and widespread agreement that serious problems with the current system of management crystallizes, the fisheries community is still struggling to understand what "ecosystem management" or "ecosystem-based fisheries management" might mean for the future of our marine resources (NMFS 1999, Link 2002, Pikitch et al. 2004). Field (2004) says that:

> *The common threads of an ecosystem-based management approach involve taking a more holistic view of managing resources in the context of their environment. For marine fisheries this must take into greater consideration the interactions between climatic and oceanographic processes, the connections and interactions between fished and unfished populations in the ecosystem and the role of humans as both predators and competitors in such ecosystems. Recognizing that all management decisions have impacts on the ecosystem being exploited, an ecosystem-based approach to management seeks to better inform these decisions with knowledge of ecosystem structure, processes and functions.*

In the past several decades, the PNW coastal marine fishery has come under severe stress from a combination of heavy fishing, poor bottom-up biological production, and a reduction of habitat in both the marine and freshwater environments. Despite being buoyed by a massive hatchery program, ocean salmon harvests declined precipitously in the 1980s as they came under management control and ocean survival rates for salmon plummeted. A number of wild salmon stocks were so depleted they were listed under the federal Endangered Species Act. In the 1990s, groundfish stock assessment caught up with management and forced a radical reduction in coastal groundfish harvests. At the turn of the 21st century, a number of groundfish stocks were listed as overfished forcing their fisheries to be managed under severely restrictive rebuilding plans, some of which are expected to extend for decades. The only coastal fisheries that seem to be able to maintain their productivities are the lucrative crustacean fisheries (Dungeness crab, pink shrimp), which seem to operate in their own regular boom and bust ways independent of much regulatory control. The warm coastal ocean era of the 1990s coincided with a resurgence of a PNW sardine fishery that was absent from the regional fishing economy for over half a century. This dynamic ecosystem has been buffered and battered by climate, fishing, and changes in both freshwater and marine habitat over the last several decades. And whereas in the 1980s and early 90s, the fishery was worth well over $150 million dockside, by 2002 its dockside value had declined to just over $100 million.

In the next five years we propose to build on our existing marine ecosystems research partnerships and results to continue developing methods and models for integrating climate and ecosystem information into decision support tools for resource managers. In the following sections we describe the full suite of work projected in this area, some of which will be supported by other funding sources. The primary management targets of this research are: (1) short-term climate impacts and (year-to-year) harvest policies; (2) decadal time scale climate impacts on ecosystem restoration planning; (3) climate and fishery sustainability; and (4) developing an improved understanding and prediction system for climate and anthropogenic impacts on estuaries and estuarine ecosystems. Specifically, we will undertake the following projects to serve these management and research goals:

Pacific Northwest Salmon:

We will continue to develop climate and habitat sensitive life cycle models for PNW coho and chinook salmon stocks. Models with these attributes are required to evaluate the combined impacts of natural and anthropogenic climate variations, harvest policies, land and water use decisions, and habitat and stock restoration strategies. To date, we have completed a pilot effort focused on integrating climate impacts on the full life cycle (marine and freshwater phases) for coastal Oregon coho salmon. These efforts will be extended to focus on additional coho and chinook stocks in the region (namely stocks in Columbia Basin, Puget Sound, the southwest Washington coast, and Olympic Peninsula waters). These efforts involve close collaborations between CSES and NOAA/NWFSC scientists, and will ultimately require linking watershed scale hydrologic models with biophysical impacts models for salmon. The holistic models will be developed in ways to support the evaluation of harvest policy, restoration planning, and fishery sustainability options.

Coastal Marine Fisheries:

We will develop climate sensitive decision support tools in support of developing ecosystem management plans for PNW coastal marine fisheries.

Our Washington Sea Grant sponsored research project has been extended through 2006 under the title*: Linking biophysics with socioeconomics: a modeling approach*. In this project the Field (2004) ecosystem model will be connected with socioeconomic models to help explore the interactions between the dynamic PNW coastal marine ecosystem and the coastal communities, which harvest its resources. There are a number of changes that need to be made to the Field (2004) model in order to make the climate linkages more realistic:

- The salmon components of the model needs to be completely reworked to include the effects of hatchery releases, changes in freshwater habitat on wild salmon production, and the effects of any time lags between ocean productivity years and salmon production years (this is particularly true for chinook salmon). In essence we are proposing to create a regional salmon production model that links into the existing salmon component in the

Field (2004) model. This effort will tie directly into the stock-specific modeling efforts described above. Some of this work will be incorporated into the Ph.D. dissertation of Rishi Sharma, a Quantitative Ecology and Resource Management student supported by the Northwest Indian Fisheries Commission.

- The whole issue of time lags between ocean plankton productivity and productivity of other model components (higher trophic level species) needs to be incorporated. Many of the harvested stocks in the model have protracted life spans and do not become available to harvest for many years after passing through their early life history stages where they are susceptible to bottom up (plankton productivity related) climate influences. The Field (2004) model needs to be restructured and recalibrated to take this into account.

- The linkages between climate change and the significant climatic processes driving the model (winter PDO, ENSO, spring transition timing, upwelling intensity, southward advection) need to be more clearly established.

These changes to the Field (2004) model are needed to more accurately represent climate impacts on ecosystem structure and dynamics in the Northern California Current region. Once these improvements are made, the model can then be used to explore likely outcomes of fishery management policy that extends well into the 21st century. Ultimately we propose to use the model to explore linkages between climate scenarios, fishing policy scenarios and the viability of PNW coastal fishing economies.

Climate Impacts on Pacific Northwest Estuaries:

NOAA's Northwest Fisheries Science Center was recently awarded a grant as a Center for Excellence in Oceans and Human Health, and the CSES will receive support for one postdoctoral fellow to provide climate expertise for the new Center. The NOAA award will support the development of a new interdisciplinary research program to enhance NOAA's ability to understand the interrelationships between marine ecosystems, climate and public health. The Center will consist of four core program areas: microbiology, ecotoxicology, marine mammal ecology, and climate impacts. CSES scientists will participate in the climate impacts part of this program by providing expertise in quantifying relationships between large-scale climate variations, local environmental changes, and variations in harmful alagal bloom dynamics. The region under study is the Pacific coast with a focus on PNW estuaries. The CSES part of the project will include retrospective analyses aimed at identifying robust links between environmental changes and harmful alagal bloom activity, and the development of quantitative models to be used as decision support tools for translating environmental monitoring and seasonal-to-interannual climate predictions into harmful alagal bloom risk assessments. Once the decision-support tools have been developed and validated they will then be used to examine longer lead time climate, land, and water use change scenarios in order to assess policy options and harmful alagal bloom risks years and decades into the future.

d. Forests

The collective ecological, cultural, and economic value of forest ecosystems in the PNW is comparable to that of water and fisheries. All of these resources are, of course, linked through the hydrological system, which makes it imperative that all components have functional integrity and can be managed sustainably. We have demonstrated teleconnections between Pacific Ocean circulation patterns, atmospheric conditions, and a diversity of forest ecosystems, fire, and carbon cycling processes extending as far east as the Rocky Mountains. Growth and productivity of coastal rain forest, high-altitude subalpine forest, and dry eastside forest respond to climatic variability at annual and decadal scales. This includes Douglas-fir, the most valuable timber species and a widespread component of forests throughout northwestern North America. Wildland fire, the most important ecological disturbance in the West, is more prevalent during prolonged warm periods (e.g., the Pacific Decadal Oscillation), which suggests that fire seasons will be longer in a warmer climate. This poses significant economic and management challenges in the years ahead. All of these factors fit the broad mission of NOAA to understand and manage for ecologically and economically sustainable ecosystems.

During 2005-2010, CSES research in the area of forest ecology will focus on (1) further improving analyses of climate impacts on forest growth, productivity and forest disturbances, especially wildfire regimes, (2) expanding tree-ring-based paleoclimate drought reconstructions, and (3) integrating these studies with hydrological models to be able to examine the effects of present and future forest management practices on the hydrology of watersheds across the region.

<u>Ecosystem Response to Climate Fluctuations:</u>

We will address the response of forest ecosystems to climatic variability and change relative to CIG priorities and within the strategic framework of the Western Mountain Initiative (http://www.cfr.washington.edu/research.fme/wmi). Specifically we will answer the following research questions:

- How are climatic variability and change likely to affect disturbance regimes, especially fire?

- How are changing climate and disturbance regimes likely to affect the composition, structure, and productivity of vegetation?

- Which mountain resources and ecosystems are likely to be most sensitive to future climatic change, and what are possible management responses?

We now have 10 years of empirical data from mountain ecosystems of the PNW and beyond. Combined with other research teams, we will synthesize these data in order to develop an integrated view of how climatic variability has affected forest ecosystems and natural resources in the PNW and the western United States. This integration will occur through limited empirical data collection, modeling, and focused workshops and publications developed by interdisciplinary teams of scientists. An annual workshop will be held for resource managers to interact with scientists, and special emphasis is being placed on communicating results useful for resource managers.

Forest Hydrology:

The effect of forest management and disturbance on aquatic resources is a problem of considerable scientific and public concern in the PNW and beyond. One of the dominant pathways by which landcover change affects freshwater fish habitat is via altering streamflow and sediment loading. As a result, vegetation management, forest fires, and roads affect the amount of sediment available for transport and the amount of surface water available to transport it. The interaction of climate with these processes has not previously been explored and is likely to be of significant importance over the next century, with implications for integrated management and conservation of forest resources and fisheries, especially PNW salmon. An enhanced ability to project the likely effects of climatic change, fire, and vegetation management on sediment transport would improve our understanding of forest-aquatic interactions and the scientific basis for forest management.

In most watersheds, slope failures (land slides) are the dominant source of sediment. Forest roads are another important, though more variable and poorly quantified, source of sediment. Surcharging of the water table by redirection of runoff from forest roads (and interception of the water table by forest roads) can initiate shallow slope failures, although current predictive models do not effectively quantify the magnitude of the contribution of forest roads to slope failures.

In the PNW, we have reasonably good databases of hydrologic features, forest land cover, and roads on public lands. We also have spatially explicit quantification of historical climatic data, projected future precipitation and temperature, and fire-climate relationships, as well as sediment data for selected river basins in the interior Columbia River basin (notably the Entiat) that have been studied by USFS. Using evolving modeling techniques to integrate these data, we intend to develop the capacity to predict expected sediment production under different conditions, including under various policy/management scenarios.

We intend to address the following research questions:

1) What are the relative contributions of sediment generation from landslides, road and road cut erosion, and surface erosion over the general landscape, and how do these relative contributions vary over the climate regimes represented by forested areas of the PNW?

2) How do the amounts and proportions of sediment generated from the above sources compare to sediment generated by extreme storms, droughts, and fire regimes, and to sedimentation amounts under forest different management scenarios?

3) How will sediment generation from PNW watersheds respond to the interaction of land cover change with climatic variability and change at decadal to century time scales?

We will modify an existing Distributed Hydrology-Soil-Vegetation Model (DHSVM, Wigmosta et al, 1994; Wigmosta and Lettenmaier, 1999), which was developed for application to PNW forested watersheds, to include the capability to represent sediment generation by slope failures, and hillslope and road erosion, as well as sediment routing through the channel system. Various forestry policy/management scenarios will be considered with respect to harvest, thinning, prescribed burning, and road construction or obliteration. We will develop capabilities for both generic predictions, i.e. for "types" of watersheds and forests, and predictions for specific watersheds (i.e., watershed(s) representative of broader landscapes or of special policy interest). We will conduct case studies on a few specific watersheds in partnership with local resource managers.

The case studies will be described via journal article(s) and also via outreach products (such as web sites and/or fact sheets) designed for CIG's forest resource stakeholders. We also intend to develop a guidebook (or portfolio) of case studies as an aid to vegetation and hydrologic planning. This product would be useful for operational planning for roads and fuel treatment (local), NEPA assessments (local to regional), and evaluation of policy/management options (regional).

e. Coasts

During 2005-2010, research on coastal environments will focus on (1) developing watershed scale integrated assessments of the multiple influences on salmon productivity and general estuarine ecology and (2) assessing the economic impacts of and alternative response strategies to coastal hazards precipitated by climate variability and/or change.

<u>Watersheds and Ecology:</u>

This is a new project that represents a major shift in the focus of our research on coastal environments. The aim is to develop watershed scale integrated assessments of the multiple influences on salmon productivity and general estuarine ecology – via the influence of anthropogenic activities (e.g., land development and land use practices, including forestry) on stream flows and habitats, and via changes in coastal ocean conditions. This project will significantly increase the integration between the Coastal Environments sub-group and the Hydrology/Water Resources, Marine Ecosystems and Forest Resources sub-groups, i.e., enhancing the horizontal integration of the Center.

The research has three main foci: understanding the linkages between the various forcing factors and estuarine ecology, analyzing these processes and their implications for resource management for specific resource issues, and defining institutional characteristics required to effectively manage integrated resource decisions.

Understanding Influences on Estuarine Ecology

- *Influence of climate variability, climate change, and anthropogenic activities on stream hydrology and habitat*. Stream hydrology and riparian and in-stream habitats are clearly affected by human activities, such as land use change. Booth (2000), for example, suggests that as watersheds approach forest cover less than 65% and impervious-surface cover greater than 10%, stream hydrology changes and degradation of stream conditions becomes measurable. How will climate variability and climate change interact with anthropogenic effects to alter these thresholds? (See Forests: Forest Hydrology for more details.)

- *Influence of climate variability and change on estuarine conditions*. We will examine the role of climate in influencing estuarine physical oceanographic properties (e.g., ocean-estuary exchange rates, mixing patterns, temperature, salinity and the tidal prism) and regulated properties (e.g., "water quality") via sea level rise and via altered stream hydrology. What effect will changes in estuarine water quality have on primary productivity? How will water quality and primary productivity changes affect secondary productivity?

Specific Case Studies

- *The impact of climate change on the Pacific Northwest shellfish aquaculture industry*. A tentative link between the PDO and the oyster condition index has been established for commercial oyster harvest in a portion of Willapa Bay (Washington) by Feist and Simenstad (2000). Can this tentative link be extended back in time and geographically to other oyster growing regions of the PNW? What management measures to mitigate adverse effects might be available to the shellfish industry?

- *The role of climate change in exotic species expansion*. A tentative link has been established between climate warming and the rapid expansion of *Spartina sp.*, an invasive weed that threatens oyster-growing habitat in Willapa Bay (Field 1997). There appears to be a consistent 32-month lag between *Spartina* growth spurts and sea surface temperature, but other factors (mean sea level and precipitation) may also be factors. We will elucidate this apparent link and its importance relative to other growth factors. If climate is a significant factor in the spread of *Spartina*, what are the technical, biological and economic implications for control and eradication programs?

Effective institutions for integrated coastal management:

- *Management by watershed.* In both Washington and Oregon in recent years there has been a growing institutional movement towards resource management on a watershed basis (as compared with traditional resource management regimes based on political subdivisions). We have begun examining how these watershed-centric management regimes are structured, how they function with respect to resource management and integration of state and federal resource management agency mandates? We wish to determine how adaptable these management regimes are to consideration of climate variability and climate change.

- *Integrated management of watersheds, estuaries, and the coastal ocean.* Broad integration of management regimes and institutions for watersheds, estuaries and the coastal ocean is lacking. Pioneering studies in this area have been initiated by PNCERS (Pacific Northwest Coastal Ecosystems Regional Study) and initial research on physical, ecological and socioeconomic sectors has begun to be published (e.g. McMurray and Bailey, 1998) forming a basis for focused, watershed-specific and estuary-specific planning and management. Given the present institutional regimes in Washington and Oregon, what forms of integrated management regimes would be most viable?

This work will be undertaken under the guidance of a stakeholders group to be composed of persons from federal, state and local government agencies; Tribal resource management agencies; the aquaculture industry; academic institutions; and private sector research organizations. Early in the effort, we intend to convene a Coastal Watershed – Estuary workshop to discuss research, monitoring, management and institutional issues.

Coastal Hazards:

Initial CSES research examined the relationships between coastal hazards, such as erosion, landslides, inundation and flooding, and climate fluctuations caused by climate variability and change. During 2005-2010, we propose to analyze the economic and policy alternatives available for addressing coastal erosion and storm-related hazards in southwest Washington and northwest Oregon under different scenarios of climate variability and change.

A focus on coastal erosion (and related storm inundation) will provide much rich material for analysis. The issues are intense – controversies around erosion, property rights, and methods of beach protection abound in Ocean Shores, Willapa, Long Beach (Washington) and The Capes (Oregon) – and have been ongoing for many years (see, e.g., Good (1994) on Oregon and the WDOE Coastal Erosion studies of the late 1980's in Washington). Although the study areas are relatively remote, they are experiencing population growth and coastal development that increases demands for protection against hazards such as erosion. Certain institutions are highly invested in the area but not capable of dealing with the issues, e.g. Shoreline Management in Washington, Comprehensive Land Use in Oregon and the US Army Corps of Engineers, to whom everyone looks for responses and protection. These institutions were fashioned in an era of shoreline accretion (due to sediment input from the Columbia River); now the era is one of an eroding shoreline and the institutional needs are different.

We will examine the economic, fiscal and policy analysis dimensions of coastal erosion and related hazards. The economic analysis will look at land and resource valuation in light of hazard risk, and property rights. Fiscal analysis will address the role of governmental institutions in financing hazard responses and providing subsidies and incentives. The policy analysis will address alternative approaches to decisions, the benefits and detriments of those alternatives and related organizational and legal process issues.

Both of these coastal research projects will be undertaken in partnership with the Washington Department of Ecology (WDOE). Upon completion, we anticipate co-publishing technical and policy reports on both topics with WDOE. To encourage further linkages between climate science and coastal management, we intend to coordinate a special section of Geophysical Research Letters on "Linkages between climate and the coastal zone."

In order to bring the findings of this research to bear on regional coastal management and planning, we will organize a science and policy workshop on “Climate and the Coasts of the Northwest.” This will bring together policymakers and scientists to discuss long-term adaptability, following the model of CIG’s successful water policy meeting (July 2001).

f. Human Dimensions

During 2005-2010 human dimensions research will focus on understanding (1) the ability of institutions to deal with intersectoral knowledge, (2) whether or not (and how) intersectoral knowledge can lead to better decision and management practices, and (3) how to develop strategies to facilitate regional adaptation to climate change over the next 50 years or so. The guiding questions for this work are listed under “B. Policy” in Appendix A.. In doing this work we have to listen carefully to managers, understand what tools they already have that they can use to respond to a changing climate, and provide what we can produce in a form they can use to apply to problems they recognize.

To this end we propose a single major study centered on the basic CIG question: the nature of stress we can expect from climate change in the PNW, in particular water and water uses; the ability of the existing institutional structure to adapt to that stress; and potential policy initiatives to increase adaptive capacity.

From the climate models, downscaling, and the hydrology work, we have reasonably good expectations of the hydrologic impacts by basin. From surveys and ongoing interaction with water managers, we have some sense of the nature of problems that exist, where, and the extent to which climate information is being incorporated into planning.

From our work in the Snake Basin, we are developing an understanding of the nature of water markets that exist in the PNW, their potential and constraints underlying water law, the extent to which they have evolved as opposed to being created, and, from a theoretical perspective, the likely characteristics of a successful water market as well as the operational limits (“political and cost-based bookends”) of water transfers. We expect, utilizing a water law expert (attorney) in Boise, to undertake a comparison of Idaho-Washington-Oregon-Colorado-California water law as it relates to market development because the law constrains policy development options to a considerable degree.

What we do not yet have is a survey of the nature of climate impacts on socioeconomic institutions by watershed or basin: the stresses that are/will be placed on the resource in each basin and the effects of climate change on those sources of stress. These can be matched with what is known about physical impacts and existing institutions to develop policy recommendations.” Our objectives are to create and enhance decision-support tools and enhance adaptive capacity with respect to climate variability and change.

The Snake Basin:

Part I

We are embarking on a modeling project to link the climate impact/hydrologic work of the CIG to socioeconomic effects in the Snake basin. This is a pilot effort that can then be extended to other basins with different hydrology, legal structures, and mixes of use. The project involves modeling the decision processes that exist in the Snake basin for water allocation and use, culminating in how much water goes to what uses, by county and/or sub-basin (we have 1990 and 1995 data for counties and sub-basins; 2000 data for counties will be available soon).

We expect to be able to trace the effects of declining snowpack and altered streamflow timing through to storage, irrigation practices, removal of land from production, water purchases for fish, municipal and industrial effects (conjunctive management), hydro availability and revenues, and potential declines of local economies.

The model will include several policy levers, allowing for analysis of various climate and policy scenarios, population growth impacts, new storage, recharge, irrigation buyouts, major drought, and dam removal, among others, including the working of water marketing/leases/rentals. A second development stage will look at secondary economic impacts, to examine the effects of climate change and policy options on rural economies.

The model will be developed in collaboration with IDWR (dovetailed with existing collaboration), BOR (2025 plan), Water District #1 (committee of nine, Upper Snake to Milner), water users association, and others who will be end users of the analyses. The Department of Commerce and Governor's office will also be interested in the secondary analyses, as well as the quantified effects of climate change.

This tool will provide a capacity to be very specific with regard to climate change impacts, to the point that individual agency planning efforts will have information they can use. The model will take output from VIC as inputs, and incorporate the major variables that impact water use and allocation: crop prices, fuel, electricity, and other production costs, water prices, both rental and permanent transfer, population and industrial growth, productivity of land, and existing water allocation, by county, for affected counties. Outputs will include water use and sectoral allocation, by county; land use (land going out of agricultural production); primary and secondary economic effects (farm incomes, retention/loss of secondary employment in farm service communities); and possibly state/local tax receipts.

This is a policy model, not an optimization/deterministic model, intended for use by enabling the modeling of specific policy choices (e.g., Bureau of Reclamation (BOR) land purchase, water transfers) as well as changes in exogenous variables (fuel and electricity costs, crop prices). As such, it will examine actions that can be taken and estimate the impacts thereof. We expect that it can and will be used by various policy and stakeholder interests to evaluate policy proposals.

Part II

We are now in a position to specify many of the features required for water marketing. We can specify the nature of underlying legal structure required, underlying conditions conducive to a market (fully appropriated watershed, adjudication), the kinds of transactions costs expected to be incurred (quantification of 3rd party effects, mitigation), and the nature of a viable governance structure (rulemaking, oversight, and recording, not outcomes). This includes several changes made to prior appropriation over the past quarter century that address most of the usual criticisms. While the existing work is based on the Idaho experience and model, a project would involve extending the model to surrounding states and examining the experience of municipalities and states that use a centrally directed structure.

Specific areas of research focus will center on adaptation, specifically the nature of institutional structure that facilitates adaptation, and expanded modeling of policy impacts. This work will be largely based on analytical capability to estimate the impact of climate scenarios, economic scenarios, and policy options (Snake model).

g. Integrated Assessment

Over the next five years, CSES efforts in integrated assessment will expand our preliminary horizontally integrated analysis of resource management with the goal of providing valuable decision support for real-life resource decisions in the PNW. This integration will focus on accounting for the complex and largely unknown interactions among the individual resource sectors (e.g., salmon recovery efforts, water management practices), regulations affecting regional resources (e.g., the Endangered Species Act), and other anthropogenic stresses (e.g., increased population and urbanization).

Integrated planning across water, forest, fishery and coastal resources has become a high priority as a consequence of the challenges of coping with the stresses brought by population growth, fully allocated water resources, shrinking forestlands, and endangered species listings for PNW salmon and spotted owls. As a result, a new management paradigm involving integrated, intersectoral management of natural resources at the watershed space scale is emerging in interagency groups like the Puget Sound Nearshore Project and the Puget Sound Action Team.

Unfortunately, the scientific underpinnings for integrating water resources planning, land use decisions, forest practices, and salmon recovery efforts are seriously incomplete. Integrated planning, research and management has been rare for PNW resources because both management agencies and research programs (including those in universities) have historically been compartmentalized along disciplinary, or single resource, lines.

In addition to the pressures noted above, PNW resources and resource management will be increasingly stressed during the next few decades by human caused climate change. CIG Research has shown the potential for significant impacts on water resources, and everything that depends on them, over the next 20-40 years. The implications of climate change for resource management in general and salmon recovery in particular have rarely been examined by PNW decision makers and never in the context of integrated resource management.

Existing and future pressures on PNW water, forest, fishery, and coastal resources highlight the crucial need for a new set of decision support tools designed to inform scientists, stakeholders, and decision-makers about the impacts of our resource decisions in the face of future climate change and population growth. Interviews with stakeholders charged with managing the region's water, fisheries, forests, and coasts have revealed that only the most technically advanced have increased their use of climate forecasts and few are preparing for potential impacts of anthropogenic climate change. Many express a high level of demand for sub-regionally based climate information about how climate variability influences the observable variation in the resources they manage and how climate change may affect those same resources.

For applicability to planning and decision making, information about climate and climate impacts (e.g., historical patterns of climate variability, forecasted climate variations, projected anthropogenic climate change, and the impacts thereof) must be provided at the "decision scale," either the watershed scale or focusing on the local coastal ocean. In order for planning studies to address the implications of climate variability and change in more than a cursory manner, however, information about regional climate change must also be translated into a form compatible with the tools and objectives of the targeted natural resources management community.

The work described in this proposal focuses on developing the understanding, products, and services necessary to (1) enhance stakeholders' familiarity with the role of climate in managed resources and (2) enable stakeholders to examine climate impacts and make decisions about potential response strategies at the watershed scale.

The proposed work corresponds with CCSP Goals 4 ("Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.") and 5 ("Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.) The decision support, information delivery and stakeholder interaction products align with NOAA's priorities under Mission Goal 2 (climate), i.e., to "establish service delivery methods that continuously assess and respond to user needs with the most recent, reliable information possible", resulting in an "increased use and effectiveness of climate information for decision makers and managers."

<u>Horizontally-Integrated Assessment of Climate Impacts:</u>

The CIG proposes a five-year program of research and outreach that builds on the research we have done to date and expands and deepens our partnerships with a wide variety of stakeholders in the region. We propose to develop a new suite of linked, interactive, decision support tools consisting of simulation models that link climate to hydrology, land and water use, forest ecology, water quality in streams and estuaries, and aquatic ecosystems. In short, we propose the construction of a "virtual Northwest" simulation model that will allow stakeholders, scientists, and decision-makers to explore the impacts of policy choices in the face of climate change and population growth scenarios.

The CIG is well-positioned to develop these tools due to our unique understanding, developed over eight years of research, of the roles that climate has played in shaping regional resources and of the impacts likely to be generated by climate change. Through the development of hydrologic and water resources models, the CIG has obtained the capacity to evaluate how climate and human actions affect watershed conditions and how they affect other resources, on a resource by resource basis. The urgent question that remains is: what are the critical *interactions* among resources (and resource management) that will shape regional impacts of population growth and human-caused climate change?

At present, our thinking is for the research to proceed at two levels:

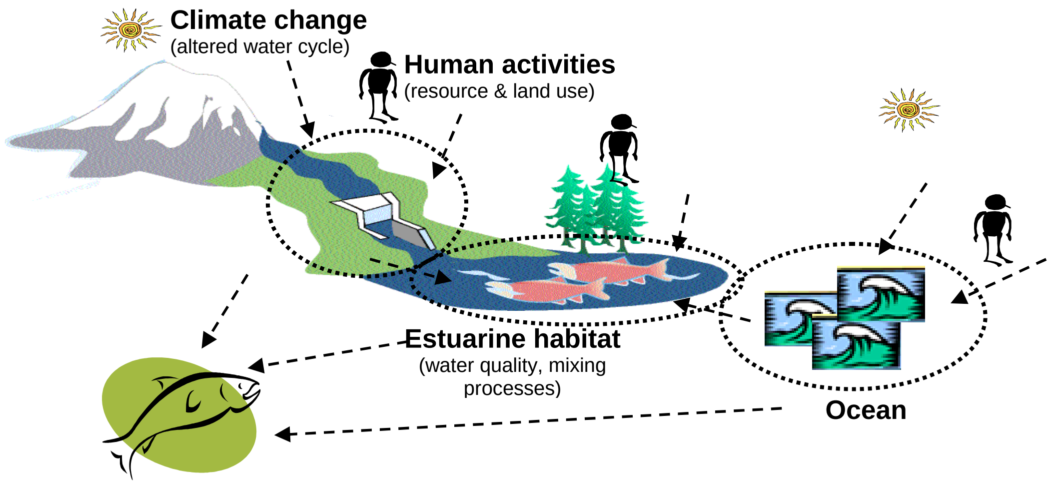
a. Developing the scientific capacity to analyze how climate change will interact with the anthropogenic effects of land development and water use to alter stream hydrology and riparian, in-stream, and estuarine habitats. This will entail examining the integrated and combined effects of simultaneous changes in hydrologic, forest, and aquatic systems, and allow users to explore the net impacts of different land and water use scenarios in the context of future climate scenarios. Components of this research were described above, under Forests: Forest Hydrology and Marine Ecosystems: Pacific Northwest Salmon.

b. Characterizing the influence of climate change and land and water use scenarios on the health and viability of coho salmon (*Oncorhyncus kisutch*). In addition to the work described in (a), this will require examining the consequences of climate change and human activities for estuarine processes, water quality, and biological productivity. Components of this research were described above, see Marine Ecosystems: Pacific Northwest Salmon and Coasts: Watersheds and Ecology.

Integrated modeling of natural and human watershed processes requires developing and integrating scientific understanding of a wide range of different processes (see Figure) occurring in freshwater, estuarine, and oceanic systems. These processes include those that influence freshwater habitat (e.g., climatic conditions, streamflow patterns, land use decisions, forestry practices, urban influences), those that influence estuarine habitat (e.g., aquaculture and coastal habitat) and those that influence ocean habitat (e.g., large scale ocean circulation patterns, fisheries). In addition, the integration must include knowledge about how changes in both freshwater and ocean systems influence estuarine habitat, and how changes in all three environments affect salmon health and viability.

Many pieces of this interconnected system have been, or are being, studied individually. Yet, the integrated picture of watershed processes has yet to be developed because (1) no one has integrated the individual disparate research efforts and (2) some key puzzle pieces are still missing. The aim of the research proposed here is to put the puzzle together by adapting existing knowledge and simulation tools to the circumstances of specific watersheds of interest, developing the missing understanding, and integrating the results into a cohesive whole.

The proposed research will focus on developing these simulation tools for Puget Sound and for a mid-size, ecologically and socioeconomically important PNW coastal estuary (e.g., Willapa Bay). The specific estuary to be studied will be determined based on an evaluation of important drivers of change and consultation with Washington State Department of Ecology (with whom we have a good working relationship), the NOAA Northwest Fisheries Science Center (with whom we are collaborating on these issues as they relate to salmon recovery planning), and local stakeholder groups concerning their primary areas of concern.



The understanding developed in this horizontally-integrated assessment will allow us to elucidate potential thresholds of change in interdependent climate-sensitive resources as well as evaluate potential adaptation options for climate-sensitive ecosystems and resources (both topics for priority CCSP Synthesis Products under CCSP Goal 4). In addition, the set of linked simulation models developed under this research will provide an innovative educational tool, allowing students to link changes in the natural and managed environments of the PNW with real policy decisions at local, regional, and international levels.

Developing and Documenting Methods for Integrated Assessment:

We will continue to develop methods of regional integrated climate impacts assessment and to document these methods, writing journal articles on (1) strategies for engaging stakeholders and (2) enhancing capacity of resource management to adapt to climate fluctuations:

Collaboration with researchers at CLIMAS (the NOAA RISA project in the southwest) will result in a paper detailing CIG's and CLIMAS' strategies for engaging stakeholders and for developing sustainable mechanisms for providing and supporting the use of climate information. The paper will compare and contrast the experiences of the two RISAs: CIG has generally developed new tools for stakeholders to use while CLIMAS focuses on individual interaction with stakeholders to support the understanding and use of existing simple tools.

We will expand the work of Snover et al. (2003) addressing the root causes and characteristics of adaptive capacity in natural resource management into a journal article.

Rhythms Of Change:

The book length manuscript detailing CIG's integrated assessment of climate impacts on the PNW will be resubmitted to MIT Press in 2004. Additional time will be required over the following years to complete any additional revisions and edits needed prior to publication.

h. Education, Service, and Outreach

During 2005-2010, the CIG proposes to significantly expand research and outreach efforts providing decision support to the region's natural resource managers. These efforts, summarized broadly below, will be driven largely by stakeholder needs using established and newly developed connections between CIG and PNW natural resource managers. Successful established components of our outreach program (e.g., the annual water and climate workshops, described previously) will be continued. In addition, since choosing whether and how to develop adaptation strategies to climate impacts is, in a broad sense, an exercise of risk management. The CIG will expand application of the risk management/decision theory framework to its work with decision makers.

Identification of Decision Support Products for Climate-Sensitive Decisions:

The CIG will expand its work with state and regional agencies to more explicitly identify key climate-sensitive decisions or risk exposures for which new research and decision-support products can be developed. Examples of climate sensitive decisions include, but are not limited to, annual hatchery and harvest decisions for PNW salmon, salmon recovery decisions on setting instream flow requirements for sensitive species, and coastal zone setback requirements. This effort will be undertaken in a partnership with selected agencies. Additional emphasis on key decisions and decision support needs will also be added to the suite of meetings and workshops held over the next five years.

Decision Support in Collaboration with the Sea Grant Program:

The CIG will work with Washington and Oregon Departments of Fish and Wildlife and Sea Grant fellows to explore how improved climate forecasts could be tailored to support decisions affecting salmon and coastal aquatic communities. Once these new products have been developed, they will enter a broader testing phase where other agencies (e.g., federal agencies or the Columbia River Intertribal Fisheries Commission) will be invited to use the products on an experimental basis for a period of time. Finally, the CIG will work to transition the products to operations in an agency or a climate service (e.g., the state climate offices or a private entity) with the capability to continually update the products. Discussions regarding this collaboration are underway.

Development of an Adaptation "Handbook":

The CIG will write and distribute an adaptation "handbook" that pulls together various theoretical considerations and practical experiences in adapting to climate variations and change. Case studies will be developed to illustrate different aspects of adaptation and how various natural resource agencies are working to enhance their adaptive capacity. The intended audience for this book is regional, state, tribal, and local resource management agencies.

The word "handbook" has been put in quotation marks because a traditional book format may not be the most appropriate. Two issues in particular suggest the need for a non-traditional design. First, we have to be constantly aware of the need to create technical translation products that make research results intellectually accessible to resource managers. Second, the importance of the timeliness criterion calls for a manual of stand-alone chapters which can be "published" whenever they become available and be updated from time to time. For these reasons, web distribution of .pdf files may be the most appropriate.

Expansion of the CIG's Web Site as a Tool for Outreach:

The CIG recently completed a comprehensive redesign of its web site in order to provide a valuable, timely, and accessible resource for decision makers, resource managers, the media, the public, and other climate impacts researchers (http://www.cses.washington.edu/cig). The website will be actively maintained to ensure that visitors are provided complete information about the role of climate in PNW natural resources, the nature and predictability of climate patterns affecting the region and forecasts of their impacts, and projected future climate change and its likely impacts. Outreach materials, information about upcoming and past workshops and meetings, data, and links to publications will also continue to be made available. We will enhance the delivery and use of information from the web site by adding additional climate and resource forecasts, mapping products (including a major emphasis on new GIS products at regional, state, and watershed scales), data, and guidance on planning for climate variability and change.

Expanded Outreach to Coastal, Salmon, and Forest Sector Decision Makers:

The CIG intends to expand its outreach efforts to the coastal, salmon, and forest sectors in addition to continuing its work in the water resources sector. This will involve CIG hosted workshops that are custom tailored to key climate-sensitive management issues for each sector, based on the successful model of annual water and climate workshops hosted by CIG. These workshops will highlight CIG findings in each sector and provide us an additional formal opportunity to learn about key topics of concern for our stakeholders.

GIS Decision Support Tool for the Pacific Northwest--The Physical Template:

Research proposed for 2005-2010 will support a decision-support system that will enable stakeholders, scientists, and decision-makers to (1) explore the impacts of climate change and human activities on the water, forest, fishery, and coastal resources in the region, (2) identify and evaluate alternative management responses, and (3) elaborate the adaptation strategies that are most likely to be effective in coping with future changes.

Conversations with fisheries managers have revealed that one of the first steps in developing the concept of marine fishery management from an ecosystem perspective is to begin to provide updates to managers on the state of the coastal ocean. Although much work is being done to monitor and understand conditions from Alaska to southern California, it has never been synthesized or put into a usable and understandable context. Because few managers in forestry, water resources, fisheries, or coastal areas know how to include climate information in their management decisions, there is a strong need for information and decision support.

The first stage of development for the decision support system is currently underway. We are building a prototype web-based climate service: a portal for visualizing and acquiring sub-regionally based information about PNW climate and climate impacts. This tool will provide users with information about patterns of climate variability and change at a variety of spatial scales for a variety of parameters important to regional resources. The intended audience is stakeholders interested in watershed-level processes and, more generally, those whom we're trying to educate about the patterns of climate impacts on the region and the magnitude of projected climate change. In addition, this will help us satisfy some of the demands on us from the UW community to provide our downscaled climate change scenarios.

The basic physical template has been developed (see work completed, described previously). We are currently focusing on mapping past and future patterns of PNW hydroclimatic conditions. We are creating static maps to show typical observations during different climatic regimes and animated maps that depict important regional climatic cadences (e.g., ENSO, PDO) and the ways in which climate fluctuations affect the seasonal evolution of different parameters, such as snow pack. These products will be provided with the appropriate contextual spatial information, e.g.: topography, political and jurisdictional boundaries, land use/ownership, and location of habitat for various PNW salmon species. They will be made available via the CIG website.

In order to ensure that the information will be provided in a form useful to regional planners and decision makers, we will work to identify the potential users and their data requirements, to develop a query-able database and a graphical user interface, and to test and evaluate this product with the users. We will utilize local input in the design of this service, beginning by surveying Watershed Planning leads in Washington's WRIA program to identify their needs for hydroclimatic information. Other potential users, to be surveyed subsequently, include inter-agency groups like the Puget Sound Nearshore Project and the Puget Sound Action Team as well as forestry and fishery management entities. By being built in consultation with resource managers and other stakeholders in the target watershed, this decision support system will directly apply to the identified information needs of regional management and policy decisions. We anticipate hosting a series of high profile watershed-based workshops to show the cadence of climate drivers at the watershed level in the PNW and to highlight these discussion support tools and their applicability for regional resource planning and policy making.

Future work will involve providing derived products, such as the probability of exceeding identified thresholds of change under different climatic conditions. For example, this tool could be used to highlight areas of high or low sensitivity to climate change across the region or to produce "vulnerability maps" illustrating the location of watersheds that are hydrologically vulnerable to climate change. We will also focus on mapping spatial patterns in the PNW coastal ocean climate for people making decisions about marine fisheries managers.

The development and application of the decision support system described here will require (1) an examination of "uses and limitations of observations, data, forecasts, and other projections in decision support" and (2) development and testing of approaches for "characterize[ing], communicat[ing], and incorporate[ing] scientific uncertainty in decisionmaking," both of which are topics for priority CCSP Synthesis Products under CCSP Goal 5).

Education on Methods and Applications of Climate Impacts Research:

International Workshop on Regional Integrated Assessment of Climate Impacts

Following on the highly successful workshops of 2002 and 2004, CIG will convene the third International Conference on Integrated Climate Impacts Assessment during summer 2006. Probable location: Cairns, Australia, with an emphasis on climate impacts in the tropics.

Infrastructure Development:

Live Access Server for Pacific Northwest Climate Data

CSES researchers have developed significant (in terms of uniqueness and size) spatial datasets of parameters relevant to the regional manifestations and impacts of climate variability and change. These datasets contain previously unavailable information about past and future climatic and hydrologic conditions as well as the characteristics of past and future forest and marine ecosystems. These data are useful to researchers both within and beyond CSES and to regional stakeholders interested in discovering the predictability of parameters of interest, planning for the impacts of climate variability, and/or preparing to adapt to the impacts of climate change. Heretofore, these data have not been easily accessible (either within CSES or beyond the group). They are stored at a variety of locations, in a variety of formats. Often their existence is unknown by CSES researchers outside of the immediate group that created them. To solve these problems, we propose developing an integrated data management system that will enable the provision of these data in a useful and efficient manner. We propose to develop web-based access capabilities using Live Access Server technology, a method originally developed and used for sharing large, georeferenced oceanographic and atmospheric datasets over the web.

Establishment of a common spatial database containing the input data used in CIG's research models and the research results of the climate impacts research will significantly increase the efficiency and consistency of the linkage and transfer of information between sectors within CIG. It will provide the data management/retrieval architecture that would underlie web scenario tools, other decision support systems, and the proposed GIS decision support tool.

Access to the data will be provided by Live Access Server (LAS) software, which is supported by Distributed Oceanographic Data System (DODS) and Ferret software. LAS will provide users access to both digital values and to simple user-specified maps.

Selected highlights of available datasets:

- Gridded (1/8-degree) historical atmospheric temperature and precipitation datasets for the PNW for 1915-2003 based on observations.

- Time series information about many other climatic and hydrologic parameters (such as soil moisture, evapotranspiration, or cloud cover) that are typically not monitored at any significant temporal or spatial resolution. Because these values are calculated within

CIG's hydrology model simulations they are available for the entire simulation sequence (1915-2003) at 1/8-degree resolution across the PNW.

- Simulated PNW streamflow for 1915-2003 (streamflow observations typically began in 1925-1945 in the PNW) and Columbia River flow at The Dalles back to 1858.

- Gridded datasets of all of the climatic and hydrologic parameters described above for the projected climate conditions of the 2020s and 2040s.

5. Answers to Specific Questions

The CSES was asked by the RISA Program Manager to respond to specific questions and, while the answers are implicit in the preceding parts of the proposal, we will here answer them explicitly.

1. Please articulate how the last five years of CIG/CSES research has assisted NOAA to expand decision-makers' options regarding the use of climate information in decision and policy-making while advancing our knowledge of integrated climate research.

Perhaps the most pervasive impact the CSES/CIG has had, across all four sectors in which we work, has been the identification and quantification of the relationships between global climate phenomena (such as ENSO and the PDO) and typical patterns of impacts that are generated within the PNW for natural ecosystems and human social activities. These impacts range from differences in distribution and abundance between salmon in Alaska and salmon in Washington/ Oregon; impacts on regional hydrologic processes and on PNW water resources systems; the conditions underlying increased tendencies for drought and for flooding; increased probabilities for forest fire; and expansion of the understanding of conditions necessary for increased tree growth and ecosystem productivity at higher elevations and decreased growth and productivity at lower elevations. The recognition of these impact patterns make the variability of climate real to our stakeholders and help them to accept the possibility of additional decision paths that take these patterns into account.

Using ENSO forecasts from NCEP and IRI, the CIG has also developed the capability to translate these large scale climate forecasts into regional climate and *resource* forecasts, which in turn extends the range and possibilities for decision support. This capability has been transferred to stakeholders like Seattle Public Utility, Bonneville Power Authority, NRCS, and other agencies who now routinely use these forecasts in their planning. Similarly, other decision tools have been developed and are being applied, e.g., climate-based long-lead hydrologic forecasts, seasonal forecasts for coho salmon survival, and forecasts of forest fire season severity in the PNW. Climate-based seasonal-to-interannual forecasts are also used by emergency management personnel particularly for logistical decisions particularly for deploying material and personnel.

There is a growing trend among Federal, State, and regional fisheries management agencies to include climate variables, particularly the PDO, in making long-term projections of fisheries recruitment for resources which fall under their jurisdiction. The first to do so was the International Pacific Halibut Commission in their stock assessments for halibut. This successful effort has led some of the Commission's staff members to recommend application of the effort to the Pacific Whiting fishery. The North Pacific Fishery Management Council and the Pacific Fishery Management Council are currently considering similar applications, particularly in respect of long term rebuilding plans for different stocks of severely depleted west coast rockfish. And the collaborative work of the CIG in concert with the NMFS Northwest and Alaska Fisheries Centers on climate impacts on the whole life cycle of Oregon coho salmon is having a major impact on decision-makers at State, Federal, and regional levels.

Recently, by popular demand, the CIG is being drawn into regional, State, and municipal level planning to adapt to scenarios of climate change and their likely effects. Studies have been requested and paid for by the cities of Seattle and Portland in respect of water resource supply; the Idaho Dept. of Water Resources has embarked on a long-term partnership with the CIG and the Northwest Power Planning Council to incorporate streamflows from the CIG's climate change scenarios into their hydrological planning efforts; and at the request of high-level decision-makers from the three PNW states the CIG developed and made available to their technical personnel a decision tool which allows them to do their own calculations on future probabilities of drought.

In this respect, and in response to the intense drought of 2001-2002, the CIG organized a workshop on September 10, 2001 on Regional Drought Preparedness in the Puget Sound Region for technical managers in an attempt to facilitate the emergence of a regional approach to drought management. Finally, we are working in partnership with the Idaho Dept. of Water Resources and the Idaho State Legislature to build a model to determine the allocation consequences and costs of alternative water policies and structure. This is a policy model, not an optimization model, intended for use by the Interim Legislative Committee working on water resource conflicts in the Snake Basin and the group that produced the recent Nez Perce settlement.

The most recent trend of demands for the CIG's work by decision-makers is represented by requests from Committees in the Idaho and Washington State Legislatures to come and brief them about the results of a new investigation which documents changes to regional climate (temperature and precipitation) since 1950 and a modeling study which produced very similar results to the actual observations. The latter study was an example of inter-RISA collaboration since Martyn Clark of CIRES, Colorado was also involved in the work. The CIG was also invited to give a presentation to the Oregon House Interim Subcommittee on Water on the CIG, its research, and decision-support products. The subcommittee was interested in learning more about how the CIG may serve as a source of technical information for their work. At the same time the CIG has been responding to specific requests by the senior staffs of the Governors of Oregon and Washington to assist them by making briefing documents on the projected impacts of climate change in the PNW available to their Tri-State Initiative.

As an explicit example, the CIG's hydrology and water resources research has focused on developing and refining streamflow forecasting systems at two time scales. Forecasts at seasonal to inter-annual time scales have been designed to support water management decisions, and climate change scenarios (with lead times up to a century) are primarily useful for long-range water planning.

Creating these experimental forecasting products has expanded decision maker's options regarding the use of climate information by creating a crucial bridge between climate information and streamflow variability, which is a fundamental driver for water resources planning and management activities.

In addition to these hydrologic forecasting products we have developed water resources models that allow us to identify and examine important issues in particular river basins. These models have also been used to develop pilot water resources applications (in many cases in partnership with water management professionals) that use our experimental forecasts to demonstrate, in concrete terms, how the forecasts can be used in water management decision support systems and long-term planning. This is a crucial step in the CIG's outreach strategy (see response to question 6).

In addition, the primary research on hydroclimatic variability over the 20th century that constitutes the foundation of the experimental forecasting systems described above has also proven to be very valuable in the context of retrospective studies and other types of integrated assessments associated with climate and water resources in the PNW.

2. Describe the team's methodology for determining the balance in its integrated research activities across the range of potential research issues.

The crucible for making those decisions is the Principals' Group of sub-group leaders which functions as the executive committee of the team. The group meets regularly, at least quarterly and whenever circumstances demand. Since CSES was created, the Co-Director of CSES also participates in these meetings. The team goes through a formal strategic planning exercise every five years.

We consider: the state of knowledge relative to the regional climate system, linkages to sectoral impacts via environmental sensitivities, the level of understanding achieved within and across sectors, and input from the large group of stakeholders about their needs and desires based on their participation in workshops and partnerships and on their responses to our quinquennial surveys of the community. We look for missing pieces and disconnections in the flow of information from climate forecasts to regional resource managers and we focus our efforts in these problem areas. We also use the feedback from our outreach program to understand where these kinds of problems are from the resource manager's perspective and attempt to balance academic research needs with those of the water resources management community.

We have also made considerable efforts to maintain an equitable balance between climatically distinct parts of the region (east and west of the Cascades, for example) and between different kinds of water resources systems (e.g. hydropower vs. urban water supply vs. irrigated agriculture). Because of limited resources, this balance has been challenging to maintain in that we are constantly confronted with the tradeoffs between our desire to create more depth in one area of research and our desire to provide broader coverage of issues that are important to different constituents in the region.

The planning is as comprehensive in scope as we can make it with decisions about priorities based on available funding.

3. Identify the capacity and gaps in the current team structure to conduct assessments and delineate the climate sensitive decision/management research needs of regional policy and decision-makers. how does the team plan to address the gaps described?

The major gaps in current team structure include post doctoral fellows of the following type: an estuarine modeler to assist us in connecting watersheds to streams to estuaries to the coastal ocean; a hydrological modeler, shared with the PRISM project to allow us to complete for the Puget Sound region work that we have done and are doing in the Columbia and Snake Basins and elsewhere on the West side of the Cascades; a hydrologist to complete the forest hydrology program we have specified; and two economists, one sociologist or anthropologist, and one lawyer to work on a wide variety of policy analytic issues at watershed, State, and regional space scales relating to options for adapting to climate variability and change over the next 50 years; re-establishing the Coastal sub-group with a sub-group leader and other members to be defined to work on the watershed management initiative; and establishing the operational human health and irrigated agriculture sub-groups as we have tried to do from the beginning of the project because this would complete our assessment of climate impacts on the full suite of climate sensitive sectors in the region.

We are attempting to fill these gaps by engaging in an aggressive fundraising campaign of which the three pre-proposals submitted to Vulcan, Inc., previously described, are but the first phase.

4. Describe how the team's strategy and plans to participate in transition processes that will facilitate the incorporation of the team's research into sustained operational settings.

There is nothing magic about the word "operational"--- the work of the region, in both the public and private sector goes on continuously and therefore the question really reduces to question 1. We constantly facilitate the inclusion of climate information into the ongoing decision making processes of stakeholders.

We participate in NOAA's definition of "operational" by becoming part of an operational forecast procedure. For example, we participate in a West-wide proposal to improve the capacity of the NWS River Forecast Centers to include climate information and forecasts in their operational streamflow forecasts. Addressing this need is a crucial step in bringing climate information and forecasts to bear on actual water management decision support systems. Forecasts must ultimately come from official operational sources to be useful for water management. Experimental forecast systems in an academic setting are an important first step for proof of concept, but these must ultimately lead to operational streamflow forecasts. We also work with NCEP to downscale the official NCEP climate forecasts to more regional bases (see sec. 4a).

5. Demonstrate how the team's planned R&D over the next 5 years is relevant to NOAA's needs.

As we have indicated in the Abstract, the work of the CSES responds to the goals of the CCSP, the CDEP and RISA Programs, and generally to the NOAA Climate and Global Change program to design and develop climate services for the benefit of the nation.

NOAA Strategic Plan for FY 2003 – FY 2008:

gives four mission goals and five mission strategies. Of these, three goals and three strategies are most germane to the work of the CIG. The pertinent mission goals are:

G1. Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management.

G2. Understand climate variability and change to enhance society's ability to plan and respond.

G3. Serve society's needs for weather and water information.

The pertinent mission strategies are:

S1. Understand and describe how natural systems work together through investigation and interpretation of information.

S2. Assess and predict the changes of natural systems and provide information about the future.

S3. Engage, advise, and inform individuals, partners, communities and industries to facilitate information flow, assure coordination and cooperation, and provide assistance in the use, evaluation, and application of information.

The CIG engages in all three mission strategies to serve the three mission goals identified above. In G1, while we do not manage, we do study how Federal, State, and municipal agencies manage the resources in the four sectors of primary concern to us, which are affected by climate variability and change. In each case, we study both the natural systems and processes, the ways in which they are affected by climate variability and change, and we assess what approaches would best assure ecosystem-based management and the extent to which what human systems do depart from the requirements of nature.

We take an explicitly ecosystem-based approached to our assessments of aquatic ecosystems (salmonids in the marine and terrestrial environments and the ecosystems of the California Current) and forest ecosystems in the Olympic and Cascade Mountains. We have also begun to develop an ecosystem-based approach to the management of the coastal zone by shifting our emphasis from a focus on coastal hazards to a focus on coastal watershed management in which watersheds, streams, estuaries, and the coastal ocean are looked at as a single system. We work to understand what the principal regional climate drivers are and how they affect the regional hydrology and water resources and the other natural resources we follow. In doing so we study how to downscale global climate systems and processes to the regional scale, we build and validate models which link climate variability to a variety of applications like water resources management, forest fire hazard assessment, forest growth and productivity, and the like.

In studying the dynamics of the natural systems, we need to extend the instrumental record by using certain paleoclimatological techniques (tree rings, geoducks, etc.) as proxy records for assisting us to assess and predict the probable changes of natural systems. In each case, we also study the socioeconomic, cultural, and political dimensions of ecosystem-based management which are parallel to the biogeophysical ones. And we study the ways in which climate variability links natural systems in each sector of concern vertically as well as horizontally.

We do all of the above in partnership with a large number of regional stakeholders whom we engage, advise, and inform, and who do the same for us, through a constant series of workshops and interactions which constitute the means for sharing information, techniques, and technology. These workshops and formal surveys also inform us in a firsthand way how these stakeholders manage their resources, what their needs are, what their decision calendars are, and how we might serve them better.

The Climate Change Science Program (CCSP)

Of the five stated goals of the CCSP, goals 4 and 5 are particularly germane to the work we do (or wish to do), followed to a lesser extent by goals 1, 2 and 3. These goals are defined by NOAA as follows:

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

Our approach to the assessment of climate change impacts in the PNW is grounded in our work to understand the climate drivers of the region over a long timescale. We address Goal 1 by research on those aspects of the climate that are particularly relevant for the PNW. We have extended the record into the past by constructing a composite timeline going back to 1600 on an inter-annual timescale. Based on our work with process models, empirical models, and conceptual models, we identify the environmental parameters to which each natural resource system in the four sectors of concern are sensitive and delineate the links between the regional climate system and the key environmental parameters we have identified. We then use our assessment of the implications of past and present climate variability as a basis for projecting impacts and proposing adaptation strategies for future climate variability and change.

Using this method for Goal 2, the regional health authorities have expressed a strong interest in having us assess the likely impacts of climate change on the incidence of morbidity and mortality of the PNW, showing the trends on a sub-regional basis using GIS techniques. In that connection, they have expressed a particular interest in increasing knowledge, as stated in Goal 2, of "… the interactions among pollutant emissions, long-range atmospheric transport, climate change, and air quality management" For this reason, we have included this item in our human health submission to Vulcan, Inc. In addition, in collaboration with the USDA's CLIMET program, we have catalyzed some regional exploration of the carbon sequestration potential of PNW forest ecosystems.

Under the rubric of Goal 3, we are particularly interested in the problems of identifying non-linearities and thresholds in the impacts of climate change and in detecting the conditions which are likely to increase or decrease the frequency and intensity of climate extremes.

The majority of our work on climate change and its impacts in the PNW are encompassed within Goals 4 and 5. Our work spans all the research foci, except for that related to transportation, concerning ecosystem and economic sector sensitivity to climate change, scientific inputs for identifying and evaluating adaptation options, and improving understanding of how changes in managed and unmanaged ecosystems interact with human institutions and infrastructure over long periods of time. All of the work we have done on climate change impacts has been done in concert with stakeholders who, the evidence shows, have recently increased the salience of these issues in their eyes and are making significantly increased demands on the CIG for relevant information. In fact, the cities of Portland, Seattle, and Tualatin have funded studies by the CIG of the likely impacts of climate change on water resources under their management.

We will continue to improve experimental streamflow forecast products by addressing the need for skillful forecasts at intraseasonal time scales, improving forecasts of extreme events such as multi-year droughts, and by attempting to better understand and to reduce precipitation uncertainties in global warming scenarios.

We intend to work with NWS River Forecast Centers and other operational agencies to improve and expand the operational capacity to produce streamflow forecasts that incorporate climate information and forecasts, with benefits to the users of these operational products. We will continue to work with stakeholders in our outreach programs to improve the ability to interpret and use these forecasts in water management decisions.

Over the past five years we have become regional experts on climate and climate-based resource forecasts, and as such we will be an essential source of information, data, and experimental forecasting products from which the NWS branch offices can build an operational foundation for providing climate services to their constituents.

NOAA Climate & Global Change Program

Finally, we point out the relationship of what we do to the ultimate goal of the Climate and Global Change program: to design and institute a climate service in whatever institutional form it eventually takes. VADM Lautenberger has expressed his strong support for a global climate observing system and is representing the U.S. at the Global Earth Observing System of Systems (GEOSS) summit. While a global climate observing system is absolutely essential to all aspects of climate services (and as mentioned above several members of the CSES are actively working on the design of climate observing systems), it, by itself, can not be sustained. The support of the public, arising from direct and demonstrable benefits obtained from the shaped products arising from the analysis of observations from the GEOSS, and the model projections initialized by these observations, is essential to the sustenance of the observing system.

Indeed, the climate observing system; the climate models used to analyze the observations and produce the model products; the climate models used to make the projections of future climate; the models needed to downscale the climate information for regional use; the accessory models of water, ecology, resources and economies, that describe the operation of the given place; the information distribution system that intimately involves the stakeholders and supports their ongoing decisions; and the appreciation that these stakeholders show by supporting the entire enterprise and petitioning their government when the enterprise is threatened: all are essential and indivisible parts of a sustainable climate service. In accordance with mission strategy 3, the constant and ongoing conversation between the producers of appropriate climate information and the stakeholders who come to depend on that information for the efficient operation of their regional systems, is the most essential, yet difficult, part of the climate service. This is the part we continually research and seek to demonstrate.

6. Identify how the team's education and outreach activities as they currently stand complement or duplicate NOAA and other agencies' climate service capacities. What does the team envision its outreach activities will be like over the next 5 years?

The CIG's outreach efforts to the PNW decision maker and resource management community are regional and local in scale and are therefore unique: they are not currently duplicated (for the PNW) by any other analogous programs either within or outside NOAA that we are aware of. According to the answer to 5., they clearly are directly relevant to NOAA's climate service capacity and complement its existing national activities.

The broad-based outreach strategy that we have developed and refined over the last five years is:

1) Work to develop skillful forecasts and improve access to these forecasts from official sources. This is academic forecasting research followed by technology transfer to the operational forecasting agencies

2) On an opportunistic basis, work with the most innovative users, one-on-one, to explore the use of various experimental products, and to develop pilot management applications for that specific user.

3) Bring the potential user community together with the innovative users who have taken the first steps in implementing experimental forecasts in order to share the lessons learned and to provide a road map for how to interpret and use probabilistic streamflow forecasts.

Step 1 is supported by forecasting research and (under separate NCTP funding) technology transfer to operational agencies.

Step 2 is associated with the CIG's current partnerships and growing list of case studies discussed in Part I, and is ongoing.

Step 3 is associated with the regular meetings and workshops sponsored by the CIG (and others) designed to increase familiarity with the incorporation of climate change scenarios in long-range water planning, and water management applications using seasonal to interannual climate forecasts.

We expect to maintain an increasingly close interaction with NMFS Northwest Fisheries Center over the next five years both in respect of the influence of climate and ocean variability on prospects for salmon recovery and on the harmful algal blooms problem in the context of the ocean and human health initiative. We also expect to maintain a relationship with the NMFS Alaska Science Center on the impacts of climate variability and climate change on the ecology of the North Pacific. *Beyond these existing contacts, we would like to propose something new, an experimental relationship with Washington and Oregon Sea Grant for the development of an extension capability in climate impacts on salmon management and climate impacts on coastal management.*

The results of our 2003 survey of stakeholders produced three findings of importance which lead us to make this proposal. In comparison to the 1997 survey results, we found that only the technically most advanced units in water resources management have increased their use of climate forecasts. What most stakeholders want from us is information concerning the ways in which climate variability influences, if not determines, the underlying observable variation in the resources they manage. When we asked them specifically what types of climate information they want, the extreme spread in responses shows that they do not know what they want or ought to want in any collective, organizational sense. These results lead us to an emphasis on optimizing the use of climate information from NOAA/NCEP, IRI, the CIG and other sources. We have to tackle this problem on a variety of fronts and not just in our workshops. Hence the proposed experimental link with Washington and Oregon Sea Grant. From NOAA, this experiment will require the resources to add two new dedicated extension agents at UW and two at OSU. The CIG will train the fisheries and coastal specialists on climate impacts and then work with each to facilitate continuing links in the field with large fishing companies and associations and with coastal managers and emergency management personnel.

7. Is the team research and decision-maker interaction overly focused on one temporal aspect of climate information and prediction or is it well balanced across the potential climate information and predictive tools available in the Pacific Northwest?

Any interaction with stakeholders in the PNW immediately indicates that the range of climatic time scales that *must* be considered in order to satisfy stakeholder needs spans the range of time scales from intraseasonal to multidecadal.

The possibility of intraseasonal predictability, either from the high latitude expression of the tropical Madden-Julian oscillation or from the aforementioned predictability of extreme events from wide, and mostly predictable excursions of the PNA pattern, gives a possibility of extended range (i.e. a week or two) planning for dealing with extreme events. We have indicated that climate variability associated with ENSO and the PDO are directly connected with regional climate variations in the PNW and through these variations, with resource variations in the four sectors of our greatest interest. We address and support the ongoing decision-making activities of the region by addressing these seasonal-to-interannual to decadal problems.

The consciousness of anthropogenic climate change has been raised in the region first by the CIG's participation in the National Assessment, then by media and other reports involving the IPCC, by CIG's continuing efforts to interpret the regional implications of global climate model projections. As the consciousness of future climate change sinks in, various governmental agencies have begun, however tentatively, a responsible planning process projecting the implications of global climate change to the region. CSES has responded to this public need for responsible information for planning.

The short answer: we balance our activities across the time scales because our responsibility to our stakeholders gives us no other choice.

6. References Cited in this Proposal

References below are those that are cited in the text and are NOT on the CSES publication website: http://www.cses.washington.edu/db/pubs/allpubs.shtml . All other papers referred to in the text can be found at this website.

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7. Budget for 2005-2010

[NOT INCLUDED IN THIS COPY]

8. Budget Comments

These budget comments are only for the period 4/1/05 to 3/31/06 since that is the only period for which the government can obligate. The years beyond the first year will have specific budget comments upon each year's submission.

All salaries are University of Washington approved or projected.

Graduate students and graduate student operating fees are University of Washington standard rates depending on year of student.

Subcontracts and personal service contracts are continuations from previous year's and have been previously approved.

Official university overhead rate applied on all items except equipment and graduate student operating fees.

Salary for the Manager of Program Operations of the Climate Impacts Group, Adrienne Karpov, will be allocated under this grant for 7.5 months @ 100% FTE. The complexity of the CIG's interdisciplinary research requires special duties that are not part of normal operations of the university. The program manager is responsible for the coordination of the communication of the approximately 45 members of the CIG and the facilitation of the efforts to integrate the research. She oversees the organization of meetings and conferences related to the research and she is the CIG's first point of contact for public and private stakeholders, city, state, and federal agencies, universities, and the media.

a. Budget Justification for increased Costs, Years 2 (2006) to Year 5 (2010)

Significant expansion in the scope of the project is proposed for Years 2-4, it being understood that hiring additional individuals carries multiplier effects in terms of equipment and travel and anticipated salary increases. Adding graduate research assistants must also provide for anticipated increases in the graduate operating fees.

Expansion in the scope of the project from Year 2 comprises adding two new sectors: irrigated agriculture in Year 2 and human health in Year 3. In addition, pursuit of the objective of horizontal integration requires expanding activities in West side coastal hydrology and coastal watershed management; adding an urban hydrology component to deal with Puget Sound cost shared with the PRISM project at the university of Washington at a 50% level; adding an estuarine modeler to link streams to estuaries to the coastal ocean; and adding a forest hydrology component to complete the horizontal linkage across the six sectors chosen for study.

As our Strategic Plan for 2005-2010 indicates, our focus for transitioning new products to users is based on the objective of optimizing the use of the new information, broadly defined as research results, which more fully explain the role of climate variability and change in determining the underlying variation of the resources managers and other stakeholders observe in the resources they manage and use. Optimizing the use of information requires more focused outreach efforts and building partnerships with larger groups of stakeholders. That in turn requires more staff. We therefore envisage adding one more outreach specialist in Year 2 and one more in Year 4 to connect the expected increase in research results to stakeholders in six sectors. Finally, we anticipate expanding our human dimensions capabilities in Year 4 by adding another faculty economist to focus on fine scale, watershed-based analysis of the economic impacts of climate variability and change in the six sectors across which we hope to be working.

b. Budget Justification for Additional Sub-contracts

Beyond continuation of the sub-contracts with Drs. Ruby Leung, Richard Slaughter, and Don Reading, we propose to re-instate the sub-contract with Professor Jim Good of Oregon State University, who had collaborated with us on coastal impacts in the period 1995-1999. Since we propose to re-establish the coastal sub-group to focus on coastal watershed management and to complete the unfinished work on coastal hazards, it is most efficient to seek assistance from Professor Good and a graduate RA to do the work on the Oregon coastal zone.

9. Other Sources of Support

NOAA/Office of Global Programs office of Climate Observations (to Center for Science in the Earth System of JISAO, UW) E.S. Sarachik, PI, 7/1/04-6/30/05, $60K.

NOAA Grant# NA04OAR4170032, Towards Sustainable Fisheries in the California Current Ecosystem, Robert Francis, PI

	Federal	Matching
2/1/04-1/31/05	$57,692	$33,310
2/1/05-1/31/06	$55,123	$33,975
2/1/06-1/31/07	$54,252	$34,653

University of Washington contribution -- $110k/yr.

Washington Dept. of Ecology support for State Office of Climatology (Mote) --$23k for 2003-2005 biennium.

NMFS Northwest Fisheries Center -- $9,141. to cover one month salary for Mantua to provide the Ecosystem and Climate team assistance in interpreting climate and oceanographic data in model simulations of rockfish recruitment.

NMFS Northwest Fisheries Center -- $100k/yr. for 5 years collaboration in the Center of Excellence in Oceans and Human Health. Focus of the CIG's work will be identifying and quantifying relationships between large scale climate variations, local environmental changes, and variations in Harmful Algal Bloom (HAB) activity.

Western Mountain Initiative (WMI) --$190k/yr. 2004—2008, USGS Global Change Research Program.

NSF Office of Polar Programs, "Role of the Southern Ocean in the global ocean circulation" $243,000, Igor Kamenkovich, PI, 5/01/2002 – 04/30/2004 (extended to 04/30/2005)

NSF Physical Oceanography Program "Collaborative research: Role of eddies in the midlatitude ocean circulation"$362,452 , Igor Kamenkovich,PI, 07/01/2004 – 06/30/2007

NSF Climate Dynamics Program, "Subantarctic Mode Water and Antarctic Intermediate Water: How Well Are They Represented in Climate Models?"24,459, Igor Kamenkovich PI, 09/15/2004 – 09/14/2005

U.S. Geological Survey Global Change Research Program , Western Mountain Initiative, David L. Peterson, PI ,$900K, 10-1-03 to 9-30-08

USDA Forest Service Pacific Northwest Research Station, -- Fire and Environmental Research Applications Team, salary support to David Peterson and Don McKenzie, $40K annually

University of Washington graduate fellowships, Graduate fellowships to Jill Nakawatase and

Melisa Holman, one academic year each, $40K

a. Pending Proposals

CIG. PACIFICNORTHWESTSIM: A Decision-Support System for Integrated Resource Management. Pre-Proposal submitted to Vulcan, Inc.-- $3.078m/3 yrs.

CIG. The Impacts of Climate Change on Human Health in the Pacific Northwest: Developing a Decision Support System for Early Warning. Pre-proposal submitted to Vulcan, Inc. $1.47m/3 yrs.

CIG. Water Management for Irrigated Agriculture in the Interior Columbia River Basin: The Role of Advanced Crop Water Estimation and Improved Hydrologic Decision Support Systems. Pre-Proposal submitted to Vulcan, Inc. $1.5m/5 yrs.

Eric Salathe. Modeling the Effects of Climate Change and Variability on the Pacific Northwest: Mesoscale Processes and Climate Impacts. Proposal submitted to NSF. $374k/3 yrs.

Nathan Mantua and Eric Salathe. Collaboration in the OSU research project on "The Role of Climate on Wildfire Emissions and Resulting Air Quality". EPA STAR proposal sub-contract. $28k/1 yr.

NASA-Earth System Science Research, "Satellite-data-based stochastic models of ocean-atmosphere interaction over the Southern Ocean: Development and application" $154,867, 09/01/2004 – 08/31/2007, I. Kamenkovich, co-PI (4 mon/yr effort).

Appendix A: The CSES Strategic Plan for 2005-2010

A. Impacts

1. What are the critical interactions among resources (and resource management) that will shape regional impacts of climate variability and change?
    - How do regional climate, hydrology, and water management affect the response of fish and forests to climate variability and change?
    - How are choices about forest management likely to affect water availability and quality under conditions of climate variability and climate change?
    - How will the loss of snowpack affect mountain ecosystems?
    - We want to add estuarine ecology, human health, and agriculture.

2. How can instruments best be deployed to identify key changes in the region's climate and natural resources and how can the data most effectively be interpreted into real time forecasts?

3. What are the relationships between intraseasonal tropical climate variations and intraseasonal climate events in the PNW?
    - Can methods for skillful weather/climate predictions be developed at timescales of 10-60 days?

4. What are the net impacts of climate variability on the region and what are the likely impacts of climate change, combined with regional trends in population growth and technological development?

5. Where are there thresholds? Which thresholds constitute potential tipping points for increasing vulnerability in ecosystems and human social systems?
    - How will climate change affect extreme events?

6. What are the greatest uncertainties in quantifying the effects of climate variability and change on ecosystems and human social systems in the region? Which uncertainties are most crucial for improving predictions?
    - What are the effects of climate change on ground water – and how does ground water influence surface resources (including ecosystems and human social systems)?
    - Quantify stock-specific sensitivities to climate, and determine the interactions of ocean, estuary, and freshwater portions.

B. Policy

1. How could cross-sectoral management improve adaptive capacity by exploiting the critical interactions across sectors and resources?

2. What adaptation strategies are most likely to be effective over the next 50 years?

- Define characteristics of resilient socioeconomic systems, and strategies for increasing resilience
- Evaluate policy efficacy, i.e., the path from policy adoption back through the physical, biological, socioeconomic structures.
- Watershed level investigations are key
- Identify the most powerful entry points for policy recommendations at different space scales (management purview, decision making processes and calendars, etc.)
- What are the space-time relationships between the regional wind climate and regional hydrology? Can these relationships be exploited to increase the reliability of the region's energy production system through some optimal balance between wind and hydropower?

3. How can resource management operationally include advances in knowledge about climate variability and change without requiring formal policy changes?
    - What do managers want to know?
    - What do managers need to know?
    - Can we develop systems such that we do not have to distinguish between "want" and "need" to know?
    - How can we systematically bring to bear the contributions of decision analysis to maximize our effectiveness in communicating risks to managers and the public?

Appendix B: Table of Contents of *Rhythms of Change*….

Rhythms of Change: Climate Impacts on the Pacific Northwest, by Edward L. Miles, Amy K. Snover, and the Climate Impacts Group, University of Washington.

Draft Table of Chapters

Appendix C: Catalog of CIG Outreach Efforts, 1998-2004

1998 - 1999

- Workshop on Climate and Water Resources Outlook (Cascade Locks, OR), date unknown, 1998
- Workshop on Climate and Water Resources Outlook (Gig Harbor, WA), October 26, 1998

1999 - 2000

- Workshop on Climate and Water Resources Outlook (Cascade Locks, OR), September 28, 1999
- Workshop on Climate and Water Resources Outlook (Seattle, WA), September 29, 1999
- Fish Expo Workboat Northwest Conference session on climate (Seattle, WA), November 1999
- Forums releasing the PNW regional report on impacts of climate variability and change (Seattle, WA), November 9, 1999; (Portland, OR), November 10, 1999; (Salem, OR), November 10, 1999
- Climate and the North Pacific Coast (Astoria, OR), May 8, 2000
- Impacts of climate variability and change: workshop at Wash. Dept of Natural Resources, May 9, 2000
- Seminars hosted weekly at CIG offices (Seattle, WA) Fall, Winter, and Spring Quarters

2000 - 2001

- Workshop on Climate and Water Resources Outlook (Seattle, WA), September 26, 2000
- Workshop on Climate and Water Resources Outlook (Portland, OR), October 5, 2000
- Workshop on Climate and Water Resources Outlook (Boise, ID), October 27, 2000
- Fish Expo Workboat Northwest Conference session on climate (Seattle, WA), November 2000
- Workshop on Climate and Water Resources Outlook (Yakima, WA), November 2, 2000
- Meeting with staffers from offices of Senators Craig (R-ID), Baucus (D-MT), Smith (R-OR), and Rep. Jay Inslee (D-WA), March 8-9, 2001
- Workshop on Climate and Water outlook for the PNW - Spring 2001 (Portland, OR), April 10, 2001
- Briefing for WA Commissioner of Public Lands Doug Sutherland, April 16, 2001
- Meeting with Paul Cleary, Director of Oregon's Dept of Water Resources, and with Barry Norris of DWR; then with Ken Messerle, State Senator, and Rep. Betsy Close, June 4, 2001 on drought issues.
- Water policy workshop: Adapting to a Warming Climate (Stevenson, WA), July 16-17, 2001
- Seminars hosted weekly at CIG offices (Seattle, WA) Fall, Winter, and Spring Quarters

2001 - 2002

- Drought preparedness exercise (Seattle, WA), September 10, 2001 aimed at Puget Sound municipal water managers to discuss strategies for increasing regional resilience to droughts.
- Workshop on Climate and Water Resources Outlook (Boise, ID), September 27, 2001
- Workshop on Climate and Water Resources Outlook (Kelso, WA), October 4, 2001
- Workshop for journalists: Climate Change and the PNW (University of Washington), November 8, 2001
- Research conference on Carbon, Forests, and Climate Change (Orcas Island, WA), November 13-15, 2001
- Meeting with provincial officials (Victoria, B.C.), January 9, 2002
- Meeting with senior stakeholders on climate and water policy (Portland, OR), March 20, 2002 to discuss implications of the CIG's climate change projections.
- Briefing for US Army Corps of Engineers (Portland, OR), March 25, 2002
- Briefing for environmental legislative assistants and staff of the PNW Congressional delegation (Washington, D.C.), April 26, 2002
- American Water Works Association regional conference half-day session on climate and water resources (Eugene, OR) May 2, 2002
- Seminars hosted weekly at CIG offices (Seattle, WA) Fall, Winter, and Spring Quarters

2002 - 2003

- International Workshop on Integrated Assessment of Regional Impacts of Climate Change (Castelvecchio Pascoli, Italy) September 16-20, 2002
- Workshop on Climate and Water Resources Outlook (Olympia, WA) September 25, 2002
- Workshop on Climate and Water Resources Outlook (Boise, ID) October 16, 2002
- Water Resources in a Changing Climate: Hydrologic Scenario Development for Long-Range Planning (Seattle, WA), April 30, 2003
- Graduate level seminar on Decision-making in the Face of Uncertainty (University of Washington), Spring Quarter 2003
- Seminars hosted weekly at CIG offices (Seattle, WA) Fall, Winter, and Spring Quarters

2003 - 2004

- Workshop on Climate and Water Resources Outlook (Boise, ID), September 25, 2003
- Workshop on Climate and Water Resources Outlook (Kelso, WA), October 14, 2003
- Paleonorthwest Workshop (Bellingham. WA), April 15-16, 2004
- Meeting on climate impacts and salmon recovery in the PNW (Portland, OR) planned for Fall 2004
- Second International Conference on Climate Impacts Assessment (Grainau, Germany), June 28 – July 2, 2004
- Seminars hosted weekly at CIG offices (Seattle, WA) Fall, Winter, and Spring Quarters