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Introduction

The mission of the United States Environmental Protection Agency (EPA) is to protect public health and to safeguard and improve the natural environment—air, water, and land upon which life depends. Achievement of this mission requires the application of sound science to the assessment of environmental problems and to the evaluation of possible solutions. The National Center for Environmental Research's (NCER) Science to Achieve Results (STAR) Program at EPA is committed to providing the best products in high-priority areas of scientific research through significant support for long-term research.

One high-priority research program identified in the Office of Research and Development's Strategic Plan is Global Change. In support of the Global Change Program, the STAR program issued a Request for Applications (RFA) in 1999 and 2000. The 1999 RFA solicited the development and demonstration of integrated assessment methodologies that address the positive and negative consequences of climate change at the regional or local scales. The 2000 RFA solicited the development and application of models that *integrate human dimensions* with *natural processes* associated with human-induced and natural climate change and variability.

Annual progress reviews such as this one will allow investigators to interact with one another and discuss progress and findings with EPA and other interested parties. If you have any questions regarding the program, please contact the Acting Program Manager, Vivian Turner (turner.vivian@epa.gov).

1999 Integrated Assessments of the Potential Consequences of Climate Change Grantees

Vulnerability Assessment of San Joaquin Basin Water Supply, Ecological Resources, and Rural Economy Due to Climate Change and Variability

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The two main objectives of this collaborative research project are to: (1) assess the vulnerability of water supply, water demand, water quality, ecosystem health, and socioeconomic welfare within the San Joaquin River Basin (SJRB) as a function of climate; and (2) provide guidance in the formulation of effective management strategies to mitigate the range of potential impacts due to climate change and variability.

This study updates and advances previous studies on climate change in California. Recent general circulation model (GCM) climate projections of present-day control climate and changing climate, due to a 1 percent annual increase in carbon dioxide from present concentrations, are being used. Data from these projections, produced by the Hadley Centre using HadCM2, are being used in a dynamic climate downscaling procedure, where the GCM data (i.e., precipitation and temperature) provide boundary and initial conditions for finer scale regional climate models (RCMs) that produce basin-area average precipitation and temperature data for basin-scale hydrologic models. Output from the hydrologic models drives subsequent impact assessment modeling. Previous studies focused only on the water resource impacts due to climate change/variability. This study goes beyond the scope of previous studies by including a suite of resources in the integrated analysis of the impacts of climate change/variability in the SJRB. Finally, this study includes the software packaging of the impact assessment model system into a decision support system that will be made available to state/federal resource trustees and provide assistance to CALFED (a joint California State and Federal program designed to resolve water issues in Northern California) on water quality and ecosystem management issues.

An integrated modeling and analysis approach is being used to perform the vulnerability assessment. The criteria used in selecting models for this study are: (a) models are generally accepted by the user community; (b) model data and scale are specific enough to describe conditions in the SJRB; and (c) model codes are available in the public domain.

The modeling and analysis approach includes six linked components: (1) hydroclimate, (2) water allocation, (3) agricultural production and management, (4) water quality, (5) fish ecology, and (6) socioeconomic impacts.

Hydroclimate: Based on the HadCM2-projected climate with a 1 percent increase in greenhouse gas concentrations and dynamical downscaling of the climate projection through RCMs to basin-scale hydrologic models, it appears that the SJRB would experience significant increases in Sierra Nevada reservoir inflow. It should be noted that compared to other available atmospheric-ocean GCMs based on an evaluation of the simulated seasonal hydroclimate cycle, HadCM2 appears to be among the wetter simulations.

Water Allocation: Based on water allocation and reservoir operations simulations for the joint water resource systems (i.e., Central Valley Project and State Water Project) of California's Central Valley (where the SJB is a subregion), it seems that increases in Sierra Nevada reservoir inflow will lead to corresponding increases in stored water. However, these storage increases are limited during relatively normal to wet seasons under climate change, where storage capacity limitations in SJRB Sierra Nevada reservoirs could present challenges in flood control, particularly in the southern SJRB. Increased reservoir inflow coupled with limited storage capacity leads to increased San Francisco Bay-Delta outflow, which translates into increased "interruptible" exportable water to south-of-Delta users in the SJRB. Interruptible denotes that the water would not be expected to be available during dry years under climate change, only during normal to wet years. This water might be used at the time of availability or in a long-term water management framework involving either groundwater banking or off-stream surface reservoir storage.

Water Quality (Preliminary): Based on water allocation and reservoir operations simulations, there are reduced requirements for releasing water necessary to support San Joaquin River (SJR) and Delta salinity management objectives. However, the release reductions are minimal to negligible during the late summer season, even with the wet nature of the HadCM2 climate change projection. Additional water quality results will be generated during the summer of 2001.

San Joaquin River Water Quality Modeling: The California Department of Water Resources' "Delta Simulation Model II" (DSM2), developed for the simulation of the hydrodynamics and water quality of the Delta, was modified to reduce the modeled area to just the SJR. This required modifications to the geometry of the model and extensive calibration runs to ensure that the reduced model responded in a similar fashion as the full Delta model. Simulations of river water quality driven by water allocation and agriculture production model results are being completed during the summer of 2001.

Agriculture Production Modeling: U.S. Bureau of Reclamation staff and University of California, Davis, researchers have developed an SJRB agriculture production model that simulates agriculture crop-choice decisions, rural economy, and subsurface hydrology (SWADE). Simulations of agriculture production driven by water allocation model results are being completed during the summer of 2001.

Model Linkage and Modeling Feedbacks: The U.S. Geological Survey's (USGS) Object User Interface (OUI), a map-based interface for managing models and model data, is being used to link impact assessment models (components 2 through 6) and to organize model data into a central data management system. Model linkage within the OUI environment is being completed in the summer of 2001. Feedback modeling between the impact assessment models will occur in the fall of 2001. (As an example feedback, consider that the water allocation model determines water available for agriculture and tributary river flows into the SJR. The agriculture production model uses water allocation results to determine crop choices, which determines irrigation drainage return flows. The river water quality model then uses tributary river flow and drainage return flow results to determine water quality in the SJR. This creates a feedback: water quality conditions in the SJR trigger water allocation constraints in the water allocation model, which must be resimulated with the updated conditions from the river water quality model until output from the river water quality model converges with input to the water allocation model.)

Model System Software Development for Resource Trustees: San Joaquin Valley managers and planners will be provided with our fully integrated decision support system (DSS). The DSS will be used to conduct further evaluations of the impacts of climate variability and extreme events and develop approaches for the mitigation of potential impacts. A user-friendly compact disk toolbox and user manual will be developed as part of this study. The DSS is being designed with minimal time required for file manipulation to formulate impact response scenarios. The DSS should allow the analyst to assess the utility of interventions such as modified reservoir operation, real-time water quality management, and adaptive management of fishery resources in mitigating some of the potential impacts of global climatic change and variability, hence reducing the vulnerability of the existing system to permanent damage. Training of the resulting DSS system will be provided to planners, operations analysts, and other users.

Assessment of the Consequences of Climate Change on the South Florida Environment

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In this project, scientists from the University of Miami's Center for Marine and Environmental Analyses (CMEA), the South Florida Water Management District (SFWMD), and the USGS-Biological Resources Division (BRD) are exploring the potential effects of climate change-induced alterations in precipitation on important ecological and societal endpoints of Biscayne Bay, a coastal lagoon adjacent to the city of Miami, Florida. It is important to understand the effects of climate change on South Florida because of the high sensitivity of the regional ecosystems and society to variability in the hydrological and climate regime. The focus of the proposed study is to examine regional ecological and economic effects that might result from climate change, using the EPA ecological risk assessment framework. During the past year, an important portion of the research was completed that focused on developing a seamless, integrated modeling framework to enable exploration of various simulation scenarios aimed at translating regional changes in precipitation into changes in the health of important ecological endpoints within Biscayne Bay and the Everglades.

In the present framework, changes in the amount, timing, and spatial distribution of precipitation can be entered into the South Florida Water Management Model that simulates the hydrology of the region. The output from this model, in the form of freshwater runoff values from surface, groundwater, and canal sources is utilized by CMEA's Biscayne Bay Hydrodynamics Model to simulate salinity fields as well as circulation patterns for this coastal bay. Changes in salinity and circulation patterns are then used by our Seascape and fisheries models to predict the impacts that different precipitation scenarios may have on the health of seagrass and hard-bottom communities, as well as associated fisheries resources. These freshwater outputs also will drive the ATLSS Model to assess effects on selected species in the Everglades.

Our initial simulations using historical weather patterns as well as two water management scenarios indicated that significant increases in precipitation can have significant effects on the growth and survivorship of seagrass species. Similarly, increases in precipitation can have negative impacts on populations of marine sponges within Biscayne Bay. Although precipitation changes were shown to impact benthic communities, the simulations indicated that water management scenarios that control the timing and spatial distribution of freshwater releases into Biscayne Bay also can be a major driver in this system. Based on the pivotal role that water management plays in controlling the hydrology of South Florida, and the near-future implementation of the Everglades Restoration Project that will modify the freshwater dynamics of the region, it was decided that all future simulations of the potential impacts of climate change should include explicitly the two primary water management options for the South Florida Ecosystem Restoration process (the restoration's base condition, 95 BASE, and the preferred water management alternative, D13R). Accordingly, results from this research will have important implications for restoration and sustainability of the regional environment as well as potential effects on the growth, development, and economy of South Florida.

A second component of the project was accomplished during the past year. In February 2001, a climate scenario development workshop was convened at the University of Miami to: (1) establish the appropriate climate change scenarios to be used in the simulations for South Florida, and (2) characterize these scenarios in sufficient detail to conduct the risk assessment. The participants of this workshop included the co-Principal Investigators as well as atmospheric and climatology scientists from the Rosenstiel School of Marine and Atmospheric Science, the NOAA Atlantic Oceanographic and Meteorological Laboratory, and the SFWMD. At this meeting, it was concluded that the simulation scenarios will include historical climate, based on the 1965-1995 record for South Florida, global climate change scenarios of ± 25 percent precipitation allocated across the year, the wet season only, or the dry season only, and a shift in the phase of the Atlantic Multi-Decadal Oscillation (AMO) from negative to positive phase.

During the following year, the stressors caused by the proposed scenarios will be characterized in terms that are relevant and necessary for the effects assessments. For example, the altered precipitation regimes will be characterized as model inputs of daily/monthly precipitation levels, spatially distributed across the South Florida landscape for a 30-year period. Ultimately, results from the simulations will be used to answer two important questions relative to the potential impacts of climate change. First, will climate change significantly alter the volumes, timing, and distribution of water throughout the South Florida system? Second, will those changes have a significant impact to ecological and societal systems?

Integrated Assessment of Climate Change Impact in the Mackinaw River Watershed, Illinois

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The primary objective of the proposed research is to complete an integrated assessment of multiple sector impacts produced by predicted changes in climate. The impact assessment will focus on locations in the Mackinaw River watershed in Illinois. The specific objectives are to: (1) develop sector specific responses to climate change; (2) identify relationships between, and among, sectors at each site and among all sites; (3) apply the impact analysis paradigm to identify and quantify local impacts produced by climate change; (4) identify mechanisms that produce an adaptive response to climate change while developing sector/system resilience to climate change impact; and (5) integrate project results with a Web-based decision support interface.

The initial stages of this research included Mackinaw River watershed stakeholder identification and interaction. Stakeholders were interviewed individually and participated in focus groups. Written notes, and digital records of interviews and focus groups were analyzed. Analysis has informed the development of scientific and technical activities in the research, and digital records have been used to identify specific stakeholder interests. The interviews also have supported refinement of sector identification and are supporting the targeting of research support activities to stakeholder needs. For example, the initial stakeholder involvement has provided a foundation for selection of the approach to Decision Support System (DSS) development and the information for adaptation of research activities as the research plan has progressed.

A specific research focus has been the development of model support for the DSS. The SWAT model is being adapted to assess climate change effects on the agriculture sector of the human system as well as hydrologic and water quality sectors of natural resource systems. SWAT 2000 has been applied to the Mackinaw basin at Congerville and has produced the information that can be used to generate profit and stream-flow subceedance-frequency histograms. Also, information has been generated for nitrate exceedance-frequency histograms, and modeling has begun of BOD-DO for the basin. Development has begun of the same information for the larger Mackinaw basin, the streamgauge for which is the Mackinaw River at Green Valley. This information is an important component of the DSS interface that connects agriculture and municipal infrastructure sectors. Other modeling efforts have applied HECRAS to small watersheds to predict flooding consequence and drainage impairment associated with changing hydrologic regimes. A stream temperature model has been developed to assist in fish population modeling and climate change effect analysis. An input-output econometric model has been developed to provide multiple sector analysis of economic issues. BASINS also has been adapted for use in the DSS. The result is that modeling support is provided for the following sectors: agriculture, insurance/finances, transportation, industry, agriculture, terrestrial ecosystems, aquatic ecosystems, land use/lanscape, water quantity, and water quality. Interviews and focus group analysis support the analysis of the quality of life and human health issues in the watershed.

The DSS has been structured, and an initial test of the DSS will be conducted with stakeholders in the summer of 2001. Structuring the DSS has involved the analysis of both model output and the requirements of stakeholders in the decisionmaking process. The DSS is structured to operate through a Web-based interface, using look-up tables developed from modeling activity, real-time use of models, and retrieval of Web-based information resources. The prototype DSS has been structured to support inquiries identified from interviews and focus groups, as well as climate change impact areas identified from the literature. Following initial testing of the prototype DSS, an iterative DSS expansion and improvement activity will use stakeholder input and continuing model development.

The proposed research will provide an example of advanced information technology applications to climate change issues in a watershed. The research will identify local impact of climate change on a typical watershed in the Midwest that provides a diverse natural resource, economic, and social setting for analysis of impacts due to climate change. The systematic accounting for sector responses, starting at the local level, will provide an essential complement to existing downscaling of GCC models. Further, the proposed horizontal and vertical integration, from an impact-type focus, will provide important sector-specific information essential to the future successful management of climate change effects. This research also features an innovative use of information technology, the development of a decision support interface, which will provide a valuable adjunct to ongoing community-based management programs in the Mackinaw River watershed.

The results of this research will be of importance to local, state, and federal water resources planners and legislators in deciding how best to cope with uncertain anticipated climate changes in the Midwest, and will inform local stakeholders about issues of importance, supporting local management programs for natural resource and municipal services.

An Integrated Assessment of the Effects of Climate Change on Rocky Mountain National Park and Its Gateway Community

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Gateway communities are concentrations of human population and commerce in close proximity to conservation areas. This project focuses on understanding how climate influences human and natural systems in Rocky Mountain National Park and its gateway community, Estes Park, Colorado. The project objectives are to: (1) assess the potential consequences of changing land-use and climate for landscape structure, aquatic biota, terrestrial wildlife, and native plant communities; (2) extend these biotic effects to predict likely changes in visitation and the implications of those changes for the local economy; and (3) based on the understanding gained above, help stakeholders identify and evaluate potential ways to respond to a changing landscape and climatic context. Using historic data on biotic responses to weather patterns, the effects of future climate change on park biota, particularly wild-life populations, were assessed. Changes were projected in landscape composition.

Scenarios based on Canadian Climate Centre and Hadley models suggest that a warming climate will offer opportunities for enhancing natural systems and simultaneously will create challenges for avoiding system degradation. These opposing effects include the following: (1) The native greenback cutthroat trout has been extirpated from most of its historic range as a result of competition with nonnative trout. The greenback now occupies cold headwaters and high elevation lakes that are marginally appropriate, unproductive habitats. Warming of these habitats is expected to increase the length of the growing season, increase productivity, and enhance the probability of success of reestablishment of native trout in the park. (2) Warming is likely to cause a large increase in the abundance of elk as a result of diminishing effects of winter weather on calf recruitment and survival. This increase would exacerbate existing stresses on the system caused by overabundance of elk. (3) Ptarmigan populations exist in naturally fragmented habitats throughout the park. Analysis of historic data on population demography in relation to weather revealed negative correlations between warm winter temperatures and population growth rates, probably as a result of asynchrony between accelerated breeding dates and food availability. The ptarmigan population in the park is in decline—it appears that warming could accelerate this downward trend. (4) Long-term effects of warming include shifts in landscape composition reflecting increases in shrublands and forest and declines in tundra. The reduction in tundra could drive enduring effects on the park's biological diversity. These changes in the natural systems in the park are linked to the performance of the human economy in Estes Park by the behavior of its visitors (see Figure 1).

To examine the linkage between natural system and visitation, a mail-back survey was designed to assess how climate change would affect visitor behavior directly through changes in weather patterns, and indirectly through climate-induced changes in park biota. The survey displays iconic representations of weather scenarios (i.e., number of days with sun, snow, and rain, see Figure 2) and changes in biota (i.e., number of elk, area of tundra, number of ptarmigan, etc.), and asks visitors how they would alter the frequency and duration of their visits in response to these scenarios. In addition, the survey assesses visitor expenditures across a range of categories, including lodging, automobile-related costs, camping fees, food and drink, and park entrance fees.

The survey was modified based on comprehensive reviews by the stakeholder advisory committee and the staff of Rocky Mountain National Park. In addition, focus groups were conducted with park users, and the survey was pretested on visitors in the park during early May. The survey will be delivered to 300 park visitors this summer.

The results of the survey will be used to parameterize an input-output model of the local economy (IMPLAN). This model will be used to project impacts of climate change on a variety of indicators of economic performance, including local output, additional jobs, and earned income.

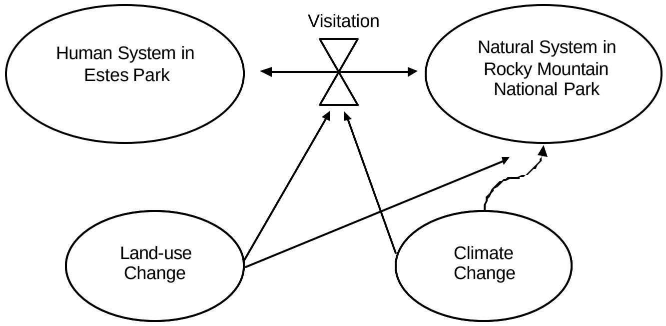


Figure 1. Changes in climate and land use may affect biotic states and processes within Rocky Mountain National Park. These changes are likely to affect visitation, which will drive change in the economy of the gateway community of Estes Park.

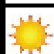
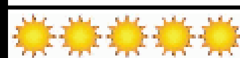
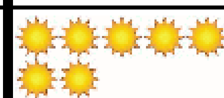
	Typical Day	*Weather Pattern 1*	*Weather Pattern 2*
Temperature			
Number of days with summer high temperature above 80°F	 3 days	 15 days	 20 days

Figure 2. Example iconic representations of weather scenarios.

Infrastructure Systems, Services and Climate Change: Integrated Impacts and Response Strategies for the Boston Metropolitan Area

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The services provided by infrastructure systems include flood control; water supply; drainage; waste water management; solid and hazardous waste management; energy; transportation; providing constructed facilities for residential, commercial, and industrial activities; communication; and recreation. The socioeconomic and environmental services they provide are essential; without them, the U.S. economy could not function and many human and environmental systems would collapse. This is particularly the case in metropolitan areas.

The objectives of the CLIMB (Climate's Long-Term Impacts on Metro Boston) project include: (1) documentation and analysis of the state of present infrastructure systems as well as the socioeconomic and environmental services provided by them in the Boston Metropolitan Area (BMA, includes the major cities of Boston and Cambridge and 99 other municipalities within approximately 20 miles of Boston—land use varies from urban to farms and open space) using various measures to indicate the contribution of these infrastructure systems and services (ISS) to the quality of life in the region; (2) determination of the integrated direct and indirect impacts of climate change, socioeconomic, and technology scenarios on the evolution of ISS and the regional quality of life over time; (3) identification and importance of policies and short- and long-term research needs for the provision of ISS that will meet stakeholder needs over time, given the uncertainties of climate and other changes; and (4) collaboration with the Metropolitan Area Planning Council (MAPC), our local partner, to ensure that stakeholders are involved, their concerns are addressed, and the project results are effectively communicated to them and the public at large and to begin engaging stakeholders in the process of preparing for potential climate change.

The approach includes: (1) work with stakeholders and experts to understand the multiple driving forces behind ISS in the BMA as well as the vertical and horizontal interrelationships of ISS demands and impacts; (2) build a dynamic analytical modeling tool that incorporates this understanding to organize data, model socioeconomic and environmental dynamics and interrelated impacts of ISS, and aid in communication of project results. This requires quantitative analysis of the impacts of climate change upon present infrastructure; (3) work with stakeholders to execute the model with various climate change, socioeconomic, and technology scenarios to achieve the research objectives; and (4) communicate with the help of the MAPC to stakeholders and the general public throughout the project.

The research will improve the risk management of the impacts on infrastructure from future uncertain climate, socioeconomic, environmental, and technology changes by showing possible impacts and driving forces behind those impacts and their sensitivities, working with stakeholders to develop short- and long-term resilient policies and programs to mitigate and adapt to impacts, and empowering stakeholders and the general public with the results.

Over the past year, major progress has been made in the CLIMB project's modeling of ISS. In addition, there was significant outreach to stakeholders that served the dual purposes of creating awareness of urban climate change issues among infrastructure managers in the Boston metro area as well as further informing the CLIMB project on key issues. The modeling advances included the following.

Modules are being built for the following sectors: Energy, Communication, Transportation, Water Supply, Water Quality, Flooding, and Public Health. These sectors have been selected for integrated analysis because they are sensitive to one or more climate features that may change under global warming, they are important to metro Boston in terms of quality of life and/or economic activity, and there are project resources and data available for the analysis.

The Energy Module of the CLIMB model has been developed on the basis of econometric analyses of relationships of fuel use by fuel type in each of the end use sectors (i.e., households, commercial, industrial and services) for each of the region's subareas. Fuel demand is compared to regional supply; relationships are being established to quantify supply as a function of regional capacity, long-distance transmission, and supply disruption by downed power lines, iced roads, and brown-outs when ambient air quality standards are surpassed. Costs of energy supply shortages, and disruptions to individual end use sectors and the regional economy are calculated and will be compared to estimates of mitigation and adaptation costs. The Communication Module has similar procedures to estimate disruption of communication lines due to iced lines, failing towers, and so on.

A comprehensive modeling framework for analyzing the impact of extreme weather events on surface transportation systems in the Boston Metro region was developed for the Transportation Module, in cooperation with the Central Transportation Planning Staff (Boston's MPO). The framework overlays spatial flood projections with networks of transportation (road and rail) infrastructure to identify those network links that will be impassable during extreme storm events as well as origin and destination areas. A model of urban transportation demand is then run to simulate climate impacts, including time lost to delays on public and private transportation, days of work lost, retail sales lost, and production lost due to disruptions in freight.

The Water Supply Module compares the demands from the household, commercial, industrial, and service sectors to the available yield of the sources in each subarea. Demands are based on population, socioeconomic, and technological changes. Subarea shortages are met if possible from the region source of the Massachusetts Water Resources Authority. Impacts of shortages are measured by a series of indicators.

Wastewater flows are used in the Water Quality Module. Because less is known about the impacts of climate change on the water quality of the CLIMB region, a detailed water quality model of a local river has been built and is being run under a variety of climate change scenarios to develop reduced form relationships between climate change, impacts, and adaptation costs. That module will be scaled up to inform water quality changes on a larger regional scale.

The Flooding Module determines the flood losses and disruption from riverine and coastal flooding. Also, it includes land losses due to sea level rise. Riverine losses are based on the 100- and 500-year FEMA flood plain maps. Coastal flooding and sea level rise losses were originally to be based upon actual expected flood and sea level rise elevations. This has been hampered by the lack of accurate elevation maps with contours less than 10 meters. Alternatives are being developed.

The Public Health Module estimates mortality and morbidity from asthma and heat stress. Regressions are now being built between health outcomes, climate, and socioeconomic variables.

Three internally consistent climate, policy, demographic, economic, and technological scenarios are being built to examine integrated impacts. They will initially use the Canadian Climate Center scenario as a guide for climate changes. The scenarios are: “Ride It Out,” “Targeted Growth,” and “Build Way Out.” They have been selected based on stakeholder response to climate change. In addition, a climate data generator has been constructed that allows generation of time series of weather events corresponding to different climates.

Impact of Climate on the Lower Yakima River Basin

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The objective of this project is to develop and demonstrate a framework to assess the localized impact of climate change and climate variability on a diverse set of interdependent interests, including agriculture, water supply, water quality, air quality, fisheries, and economics. The goal of this project is not to develop any specific new process models, but to integrate existing models to ensure that the linkages between the various models are appropriately represented. Because any such assessment is subject to considerable uncertainty, this framework will explicitly consider the generation and propagation of assessment uncertainty. The framework also will evaluate the tradeoffs associated with adaptation alternatives such as farm management practices and reservoir operations. The framework will be demonstrated on the Lower Yakima River Basin, WA. The assessment results and adaptation tradeoffs will be made available to the stakeholders via the Internet. The proposed framework will: (1) focus on the horizontal integration, (2) express the impact of various adaptations as tradeoffs between endpoints, and (3) quantify uncertainty.

A diverse team of experts has begun developing an integrated assessment framework. The framework will assess the efficacy and tradeoffs associated with adaptation alternatives such as cropping schemes and reservoir operations. The framework is being demonstrated on the Lower Yakima River Basin in central Washington State. The assessment results and tradeoffs will be made available to the stakeholders via public meetings and the Internet.

The objectives of the project will be achieved in a phased approach over 3 years. During the first year, a vertical assessment of climate, surface water supply, crop production, and economics were preformed. This activity tested the highest priority modules, while simultaneously helping to define the required modifications in the complete suite of modules required for the more highly interdependent (horizontal) assessment. The initial software requirement specifications for the framework were completed in the first year.

A public workshop attended by nearly 50 individuals was held in Yakima, WA. Individuals from federal and state agencies as well as nongovernmental organizations were in attendance, in addition to a number of interested citizens.The workshop was cosponsored by this project and a NOAA-funded project being conducted by the University of Washington. Since this workshop in November 2000, interest in climate has increased dramatically in the Yakima Basin due to a serious drought that is occurring throughout the Pacific Northwest. Irrigation districts with junior water rights are currently expected to receive only 30 percent of their water allocation. The Governor of Washington State has declared a drought emergency. Combined with the drought, the region is experiencing the largest return of salmon in several decades and a serious power emergency. These unique conditions provide an opportunity to observe some efforts at adaptation to climate variability. Instream flow targets have been relaxed, water rights have been bought and traded,and hydropower-generating reservoirs have been heavily drafted to adapt to the drought conditions. The efficacy of these adaptations will be seen throughout the summer and into the next water year.

The need for an improved assessment framework has been highlighted by unintended/unpredicted consequences of certain adaptation strategies. For instance, buying water rights from farmers to maintain instream flows, while economically fair to farmowners themselves, provides no comparable compensation to resident and migrant farmerworkers or farming supplies and equipment providers dependent on the displaced farming activities.

A project Web site was developed and made available to the public. The Web site is being regularly maintained and updated. It will eventually provide access to decision, model, and data toolboxes.

The preliminary vertical assessment tested primarily the hydrologic, crop, and economic modules. DHSVM was the hydrology model used to estimate the streamflow and water availability under a variety of base and +2°C climate conditions. The model was calibrated using gridded reconstructed climate data and reconstructed natural flow estimates. CROPSYS was employed to estimate the yields of a variety of crops (e.g., alfalfa, sweet corn, potatoes, and winter wheat) under baseline conditions, +2°C conditions, and +2°C/560 ppm CO_2 conditions. IMPLAN was used to estimate the impacts to regional employment for 100 percent, 80 percent, 60 percent, 35 percent, and 20 percent water availability.

The critical requirements for the framework have been identified in terms of accountability, accessibility, and adaptability. To ensure accountability, the framework must provide tools to help planners develop accountable decisionmaking processes and to allow users to understand how decisions were made. For instance, the framework should: (1) clearly articulate the tradeoffs between multiple objectives; (2) communicate the likelihood of making decision errors that result from model and data uncertainty; (3) create a bias towards robust alternatives; (4) facilitate the sharing of process knowledge; and (5) show the models, data, and assumptions used to reach decisions.

To ensure accessibility, the framework should provide reliable and rapid access to models, data, and the rationale that underpins decisions; provide the ability to "drill-down" through decisions, data, and models; ensure maximum access by being Web-accessible; and provide safe collaboration for the decisionmaking process.

As with all technology-based approaches, the framework must adapt continuously and rapidly to new data, models, and needs or the system will soon be obsolete. The framework also must assist planners to be adaptive in their management approach, giving them greater flexibility and responsiveness. For instance, the framework should incorporate a modular modeling design that allows new data and models to be integrated into analyses; support real-time assimilation of data by providing tools to automate the calibration process; provide tools required to support adaptive management; and streamline environmental planning to allow it to occur earlier in the planning process.

The second year's activities will include finishing development and testing the framework and completing the horizontal integrated assessment. The third year will focus on the assessment of adaptation options and evaluation of the stakeholder communication process. Project staff will work closely with the Tri-County Water Resource Agency to ensure that assessments are relevant to stakeholders and communicated in a manner that is most likely to be understood.

2000 Assessing the Consequences of Human Activities and a Changing Climate Grantees

Close-Coupling of Ecosystem and Economic Models: Adaptation of Central U.S. Agriculture to Climate Change

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The overall objective of this project is to significantly advance the state-of-the-art in modeling impacts of climate change in agroecosystems by moving beyond the loose coupling of unrelated and independent disciplinary models. Specific objectives are to: develop methods to couple existing ecological and economic models that can be used to assess the impacts of climate change in agricultural ecosystems; simulate the ecological and economic impacts of climate change on agriculture in the central United States, using data at various scales (field/farm, county and Major Land Resource Area [MLRA]) and using a range of climate change scenarios and sensitivity analyses; and investigate the dynamic and spatial properties of agricultural ecosystems to assess how estimates of the impacts of climate change are affected by the choice of spatial scale, temporal scale, and degree of model coupling.

In this study, a conceptual framework for closer model coupling will be developed, and the close coupling of an ecological model with an economic decision model will be implemented. The study will investigate how the ability to simulate behavior in response to climate change is affected by the temporal and spatial scales of analysis, the degree of coupling of the models, and the dynamic properties of the models. The research will be conducted for one of the most important agroecosystems, the crop-based system of the central United States.

To meet the first objective, processes in ecological models will be linked with land use and input use decisions in economic models, so that the type and strength of feedback between ecological and economic processes is suitably represented.

To meet the second objective, to simulate the ecological and economic models, climate scenarios will be derived from historical climate data and from the results of global circulation models (GCMs) that have been appropriately downscaled. Climate data sets will be developed to conduct analysis of sensitivity to changes in mean temperature and precipitation changes, as well as changes in variability.

The third objective is to investigate the dynamic and spatial properties of agricultural ecosystems and to assess how they are affected by spatial scale, temporal scale, and degree of model coupling. These properties will be compared at the farm/field, county, and MLRA scales in the central United States using primary data collected by the Principal Investigators, and secondary data collected by various state and federal agencies.

The possibility of successfully coupling ecosystem and economic models will depend on the level of data aggregation and spatial scale. Such coupling is expected to be most successful on a site-specific basis, and less successful as data are spatially and temporally aggregated. Coupling ecosystem and economic models will, at least in some important cases, lead to significantly different estimates of climate change impacts on agriculture than is obtained from uncoupled models. In addition, significant effects of spatial and temporal aggregation on impacts of climate change are expected.

Implications of Climate Change for Regional Air Pollution, Health Effects and Energy Consumption Behavior

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The objective of this project is to develop a scientifically credible modeling facility that will help policymakers and analysts understand the effects of human activities on climate change and variability as well as the possible human responses and adaptations to climate change and variability.

This research approach involves four major modeling elements: (1) climate change and variability, (2) electrical energy demand and production, (3) regional air pollution, and (4) human health effects associated with air pollution exposure. Using the Maryland/Northern Virginia/DC/Delaware area as a case study, the air pollutants that will be focused on are tropospheric (ground level) ozone and particulate matter (PM_{10} and $PM_{2.5}$) because of their important health effects (including increased morbidity and premature death).

The modeling system used for these pollutants will be Models-3, which is installed and functioning in-house. (MM5 also is installed and functioning in-house). Emissions inventory management and projections are accommodated within Models-3. Climate change and variability will be modeled using downscaled exogenously derived scenarios for a suite of time horizons.

Average electric demand modeling for residential and commercial sectors will be accomplished using a suite of the latest generation Electric Power Research Institute (EPRI)-developed tools (respectively, REEPS and COMMEND). Changes in demand distributions over time will be accomplished using a standard load shape and short-term load forecasting model (HELM-PC, another EPRI product). Widely used electric power sector simulation approaches will translate demand distributions into fuel use and emissions by electricity generators. Transportation-related climate effects will be modeled through altered VOC and NO_x emissions as a result of decreases in vehicle miles traveled and changes in electricity demand caused by the declaration of ozone pollution alerts. Finally, human health effects modeling will be performed with PM and ozone concentration-response functions described in EPA's Section 812 study, in conjunction with other existing (locally derived) epidemiologic models and newly developed methods relating urban air pollutant exposure and selected morbidity and mortality endpoints.

The principal result of our work will be a comprehensive yet computationally tractable tool for analyzing interrelationships between selected human activities (including transportation), energy production and consumption behavior, ambient air pollution, and associated health effects.

Modeling Heat and Air Quality Impacts of Changing Urban Land Uses and Climate

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Heat waves and elevated concentrations of ozone and fine particles represent two significant current public health stressors in the New York metropolitan area. Both of these stressors may be impacted by future changes in the global climate as well as continued expansion of human-dominated land uses in the region. To date, there has been little effort to link climate change and land use/land cover (LU/LC) models in assessments of potential future impacts of heat stress and air quality.

The proposed study will link human dimension and natural sciences models describing the behaviors of these systems to yield improved tools for assessing the future public health impacts of climate change in the context of existing environmental stressors. The model will be applied to the 31-county New York metropolitan east coast (MEC) region. The following questions will be addressed: (1) What changes in the frequency and severity of extreme heat events are likely to occur over the next 50 years due to a range of possible scenarios of LU/LC and climate change in the MEC region? (2) How might the frequency and severity of episodic concentrations of ozone (O_3) and airborne particulate matter smaller than 2.5 µm in diameter ($PM_{2.5}$) change over the next 50 years due to a range of possible scenarios of LU/LC and climate change in the MEC region? (3) What is the range of possible human health impacts of these changes in the MEC region? (4) How might projected future human exposures and responses to heat stress and air quality differ as a function of socioeconomic status and race/ethnicity across the MEC region?

An integrated model will be developed linking models for LU/LC, global climate change, regional climate change, atmospheric chemistry and pollution transport, and the impacts of heat stress and air quality on public health. Four scenarios of LU/LC change and three independent GCMs will be analyzed. Impacts will be examined during the decades of the 2020s and 2050s.

The research will provide improved tools for integrated assessments of future public health risks due to heat and air quality changes that are driven by climate change/variability and changes in LU/LC. In addition, the research will lead to a better understanding of the driving forces behind long-term environmental changes, and the role played by socioeconomic and demographic factors in the resulting human impacts.

Climatic and Human Impacts on Fire Regimes in Forests and Grasslands of the U.S. Southwest

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This project seeks to improve ecosystem health and sustainability in the Southwestern United States through developing a better understanding of the effects of interactions among climate, human activities, and wildland fire. The project provides a unique means for assessing how human factors combine with natural processes to affect fire regimes—and thus ecosystem sustainability and biodiversity—under different climatic and biotic contexts.

Where existing fire models focus almost entirely on biophysical factors, fire behavior, and weather conditions, this project involves development of a GIS-based model that integrates data from dynamical and empirical natural and social science models. Also, it includes institutional and discourse analyses of non-quantitative factors influencing decisionmaking.

The integrated model will be applied, together with knowledge gained from the institutional and discourse analyses, in a comparative case study of the Chiricahua, Huachuca, and Santa Catalina Mountains in Arizona, as well as the Jemez Mountains in New Mexico. A crucial component of the project will be iterative interactions with fire and ecosystem managers, including model testing. The final products of the project will be introduced at a symposium for managers and researchers, scheduled to coincide with fire management planning and budgeting for the 2003 fire season.

The integrated model is explicitly designed to be used for making wildland fire management decisions for individual seasons, in the context of risk over decades of future climate, land use, and social change. The research products will be made available through an innovative new map server on a University of Arizona Web Site. Informational materials also will be produced for distribution to the general public and/or displayed in visitor centers.

In addition, the integrated model will enhance the understanding of the complex human and natural forces contributing to fire regimes in the Southwest, allowing for better informed decisionmaking among fire and resource managers. The project provides a means for reducing risk to ecosystem sustainability, biodiversity, as well as to human settlements and activities, and provides an indispensable foundation for future development of improved process-based models.

The project addresses the EPA-designated high-priority area of "Ecosystems." By integrating human land-use factors in the context of climatic variability and biotic conditions, the project specifically addresses the question, "How might climatic changes, in combination with changing land-use patterns, affect forest health, biodiversity, and ecosystem function?" In exploring the interactions between human activities, weather events, and fuel load conditions, the project also provides the spatial and temporal specificity needed to address the question, "How might land-use choices increase or decrease ecosystem vulnerability to extreme weather events?"

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