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

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Project Summary

Gateway communities are concentrations of human population and commerce in close proximity to conservation areas. We propose to assess effects of changes in climate and land-use on Rocky Mountain National Park and its gateway community, Estes Park Colorado. Specifically, our objectives are to:

_ Assess the potential consequences of changing land-use and climate for landscape structure, water quality, aquatic biota, terrestrial wildlife and native plant communities.

_ Extend these biotic effects to predict likely changes in visitation and the implications of those changes for the local economy.

_ Based on the understanding gained above, help stakeholders identify and evaluate potential ways to respond to a changing landscape and climatic context.

In gateway communities like Estes Park, natural processes are tightly linked to commerce by the behavior of Park visitors. To represent this link, we will investigate 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). Using human responses to mediate climate and land-use drivers, we will extend effects of climate change to the local economy.

The project will be organized in three phases. In Phase One, we will conduct a preliminary assessment dealing broadly with natural processes and human economic behavior. In Phase Two, we will assemble stakeholders to react to the preliminary assessment and to inform our science team about interventions that could exploit beneficial effects of climate change and ameliorate harmful ones. We have enlisted three partners, Rocky Mountain National Park, the Estes Valley Improvement Association, and the National Parks and Conservation Association to help organize the stakeholder assessment process. In Phase Three, we will use stakeholder input to focus the assessment on evaluating plausible alternatives for coping with climate change.

Our partners have committed from the outset to help us disseminate findings and, where appropriate, to incorporate those findings into advocacy, management, and policy. Thus, we are confident that the science we propose will achieve results by helping citizens, managers, and advocates anticipate and cope with effects of a changing climate.

Keywords: integrated assessment; climate change impacts; Rocky Mountain National Park area

PROJECT DESCRIPTION

OBJECTIVES

A fundamentally important component of the nation's effort to protect the environment requires managing areas of land to sustain ecological process and to protect biological diversity (Halvorson and Davis1996, Szaro and Johnson 1996). Such "conservation areas" include national parks, wildlife refuges, national forests, nature reserves, and other lands, owned publicly and privately. Historically, a prevailing view held that such areas could be protected by simply proscribing incompatible human uses. In contrast, a contemporary view recognizes that conservation areas are imbedded in context that often differs markedly in its composition and behavior (Botkin 1990, Pickett et al. 1992). Many of the internal dynamics of conservation areas, areas ostensibly "protected", respond in a sensitive ways to these external conditions (Pickett et al. 1992). It follows that a central challenge in efforts to assure environment quality depends on assessing and managing the effects of a changing context on the nation's conservation areas (Halvorson and Davis 1996).

Climate determines vital conditions affecting all ecological and human processes, and thus, can be seen as the ultimate environmental context. Recent research conducted in the Rocky Mountain region strongly suggests that land use change influences climate and feeds-back to land surface processes, vegetation changes, and watershed hydrology (Pielke et al 1997a,b; Baron et al. 1998a; Stohlgren et al. 1998; Chase et al. 1997). Moreover, climate interacts dynamically with alterations of the land surface caused by natural processes and human actions (Pielke et al. 1997a, Stohlgren et al. 1998).

Here, we propose to assess the consequences of changing climate and shifting patterns of land-use for an important conservation area, Rocky Mountain National Park, and its gateway community, Estes Park, Colorado. Specifically, our objectives are to:

- Assess the potential consequences of changing landscapes and climate for Park visitation, air and water quality, landscape composition and pattern, dynamics of wildlife populations, and integrity of native plant communities.
- Extend these biotic effects to predict likely changes in human behavior and the implications of these changes for the local economy.
- Based on the understanding gained above, help stakeholders identify and evaluate potential ways to respond to a changing landscape and climatic context.

These objectives are motivated by several observations. A fundamental demographic trend in contemporary America has been the movement of people from cities to suburbs (Diamond and Noonan 1996). However, suburban America is beset with many of the ills of urban areas---congested traffic, development void of aesthetic character, air and water pollution, and degradation of natural environments that results in fragmented landscapes and loss of biological diversity (Beatley and Manning 1997). It appears that disillusionment with conditions in suburban America is motivating new patterns of migration (Howe et al. 1997).

Increasingly, regional mobility fostered by enhanced telecommunications and early retirement is allowing people to choose to live near the environmental amenities offered by the nation's conservation areas (Nelson 1992, Howe et al. 1997). The towns and cities growing in response to this migration are known as "gateway communities." A few examples of such communities include Red Lodge Montana, Jackson Hole Wyoming, Banff Alberta, Traverse City Michigan, Gatlinburg Tennessee, and Tremont Maine. In all of these examples, a large conservation area is closely juxtaposed with a rapidly growing human community. Rapid growth of the human population in these areas compels changes in land use that amplify the contrast been the "natural" landscape inside the conservation area and the human-dominated one outside (Howe et al. 1997).

Rocky Mountain National Park and its gateway community, Estes Park, offer a classic case of an important conservation area juxtaposed to an increasingly human-dominated landscape. The population of Estes Park has grown 20% in the past 6 years (U.S. Census Bureau, 1997). The number of housing units in the Estes Park valley has grown steadily at a rate of nearly 4% per year since 1960 (derived from Larimer County Tax Assessor 1997). The area of land used for residential development increased from 19 ha in 1900 to 2107 ha in 1990 (Larimer County Tax Assessor 1997).

Both systems, the park and its gateway, are likely to be affected by a changing climate. In addition, the effects of climate change on the Park will almost certainly interact with the effects of a changing land context along the park boundary. Thus, the interactions of land-use and climate changes emerge as important agents that may modify the human-environmental context, an important source of stress on a suite of ecological processes with the park.

Although the mission of the park is to preserve and protect these processes, actions chosen to respond to effects of a changing context create important feedbacks to the gateway community by modifying the behavior of park visitors. Visitation links natural properties in the park to economic processes in the gateway community simply because, commerce in Estes Park is heavily dependent on revenue provided by park visitors. Thus, park managers are challenged to cope with the effects of changing climate on natural systems, while remaining responsive to the impacts of coping mechanisms on the preferences of visitors and their local economic behavior.

In the subsequent sections, we outline a project designed to help decision-makers inside and outside the park, anticipate the effects of changing-land use and a changing climate. In so doing, we will work with stakeholders to identify and choose among coping mechanisms that can preserve natural processes in the park and maintain quality of life for the people in its gateway community.

APPROACH

Overview

Our research team will assess the combined impacts of climate change and shifts in land-use on ecosystem properties and processes at watershed scales. The work will be integrated horizontally by examining a suite of ecosystem responses extending broadly across terrestrial and aquatic systems (Table 1). The work will be integrated vertically by extending predictions of climate and land-use models to responses of the natural system and extending these responses to human behavior and its consequences for economic activity in the gateway community (Table 1).

The assessment will emphasize synthesis of current data and knowledge using existing models and data sets (Table 1). With a few exceptions, we will not seek new experimental findings or develop new modeling approaches. We will organize the work into three consecutive phases: 1) A preliminary assessment providing broad insight into potential responses of the Estes Valley ecosystem to future land-use and climate change; 2) A process of collaborative design in which diverse stakeholders respond to the preliminary assessment and provide direction to the science team to refine future work; and 3) A focused assessment where the science team responds to the collaborative design process to identify key vulnerabilities and opportunities and to evaluate feasibility and efficacy of potential coping mechanisms. Each of these phases is described below.

Preliminary Assessment

The project will focus on understanding the amplifying and dampening effects of climate and land-use change on several existing environmental stressors within the Estes Valley. These stressors include the following.

Fragmentation of habitats at the Park boundary: Historical records from the county tax assessor combined with land cover maps reveal that large areas of grassland and forest that once offered intact mosaics of habitat have increasingly become fragmented by residential development and associated infrastructure in the Estes Valley (Stohlgren et al. 1995, Hobbs and Theobald 1997). Over 70% of the winter habitat for elk (*Cervus elaphus)* populations outside the Park boundary have been developed at densities exceeding 1 house per 5 ha (Hobbs and Theobald 1997). These fragmenting effects are believed to increase vulnerability of a range of plants and animals to local extinction.

Overabundance of native ungulates: Numbers of elk wintering in the park has doubled since the 1970's (Stohlgren et al. 1995) and the total elk population in the Estes Valley appears to exceed energy and nitrogen based estimates of habitat carrying capacity within the park (Hobbs et al. 1982). Populations of native ungulates, particularly elk, have reached levels that are widely believed to cause lasting harm to diversity of plant communities within the Park (Hess 1993, Baker et al. 1997, but also see Suzuki et al. 1999). In particular, excessive browsing by elk has caused a decline in regeneration of aspen (*Populus tremuloides*) and an increase in their susceptibility to diseases and fungal infections (Baker et al. 1997). These populations also come into conflict with the human community, causing traffic accidents and damaging ornamental plants (Hobbs abstract).

Invasion of exotic plants: Exotic plants are believed to harm integrity of native plant communities within approximately 30% of the park's area, especially in areas of high visitor use (such as viewpoints and trailheads) and in proximity to developed areas along park boundaries (Stohlgren et al. 1997). A 1991 survey estimated approximately 1.5 million m^2 of Canada thistle, 20 thousand m^2 of toadflax, and 30 thousand m^2 of leafy spurge in the park. Moreover, exotic plants within the park tend to invade areas that are high in soil nitrogen and native species richness (Stohlgren et al. 1999).

Declines water quality and impacts on aquatic biota: Long term observations from catchments within the park (Baron and Denning 1993, Baron and Campbell 1997) reveal steady increases in nitrogen deposition (3 to 4 kg N/ha/yr) resulting from air pollution produced by urbanization outside the Park. These sources of pollution, interacting with climate change, create extraordinary potential to degrade habitat for lake and stream biota.

Competition for water: Runoff from the Big Thompson watershed supplies water for drinking, irrigation, recreation, and groundwater recharge. Approximately 2.3 million people use these water supplies (Dennehy et al. 1993).

High levels of visitor use: Visitation to the park has almost doubled during 1960 to 1992 from 1.54 million visitors in 1960 to 2.94 million in 1992 (Stohlgren et al. 1995). As noted above, visitation is associated with invasion of exotic plants and contributes to air and water pollution within the park.

Changes in disturbance regimes: Density of coniferous woodlands has increased throughout the Front Range, largely as a consequence of fire suppression. As a result, many forests are overstocked and are subject to insect outbreaks and disease (Veblen and Lorenz 1991).

Managers within the park and citizens who live around it are challenged by uncertainty about the ways that these stressors will respond to continued changes in land-use combined with future changes in climate. We will reduce that uncertainty by conducting a three-tiered assessment (Table 1).

Tier 1: System Drivers

Climate change: We will forecast future climate and land-use patterns (Table 1). Climate scenarios will be generated based on historical weather station data, gridded interpolated data analysis, projected meso-scale climate model predictions and derived analog scenarios (Kittel et al. 1997). These data are part of the suite of climate data sets currently being used for the regional analysis of the US National Climate Impact Assessment sponsored by the U.S. Global Change Research Program and the Office of Science and Technology Policy (see VEMAP website at http://www.cgd.ucar.edu/vemap/V2.html). Multi-year climate analysis will involve analysis of changes in annual rainfall, snowfall, annual mean minimum and maximum temperatures, and days above freezing. Seasonal analysis will include changes in key climate related variables, such as the length of growing season, rainfall during the growing season, date of year daily average air temperature reaches above zero. Climate phenomenon refers to climate events such as the first hard freeze, rainfall exceeding 30 cm in a day, rain events on frozen ground, and other climate triggers affecting environmental conditions. In addition to these climate variables, we will also evaluate derived variables such as evapotranspiration, potential evapotranspiration, runoff, and soil moisture deficit. Baseline scenarios of climate and climate variability will be generated for various climate parameters and applied to sectoral components such as the hydrological or ecological systems to determine the impact of changes in the snow deposition and runoff, vegetation changes, and forage availability.

Land-use change: To forecast possible impacts of future development in the Estes Park Valley on natural systems, we will use a spatially-explicit model representing important influences on land-use, including general development pressure and human and and geographic factors influencing the location of development (Theobald et al. 1997, Theobald and Hobbs 1998). Because changes in human population are the main "driving force" of land use change, we will use widely available demographic data and projections to forecast development pressure. We will convert estimates of development pressure to the number of new housing units using a conversion ratio (people per house) based on historical data from the county tax assessor and the Census Bureau. The new housing units will be distributed across the landscape in response to locational factors to project future development patterns. Finally, the model will respond to potential land use planning actions, such as changes in zoning, clustering development, and conservation easements and purchases, to provide a "what if…?" environment for generating and evaluating alternative scenarios (Theobald and Hobbs 1998).

Tier 2: Biotic responses

*Effects on landscape structure and composition***:** Responses of composition and distribution of vegetation to changing land-use and climate predicted above will be simulated using the SAVANNA ecosystem model. (Coughenour 1992,1993, ms. in prep.). SAVANNA is a spatially explicit model that includes process-oriented sub models of carbon flows through three trophic levels, plant and soil water budgets, and plant and animal population dynamics.

SAVANNA requires digital maps of elevation, slope and aspect, soil, vegetation, hydrology, water sources, wildlife distributions, and fires. Our research team has assembled these data for the Estes Valley (Hobbs and Theobald 1997). The vegetation map is disaggregated into woody cover, woody plant height, herbaceous root biomass, and percent compositions of plant functional groups during model initialization. Human land use maps are used to compute restrictions on wildlife movements, and vegetation composition, which in turn affect wildlife range maps and vegetation properties in the model.

The model has been, or is being applied to numerous sites, including Rocky Mountain National Park, Yellowstone (Coughenour and Singer 1996a,b), Pryor Mountain Wild Horse Range (Montana), Wind Cave N.P., Elk Island N.P. in Alberta (Buckley et al. 1995), the savannas of Africa (Coughenour 1992, ms. in prep., Kiker 1998), and Inner Mongolia (L. Christensen et al. 1998, ms. in prep.).

SAVANNA simulates spatial units in parallel, at three nested spatial scales. At the coarse scale, the region or landscape is covered with grid-cells which are typically 100m wide. Within grid-cells are spatially inexplicit landscape positions, which are invariant over time. Within these sub-areas, herbaceous, wooded and shrubby patch types are simulated, and these are dynamic outcomes of simulated plant cover. The model operates on a weekly time-step and is driven by monthly rainfall and temperature maps, which are dynamically interpolated from base station data accounting for topographic effects (Coughenour 1992). A solar radiation submodel calculates incident radiation as a function of date and topographic position. A snow submodel simulates snow water inputs and melting as a function of temperature and radiation. The site hydrology submodel simulates soil water balance as affected by runoff, infiltration, transpiration, evaporation, and interception.

Effects on populations of native ungulates: Multiple populations of animals can be simulated by the SAVANNA model. The model predicts energy balance of individuals and their foraging, spatial distributions, reproduction and mortality. Population dynamics respond to climate through effects on forage production and snow cover, and subsequent effects on animal energy balance. Ungulates are dynamically distributed over the landscape in response to environmental conditions such as forage availability, snow depth, topography, cover, land-use and water. We will use the model to predict changes in abundance and distribution of elk throughout the Estes Valley in response to changes in land-use and climate.

Effects on bird communities: We will assemble existing information on relationships among habitat quality and structure and avian population and community status and distribution for the major vegetation types within the Estes Valley. Predictions of SAVANNA and the land-use simulator will be combined with habitat relationship data to predict plausible future effects of climate change on bird populations and communities. We will also identify major sources of uncertainty associated with these predictions.

Effects on invasive plants: We will use statistical models to quickly assess current invasive species patterns, to determine which habitats and communities are most vulnerable to invasion, and predict the spread and potential effects of invasive species. New spatial modeling capabilities (e.g., GIS-based categorical co-kriging and spatial discriminate analysis) developed at Colorado State University (Stohlgren et al., in preparation) will be used to create maps of distribution, probable distribution, probable rates of spread and"uncertainty maps". These maps will report the confidence in predictions to land managers. We will also advance information management, data

Table 1. Vertical and horizontal integration in Preliminary Assessment. Data sets and models shown in italics will be developed. Those in plain type are currently available for use in the assessment. Models are described in the text below.

Tier	System / Sector	Scientific Staff	Data sets and models
Drivers	Climate	Ojima	Historical climate data sets, and scenarios derived from Hadley Climate Centre and the Canadian Climate Centre.
	Land-use	Theobald	Land-use simulator, relevant GIS coverages, census data
Biotic Responses	Aquatic systems	Covich, Baron	Continuous climate, discharge, deposition chemistry, and water quality since 1983 for Loch Vale watershed, USGS hydrologic discharge records for major waterways draining the park; Paleoclimate, trophic status, and atmospheric deposition trends through the Holocene (records for assessing current rates of change) from several locations in the park; RHESSys (Band et al. 1993, 1996), and CENTURY, as well as linked RHESSys/Century.
	Landscape Structure	Coughenour	SAVANNA and site specific parameter set.
	Wildlife	Hobbs, Coughenour, Galbraith	Elk population data. Avian habitat relationships. SAVANNA.
	Plant Communities	Stohlgren	Data from >100 multi-scale vegetation plots. Spatial models being developed.
Human Responses	Visitor behavior	Loomis	*Regression models predicting visitor use, visitor surveys*
	Local economy	Wieler	IMPLAN and Larimer County parameter set

sharing, and outreach capabilities by linking existing field data to summary tools, GIS display tools, and new predictive modeling tools with www-sites. The techniques refined here can be immediately applied to evaluate and model invasive plants, animals, and diseases in other areas.

Effects on aquatic systems: We will use the Regional Hydro-Ecological Simulator System, (RHESSys) to link changes in climate and land-use to changes in lake and reservoir levels as well as stream flows and their variation over time. The effects of regionally driven climate change on seasonal and annual discharge are difficult to predict because of the importance of fine-scale topographic and microclimatic variability. However, RHESSys simulates the sensitivity of vegetation productivity, runoff, evaporation, and transpiration in topographically complex terrain. The model has been successfully applied to watersheds of different sizes in Rocky Mountain National Park (Lammers 1998, Baron et al. 1998, Baron et al in review). The basins were nested from smallest to largest, and include the 6.6 km^2 Loch Vale Watershed, the 200 km^2 Big Thompson Watershed, and the entire 200,000 km^2 South Platte Basin. These local-scale studies have successfully reconstructed records of hydrologic flow lending confidence to our application for predicting of stream discharge under different climate and land-use scenarios.

Changes in simulated hydrologic patters will be used to predict likely effects on ecosystem services including fisheries production, microbial breakdown of organic matter, and ground water recharge (Covich 1993 Meyer 1997a, 1997b). A temperature submodel will be run to determine the potential for thresholds to be overcome for invertebrate and trout species (Hauer et al. 1997). Stream and lake chemistry are defined by snowmelt that flushes pollutants from the snowpack, and nutrients and metals from soils (Baron et al. 1998a, b, Campbell et al. 1995). Warming scenarios predict earlier snowmelt, including some melt that occurs throughout the winter. This has important implications for water quality by reducing the magnitude of snowmelt-pulsed pollutants during spring (Baron et al. in review). However, while warming may be beneficial in the spring, warmer water temperatures coupled with increased atmospheric deposition of nutrients (a given due to urban growth) will lead to increased eutrophication (Baron et al. in review).

Tier 3: Human responses

Visitor behavior: Changes in climate and land use are likely to drive changes in visitation patterns within the park, and in so doing create changes in the economy of the Estes Valley. We will explore direct and indirect economic effects of climate change in three linked studies.

We will use historic records of weather patterns and visitation rates within the park to construct predictive regression models. We have successfully used this modeling strategy to link climate change to reservoir and beach recreation (Loomis & Crespi 1998). Specifically, we would estimate the following regression model using the monthly visitation and weather data:

$\text{Visitor Use}_t = \text{Func}(\text{Temperature}_t, \text{Precipitation}_t, \text{Snowcover}_t, \text{TrailRidgeRd}_t, \text{LongsPeak}_t, \text{PriceGasoline}_t, \text{EstesParkPopulation}_t, \text{FrontRangePopulation}_t, \text{Income}_t)$

where:

Temperature_t,= monthly average temperature

Precipitation_t, = monthly precipitation

$Snowcover_t$,= inches of snowcover at Bear Lake at month t
$TrailRidgeRd_t$, =dummy variable for whether Trail Ridge Road is open in month t
$Longs\ Peak_t$, = dummy variable for whether Longs Peak Trail is a non-technical climb (depending on snowdepth) in month t
$PriceGasoline_t$, = Inflation adjusted price of gasoline in month t
$EstesParkPop_t$, = population of Estes Park in month t
$FrontRangePop_t$, = population of the Front Range area of Colorado in month t
$Income_t$ = inflation adjusted disposable per capita income of Colorado in month t

The estimated coefficients from this model would: (a) indicate if visitation was statistically related to climate change related variables such as temperature and snow cover, and (b) allow forecasting of visitor use with projected climate change induced increases in temperature, reductions in snow cover, and consequent earlier openings of Trail Ridge Road and Longs Peak Trail. The climate scientists on this proposal would provide such projections of the climate variables to allow for the forecasting of visitor use.

We will also examine changes in visitors' local expenditures that might result from changes in visitor use. We will survey attitudes and preferences of visitors to the park. Because many visitors are on multi-destination trips, the contingent valuation method will be used (Loomis & Walsh, 1997), which allows for the focused assessment of visitors' likely expenditure changes for different recreational situations. In this case, the survey would be used to determine how visitors would change their behavior in response to changes in the natural system identified in Tier 2 (above), for example, vegetation (e.g., aspen), fisheries, wildlife diversity and abundance.

We will conduct an intercept survey as visitors leave Rocky Mountain National Park. Individuals will be stopped as they leave parking lots such as Bear Lake, Shuttle Bus parking, Sprague Lake, and Alpine Visitor Center, and given a mail-back survey with a postage-paid return envelope.

Impacts on local economy: Impact of these varying scenarios on the economy of the gateway community will be estimated through social accounting methods. Predicted changes in visitor use will be used in combination with visitor expenditure data collected from the visitor survey to drive an economic impact assessment of the varying scenarios using IMPLAN. IMPLAN is a social accounting model widely used to convert changes in expenditures into changes in local income and employment (e.g. Weiler et al. 1998). We will take advantage of the refined IMPLAN-based Fiscal Social Accounting Matrix being developed for the State of Colorado's Office of State Planning and Budget by the project's regional economist, among others. Such a social accounting model provides a measure of household, industry, and public finance impacts of economic changes to a community, through a system of interrelated institutional accounts that describe the structure of a local economy. In this case, changes in visitor numbers and expenditures would lead to increased demand for local goods and services. The affected industries would in turn require additional inputs to meet this new demand, which would lead to additional demand for both local and imported goods and services. New jobs and greater household income would lead to further increases in local demand. The resultant 'multiplier' effect of new expenditures through the local economy can thus be described both for the community as a whole, as well as its component parts.

Collaborative Design

We developed a process we call Collaborative Design to obtain advice and guidance from stakeholders on formulation of information systems used to support policy decisions on land-use (Theobald et al. *in review*, Dale et al. *in review*: sidebar7, Duerkson et al. 1997, Hobbs et al. 1997). Here, we modify the process to apply to our integrated assessment.

The first stage of Collaborative Design requires agency or private sector partners who are likely to use the results of the assessment in decision-making or advocacy. In essence, these partners include people and institutions responsible for management, or whose mission is to influence management and policy through established decision-making processes. In our project, these partners will include Rocky Mountain National Park, The Estes Valley Improvement Association, and the National Parks Conservation Association (see partner letters, attached). These partners will 1) help to identify and recruit stakeholders to participate in Collaborative Design, 2) will distribute findings to diverse constituents, and 3), where appropriate, will advocate for apply findings directly to management and policy decisions.

In addition to the partners themselves, potential stakeholders who will likely be affected by climate and land-use change include a variety of people in the Estes Valley including visitors, town residents, business owners, water users, local government, and regulatory agencies. Within these broad groups each stakeholder may have different objectives and may face different financial, technical, political, and legal incentives and constraints.

In the second stage of Collaborative Design, the research team will work closely with the local partners to prepare a stakeholder workshop. Up to 20 stakeholders will be invited to participate, including the partners. The science team will identify no more than 12 key findings emerging from the Preliminary Assessment, above. These key findings will be described in lay-oriented briefing papers and explained to participants in the workshop. Participants will be asked to help the science team:

- *Define the environmental and socioeconomic issues of greatest interest.*
- *Identify coping strategies targeting these issues that could benefit from research and information on climate change.*
- *Establish research objectives that will assist decision makers in planning and management by providing information on potential impacts, the tradeoffs associated with coping strategies, and short and long term research needs.*

After the workshop, we will summarize important outcomes and distribute these summaries for comment by partners and stakeholders. We will hold post-workshop discussions with sub-groups of participants to clarify concerns of individual stakeholders.

In conducting the stakeholder workshop, we will draw on guidance for designing climate change assessments, particularly information about establishing goals and objectives (e.g., Benioff et al., 1996) and our experience in providing on-site technical assistance for climate change adaptation assessments. We will also draw on our familiarity with literature describing the techniques applied in successful stakeholder alliances and public involvement efforts (e.g., U.S. EPA, 1997; NRLC, 1997; Dinar and Loehman, 1995; AWWARF, 1995). We anticipate that the format for the meeting will be relatively informal to allow for plenty of give-and-take among participants. However, we may draw on techniques typically applied in focus groups to ensure that the discussion elicits comments on particular issues.

Thus, the primary result of the Collaborative Design process will be a refinement and prioritizing of the issues raised in the Preliminary Assessment. This will allow the science team to prepare a Focused Assessment (see next section) evaluating alternative coping mechanisms, those most likely to be implement and those most relevant to concerns of stakeholders. The outcome of the assessments will provide the insight to cross-sectoral linkages related potential impacts that one sector may have on another. Identifying these linkages within the integrated framework developed in this project will allow land use managers to focus on how to minimize impacts on other sectors of the human-environmental complex of the Rocky Mountain National Park area.

Focused Assessment

Because the process of Collaborative Design will inform the science team about issues that require greater or less attention and will identify coping alternatives that are more or less likely to be implemented, the work proposed in the Focused Assessment cannot be described in detail before Collaborative Design is implemented. However, we can outline the following general approach.

The main idea behind the Focused Assessment is to use the tools outlined above in a narrower analysis informed by Collaborative Design, allowing greater attention to potential interactions among a smaller number of sectors than we considered in our Preliminary Assessment. We refine our work in two processes.

First, we will adjust our investment horizontally to focus on sectors of greatest concern to stakeholders and partners. This focus will reflect two aspects of Collaborative Design. First, we will concentrate on issues believed to be most relevant to the lives of people in Estes Park, and most important to the Park's mission of sustaining ecological processes. Second, we will concentrate on issues that can be feasibly addressed with coping mechanisms, mechanisms that have plausible likelihood of being implemented. This two step adjustment will eliminate issues that are considered less relevant to stakeholder concerns, as well as those that are relevant but are intractable to management intervention.

Second, we will increase our emphasis on evaluating alternatives for coping with harmful effects of climate change and seizing opportunities to respond to helpful effects. For example, if models predict increased visitation to the park, and this increase in visitation emerges as an important concern for stakeholders, we will structure the Focused Assessment to include examining alternatives for enhancing economic benefits to Estes Park, while informing the park about feasibility of managing visitor use to minimize impacts on natural systems.

EXPECTED RESULTS AND BENEFITS

We believe the process that we develop here can be used as model for conservation area protection throughout the U.S. A recent survey of National Park superintendents revealed that 85% of the nation's parks must cope with serious environmental threats emanating from their borders (U.S. General Accounting Office 1994). Moreover, climate change has been identified as one of the primary management dilemmas confronting the parks. Because of the close juxtaposition of parks and gateway communities and the close coupling of the dynamics of natural systems within the parks and human systems in gateways, coping with change requires an integrated effort in ecosystem assessment and management throughout the nation (Halvorson and Davis 1996, Howe et al. 1997). Our approach provides that integrated assessment. We believe it will be widely copied.

We also offer results and benefits to a more narrow clientele. Our project has been designed from the outset in close collaboration with policy partners, Rocky Mountain National Park and the National Park and Conservation Association. The project offered here has the full participation of managers with the wherewithal to implement our findings and an advocacy group with the ability to communicate them to a committed audience of stakeholders. Thus, we have targeted achieving results from our first organizational meeting.

Finally, we will offer products of value to ecosystem science. Many of our best-loved conservation areas are tightly linked to the performance of human economies. Our work joining human economies to responses of management to environmental stress represents a new and important contribution to understanding and managing ecosystems that people value.

STRATEGY FOR COMMUNICATING RESULTS

Results will be communicated to five target audiences: 1) Local citizens; 2) Citizens from the region and nation with an interest in park management; 3) Park management; 4) Local governments of gateway communities; 5) the scientific community.

Our Collaborative Design Process will greatly facilitate person-to-person communication of results in local community. We will involve the local and regional press in this process from the outset. Briefing papers prepared for the Collaborative Design process will be condensed to provide press releases.

The National Parks and Conservation Association has committed to communicating findings to their membership and the general public by covering the project in their bi-monthly magazine, on their web-site, in grassroots newsletters, and via press releases to regional media (see letter, attached).

Rocky Mountain National Park staff are committed to reviewing findings and, where appropriate, incorporating them in management decisions. They will communicate findings to park visitors through interpretive programs, including naturalist talks, videos, and visitor publications.

The science team will submit a manuscript to the America Planning Association Monograph series (e.g., see Duerksen et al. 1997) describing the results of the project. These monographs are targeted toward local government staff and are widely read by people able to influence municipal and county governments. In addition, we will summarize key findings on an attractive, interactive web site. The address of this site will be referenced in all publications (above). Our project team has substantial experience in developing and maintaining such sites (e.g., see ndis.nrel.colostate.edu.)

Finally, we will submit publications to peer-reviewed ecological journals.

GENERAL PROJECT INFORMATION

The project will be organized as follows. Hobbs will provide overall leadership and coordination. Ojima and Theobald will provide scenarios for land-use and climate change. Modeling and assessment of effects on landscape composition and its implications for wildlife will be done by Hobbs, Coughenour, Galbraith and a post-doctoral fellow. Stohlgren will lead work on plant communities, while Covich and Baron will conduct aquatic assessment studies with the help of a Ph.D. student. Economic responses will be examined by Loomis and Weiler and a graduate student. Stephanie Lenhart and Brian Hurd (Stratus Consulting) will help organize the stakeholder process.

We are challenged to apply limited resources to achieve broad horizontal integration across multiple sectors while assuring vertical connections among driving variables, natural systems, and human economies. We will use two strategies to rise to this challenge. First, we have assembled a science team unequaled in ability to deal with ecological and economic issues confronting Rocky Mountain National Park in the context of changing climate and land-use. The strength of our science teams comes in part from training and experience, but also from our ability to leverage previous work in the park to meet the needs of this project. Almost all of the principals have done studies in the park (e.g., see Hobbs et al 1982 Baron et al. in 1998a,b; Stohlgren et al. in press, Chase et al. 1997), and the data and models that have come from these earlier studies will greatly reduce the investment needed to provide horizontal breadth in our assessment.

Second, we are currently engaged in work that leverages many of the tasks outlined above. Hobbs is building stage-structured models of the parks elk herd to evaluate alternatives for population regulation, and Coughenour is using the SAVANNA model to evaluate impacts of elk grazing on plant communities. Baron is continuing her research of long-term ecological research in Loch Vale Watershed and the surrounding Front Range. Her work emphasizes understanding hydrological and ecological responses to climate variability, both caused by global climate change and regional land use patterns. Stohlgren is active in three research programs in Rocky Mountain National Park including studies on global change, invasive plant species, and long-term inventory and monitoring of natural resources. Ojima is active in climate and land use change studies for the US National Assessment and will be able to contribute results from this analysis toward this project. Covich is currently researching the impact on hydrological variability on stream ecology in Rocky Mountain National Park and will be able to provide results of that study to this project.

Schedule

July--December 1999	Develop alternative climate and land-use scenarios; Preliminary assessment of environmental conditions; Identification of potential cross sectoral links between environmental and human-dominated properties
January-December 2000	Apply alternative scenarios in preliminary assessment Determine opportunities and vulnerabilities for various land use options;
January-July 2001	Collaborative Design
August-June 2002	Focused Assessment

QUALITY ASSURANCE NARRATIVE

Ecosystem studies: All spatial data produced for this project will be compliant with the Federal Geographic Data Committee standards. The simulation models used in this study have been peered reviewed and published in the scientific literature. Specific application of the models to the Rocky Mountain National Park area has in many cases been carried out and have been verified by comparison to existing observational data of climate, hydrological, and ecological variables. In the proposed study we will make use of the existing measurement data of climate, water, vegetation, wildlife, habitat extent, and soils available to cross-verify model simulations to these data. We use spatial and standard statistical tests to evaluate the relationships between observed and simulated results. Spatial patterns used in the study will verified using other geographical data to insure that representations of the boundaries and land use patterns match to park and county records. Use of remote sensing data will also aid in verifying landscape patterns of park resources.

Economic studies: Regression models will be run to forecast visitor use under differing climate scenarios. Once preliminary results have been established, sensitivity analyses will be conducted to determine the key variables in determining changes in visitor behavior. In addition, tests for serial autocorrelation, common in such time-series but which can lead to lower estimator efficiency, will be run with remedial measures being applied where necessary.

In our survey studies of visitors, we will elucidate expenditure patterns through contingent valuation methods. To insure external validity of the survey results, steps will be taken to achieve a high visitor survey response rate. The team's experience with visitor intercept surveys with postage paid return envelopes and follow-up mailings often result in survey response rates of 68-78% (Loomis & Larson, 1994). All survey data will be error-checked for out-of-range observations, along with re-checking comparisons to the original surveys.

Our economic analysis will incorporate the results from the first two studies to evaluate impacts of differing climate scenarios on local economies. As stated above, this STAR project would use the refined IMPLAN-based Fiscal Social Accounting Matrix being developed for the State of Colorado's Office of State Planning and Budget by the project's regional economist, among others. Through this cooperation with the state, a wider range of data sources can provide alternative means to ensure the most precise data possible. In addition, IMPLAN data and model results regarding income and employment by sector will be verified against external (local, state, and national) sources.