United States
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Proceedings

1999 STAR Integrated Assessments of Global Change Progress Review

September 13-14, 1999
Arlington, Virginia

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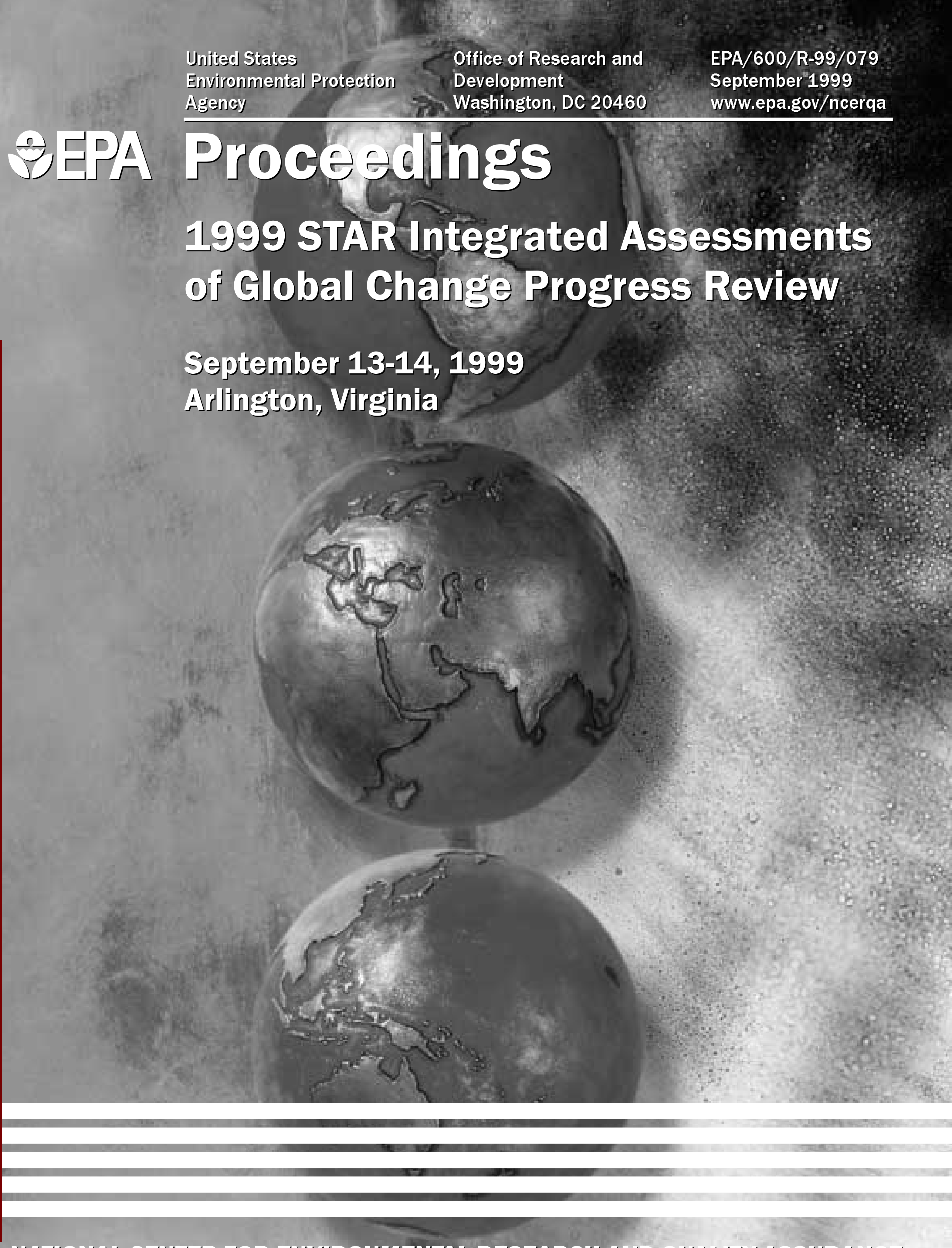

NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH AND QUALITY ASSURANCE

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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 and Quality Assurance's (NCERQA) 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 1996 and 1999. The purpose of these solicitations was to request proposals that led to the development and demonstration of integrated assessment methodologies that address the positive and negative consequences of climate change at the regional or local scales.

Annual progress reviews such as this one will allow investigators to interact with one another and to discuss progress and findings with EPA and other interested parties. If you have any questions regarding the program, please contact the program manager, Barbara Levinson (levinson.barbara@epa.gov) or Brian Sidlauskas (sidlauskas.brian@epa.gov).

A Regional Assessment of Land-Use Effects on Ecosystem Structure and Function in the Central Grasslands

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Agricultural Research Service, U.S. Department of Agriculture, Washington, DC

The central grassland region covers a large proportion of the contiguous United States and has experienced dramatic alterations through human land-use management. These changes in land-use have caused significant changes in ecosystem attributes that are important to regional dynamics and sustainability, including plant community structure, net primary productivity, carbon storage, trace gas flux, and regional climate. The objectives of the project are to: (1) assess regional patterns in key ecosystem attributes across the central grassland region in its current condition compared with presettlement conditions (i.e., land-use, plant community structure, carbon storage, net primary productivity, atmosphere-biosphere interactions, and trace gas flux); and (2) evaluate the consequences of potential changes in land-use and climate across the region for ecosystem structure and function.

This year, the project has made a great deal of progress in three different areas: (1) understanding the efficiency of fallow systems across the region; (2) estimating the effect of dryland and irrigated agriculture on carbon balance; and (3) assessing the sensitivity of the regional climate to land-use changes.

Regional data were used to compare the productivity and water use efficiency of rangelands, conventional wheat-fallow systems (alternate year cropping), and continuous wheat systems (cropped each year). It was found that farmers do not crop contin-uously until annual precipitation is relatively high, with continuous systems representing 50 percent of wheat systems at 600 mm annual precipitation, and 80 percent at 800 mm. Results show that at the same precipitation level, continuous wheat is 1.75 times more productive than wheat-fallow, and that continuous cropping is viable and more productive at average annual precipitation levels of 390 mm and greater. If this analysis is correct and a large part of the Great Plains that is currently under the summer-fallow management system could be converted to continuous cropping, it would have very significant ecological and economic effects on the region. Grain yield per unit area would effectively be doubled (a factor of 1.75 in this analysis) for the converted area. Carbon balance could be dra-matically shifted as well, with higher crop production and lower cultivation frequency.

Although many studies have been conducted on the effects of cropping on historical soil organic matter stores, no data are available on the effects of current cropping on the annual carbon balance of the Great Plains. In summer 1998, two Bowen Ratio systems were installed to estimate carbon flux from dryland wheat-fallow and irrigated corn. It was found that irrigated corn systems have a strong potential for positive net ecosystem production (carbon capture), particularly during July and August, and that dryland wheat-fallow has negligible carbon loss or capture, except during its peak growth months (May-June) (see Figure 1). The data from this year will help to assess what the annual carbon balance is for these systems.

An atmospheric model (RAMS) has been successfully linked with two biogeochemical models (GEMTM and CENTURY), demonstrating that the models appropriately represent system dynamics. Among the major results of these simulations are the importance of land-use change and the biological effect of doubled CO_2 on vegetation; both of which exerted major effects on simulated seasonal weather in the central Great Plains. On these time scales, the radiative effect of doubled CO_2 was minimal. These results indicate that climate prediction is a much more difficult task than assumed in the Intergovernmental Panel on Climate Change reports, for example. A vulnerability perspective, as discussed in Pielke et al. (1999), appears to be a more fruitful approach to climate change risks.

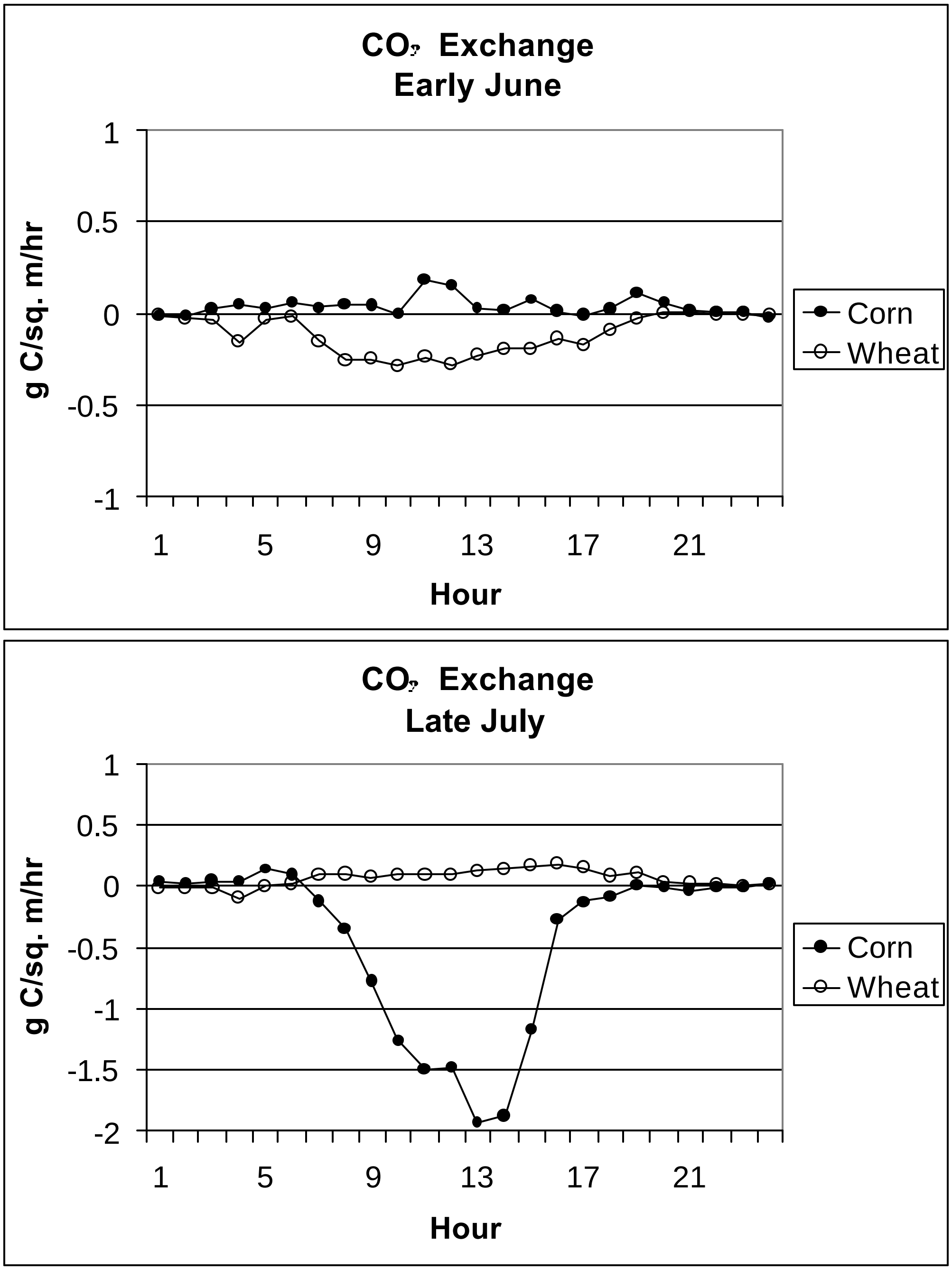

Figure 1. Carbon dioxide exchange as measured in the summer of 1998 using two Bowen Ratio systems.

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

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

The are several compelling reasons for updating and advancing previous studies on climate change in California. First, the proposed study will use new model output with fine-scale (12 km and sub-basin area averaged) resolution initialized and forced with new general circulation model output. Second, the proposed study is an integrated analysis of the impacts of climate change/variability on the resources of the San Joaquin River Basin. The previous study focused only on the water resource impacts due to climate change/variability. Third, this study will focus on a user product and provide assistance to CALFED (a joint California State and Federal program designed to resolve water issues in Northern California) in important water quality and ecosystem management of the subregion.

An integrated modeling and analysis approach will be adopted in performing the vulnerability assessment phase of the proposed study. The criteria used in selecting models for this study are: (1) general acceptance of models by the user community, (2) specificity of model data and scale to describe conditions in the San Joaquin River Basin, and (3) model codes are all in the public domain. The modeling and analysis approach is divided into six linked components: (1) weather and climate, (2) water supply allocation and streamflow, (3) agricultural pro- duction and management, (4) water quality, (5) fish ecology, and (6) socioeconomic impacts.

The principal expected benefit of the proposed work is a better assessment of the San Joaquin Valley Subregion to climate variability and extreme events. Partnerships with key water and ecosystem managers in the San Joaquin Valley will enable effective and rapid use of future planning and provide assistance to the CALFED Program.

San Joaquin Valley managers and planners will be provided with a 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 to 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 will allow the analyst to assess the utility of interventions such as reservoir reoperation, real-time water quality management, and adaptive management of fishery resources in mitigating some of the potential impacts of global climatic change and variability. This will reduce the vulnerability of the existing system to permanent damage. Training on 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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The objective of the project is to examine, using previously developed state-of-the-science simulation models, the potential effects of climate change scenarios on the South Florida regional environment. Effects of the selected climate change stressors will be assessed on the following physical, ecological, and societal sys-tems: (1) regional surface and groundwater hydrology; (2) freshwater runoff into coastal estuaries and associated salinity changes; (3) seagrass, hard-bottom, and mangrove community productivity and distributions; (4) estuarine fish and invertebrate populations; (5) economics of recreational fishing; (6) wetlands hydroperiod in the Everglades; (7) wading bird populations and other Everglades ecological attributes; (8) urban and agricultural water supply; and (9) urban flood control. This diverse suite of effects endpoints provides an integrated perspective on relevant risks to humans and the environment.

The proposed study will be organized using the EPA ecological risk assessment framework. This frame-work was substantially developed under the leadership of two Center for Marine and Environmental Analyses (CMEA) co-principal investigators (co-PIs) (Harwell and Gentile 1992; Gentile et al. 1993). CMEA has con-ducted several projects to implement the ecological risk framework to address real-world problems (e.g., the comparative ecological risk assessment of spills of fuels in Tampa Bay [Harwell et al. 1995; Ault et al. 1995]). To assess climate change risks in South Florida, a series of significant ecological/societal endpoints has been selected that can be analyzed with simulation models that already have been developed by the co-PIs at the CMEA, South Florida Water Management District (SFWMD), and U.S. Geological Survey Biological Resources Division (USGS-BRD). The models include the CMEA Biscayne Bay Hydrodynamic Model, the CMEA Biscayne Bay Seascape Model (including sea-grass, hardbottom, and mangrove communities), the CMEA Fish/Shrimp Community Dynamics Model of recreationally important fish and invertebrate species, the SFWMD's South Florida Water Management Model (SFWMM), and the wading bird components of the Across Trophic Level System Simulation (ATLSS) Model.

Based on the ecorisk framework, the following tasks will be conducted in the proposed study: (1) a series of climate change stressor scenarios will be developed by using a series of available general circul-ation model outputs, drawing on the extensive literature on climate change (e.g., Hougton et al. 1990), and convening a workshop of experts to develop scenarios (discussed below); (2) the suite of climatic scenarios will be input to the SFWMM to produce predictions of the resulting hydrologic conditions for the region; (3) the output from the SFWMM will be used to drive the Biscayne Bay Hydrodynamic Model; (4) the Biscayne Bay Hydrodynamic Model will simulate salinity changes for each scenario; (5) the salinity regime will be input to the Biscayne Bay Seascape Model to predict changes in the productivity and distribution of seagrass, hard-bottom, and mangrove communities; (6) the results for each scenario from the seascape model and from the hydrodynamic model will be used to drive the trophodynamics model; (7) the results from the trophodynamics model will be used to drive the assessment of effects on recreational fishing in the Biscayne Bay/Florida Keys area; (8) the results from the SFWMM Model also will drive the ATLSS Model to predict changes in wading bird populations; (9) the results from the ATLSS Model will be used to assess the societal effects of altered wading bird populations; (10) the results from the SFWMM also will be used to assess the economic effects of changes in water supply and flood control; and (11) based on all of these stressor-effects analyses, the research team will prepare an overall risk assessment on the ecological and societal risks from climate change in South Florida, including an assessment of the implications of the restructuring of the Central and Southern Florida Flood Control Project (C&SF) on these risks, as well as an assessment of major sensitivities and uncertainties in the analyses.

This project will produce a series of scientific articles that delineate the risk assessment methodology used for regional-scale implications of climate change, describe the potential risks to the ecological and societal systems of South Florida, and explore the range of vulnerabilities of the region to climate change, including explicit consideration of the present state of uncertainty that exists about the specific regional physical stressors that would result from global climate change. The study also will constitute a prototype for fully integrated assessments that address all physical, ecological, and societal systems in a region, incorporating the "horizontal" (across sectors, ranging from freshwater and estuarine ecosystems to urban systems, and reflec-ting multiple levels of organization), and "vertical" (from climate change stressors through hydrological, ecological, and societal effects) integration. Issues that will be addressed in the study include: (1) an improved understanding of the current responses of the environmental and human systems to climate variability in South Florida across ecosystem types and across different time scales of variability; (2) exploration of how climate-induced changes in physical stressors would exacerbate or ameliorate those system responses to variability; (3) suggestions of relative vulnerabilities and needed coping management options; and (4) identification of important uncertainties that would suggest priorities for research and further analyses. Moreover, results of this project are expected to have particular importance to the design of the new C&SF system and/or its operational management schedules—issues that are especially timely and critical to address at this time.

The vulnerability studies will highlight the relative risks to various parts of the ecological and societal systems of the region, potentially allowing assignment of priorities for risk reduction strategies. Through the partnership with SFWMD and its extensive communications network, the results will be broadly disseminated to decisionmakers, stakeholders, and the general public.

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

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The Mackinaw River and its corridor is one of the highest quality ecosystems in Illinois, with water quality rated as excellent but threatened. Although land-use is predominantly agricultural, urban expansion pressures, both direct and indirect, affect land and water resources. This project will identify and quantify the consequences of climate variability and change on human and natural systems in the Mackinaw River Basin. The objective of this project is to complete an integrated assessment of multiple sector impacts produced by predicted changes in climate using models, standards, and innovative analysis tools.

System categories and associated sectors for the watershed have been identified. Human environment systems have industrial, agricultural, municipal, and regulatory sectors. The physical environment system has water resources and landscape features (e.g., topography, roads, and drainage systems) as the principal sectors. Living environment systems have aquatic ecosystems, terrestrial ecosystems, and human health as the principal sectors. Project objectives include: (1) developing sector-specific responses to climate change; (2) identifying relationships between and among sectors at multiple sites, and among all sites; (3) applying an impact analysis paradigm to identify and quantify impact; (4) identifying mechanisms that produce an adaptive response to climate change while developing sector/system resilience to climate change impact; and (5) integrating project results with a Web-based decision support interface. The proposed analysis will develop site and sector response spectra that, in turn, will support a consequence and severity determination for an impact assessment. Vertical integration is based on specific climate system changes and layers of cross-cutting analysis that are defined by impact type.

The proposed research has three phases; these phases address separate work activities, but are highly interconnected and will occur concurrently through the research project. Phase one will: (1) identify climate change phenomena; (2) identify, for selected locations in the Mackinaw River watershed, a sector-by-sector response to climate variability; and (3) identify the expected change in sector elements, considered singly and aggregated within and across sectors. Phase two will identify the local impact of climate change with particular emphasis on economic, environmental, and social impact aggregations, where impact will first be assessed at the element/sector level, then analyzed for sector pairs and multiple-sector integration. Phase three will: (1) implement a Web-based system to support involvement from local collaborators, and (2) provide an innovative use of information technology to involve local community elements in impact analysis.

This project was initiated in July 1999, with the development of an approach to assess community understanding of climate change and use individual and group responses to identify climate change impact. Initial findings challenge a commonly accepted workshop approach. Local watershed partners have been involved in planning and management activities for more than 5 years, and workshop attendance has dwindled in recent community involvement efforts. It is expected that the proposed Web-based decision support system will provide a new paradigm for integrating community perceptions in a multiple sector analysis of climate change effects.

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

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Gateway communities are concentrations of human population and commerce in close proximity to conservation areas. This project will assess the effects of changes in climate and land-use on 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, water quality, 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) help stakeholders identify and evaluate potential ways to respond to a changing landscape and climatic context, based on the understanding gained above.

In gateway communities like Estes Park, natural processes are tightly linked to commerce by the behavior of visitors. To represent this link, responses of visitors to direct effects of a changing climate (e.g., seasonal shifts in opening of roads and trails), as well as responses to indirect effects mediated by changes in the natural system (e.g., changes in wildlife populations, landscape structure, aquatic biota), will be investigated. Using human responses to mediate climate and land-use drivers, the effects of climate change will be extended to the local economy.

The project will be organized in three phases. In phase one, a preliminary assessment dealing broadly with natural processes and human economic behavior will be conducted (see Figure 1). In phase two, stake-holders will be assembled to react to the preliminary assessment and to inform the project science team about interventions that could exploit beneficial effects of climate change and ameliorate harmful ones. Three part-ners have been enlisted (Estes Valley Improvement Association, National Parks and Conservation Associ-ation, and Rocky Mountain National Park) to help organize the stakeholder process. Phase three will use stakeholder input to focus the assessment on evaluating plausible alternatives for coping with climate change.

Because the partners are committed to disseminating findings and, where appropriate, to incorporate those findings into advocacy, management, and policy, the proposed science will achieve results by helping citizens, managers, and advocates anticipate and cope with effects of a changing climate.

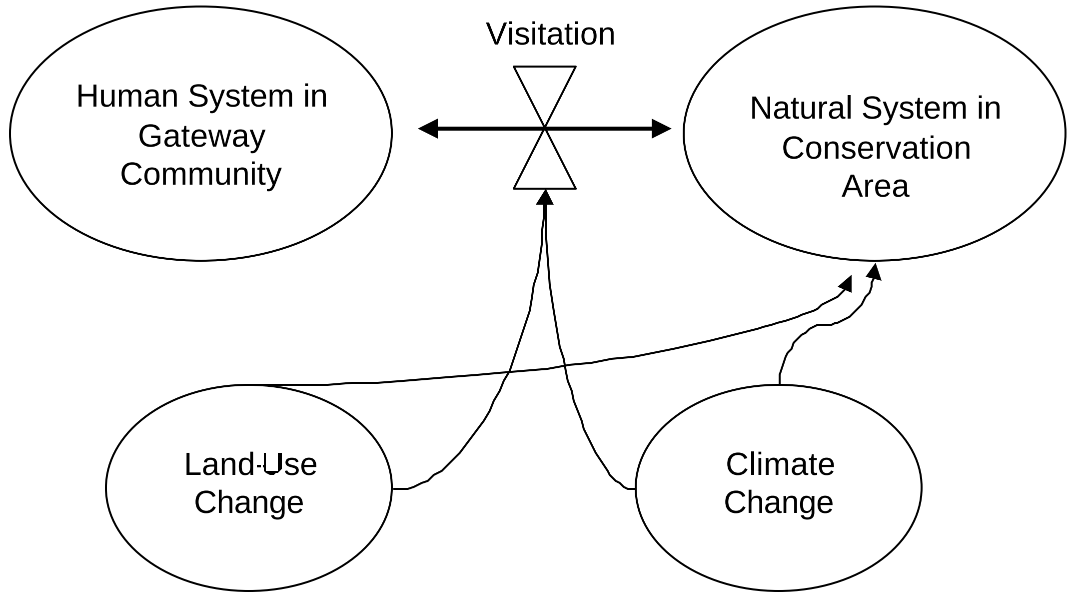

Figure 1. Linkages between natural processes and human economies in gateway communities.

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

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Matthias Ruth
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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, and providing constructed facilities for residential, commercial, and industrial activities, communication, and recreation. The infrastructure industry is one of the largest contributors to the U.S. Gross Domestic Product. The real value of infrastructure, however, is that the socioeconomic and environmental services it provides 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.

Although infrastructure systems and services (ISS) are designed according to socioeconomic and environmental conditions that are very sensitive to climate (e.g., energy and water demands, wind and water loads) and have interrelated impacts upon each other, there have been no major integrated assessments of the impacts of climate change on metropolitan ISS in the United States. Several researchers have shown that the possible economic damages to ISS due to climate change are the same as or larger than damages to agriculture. Infrastructure systems last considerably longer than decades (some a century or more) and provide the footprint and direction for future ISS and related future socioeconomic activities and environmental quality. Hence, it is important that decisionmakers understand the short- and long-term consequences of climate change on ISS. This includes both local and regional decisionmakers because they make most infrastructure-related decisions, and state and national decisionmakers because they provide policy guidance.

The objectives of this project include: (1) documentation and analysis of the state of present infrastructure systems and 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 indicators to indicate their contribution 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 future 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 infrastructure services 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) to ensure that stakeholders are involved, their concerns are addressed, project results are effectively communicated to stakeholders and the public at large, and stakeholders are engaged in the process of preparing for potential climate change.

The approach of the project includes: (1) working with stakeholders and experts to understand the multiple driving forces behind ISS in the BMA and the vertical and horizontal interrelationships of ISS demands and impacts; (2) building a dynamic analytical modeling tool that incorporates this understanding and uses indicators to organize data, model socioeconomic and environmental dynamics and interrelated impacts of ISS, and aid in communication of project results; (3) working with stakeholders to execute the model with climate change, socio-economic, and technology scenarios to achieve the research objectives; and (4) communicating results, 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.

Regional Hydrologic Consequences of Climate Change: Regional Assessments in a Global Context

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The objective of this project is to conduct hydrologic and water resource assessments of climate change and their evolution during the timeframe of the EPA Hydrologic Vulnerabilities Program. A brief summary is provided of assessments performed for six U.S. water resource systems for the 1995 Intergovernmental Panel on Climate Change (IPCC) Report (and subsequently updated for a 1997 Office of Science and Technology Policy Workshop). The six case study sites include: large, multireservoir systems (i.e., Columbia River, Missouri River, and Apalachicola-Chatahoochee-Flint [ACF] Rivers); small, one- to two-reservoir systems (Tacoma and Boston); and a medium-sized system (Savannah River). The climate change scenarios were based on results from transient climate change experiments performed for IPCC in 1995. For those river basins where snow plays an important role in the current climate hydrology (Tacoma, Columbia, Missouri, and, to a lesser extent, Boston), changes in temperature dominate changes in seasonal streamflow hydrographs. In these systems, spring snowmelt peaks are reduced and winter flows increase, on average. Changes in precipitation generally are reflected more in the annual total runoff volumes than in the seasonal shape of the hydrographs. In the Savannah and ACF systems, changes in hydrological response are linked more directly to temperature and precipitation changes than in the snowmelt-dominated systems. Impacts on system performance were linked strongly to the hydrologic changes and the amount of buffering provided by the system's storage capacity. For most sites, the effects of nonclimatic effects such as demand growth on future system performance would exceed the effects of climate change over system planning horizons.

One of the six systems, the Columbia River, was revisited as part of the ongoing U.S. National Assessment of Climate Change. Two of the four general circulation models (GCMs) (United Kingdom Meteorological Office/Hadley Center and Max Planck Institute), for which results were made available for the U.S. National Assessment, were chosen to bracket the sensitivities within the Columbia River Basin. Gridded (daily) historical records of precipitation and temperature at 1/8 degree spatial resolution were perturbed according to the GCM results and then used to drive the variable infiltration capacity (VIC) macroscale hydrology model of the basin. The altered streamflow simulated for each scenario was used to drive a reservoir model. Although different GCMs showed somewhat different seasonal patterns for temperature change, the climate changes caused relatively large changes in winter snowpack and a substantial shift toward increased runoff in winter with decreased runoff in summer and fall. These changes in streamflow would reduce spring nonfirm energy production, would have negative consequences for flood control and navigation, and would create increased competition for water during the spring, summer, and early fall due to irrigation, instream flow, and recreation.

An ongoing phase of the study is to evaluate the sensitivity of major global river basins to climate change. The VIC hydrology model has been applied to 42 major river basins, ranging in size from approximately 45,000 km^2 (Victoria River Basin in Australia) to 4,600,000 km^2 (Amazon River Basin—area upstream of the gauge). The hydrology model has been calibrated to current climate for each of the individual rivers, and climate sensitivities were evaluated using the same two GCM runs produced for the National Assessment and used in the Columbia study. Results for five of the river basins in contrasting hydroclimatic regions (i.e., Amazon, Congo, Yenesei, Mississippi, and Yangtze) are examined in detail, with attention to the sensitivities of particular elements of the surface water balance and implications for water management.

Analysis of the Effect of Changing Climate Variability on Crop Production in the Southeastern United States: An Integration of Stochastic Modeling, Regional Climate Modeling, Crop Modeling, and Economic Modeling

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University of South Carolina, Columbia, SC
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Oregon State University, Corvallis, OR
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This project investigates the effects of several different types of spatial and temporal variability of climatic change on crop production in the southeastern United States. The overarching goal is to establish the sensitivity of the regional economics to changes in crop yields resulting from a range of changes in temporal and spatial variability of climatic changes.

In the current phase of the project, differences are being determined in crop responses and regional economics to two different spatial scales of climate change: one from a control and doubled CO_2 experiment of a coarse resolution general circulation model (GCM), and the other from the control and perturbed runs of a high resolution regional climate model that uses the coarse resolution GCM for boundary conditions. High resolution (50 km) control and doubled CO_2 runs of the regional climate model (RegCM) have been produced over the southeast using boundary conditions from the CSIRO (approximately 4 degree resolution) climate runs. The coarse and fine resolution scenarios have been applied to two different sets of crop models (CERES and EPIC). The crops modeled included: corn, cotton, rice, sorghum, soybean, and wheat. The baseline simulated crop responses were determined from a dense network of about 500 climate stations, gridded at the 50 km scale, as were the other inputs to the crop models. Runs of the effect of the two resolutions of climate change only and climate change plus direct CO_2 have been completed. The responses of the crop models have been examined on several different spatial scales: at the level of the 50 km grid scale (the scale of the observations and regional model), the scale of the entire region (southeast), and the scale at which the yield results were aggregated for input to the Agricultural Sector Model (ASM) (state level).

Significant differences were found in the changes in yields (climate change versus baseline) based on which resolution of scenario was used. For example, most crops experienced decreases in yields in both scenarios (climate change only case), but the decreases were larger in the case of the RegCM scenario, when considered over the region as a whole. Aggregated on the state level, contrasts were complex. For example, for corn, many of the deep southern states experienced larger yield decreases with the coarse scenario, but the Carolinas suffered larger decreases with the fine scenario (see Table 1). Finally, the crop yields for the other regions of the United States were modeled using two different resolutions of the scenarios to complete the necessary input for the ASM.

Results of the economic model, which will indicate whether the scale effect of yield changes carries over to the agricultural economics of the region, will be presented.

Table 1. Thirty-six-year mean base simulated yields (kg/ha) and percentage yield changes from base for dryland corn averaged on a state-by-state basis.

State	Base Yield	Percent Change From Base Yield			
	(kg/ha)	CSIRO[*]	RegCM[^]	CSIRO (540 CO_2)[‡]	RegCM (540 CO_2)[§]
Alabama	7,643	-10	-5	+4	+9
Arkansas	6,553	-8	-4	+7	+12
Florida	6,313	-18	-7	-1	+10
Georgia	7,545	-17	-16	-3	0
Louisiana	7,214	-13	-7	+1	+7
Mississippi	7,780	-19	-7	+2	+4
North Carolina	9,089	-13	-34	+1	-18
South Carolina	8,263	-18	-29	-4	-14
Tennessee	9,628	-13	-26	-2	-12

[*]Climate change scenario constructed with a Global Circulation Model (coarse resolution).

[^]Climate change scenario constructed with the National Center for Atmospheric Research Regional Climate Model (fine resolution).

[‡]Same as CSIRO climate change scenario, but it accounts for physiological effects of increase in CO_2.

[§]Same as RegCM climate change scenario, but it accounts for physiological effects of increase in CO_2.

Integrated Assessment of the Public Health Effects of Climate Change for the United States

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The objectives of the project are to assess the potential impact of climate change on important regional public health endpoints, including vector-borne diseases (Hantavirus, dengue, and Lyme disease) and water-borne diseases (cryptosporidiosis and cholera), and to appropriately characterize and communicate this information to support policy development and analysis. The approach used varies by disease outcome being studied. For example, satellite remote sensing is being used to assess climate and land-use contribution to risk for Hantavirus and Lyme disease, and sea surface temperatures are being used in the case of cholera. Process-based models of disease risk and general circulation models (GCMs) are used for dengue fever, but multiple methods such as geographic information system (GIS), time series analysis, hydrological model-ing, and downscaled GCMs are employed in the cryptosporidiosis project.

Because the analyses of the five diseases under investigation are at varying levels of completion, results are listed separately at this time:

Hantavirus: The Hantavirus/El Niño analysis showed that high-risk areas for Hantavirus Pulmonary Syndrome can be predicted based on satellite-generated risk maps of land cover more than 6 months in advance. Predicted risk paralleled vegetative growth, supporting the hypothesis that heavy rainfall from El Niño in 1992 was associated with higher rodent populations that triggered the Hantavirus outbreak in 1993. Satellite images from 1995, a non-El Niño "control" year, showed low risk in the region, whereas the images from the 1998 strong El Niño again showed high-risk areas. Trapping mice in the field (collectors blinded to risk category), validated these satellite-generated risk maps with mouse populations directly related to risk level.

Dengue: The dengue fever transmission model (DENSiM) has been parameterized for the study sites (Brownsville, New Orleans, and Puerto Rico), and model runs have been completed for Brownsville, Texas, using the Hadley Center HADCM2 and VEMAP interpolated climate projections for the years 2030, 2060, and 2100. Transmission risk shows very high sensitivity to relative humidity and temperature (e.g., excessive dryness limits mosquito survival). Also, although warm temperatures generally increase trans-mission dynamics, the extreme high temperatures predicted by HADCM2 for Texas diminish the risk of dengue in this location. It is expected that the study sites on the island of Puerto Rico will show opposite trends; however, model runs are pending the Centers for Disease Control and Prevention's (CDC) human case data.

Lyme disease: Tick survey data has been analyzed for the mid-Atlantic region and validates land-use predictions for Lyme disease risk. The extent of forest edge remains the strongest predictor for tick abundance. Landcover for the mid-Atlantic region has been classified by use of satellite Landsat imaging. A U.S. Department of Agriculture Lyme disease simulation model has been improved to better account for humidity and temperature, and spatial modeling of tick abundance using generalized linear mixed models will be applied for more accurate risk prediction, given a GIS of landcover.

Cryptosporidiosis: The historical analysis of extreme precipitation and water-borne disease outbreaks in the United States from 1946 to 1994 shows spatial clustering of outbreaks indicating high-risk geographical regions by water basin. The fall season contained the highest proportion (40%) of surface water-related outbreaks preceded by heavy rainfall events; winter, spring, and summer percentages were 25, 35, and 32 percent, respectively. Climate downscaling from the Max Planck GCM is complete for the mid-Atlantic region and a hydrological runoff model for a watershed in Lancaster County. In a random sampling of 50 farms within the 100-year floodplain of a major creek in Lancaster County, more than 60 percent tested positive for cryptosporidium oocysts in field manure samples. Economic analysis for baseline costs of cryptosporidiosis cases has been completed.

Cholera: In the Chesapeake Bay, preliminary analysis shows a strong correlation between warmer water temperature and the presence of *Vibrio cholerae*. In 1998, a cholera epidemic occurred in Lima, Peru, with more than 1,000 reported cases. Surveillance of sewage water for cholera was strongly associated with ambient temperature, and the peak number of cases lagged 3 weeks behind a peak in ambient temperature. Regarding the 1991 epidemic in Peru, 11 patients have been identified as the probable first indicator cases, occurring during the period between late October 1990 and January 1991.

Many of the diseases under investigation are highly seasonal; however, the contribution of weather factors or habitat is not fully understood. For Hantavirus, the ability to use satellite images of habitat features to predict disease risk far in advance is a valuable tool for disease prevention. For Lyme disease, preliminary results confirm the importance of land-use features in determining tick abundance. The dengue fever analysis demonstrates how sensitive transmission risk is to specific weather parameters, and future risk projections will be highly site specific. The historical analysis of waterborne diseases shows that precipitation likely contributes to the occurrence of these outbreaks. Hydrological modeling of future risks, however, is necessary considering the balancing between heavier rainfall projections versus warmer temperature (thus, more evapotranspiration). For cholera, although the role of algal blooms preceding the 1991 epidemic remains undetermined, evidence is now shown of a link between ambient temperatures, *Vibrio cholerae* in sewage and the marine environment, and cholera outbreaks.

Incomplete analyses will be finalized. For example, matrices of downscaled climate data for the Southeast (per Dr. Linda Mearns) will be applied to the Puerto Rico study sites, and human immunity data will be obtained from the CDC Dengue Laboratory in San Juan. For cryptosporidiosis, precipitation/outbreak analysis is being conducted at the watershed level to better determine the contribution of rainfall in predicting risk of outbreaks. The last component of the cryptosporidiosis risk model that links rainfall and runoff to reported oocyst counts at treatment facilities in Lancaster County now can be completed with recently acquired data. For cholera, sea surface data for 1997 and SeaWifs satellite data for algal blooms in 1998 have been obtained. Also, water samples of algae are still pending from the Peruvian collaborators for this project. Although all project-specific analyses are being completed, the overall integrated assessment will incorporate the completed models into an integrated framework communicated though a Web site.

Integrated Assessment of Economic Adaptation Strategies for Climate Change: Impacts on Midwestern Agriculture

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The project goal is an integrated assessment of potential adaptive responses for the agricultural sector in the midwestern Great Lakes states (i.e., Wisconsin, Michigan, Illinois, Indiana, and Ohio) to maintain productivity and profitability. Using ecosystem and economic modeling, realistic scenarios of potential impacts of global climate change on midwestern agriculture will be assessed as well as potential adaptive responses in the agricultural sector. Specific objectives of the project are to: (1) develop detailed characteristics for representative firm farms in 10 agricultural regions chosen by spatial analysis of soils, climate, crop mixes, and production systems throughout the midwestern Great Lakes region; (2) use interactive crop production and ecosystem models (DSSAT and CENTURY) and develop submodels to analyze representative firm farms in these 10 agricultural regions; (3) evaluate alternative farm decisions using a linear programming model (PC-LP) to evaluate crop mixes and production factors such as irrigation, drainage, fertilization, pest control, and tillage. Resulting information about optimal or desirable systems provides input for crop production and ecosystem models to determine effects of such decisions on and within regionalized agroecosystems; (4) develop three realistic but distinctly different climate scenarios based on regional-scale projections of possible future climate conditions as derived from a current general circulation model (HADCM2); (5) evaluate effects of alternative production policies on crop mixes and production systems in terms of economic impacts on regional producers and ecological impacts on regional agroecosystems under current climatic conditions; (6) assess the effects of climate change and various adaptive responses on firm farm decisions in the 10 agricultural regions. Specific risk events common to different agricultural practices and systems will be assessed and used to compare desirability of alternatives. Aggregate results will allow comparisons among the agricultural regions as well as an assessment for the entire midwestern Great Lakes region; and (7) assess the nature, extent, and consequences of adaptation strategies of representative crop producers in response to the effects of climate change.

An evaluation of the effects of climate change on midwestern crop agriculture is being conducted in three distinct ways. First, the effects of climate change on midwestern crop ecosystems are evaluated using future climate scenarios and geographic information system-based crop production simulation modeling. Second, the possible effects of resulting altered agroecosystems on farm management decisions are evaluated using an economic decision model, and results from these analyses become inputs for additional crop production modeling. Third, aggregate results of likely agroecosystem and farm decision effects will be used to evaluate both farm firm and midwestern regional impacts.

Ten specific representative agricultural regions have been identified, and appropriate soil, climate, and other relevant data for these locations have been assembled. Representative farms (size, resources, machinery stock, etc.) have been structured for each region representing larger commercial farms that are expected to produce the major portion of agricultural commodities.

Recent efforts focus on improving climate data, obtaining current climate change projections from the Hadley Center, and using the DSSAT crop modeling system. Four expert panels have addressed the topics of crop adaptability—pests, plant protection strategies, and climate interactions; cropping systems and production technology; and market and institutional drivers of change in agriculture.

Indications are that successful adaptation within the midwestern Great Lakes states can meet the challenges of global climate change. Crop stability will be preserved with no major shift to different basic commodities in the region. Several critical adaptation vehicles are already in place in both public and private sectors.

This project will continue scenario analysis, complete economic/production simulation analysis, and continue institutional analysis.

A National Assessment of the Impact of Climate Change on Water Resources

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The primary goal of the project is to develop and implement a methodology for evaluating the vulnerability of surface and groundwater resources in the United States, by region, under existing and future climate conditions. Unlike previous investigations that evaluate the impact of climate change on either water supply or demand, this study recognizes the need to develop an integrated water resource systems approach modeling the complex feedback mechanisms that exist among climate, hydrology, economics, and water demand. The integrated approach of this project will lead to an evaluation and assessment of the reallocation and other changes that may take place in each region, when climate change influences the supply and demand of ground and surface water resources. A secondary goal is to develop numerous regional assessment methodologies, at various spatial and temporal scales, to enable determination of the largest scales that still capture the impacts of climate on water resources, including all relevant agricultural, industrial, and municipal uses of both ground and surface water resources.

The research was performed during the period between October 1996 and August 1999, with a 1-year no-cost extension. The final goals of the project are expected to be achieved by September 2000. Because much of this work either has been published already or is in preparation for publication, this summary excerpts key conclusions derived from various refereed journal articles that were supported solely by this grant.

In a publication entitled *The Regional Persistence and Variability of Annual Streamflow in the United States* (*Water Resour Res* 1998;34:12), it was found that 18 broad water resource regions of the United States are homogeneous in terms of the year-to-year persistence of streamflow, whereas smaller subregions are required to obtain homogeneity in terms of the interannual variability of streamflow. A second publication entitled *Regional Regression Models of Annual Streamflow for the United States* (*J Irrigation Drainage Eng* 1999;125:3) showed regional models that relate the mean and variance of annual streamflow to climate and geomorphological characteristics of 1,553 watersheds located within the 18 water resource regions of the United States. These relations are remarkably precise with adjusted R^2 values ranging between 90.2 and 99.8 percent across the continent. These relationships are used in subsequent studies to investigate the impact of climate change on annual streamflow. In a third study entitled *Indicators of Impacts of Global Climate Change on U.S. Water Resources* (*J Water Resour Planning Manag* 1999;125:5), one climate change scenario was used to illustrate that primary impacts of global warming should occur in the western United States and include: (1) fewer relative stresses on hydroelectric systems due to an increase in energy supply from other sources, and (2) more stresses on available water resources due to increases in total withdrawals and, in some cases, decreases in streamflows. In a fourth study entitled *Storage Reservoir Behavior in the U.S.* (*J Water Resour Planning Manag* 1999;125:5), a simple hydroclimatologic model, a general circulation model, is combined with a reservoir system model and a national inventory of reservoirs leading to comparisons of the reliability, vulnerability, and resilience of reservoir systems across the United States under current and a future climate scenario. Less water availability and increased overall hydrologic variability were found under one future climate scenario leading to corresponding decreases in the resilience, and corresponding increases in the vulnerability, of reservoir systems. *Factors Influencing the Present Cost of U.S. Public Water Supply* (*J Water Resour Planning Manag*, under review) showed that present water supply costs in the United States only are related to the quantity of water supply with other variables, including climate, playing a negligible role. A sixth study entitled *The Regional Calibration of a Watershed Model* (*Hydrological Sci J*, under review) introduced a new method for the calibration of a watershed model to many basins in a region, simultaneously. The approach used leads to excellent reproduction of the behavior of stream flows at all sites in the region, while simultaneously leading to remarkably accurate regional relationships between model parameters and geomorphic watershed characteristics. This new approach, tested initially in the southeastern United States, will enable regionalized monthly water balance models for all regions of the United States.

Using the remaining funds for this project, an effort will be made to integrate all the results of the above studies to achieve the final goal: an integrated evaluation and assessment of the reallocation and other changes that may take place in each region when climate change influences the supply and demand of ground and surface water resources.