EXECUTIVE SUMMARY: POLICY SCOPE

Through innovative scientific research on how the Pacific Northwest's natural resources are affected by predictable climate variations, the Climate Impacts Group (CIG) at UW provides a service to the region and helps guide resource managers toward more informed decisions relative to the implications of climate variability and change. CIG's unique focus on is on the intersection of climate science and public policy – performing basic research aimed at understanding the consequences of climate variations for the region, and ensuring that this information is applied to regional decisions. Past CIG work has helped to improve understanding of how historical and predicted future patterns of climate variability and change are likely to influence the PNW. CIG activities are focused on the states of Washington, Oregon, and Idaho, along with that portion of the Columbia River Basin lying in Montana and British Columbia.

CIG was initiated in July 1995, with primary funding from the NOAA Office of Global Programs (OGP), and additional internal support from the University of Washington. Initially, OGP funding was limited, and four sectors were identified for early work: hydrology and water resources, fisheries, forestry, and coastal processes. Based on its successes in the first five years, CIG is now seeking additional funding that would allow expansion of activities in the "core" areas, and additional work in forest hydrology, agriculture, and human health. This support will enable CIG to provide regional planners, decision-makers, and natural resource managers with valuable knowledge of the ways in which crucial regional resources are vulnerable to changes in climate, and how this vulnerability could best be reduced. CIG's established connections with key regional stakeholders and its experience working directly with natural resource managers will ensure that the proposed research will result in information that will not only be *useful*, but will be *used* to shape decisions in the PNW.

Additional support in the amount of $5M over five years would allow CIG to:

Improve our understanding of climatic processes operating in (and on) the PNW, by:
producing climate information at higher resolution than is currently available, for application to climate impacts studies, streamflow modeling, etc.; understanding the potential for extreme weather events; and defining the natural range of variability in regional climate.

Enhance regional ability to forecast and cope with variations in water supply, by:
developing a regional streamflow forecasting facility; characterizing the range of natural (climate-caused) variations in water supply and the capability of the current water resources management system to cope with these variations; and significantly improving the accuracy of streamflow modeling and forecasting methods.

Provide fisheries managers tools to improve management of endangered PNW salmon, and other economically and ecologically important fisheries resources, by:
developing a coho (salmon) lifecycle model to evaluate the likely impacts of climate change on this and other salmon populations; determining the vulnerability of Puget Sound salmon – particularly chinook, recently listed as threatened under the ESA – to future climate change; and characterizing the role of climate in the Washington-Oregon estuarine and coastal marine ecosystems.

Enhance the resilience of PNW forests – and thereby the region as a whole – to variations and future changes in climate, by:

facilitating use of climate information in forest management decisions; evaluating strategies for using PNW forests as "carbon sinks," i.e., for long-term retention of carbon; and evaluating the role of forest management practices in the regional water cycle.

Reduce climate-related risks to the coastal zone, by:

proposing fiscal and/or economic incentives to reduce the risks associated with coastal erosion and flooding; evaluating policy and management responses to the risks associated with future sea level rise; and developing an integrated analysis of coastal watershed management – to determining the consequences of inland forestry and water resources management decisions for coastal resources.

Mitigate the risk of human disease associated with a changing climate, by:

evaluating the direct effects of temperature – and temperature changes – on human mortality and disease patterns; and determining the indirect effects of climate change on vector-borne diseases, such as hantavirus and lyme disease; on health of coastal communities, through harmful algal bloom activity and incidence of shellfish poisoning; and on air quality and its effect on respiratory disease.

Characterize – and propose ways to reduce – the vulnerability of PNW agricultural productivity to climate variability and change, by:

identifying the implications of climate change for the types of crops grown in the PNW, their demand for water, and the opportunities and costs associated with a longer growing season; evaluating the potential for using water markets to alleviate conflicts among water users in the interior Columbia River basin; and suggesting ways for regional growers to use information provided by climate forecasts to decrease their vulnerability to climate variations, and

Improve regional natural resource management decisions, by:

identifying the human activities and institutions in the PNW that are most sensitive and vulnerable to climate variability and change; determining the necessary conditions for increasing the social utility of climate, and climate impacts, forecasts, and working with both the producers and users of these forecasts to improve their use; and characterizing how new – climate-related – information could be most effectively introduced into regional planning and decision-making.

Provide the PNW with powerful decision-making tools, by:

implementing a full-scale analysis of the sensitivity of the PNW to climate variability and change, and providing this information in a form useful to resource managers; and designing and applying a GIS-based decision-making tool for fine-scale qualitative and quantitative policy analyses and providing this tool to the regional stakeholder community.

EXECUTIVE SUMMARY: TECHNICAL SCOPE

Through innovative scientific research on how the Pacific Northwest's natural resources are affected by predictable climate variations, the Climate Impacts Group (CIG) at UW provides a service to the region and helps guide resource managers toward more informed decisions relative to the implications of climate variability and change. CIG's unique focus on is on the intersection of climate science and public policy – performing basic research aimed at understanding the consequences of climate variations for the region, and ensuring that this information is applied to regional decisions. Past CIG work has helped to improve understanding of how historical and predicted future patterns of climate variability and change are likely to influence the PNW. CIG activities are focused on the states of Washington, Oregon, and Idaho, along with that portion of the Columbia River Basin lying in Montana and British Columbia.

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Additional support in the amount of $5M over five years would allow CIG to:

Climate Dynamics and Diagnostics. Improve the ability to downscale seasonal to interannual climate forecasts, as well as long-term climate predictions, using a combination of dynamical models and statistical methods; and construct, using instrumental sources over the last century, and paleo indicators over the last 5-6 centuries, the best available record of the region's long term climate, and provide that information in a form useful for planners;

Water Resources. Develop a regional experimental long-range hydrologic forecast facility using evolving state-of-the-art climate forecast methods, and provide training to regional water managers on the use of the new forecast tools; develop and test alternative methods of operating the Columbia River reservoir system, including implementation of new forecast methods; and develop methods for incorporating new data sources, including satellite remote sensing, in hydrologic forecasts;

Aquatic Ecosystems. Develop lifecycle models for coho salmon to examine the relative utility of species restoration strategies in the face of human-caused habitat and climate changes; determine how climate variations will affect the survivability of Puget Sound salmon, in particular to aid management decisions concerning Puget Sound chinook, which were recently listed as threatened under the Endangered Species Act; characterize the role of climate in the Washington-Oregon estuarine and coastal marine ecosystems, in order to provide regional managers with the tools to increase the effectiveness of resource management decisions and the resilience of crucial coastal ecosystems.

Forest Resources. Identify how to incorporate an understanding of natural climate variations and future climate change into forest ecosystem management, and assist the regional forest management community in applying this information; evaluate strategies for use of PNW forests for long-term retention of carbon and determine the role of current and future forest management in carbon sequestration; and evaluate the role of forest management practices in the regional water cycle.

The Coastal Zone. Identify combinations of fiscal and economic incentives that could be used to reduce the risks associated with coastal erosion and flooding; analyze the risks of future sea level rise and evaluate possible policy and management responses within the existing regulatory framework; and develop an integrated analysis of coastal watershed management in order to provide regional managers with information about how upland forestry and water resource management practices affect coastal resources.

Human Health. Evaluate the *direct* effects of temperature on human mortality and disease patterns; and the *indirect* effects of climate variability and/or change on (1) vector range and diseases such as hantavirus and lyme disease; (2) coastal communities, through harmful algal bloom activity and resultant human diseases such as *vibrio parahemolyticus*; and (3) air quality and its effect on respiratory diseases.

Agriculture. Evaluate the implications of climate change for agriculture in the PNW (crop type, water demand); evaluate the potential for use of water markets to cope with conflicts resulting from increasing competition over water resources in the interior Columbia River basin; and identify the ways in which major PNW crop types are vulnerable to predictable patterns of natural climate variability, in order to suggest ways for regional growers to make better use of climate forecasts.

Human Systems. Identify the human activities and institutions in the PNW most sensitive and vulnerable to climate variability and change; determine the necessary conditions for increasing the social utility of climate, and climate impacts, forecasts, and work with both the producers and users of these forecasts to improve their use; and characterize how new (climate-related) information could be most effectively introduced into regional planning and decision-making.

Integrated Decision-Making Tools. Implement a full-scale analysis of the sensitivity of the PNW to climate variability and change; and design and apply a GIS-based decision-making tool for fine-scale qualitative and quantitative policy analyses and provide this tool to the regional stakeholder community.

CLIMATE IMPACTS RESEARCH

AT THE

UNIVERSITY OF WASHINGTON, 1995-2005

Summary: Through innovative scientific research on how the Northwest's natural resources are affected by predictable climate variations, the Climate Impacts Group (CIG) at UW has provided inestimably valuable services to the region and has guided resource managers toward more informed decisions. The CIG outlines here how it would build on this foundation of basic and applied research, increasing its value to a region uniquely well suited to becoming more "climate-wise".

Natural resource management, including farming, hydropower production, ecosystem management, and a host of other pursuits, perpetually faces the challenge of coping with uncertainty in what benefit or damage the climate will bring. Advances in seasonal climate forecasting now provide a glimpse of what the climate might bring in the next 3-12 months, especially in the western U.S., and natural resource managers are consequently able to make better-informed decisions. In addition, there is a growing consensus among scientists that Earth's climate is changing in ways unprecedented in human history, raising the prospect that natural resource managers will perpetually be adjusting to new conditions. With these challenges and opportunities, effective links between climate scientists and natural resource managers would be inestimably valuable.

The Climate Impacts Group (CIG) at the University of Washington is just such a link, and its trailblazing efforts in basic and applied research, combined with its understanding of the context within which resource management decisions are made, have earned it respect from natural resource managers in the Pacific Northwest and from academics worldwide. By limiting its attention to the states of Washington, Oregon, and Idaho, along with that portion of the Columbia River Basin lying in Montana and British Columbia, the CIG has made great progress in elucidating patterns of climate variability and their impacts on four valuable types of resources: water, forests, aquatic ecosystems (primarily salmonids), and the coasts. Understanding these patterns and their impacts forms a crucial foundation for understanding how global climate change is likely to influence the PNW. CIG is committed to regional outreach and education, and works closely with regional decision-makers to ensure that our research products are both *useful* and *used* to inform management and planning decisions.

CIG was formed in July 1995 with enthusiastic support and guidance from the Office of Global Programs at NOAA, and since 1999 has attempted to extend its efforts to include human health, forest hydrology, and irrigated agriculture, but these attempts have been thwarted by a shortage of funds. CIG is well poised to provide the PNW with the capability for assessing the likely impacts not only of future changes in climate, but of alternative policy responses. The additional support required to develop this capability fully is detailed here.

MAJOR SUCCESSES, 1995-2000

Scientific Understanding of Climate and its Impacts in the Pacific Northwest (PNW)

1) Identified the natural patterns of climate variability in the Pacific Northwest.
2) Demonstrated that these patterns are dominated by two predictable, large-scale patterns of climate variation over the Pacific Ocean: the El Niño/Southern Oscillation (ENSO) (which varies on a time scale of 2-7 years) and the Pacific Decadal Oscillation (PDO) (which seems to vary on a time scale of 40-50 years). Warm phases of ENSO or PDO often bring warmer, drier weather in winter and spring, and cool phases have the opposite effect. The predictability of ENSO and PDO 3-12 months ahead thus provides advance warning about winter and spring climate in the PNW.
3) Demonstrated that PNW snowpack and streamflow are higher in cool phases of ENSO and PDO and lower during warm phases; extremes (droughts or floods) are much more likely to occur when ENSO and PDO are in phase.
4) Simulated the projected effects of climate change on the hydrology and water resources of the Columbia River Basin, one of the largest in North America, and the source of much of the electricity generated in the PNW. Climate change would primarily result in changes in snow accumulation and melt, and a shift in streamflow timing toward increased winter runoff, earlier spring snowmelt, and reduced summer flows.
5) Developed a tool for making ensemble (multiple) forecasts of Columbia River streamflow up to 12 months in advance, using predictions of ENSO and PDO phases. Initial estimates suggest that such forecasts could result in an average annual benefit of over $100 million/year for hydropower alone, while preserving or enhancing fisheries protection and flood prevention capabilities.
6) Discovered the enormous impact of the PDO on the distribution and abundance of Pacific Northwest salmon from Oregon to Alaska. During warm phases of the PDO, salmon are more plentiful than usual off the coast of Alaska but less plentiful off Washington/Oregon. During cool phases of the PDO, the opposite is true.
7) Suggested a connection, later verified, between episodes of increased coastal erosion and El Niño events. The key factors are a more southerly direction of storm-driven waves and higher than normal sea level in the northeast Pacific Ocean.
8) Demonstrated a connection between the PDO and the rate of forest growth, and showing that forest fires are larger and more frequent during the warm phase of PDO.

International Scientific Leadership

1) Influenced the field of climate impacts research and natural resources planning and management via a series of published papers in peer reviewed journals.
2) Compiled research findings in a book-length manuscript to be submitted to MIT Press in early 2001.
3) Pioneered and helped to institutionalize a new subfield of science in the U.S. now called "Climate Impacts Science."

4) Convened both regional and international scientific gatherings to promote interdisciplinary Climate Impacts Science.
5) Served on advisory boards for various climate-related research efforts.

Influence on the Region's Management of Natural Resources

1) Promoted the effective use of climate forecasts and other climate information by natural resource managers throughout the PNW. CIG advocates linking an understanding of climate dynamics, climate forecasts, and the anticipated impacts of climate variability and climate change for use by planners, decision-makers, and natural resource managers in the sectors of concern. Avenues of communication include annual meetings for a broad audience, press briefings, targeted briefings for specific audiences like water resources managers ("water workshops"), and one-on-one meetings with federal, regional, state, local, and tribal officials. Our capability in this arena has had direct immediate and lasting benefits for regional resource management, and is our contribution to the vision of a new National Climate Service currently under consideration at the federal level.
2) Coordinated and conducted a high-level discussion of the regional impacts of climate change among a broad range of stakeholders at a workshop conducted on behalf of the Office of Science and Technology Policy, the White House, and the U.S. Global Change Research Program (USGCRP) (Summer 1997). CIG worked with the Northwest Council on Climate Change to draw a wide-reaching stakeholder group to this event. Some participants have subsequently shown visionary leadership on the climate change issue in a wide variety of contexts, both government and non-government, and continue to incorporate CIG's climate information into their decision-making processes.
3) Produced the first report on a regional assessment of climate impacts (November 1999) as part of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change (conducted by the USGCRP).

These successes, both in the academic realm and in public policy, have demonstrated the inestimable value of an "end-to-end" regional climate assessment, linking one end (understanding of past, present, and future climate) to the other end (decisions concerning natural resources), in the context of other factors, notably population growth and policy constraints. The application of climate information to urban water management shows the value of this type of work. Urban water supply planners in the PNW must plan for a rapidly growing population, while constrained by changing rules intended to save native salmon runs from extinction. Predictions of ENSO and PDO can help managers improve their decisions each year, as they did in 1997-98 when CIG assisted the City of Seattle in planning for, and thereby averting, a possible El Niño-related water shortage. In the longer term, a reduction in summer water supply caused by a warming climate will exacerbate the problems caused by rising demand. Climate change, population growth, and other stresses will all converge to create major challenges for both the ecosystem- and socioeconomic health of the region, and CIG's research and outreach capabilities will become increasingly needed and valuable.

To meet even the present needs articulated for the PNW would require approximately $2.0 million per year. CIG is currently funded at a level of $1.1 million per year from the combined sources of NOAA/OGP and internal University of Washington sources. The enhancements that would result from a higher level of funding over the next five years are detailed below.

A DETAILED PROGRAM OF RESEARCH, 2001-2005

Climate Dynamics and Diagnostics

Understanding how climate affects natural resources and human systems rests squarely on an understanding of climate itself. CIG's climate research has established a solid foundation supporting our regional climate impacts study, but crucial uncertainties remain: how can we translate large-scale climate information into a form useful for the PNW? What is the true range of natural climate variability in the region? Can we predict these variations?

With an expanded research program, we could develop the capability to **produce more useful climate information at higher resolution, understand the potential for extreme weather events, and better define the expected range of variability** in regional climate.

- In order to assess climate impacts at the scale of individual watersheds (on scales of 1 to 100 km^2), we must have climate information of significantly higher resolution than that typically produced by climate models. For climate model output to be useful for short-term climate forecasts (one to a few seasons lead-time) or for creating scenarios of long term anthropogenic climate change (a few to many decades lead time), it must therefore be "downscaled" to higher resolution. Downscaling climate data over the PNW is particularly problematic due to the region's complex topography, and cannot be done well with the present generation of coupled land-atmosphere-ocean models. We will develop and evaluate an approach combining dynamic downscaling techniques based on established high-resolution weather prediction models (the Penn State/NCAR MM5 model) with a second stage statistical-dynamical algorithm. With these tools, we will develop high quality, high resolution data sets suitable for input to regional hydrologic models.
- Floods, droughts, hard freezes, storms, and other extreme events often have dramatic impacts on a region and pose significant challenges to local and regional managers. Future work will enable us to better understand the likelihood of extreme daily weather events – the year-to-year and decade-to-decade variability in their frequency. Have there been long-term trends in the frequency of significant weather events? What are likely future trends? Specifically, we would conduct a detailed assessment of extreme weather over the last century, including floods and droughts, snow storms, extreme cold, and wind storms, to determine whether and how the occurrences of these events have changed over time.
- Although the historical ("instrumental") records of PNW climate, dating back about 120 years, have been immensely useful in characterizing the region's natural climate variability, they have not shown us the true range of possible climate variation. We must turn to "proxy" records like climate-sensitive tree rings and lake sediments to deduce climate variations on longer timescales – at least back to the 15th century – in order to ensure that natural resource management systems are robust to the real range of possibilities. We will construct a high-resolution (annual) PNW paleoclimate record for the past 500 years using tree-ring chronologies and a decadal resolution paleoclimate record for the past 2000 years based on lake bed sediment cores. These reconstructions will allow us to definitively characterize the range of variation in regional climate, specifically providing proxy time series for (1) PNW snowpack, precipitation, temperature, and drought frequency and severity; and (2) the Pacific Decadal Oscillation (PDO).

Water Resources

Water resource managers have two primary concerns: how much water will be available, and when? CIG research has quantified the connections between these crucial aspects of water supply (including the likelihood of droughts and floods) and ENSO, PDO, and climate change. To date, CIG has mainly focused on the Columbia River Basin. Because regional water managers have repeatedly requested more detailed local information, current efforts are focusing on a) developing a finer-scale analysis of water management issues and processes in the Snake River basin (through collaboration with University of Idaho scientists); b) expanding our hydrologic modeling capability to include the effects of climate variability and change on forest hydrology; and c) modeling the hydrology and water resources of the more urban watersheds west of the Cascade Mountains, where we are the first to examine the combined implications for water resources planning of climate change, population growth, and the stresses associated with listing of regional salmon runs under the Endangered Species Act (ESA).

Enhancement of CIG funding would allow us to **develop a regional forecasting facility, expand our understanding of past climate-driven water resource variations, and integrate new sources of data** (including satellite data) into our modeling effort. All of these efforts would enable us to provide the more detailed, locally-specific information desired by water resource managers:

- CIG would develop a regional experimental long-range hydrologic forecast facility to produce ensemble streamflow forecasts for a variety of locations within the Columbia River basin. We would expand our annual water workshops to include training in the use of these forecasts, in order to rapidly improve the decision-making tools of regional water managers and water users. Our long-range forecast center would incorporate ensemble climate predictions produced by NCEP and other centers, downscaled over the Columbia River basin using a regional mesoscale model in development at CIG. Such a facility would be patterned after the existing Northwest Regional Modeling Consortium, which produces weather (36 hour) and experimental streamflow forecasts over a domain that includes the Olympic Mountains and the west slope of the Cascade Mountains.

- By expanding our understanding of past streamflow variations (on decade to century time scales), we would evaluate – and potentially improve – the robustness of the Columbia River water resources management system. Direct measurements of Columbia River streamflow (on a monthly timescale) extend back to 1878; we would reconstruct annual flows (and link them to precipitation and temperature patterns) back to 1858, using observations of peak annual flows. This would provide a far longer horizon of knowledge than is usually incorporated in water management, and would allow us to define (1) how well the existing water management system can be expected to perform, given this more complete understanding of natural streamflow variability, and (2) how our improved streamflow forecasts could improve water management.

- We would significantly improve the accuracy of streamflow modeling and forecasting methods by incorporating evolving data sources, especially remote sensing data, into our modeling and forecasting processes. Errors in initialization of hydrologic models are recognized to be a significant source of forecast error – only recently has data assimilation, widely used in meteorological forecasts, begun to evolve as a tool for initializing hydrologic forecasts. Newly available and planned sources of remotely sensed data will be used to improve model initialization, such as the snow data now available from MODIS (snow extent products at 0.5 km spatial resolution), and that will be available with the upcoming launch of NASA's EOS Aqua satellite (passive microwave snow water equivalent products (AMSR)). Improved model initialization holds promise not only for improving the accuracy of hydrologic forecasts, but of producing space-time "nowcasts" of hydrologic variables like soil moisture that are potentially useful in their own right.

Aquatic Ecosystems

Two intertwined issues confront managers of aquatic and marine ecosystems: how to set the annual catch limits for various fisheries before the size of the return is accurately known, and – a task that has embroiled political leaders throughout the region – how to rescue salmon runs listed under the Endangered Species Act. In both cases, regional leaders benefit from CIG's progress in understanding how climate affects salmon during the early, freshwater phase of their life cycle. However, the **response of salmon and other species to ocean conditions** is a critical unknown factor. CIG, by identifying the effects of the PDO on many runs of Pacific salmon, has provided valuable and widely used input to annual harvest management decisions. Enhanced CIG funding would allow us to:

- Develop a hierarchy of lifecycle models for coho salmon to examine the relative utility of species restoration strategies in the face of human-caused habitat and climate changes. Models of this type presently make extremely crude assumptions about the impacts of changing ocean and estuary conditions on coho survival. By improving the estuary and ocean components of these models, we will be able to make much more quantitative assessments of climate change impacts on selected salmon populations than is now possible.
- Determine how climate variations will affect the survivability of Puget Sound salmon, in particular Puget Sound chinook, which were recently listed as threatened under the ESA. Puget Sound, the finger of salt water that protrudes deep into Washington State from the Pacific Ocean, is a transition zone between the freshwater and open ocean environments that appears to buffer salmon against changes in ocean properties associated with ENSO and PDO. Will the beneficial juvenile salmon marine habitat provided by large estuaries like Puget Sound be affected by future climate change?
- Characterize the role of climate in the Washington-Oregon coastal marine ecosystem. Many PNW coastal communities benefit from commercial and recreational fishing and shellfish aquaculture, which are dependent on a healthy coastal marine ecosystem – economically important components include groundfish (such as sturgeon, perch, lingcod, and sole), salmon, crustaceans (such as Dungeness Crab and several species of shrimp), and coastal pelagics (such as herring, smelt, rockfish, and sole). By understanding the role that natural climate variations and future human caused climate change play in sustaining or unhinging this system, we would provide regional managers with the tools to manage coastal resources in harmony with, rather than in opposition to, forces of change outside their control. Thus, we could increase the effectiveness of resource management decisions and the resilience of crucial ecosystems.

Forest Resources

CIG's research on how climate affects the highly productive forest ecosystems of the PNW has primarily focused on how ENSO and PDO affect forest growth and disturbances, especially forest fires. We intend to build a broader base to **document the effects of past climatic variability on the region's forest ecosystems**, which range from temperate rainforest to dry savanna, in the context of both "natural" ecological dynamics and forest management activities.

We have assembled data bases that provide the empirical input for ecosystem models, which will be used to **estimate the effects of different climate change scenarios on forest productivity, distribution and abundance of plant species, and fire disturbance**. Enhanced funding for CIG would facilitate expansion of work in the forest sector in three areas:

- Identify how an understanding of ongoing (natural) climate variability and expected future climate change could be incorporated into forest ecosystem management. Our research findings to date (demonstrated connections between forest growth and disturbance and climate) and anticipated in the future (the likely impact of human-caused climate change on regional forests) have useful application to forest management. Stimulating such application will require an understanding of the context within which such management decisions are made. This work would therefore include enhanced interaction with the forest management community, drawing on CIG's experience creating its workshop series on application of climate information to management of water resources.
- Evaluate possible strategies for use of PNW forests for long-term retention of carbon, and determining the effect of current and future forest management in the region on carbon sequestration.
- Evaluate the role of forest management in the regional water cycle. Because forested areas in the PNW have a disproportionate role as the source of much of the region's streamflow, it is crucial for regional decision-makers to understand the effects of climate variability, climate change, and management practices on the region's forests, and in turn on water runoff and streamflow amounts and timing. Through its established connections with forestry and water resource managers, as well as federal, regional, state, local, and tribal officials, CIG would ensure that these research findings would be used to inform regional management.

The Coastal Zone

CIG has made some progress at identifying how **the economically and ecologically unique coasts and estuaries of the Pacific Northwest are sensitive to climate variations and change**. However, CIG's coastal work has been curtailed in recent years due to funding limitations. Enhanced funding would allow us to restart this effort and to accomplish the following:

- Complete our work on the risks of coastal erosion and flooding, in Oregon and Washington, that are associated with different patterns of climate variability. In particular, we would examine the potential economic effects of such risks and the alternative ways in which different combinations of fiscal and economic incentives can be used to alleviate these risks.
- Analyze the risks of future sea level rise and evaluate possible policy and management responses. Perhaps the best understood component of future change in the coastal marine environment is the accelerated sea level rise that will occur as

a result of both past and future greenhouse gas emissions. Rising sea level could cause or exacerbate a number of problems in the PNW, including coastal erosion, flooding, and inundation. Our analysis of possible policy response to sea level rise would build on work on coping with sea level rise done by Washington State's Department of Ecology in the early 1990's, since which time the regulatory framework has changed.

- Develop an integrated analysis of coastal watershed management. Because coastal watersheds extend inland – even to the crest of the Cascade Mountains – effective watershed management must integrate an understanding of how coastal processes are affected by both climate and terrestrial processes, including forest hydrology and urbanization effects. How do forest management's effects on streamflow affect estuarine and coastal circulation and ecosystems? How will climate variability and climate change affect the spread of exotic or invasive species like the cordgrass *Spartina alterniflora* (Loisel), which threatens commercial oyster beds in Washington State?

Human Health

The Pacific Northwest enjoys good health according to most measurable health indices. How will this change with a changing climate? Although much has been published from tropical and arctic zones, little is known about the impact of climate change in temperate areas. Will these zones be "tropicalized," as posited by some investigators, and see the incursion of tropical diseases such as Dengue Malaria (malaria existed in Washington state until the mid 19^{th} century). Or will shifts be subtler, with the gradual exhaustion of public health systems in the face of fresh water quality decline, multiple extreme weather events, and a gradual deterioration of clean air? By linking carefully detailed climate scenarios and multiple existing datasets on human disease and mortality we will be able to **define more completely the future which awaits our human community**. Public Health systems are local systems. Our research will be applied research carried out collaboratively with decision-makers at local and state level public health agencies, following the model successfully implemented in CIG's water resources sub-group. In this way we will assure that the findings will be valuable in planning responses to **mitigate human disease in the face of a changing climate**. With enhanced CIG funding, we would:

- Evaluate the *direct* effects of temperature on human mortality and disease patterns. After establishing the link for current climate, we would use climate change scenarios to project how mortality and disease patterns would change in the future.
- Evaluate the *indirect* effects of climate variability and/or change on (1) vector range and diseases such as hantavirus and lyme disease; (2) coastal communities, through harmful algal bloom activity and resultant human diseases such as *vibrio parahemolyticus* (a water borne bacterial disease that is becoming widespread in PNW oysters); and (3) air quality and its effect on respiratory diseases.

Agriculture

Agricultural productivity – which is a significant component of the economy of the PNW – is undoubtedly sensitive to climate variability, and CIG has long intended to include agriculture in its studies, but funding has so far not permitted it to be included. However, CIG's strengths in hydrological modeling have begun to be applied to agricultural issues related to water supply for irrigation, and these would be expanded with increased funding. CIG is working with colleagues at the University of Idaho to analyze the complex interactions between **irrigated water supply and demand in southern Idaho** (the upper Snake River). With increased funding, this approach could be applied to understand hydrology-water resources-agriculture interactions elsewhere in the PNW; in particular in Washington's Yakima River basin, a producer of a significant percentage of U.S.-grown apples, sweet cherries, pears, asparagus, spearmint, and hops.

Enhanced funding would also allow us to **examine the sensitivity and vulnerability of PNW agriculture** to climate variability and change – and how the region could best minimize this vulnerability. We would broaden our study to include dry land agriculture, and agricultural west of the Cascades (especially in Oregon's highly productive Willamette Valley). Major elements of this work would be to:

- Evaluate the implications of climate change for the types of crops grown in the PNW, their demand for water and transportation facilities, and competitive implications in comparison with other regional and global markets and competitors. Evaluate the potential for crop substitution to cope with the impacts of climate change, and the opportunities and costs (especially in terms of increased water usage) likely to be associated with longer growing seasons.
- Evaluate the potential for use of water markets in the interior Columbia River basin, and implications for and of water laws, especially in Washington and Idaho. PNW water resources are becoming increasingly stressed by the impacts of growing populations. CIG's research has shown that the likely increases in demand for water in the PNW spell bitter conflicts between irrigated agriculture, flood control, fisheries protection, and hydropower production. Future work evaluating the role that water markets could play in this future will be supported by our current efforts to develop linked hydrologic, water resources, and institutional models of the upper Snake River.
- Identify the major PNW crop types that are most vulnerable to predictable patterns of natural climate variability, and evaluate how regional growers could make better use of climate forecasts.

Human Systems

CIG strives not only to understand the degree to which society is sensitive to climate, but to suggest how society could increase its adaptability, or resilience, to climate variations. Regional planners make decisions with long-term implications each year. How could these be used to improve the adaptability of the PNW to climate variations and climate changes?

Past work has highlighted the need to **improve natural resource management decisions** with the use of climate information, and many of the hurdles that must be overcome before this is possible. CIG's institutional sub-group has shown that simply providing accurate climate information is not sufficient; it must be translated into location- and resource-specific impacts for managers to make use of it – many management decisions are made despite climate information to the contrary. For all major environmental problems, the realities of human socioeconomic, legal, and organizational systems ("human institutions") will determine whether solutions to these problems can be found and implemented. Future work would focus on how best to **provide the region's planners and decision-makers with the tools to use climate information** in their operations:

- Which human activities and institutions in the PNW are most sensitive and vulnerable to climate variability and change? How well do they cope with this vulnerability today? With the added stresses of population growth, climate change, and the impacts of ESA listing of salmonids, how might they cope in the future?

- Where are the stress points for policy-making and policy implementing systems? Where could new information be most effectively introduced into regional planning and decision-making? Specifically, in the case of the Snake River, what are the expected impacts of energy deregulation on the water resources system, and how could new information be introduced into planning procedures in this context?
- What are the necessary conditions for increasing the social utility of climate – and climate impacts – forecasts? Answering this question will draw on the intimate understanding of the governing human systems that CIG has developed to date, for water resources, fisheries, forestry, and coastal issues. With additional funding, we could do so for agriculture and human health.

A Decision-making Tool: Multi-dimensional Integration

CIG has clearly illustrated the interconnectivity of climate-related natural resources decision making in the PNW. Most regional climate impacts are driven by climate-driven changes in the regional hydrology. In addition, both the natural resources and the human systems of the PNW are strongly affected by one another. For example, timber clear-cutting in riparian zones may cause erosion, increased sediment supply to streams, and suffocation of incubating salmon eggs. Understanding the dynamics of these linkages is very difficult, since different ecosystems, and different political and socioeconomic systems, respond on different time and space scales. Given the complexity of this tightly-knit web of connectivity, how should decision-makers cope with natural climate variations and prepare for the unknown of future climate change?

With the completion of the research outlined above, CIG will have the required scientific understanding of regional processes (both natural and social) to support important **decision-making tools**. To provide the region with powerful research, planning, and teaching tools for analyzing the consequences of climate variability and change and of alternative response strategies, we would:

- Design and apply a regional physical "template" as a foundation for both **qualitative and quantitative policy analyses** at a finer scale than is currently possible. This "template" will be a geographic information system-based quantitative virtual reality of the PNW, with fine-scale information not only about climate impacts, but the regulatory, socioeconomic, and ecological environments in which they will occur.
- Implement a full-scale **analysis of the sensitivity of the PNW to climate change**, using scenarios of future changes in regional climate derived from global climate model simulations.