Climate Change Impacts on New Mexico's Mountain Sources of Water

Introduction. New Mexico faces a daunting challenge—the State's demand for fresh water exceeds the supply from all sources. The problem will be exacerbated in the 21st Century by a combination of factors, including global climate change, increasing population, constraints associated with traditional water rights and interstate water compacts, and the general lack of scientific knowledge applicable and available to local and regional planners and policymakers. This convergence of natural and human pressures on the state's water supply creates a serious and urgent challenge in NM and requires a parallel, multi-faceted solution that combines scientific as well as socio-economic approaches.

The largest source of surface water in NM is the Rio Grande, which derives between half and three-quarters of its dependable surface water supply from high elevation snowpack in its northern, mountainous headwaters region. Worldwide, many mountain regions are experiencing the effects of climate change, almost certainly associated with anthropogenic forcing of the global climate system (*1*). Recent research highlights the impact of ongoing warming trends on western U.S. snowpacks (*2*). Regional warming trends can have particularly profound hydrologic effects on snow-dominated systems at relatively low latitudes near the current southernmost extent of snow, such as exist in NM. Long-term climate changes combined with sporadic extended droughts, which have more severe effects in a warmer climate, present an extreme challenge to water management in NM. Thus, it is critically important for NM to understand the effects of global climate changes on its mountain sources of water.

Understanding the effects of global climate change on NM's water supply requires a consideration of the entire seasonal cycle of inflow and depletions of the Rio Grande's complex hydrologic system. Currently, the hydrologic system is inadequately monitored at high elevations where snow-related processes are of central importance. Mountain snowpack supplies most of the streamflow, while mountain valley hydrologic processes control the timing and magnitude of hillslope runoff into streams. Furthermore, summer rainfall accounts for up to half of total precipitation in southern NM along the downstream reaches of the Rio Grande. Summer precipitation is frequently intense but sporadic and uneven compared to winter precipitation. Research suggests that the strength of the monsoon circulation in summer may be controlled in part by surface fluxes associated with previous winter snowpack, implying that the entire season cycle needs to be considered to understand, and predict, the effects of climate change. NM needs a more robust hydrologic infrastructure to fill in critical gaps needed to develop a better understanding of the relationship of high elevation events to downstream water supplies.

Understanding the effects of global climate change on NM's water quality presents corresponding challenges. The Earth's major biogeochemical cycles are being perturbed by human activities at local, regional, and global scales, and understanding these processes is recognized as one of science's Grand Challenges (*3*). In NM, the sensitivity of snowmelt-dominated rivers, such as the Rio Grande, to climate changes makes these ecosystems excellent candidates for the biogeochemical characterization of the responses of water quality and solute fluxes to changes in temperature and precipitation. Monitoring environmental responses to climate change can help NM protect and maintain the quality of its water under varying climatic conditions.

The generation of hydroclimatic change simulations considered reliable enough on the local scale to guide skeptical policymakers will be an enormously challenging and difficult task, but we can think of no more important, potentially transformative project in the environmental sciences today. To create possible future scenarios for public discussion, researchers need to integrate existing data and new measurements into algorithms that model the impact of global climate changes and human activity on the state's environment with particular attention to the quantity and quality of NM's water supply. Most existing climate change models describe large-scale phenomena but lack sufficient resolution at the watershed scale where state and local policymakers need decision support. Re-scaling existing models, using local and regional data to fill in gaps, and improving the accuracy of algorithms are necessary steps to ensure the relevancy of the models to NM's water policy and planning efforts.

Climate changes are affecting natural environments around the world. In NM, climate changes are altering processes associated with the water supply, which sustains the state's economy and determines to a great extent the quality of life. In 2004, Governor Richardson recognized the importance of water to the state and region when he said, "Water is not only the lifeblood of New Mexico, it is the most urgent environmental and economic development issue across the Western United States." Today, concerns about water serve as a powerful driver for collaboration, investigation, conservation, education and participation in discussions about the State's future. The resulting confluence of natural and human activities

focused on water has the potential to make NM a laboratory for climate change research and a model for science-based public policy. NM EPSCoR recognizes these developments as an opportunity to move forward with an agenda that serves science and society in NM and more broadly.

This NM EPSCoR Research Infrastructure Improvement proposal (RII3) seeks to improve observational modeling and analysis of high elevation hydroclimatology in NM by strengthening the instrumentation and modeling infrastructure. The proposed RII improvements build on improvements realized through NM's current EPSCoR award (for the measurement of water and energy fluxes) and leverage the NSF investment in hydrologic observations in northern NM implemented by SAHRA, a Science and Technology Center. The scope of the proposal differs significantly from previous efforts in two ways: (1) it connects infrastructure development, designed to improve long-term, multi-scale monitoring of streamflows in high elevation watersheds, to downstream flows that directly affect large populations; and (2) it expands educational and outreach activities designed to provide a scientific underpinning to public policy discussions in NM. This multi-disciplinary, multi-scale effort will transform climate change science and policymaking in NM by providing the tools required for quantitative, science-driven discussion of difficult water policy options facing the State in the 21st Century.

Roadmap to this Proposal. Section 1 provides an overview of NM's academic research and development enterprise including the state S&T, education, and cyberinfrastructure plans. **Section 2** summarizes activities supported by the first six years of EPSCoR funding. **Section 3** explains how the focus of this proposal was initially selected (including results from analysis of strengths, barriers, and opportunities) and subsequently refined. **Section 4** describes plans to improve research infrastructure, cyberinfrastructure, and human infrastructure. **Section 5** explains how the project will be managed over the next five years and how progress can be sustained beyond the award's lifetime. **Section 6** concludes with a synopsis of the project's intellectual merit and broader impacts.

1. NM's Academic Research and Development Enterprise: Status and Overview

1.1 Background. NM is a land of stark contrasts. Its beauty and natural resources stimulated a population growth rate of 20.1% from 1990 to 2000. However, the state's economy (47th in 2002) and near bottom ranking in per capita income created a huge negative impact on the R&D capacity of the universities. NM universities had an increase in Federal R&D spending from 2001 to 2006 of $47M (20%); however, nationwide the increase was 36%. Also, although NM was ranked 8th in Federal R&D spending in 2004, the two national labs received over two-thirds of this funding, of which the universities (Figure 1) received little funding.

NM became an EPSCoR state in December 2000 and in March 2002 received a RII award (RII1; EPS-0312632 for $6.2 M) focusing on natural resources, nanotechnology, and connectivity. A second award in March 2005 (RII2; EPS-0447691 for $6.75 M) built on the first award and addressed three critical issues of state and national importance: nanotechnology, education, and water. A notable outcome of prior funding was recognition that NM critically needed a plan to guide its R&D investments.

1.2 The NM State Science and Technology (S&T) Plan. NM EPSCoR became an active participant in the development of the state's S&T Plan in 2003. By commissioning an "environmental scan" of research indicators, NM EPSCoR engaged the Governor's office and key stakeholders in discussions (through statewide focus group meetings) leading to the conceptualization of a NM plan for S&T infrastructure improvement. It was not until 2006, when two EPSCoR State Committee members, Dr. Tom Bowles (the Governor's Science Advisor) and Stephan Helgesen (Director of the Office of Technology, State Economic Development Department) began working together, that state government achieved the synergy needed to move this initiative forward. During the past two years, development of the NM S&T Plan has rapidly progressed. Efforts included examining plans from other states, holding two Town Hall Meetings and numerous working group meetings across the state, and soliciting additional input from several hundred citizens. The final plan will be submitted to the legislature in early 2008.

The draft NM S&T Plan identifies strategic priorities for the state (see Table 1). In addition to creating a vision for NM, the plan recommends specific initiatives that provide an integrated and coherent pathway from investments in very basic R&D through technology maturation to final commercialization or sustainability. Two initiatives are particularly relevant to this RII proposal. The first initiative—the NM Computing Application Center (NMCAC)—has been approved and is scheduled for completion in summer 2008 (*4*). The centerpiece of NMCAC is an SGI/Intel High Performance Computer system (HPC) capable

of 172 trillion calculations per second (172 teraflops) which, for a short time at least, makes it one of the five most powerful supercomputers in the world. NMCAC also includes three "exemplars" (2 teraflop systems with the same architecture) that will be located at the three research universities (UNM, NMT, NMSU). Cumulatively, the four HPCs provide the computing power required for the modeling efforts described in this proposal and represent a significant State contribution to the EPSCoR initiative. A second relevant initiative established the Water Innovation Fund that follows Governor Richardson's focus on State water reform legislation, which named 2007 as the "Year of Water." The fund represents one of many opportunities for sustaining the research infrastructure improvements proposed for RII3.

Abbreviation – Partnering Institution:

Diné – Diné College (Navajo Nation *TCU)
SJC – San Juan College
NNMC – Northern New Mexico College (**HSI)
VCNP – Valles Caldera National Preserve
LANL – Los Alamos National Laboratory
SFIS – Santa Fe Indian School
NMHU – New Mexico Highlands University (HSI)
UNM – University of New Mexico (HSI)
SIPI – Southwestern Indian Polytechnic Institute (TCU)
SNL – Sandia National Laboratory
NMMNHS – NM Museum Natural History and Science
ENMU – Eastern New Mexico University (HSI)
NMT – New Mexico Tech
WNMU – Western New Mexico University (HSI)
NMSU – New Mexico State University (HSI)
CDNP – Chihuahuan Desert Nature Park

*TCU—Tribal College or University
**HSI—Hispanic Serving Institution]

[See Appendix A for faculty and student demographic and enrollment data.]

Figure 1. NM EPSCoR's Academic, Federal, Museum, and National Laboratory Partners.

Table 1. The Seven Priority Areas in the NM Science and Technology Plan.

- **Energy, Environment, Water** – renewable energy sources, socio-economic research, impact of global climate change on NM, clean water, remote sensing, modeling of biosystems, impact of forest thinning, atmospheric modeling, soil, air, ands water remediation, groundwater issues, hydrology, sensors, modeling, watershed sustainability, conservation, water quality, desalination, use of brackish water, use of oil and gas field water
- **Information Technology** – high performance computing, innovation in algorithm development, information use and data mining, geospatial information, networks (including sensor networks), adaptable architectures, data imaging, visualization, cyber-security
- **Education** – K-12 though post-graduate and continuing education, public STEM awareness
- Aerospace – aerospace and space sciences
- Bioscience – bioscience and biotechnology
- Nanotechnology – micro, nano, and quantum systems
- Economic Development – basic R&D, through technology maturation to commercialization

1.3 NM Cyberinfrastructure and Education Planning. Notably, the NM State S&T Plan includes information technology and education as priority areas, thereby endorsing the Information Technology Plan (*4*) as well as NM Public Education Department (PED; *5*) and Higher Education Department (HED;

6) plans. In addition to the $11M investment in NMCAC, NM is significantly advancing connectivity to all colleges and universities throughout the state. The first phase of implementation, now underway, will connect the three research universities and the regional universities (NMHU, ENMU, NNMC, and WNMU) to the National LamdaRail. Each university will have state-of-the-art visualization centers and distance education facilities. The next phase of implementation will deploy a hub-and-spoke model whereby the research and regional universities serve as the hubs for high-speed connections to the state's Tribal and community colleges. Currently, the NM HED is embarking upon an ambitious plan to break down transfer-of-credit barriers among the state's colleges and universities. The plan allows credit earned at any college in the state to transfer to any other institution, thereby enabling students to move easily from a community college to a regional or research university. Building on the improved connectivity among institutions of higher learning, the plan will allow courses taught at one university to be delivered electronically to other schools in the state. This capacity for distance education is critical in NM where requisite faculty members are not present on every campus and travel times between campuses are long.

In the education arena, NM EPSCoR helped establish a new Bureau for Math and Science Education at the PED. After co-sponsoring a statewide Town Hall in 2005 that recommended the new bureau to the State Legislature, NM EPSCoR joined the bureau's first Advisory Committee and helped shape a comprehensive long-range strategic plan for math and science education reform in NM (*A Strategic Action Plan for Advancing Math and Science Education in New Mexico, 2007-2010* (*5*)). The plan includes a focus on strengthening "the content and pedagogical knowledge, and leadership skills of math and science educators and administrators to transform instruction" and to "provide all students with challenging curricula, engaging instruction…that encourage real world, inquiry-based problem solving."

2. Results from Relevant Prior NSF Support

2.1 Overall. Since NM became an EPSCoR state in 2001, the amount of NSF funding awarded has increased from $25M in FY01 to $39M in FY07, an increase of over 50%. During the same period, dollars awarded for EHR increased from $26M to $39M, changing from 1% of NSF EHR awards in FY01 to 1.6% in FY07, and resulting in substantial improvements to the human infrastructure by helping to develop a workforce capable of scientific research.

Although the funding rate for NM proposals submitted to NSF dropped slightly from FY01 (29%) to FY07 (26%), the national rate fell even more—from 31% to 26%. Since FY05, the funding rate for the state's three major research universities has steadily increased while the funding rate for other submitters in the state has declined.

2.2 Hydrology/Natural Resources. To provide scientifically rigorous information about the natural resources of the state, RII1 developed the Institute for Natural Resource Analysis and Management (INRAM), a collaborative of statewide facilities. INRAM created an integrated biodiversity database with specimen information from 20 individual collections in a common format; purchased state-of-the-art chemical analysis equipment for dedicated labs at SJC and NMSU and implemented successful training programs in laboratory techniques for undergraduate and graduate students; acquired state-of-the-art GIS equipment for NMSU, offered GIS training for students, and produced innovative prototype evapotranspiration (ET) maps based on models and satellite imagery. The Forest/Land Management component of INRAM is now written into the Federal Southwest Forest Health and Wildfire Prevention Act of 2004. In 2005, AAAS determined that INRAM had attained its goals and become self-sustaining.

The INRAM investment in ET infrastructure and modeling formed the basis for the RII2 focus on becoming a leader in instrumentation and algorithm development for regional hydrologic modeling and ET estimation in semiarid environments. Key achievements include:

- NM EPSCoR Fluxnet, an 18-site high density ET network with real-time, state-of-the-art instrumentation in the Rio Grande corridor (>60,000 km^2) from northern NM mountains to the Mexican border, developed by RII2.
- Two new faculty hires to fill critical gaps in expertise. RII1 provided a start-up package at NMT for Enrique Vivoni, who led the hydrologic modeling and geospatial analysis effort in RII2 and is one of the faculty leads for the current proposal. RII2 provided a start-up package at UNM for Marcy Litvak, who brought expertise in upland, pinon-juniper shrub and pine forest 3-D eddy covariance ET flux measurements, complementing existing expertise in riparian and agricultural zones.

- A $300K match from the NM Legislature to supplement the ET network. NM EPSCoR Fluxnet now provides ground-based measurements in riparian, agricultural, upland grassland, desert shrubland, and pinon-juniper areas of the watershed.
- Integration of ET data with real-time remote imagery and state-of-the-art modeling to increase the predictability of hydrological models of the watershed. RII2 increased connectivity between ground-based and satellite-based data and the analysis and modeling facilities, and enabled timely visualization and dissemination of geospatial model outputs for use by the user community (*7*).
- New collaborations between the hydrology group (including three post-docs, five graduate students, and four undergraduate students) and LANL and SNL.
- Numerous models and publications, including two that are guiding NM water policy (*8,9*).

2.3 Nanoscience. Before NM became EPSCoR-eligible in 2000, NM S&T leaders defined micro and nano systems as a top research and economic development focal area. Concurring on the importance of this area, NM EPSCoR RII1 and RII2 developed a Distributed Nanomaterials Characterization Network (*10*) involving equipment/facilities and faculty at six academic institutions, LANL, and SNL. EPSCoR purchased 14 significant pieces of equipment at five universities and one community college, ranging from a high resolution FESEM (Hitachi S-5200) at UNM to a SJC lab designed to support elemental and molecular analyses for research and teaching. The infrastructure substantially enhanced interactions among nanoscientists; produced several inter-institutional collaborations; and resulted in new collaborations with the Department of Energy (DOE) LANL/SNL Center for Integrated Nanoscience Technologies (CINT) that enabled EPSCoR faculty to be among the Center's first users. EPSCoR-enabled equipment was a prime factor in UNM's inclusion in the NSF National Nanoscience Infrastructure Network (NNIN). Albuquerque is now the only city in the country with nodes in the DOE (CINT) and NSF (NNIN) nanotechnology networks. The nanoscience group will graduate from NM EPSCoR at the conclusion of RII2. Key achievements include:

- Provided start-up packages for nine new faculty hires (4 female) at three universities.
- Co-authored publication in the April 23, 2004 issue of *Science* (*11*).
- Setting a world record with 5.2 percent efficiency for organic solar cells (*12,13*).
- Strengthening the UNM-established Center for Biomedical Engineering (CBME). EPSCoR faculty member Gabriel Lopez was appointed Director, and NM EPSCoR contributed to start-up packages for 2 new female biomedical engineering faculty in CBME. The 2007 NM Legislature invested $856K for faculty and equipment to expand CMBE and to develop undergraduate and graduate degree programs in Biomedical Engineering. CBME is a top priority for funding in the 2008 legislature.
- CBME faculty serve as PI/Co-PI on the NSF Partnerships for Research and Education in Materials (PREM) grant that includes a successful outreach program with local bilingual public schools.
- EPSCoR investments in chemistry at SJC were leveraged to win an NIH Bridges to the Baccalaureate Degree Program award in 2005, serving students of a majority Native American and Hispanic community college adjacent to the Navajo Nation.
- State approval in January 2007 to offer a graduate degree program in Nanoscience and Microsystems (NSMS) at UNM, which was a goal of the EPSCoR initiative. The interdisciplinary NSMS degree program is offered jointly by the UNM College of Arts and Sciences and School of Engineering. More than 70 faculty in nine academic departments worked together to develop the degree program. NMSU and NMT support the degree program by offering additional classes. The first joint class offered in fall 2007 had over 60 students from the three Universities.

2.4 Cyberinfrastructure. NM EPSCoR significantly increased connectivity through the addition of T-1 lines to three regional universities in 2003 doubling their capacity. RII2 contributed to the purchase of a supercomputer cluster for nanoscience research at UNM, which is available to EPSCoR researchers statewide, and purchased supercomputer clusters and storage at UNM and NMT for hydrology data storage, analysis, and modeling.

2.5 Education. The EPSCoR education program focused on multi-disciplinary place-based teaching and learning in the hydrologic and nanoscale sciences, and on engaging, challenging, and mentoring students and teachers. For instance, the Nanoscience education initiative worked with 43 of 89 NM school districts and the Eastern Navajo Agency, Southern Pueblo Agency, BIA, Navajo Nation and Santa Fe Indian School. The initiative included teachers of all grade levels, although high school math and science teachers were the primary participants during the five years of workshops and seminars. The students

taught by the teacher-participants reflect the minority student population in rural NM; approximately 31% of the students were American Indian, 40% Hispanic, and 28% Anglo. In addition, EPSCoR faculty developed nanoscience curriculum materials for the Master of Science Teaching (MST) program at NMT. More than 100 teachers participated in the EPSCoR nanoscience component of the MST program and the statewide semiannual professional development workshops. The hydrology education initiative had a similar impact and both programs provided classroom kits, graduate credit to enrollees, and mentoring throughout the school year.

2.6 Outreach and Communication. NM EPSCoR developed a strong outreach program within the state. Key results include a broader understanding of EPSCoR among its constituents; partnerships critical to sustainability; and initial development of the State S&T Plan**.** NM EPSCoR organized planning meetings; initiated an annual NM EPSCoR Day at the state capital; and in partnership with SNL and LANL, organized and hosted the 2003 Annual DOE EPSCoR Conference in conjunction with the first national CINT User Workshop.

3. Overall Strategy to Improve NM's R&D Competitiveness

3.1 NM's Strengths, Barriers, and Opportunities. In preparation for RII3, the NM State EPSCoR Committee (SEC) assessed strengths, barriers, and opportunities at its institutions to determine areas for further development of infrastructure in support of research, education and innovation. The SEC conducted this assessment in conjunction with the committee that developed the state's S&T Plan as a way to coordinate effort and leverage the significant overlap in membership between the two groups. Highlights of this assessment appear in Table 2.

Table 2. NM Strengths, Barriers, and Opportunities for its Academic R&D Enterprise

Strengths
- Significant S&T resources at the universities and the national labs
- Extremely high cultural and ethnic diversity of its citizens
- Beauty of the state and abundant natural resources that are attractive to individuals and businesses

Barriers
- Critical Mass—the isolated nature of intellectual capital in our universities and inter-institutional barriers that make it difficult to compete for large multi- and interdisciplinary programs
- Collaboration—lack of statewide collaboration and collaboration technology infrastructure for research
- State-of-the-Art Research Instrumentation—difficulty in obtaining state funds directly, or matches for federal funds for expensive instrumentation
- Diverse, Educated Workforce—lack of a diverse, scientifically- and technologically-literate workforce

Opportunities
- Leverage state investments by drawing on strengths at universities and national labs
- Utilize advanced communication networks and collaboration technologies to build research critical mass
- Integrate and coordinate state investments by taking into account federal basic R&D and infrastructure support
- Capitalize on NM's cultural and ethnic diversity

3.2 Strategic Selection of NM's R&D Focus. The NM SEC reviewed broad proposal areas for possible inclusion in RII3. Through formal evaluation, the focus areas were narrowed to five pre-proposals (environmental engineering, cognitive science, two dealing with aeronautics and aerospace, and climate change). The Committee used external peer reviews as the basis for debate and discussion of the merits of each pre-proposal. Climate change emerged as the Committee's focus for the RII3 proposal because it aligned most closely with NM S&T priorities.

3.3 Refining the RII3 Focus. After the NM SEC selected the strategic R&D focus, NM EPSCoR refined the focus in four steps. First, NM EPSCoR held numerous meetings throughout the state to verify that critical gaps and needs would be met by the proposed infrastructure improvements. The effort engaged stakeholder organizations (e.g., the national labs, NM Office of the State Engineer, Federal agencies

such as USDA-NRCS and the Valles Caldera National Preserve, as well as water conservation districts, private foundations, and the independent sovereign pueblos) in planning meetings to understand needs and perspectives, to optimize and leverage resources, and to foster sustainability. Second, program participants selected northern NM as the geographic focus to maximize the benefits to science, education, and society (i.e., installing critical and innovative infrastructure in the important and understudied watersheds that serve as tributaries to the Rio Grande and that encompass numerous pueblos and acequias). (The importance of location to research, education, and diversity is discussed further in Sections 4.4 and 4.6.) Third, NM EPSCoR directly linked the proposed RII3 investments and activities to outcomes and impacts as described in the Evaluation and Assessment Plan (Section 5.2). Equipment to fill critical gaps or underpin transformative research, as well as cyberinfrastructure and research activities designed to foster collaboration and innovation, received preference for inclusion in the proposal (see 4.4 and 4.5). Fourth, NM EPSCoR selected cyberinfrastructure (4.5) and education (4.6) activities and programs that could "close the loop" by disseminating results to teachers and students as well as decision-makers and the public.

4. Implementation Plan for NM EPSCoR RII3

4.1. Motivation and Scope of Research Supported by EPSCoR Infrastructure. Climate change projections indicate that surface temperatures in continental interior regions will increase significantly more than the global average (*1*). The hydrologic impacts of the warming trend are projected to include later transition from rain to snow in the mountains, higher snow line, less total snowpack, earlier snowmelt in springtime, and increased evapotranspiration (ET) rates in the warm season. As a result of these changes, hydrographs in western snow-dominated river systems will peak earlier in the year and total stream flows will likely decline. Global model projections are qualitatively very consistent on these points.

Despite the obvious importance of these projections, their coarse resolution presents serious limitations to regional and local water management. To address these challenges, NM EPSCoR proposes to develop a climate monitoring system in NM to: (1) assess current hydroclimatic change in existing model simulations and datasets; (2) scale-down and apply climate change projections to several key watersheds selected for intensive study; and (3) develop an innovative, sustainable regional hydroclimatological modeling and monitoring capacity capable of generating quantitative hydrologic information useful to stakeholders, including consideration of the statewide socioeconomic impacts of changing flows. The overall goal of developing a multiple-scale, end-to-end picture of hydrologic processes is to frame a science-based statewide policy discussion of water resource management based on significant enhancements to the observational network and the analysis of network measurements.

To augment this multi-scale strategy, the proposed research will consider the socioeconomic impacts of basin-scale hydrologic changes to traditional water supply systems (acequias) that have been an integral cultural feature of NM for centuries. Acequias and their communal management systems provide unique physiographic and cultural elements to help understand effects of changing mountain hydrology on land and water use, ecosystem change, and stream flow. Acequias play a central role in the interactions between surface water and groundwater that modulate and change the timing of the transmission of hillslope runoff to stream flow. Water diverted from stream channels is dispersed over the landscape by acequia systems. The selected study areas are important for mainstem flows in the Rio Grande and for the extensive acequia systems in these basins. Climate change will likely exacerbate pressures to share water according to hydrologic conditions rather than on customary practices. Thus the villagers who depend on acequias for water supplies are among the most vulnerable people in the state.

4.2 Targeted Research Areas

4.2.1 Large-scale climatic influences on NM. Understanding the hydrologic response to climate change requires the characterization of large scale climatic variability—observed and projected—and its relationship to regional climate variability affecting mountainous regions in southwestern North America. Observations unambiguously indicate that temperatures have been increasing throughout the Southwest in recent decades. Global climate model studies attribute much of the observed increase to greenhouse gas concentrations and project that temperatures will continue to increase at an accelerated rate (*1,8*). However the coarse spatial scale and continuing uncertainties in the scenarios developed from IPCC projections (associated with precipitation trends, climate variability and regional land surface feedback mechanisms) make it difficult for local and regional policymakers to incorporate the information into their water management deliberations. To reduce these uncertainties, the proposed research will address the

influence of large scale atmospheric circulations on regional and local atmospheric processes and explore how hydrometeorological fluctuations propagate into changes in surface flows downstream.

Climate change uncertainties are associated with global coupled model projections across southwestern North America (*14*). The Fourth Assessment report projects a large decrease in winter precipitation in this region (*1,15*), which would have devastating consequences in the Southwest. To assess the accuracy of this projection, it is necessary to examine the changes in the leading circulation modes affecting western North America in 21st Century coupled climate simulations.

In particular, the El Niño-Southern Oscillation (ENSO) cycle provides a strong interannual signal in the current climate on cold season precipitation and subsequent streamflow in the Southwest (*16-18*); however, the ENSO signal in current IPCC projections is quite varied (*19,20*). Decadal Pacific fluctuations modulate the ENSO signal in the Southwest (*21-23*), which make it important to examine this mode of variability in the simulations to properly understand the climate change scenarios.

Research will examine the covariability of precipitation and land surface anomalies in these projections as they relate to the Southwest. Land-atmosphere feedbacks associated with snowpack at high elevation may be of first-order importance in modulating the transition from winter to summer precipitation in the current climate (*24*). Although the major rivers originate in snow-dominated mountain headwaters, the downstream areas of the state receive a disproportionate amount of precipitation and tributary inflow during the summer season, associated with the North American monsoon. Characterizing and properly simulating the full seasonal hydrologic cycle in regions with winter snowpack is therefore critical for process-based analysis and for projections of stream flows in NM, motivating this proposal's focus on the upstream portion of the Rio Grande in northern NM.

4.2.2 Linking climate to hydrologic variability. Hydrologic information is derived from observations and simulation of climate variability and change. This information may be based on simple empirical data, such as the observed correlation between ENSO fluctuations and river flows in NM (*17*), or it may result from linear water balance modeling to characterize downstream flows (*25*). Studies such as these suggest that the large-scale climate changes projected for NM should yield smaller streamflows. Currently, however, NM has neither the watershed-scale observational data base nor the coupled atmosphere-land surface-hydrology modeling capability needed to examine and understand these processes. RII3 research would enable the meaningful quantification of streamflow projections needed by policymakers, and it would lead to transdisciplinary and potentially transformative efforts to understand and simulate physical processes that couple large-scale climate fluctuations with watershed-scale hydrology, thus affecting stream flows statewide.

The physical processes to be considered will include: (a) elevation-dependent generation of precipitation at temperatures near freezing (in winter) and associated with thunderstorm development (in summer) in a region of sharp and complex orography; (b) quantitative understanding of snow accumulation and ablation processes; (c) runoff generation associated with precipitation and snowmelt in these watersheds; (d) the dependence of (a)-(c) at the watershed scale on vegetation and soil moisture, and feedbacks between land surface conditions and the atmosphere, focusing on precipitation.

4.2.3 Coupled Climate—Hydrological Models. The local expression of large-scale climate change exerts a primary control on the hydrologic response of the basin. In mountainous regions like NM, orographic precipitation is one of the main local modulators of global climate change. Orographic precipitation is often a nonlinear process, and changes in orographic precipitation may not easily be parameterized in terms of changes in the large-scale circulation. Many studies show that resolution of about 20 km or less is needed to try to characterize the regional effects of large-scale climate variability in mountainous terrain. We propose a transformative effort to downscale climatic variability directly to a hydrologic model, which requires resolution on the order of 100 m or less.

To probe the sensitivity of orographic precipitation to changes in the large scale circulation, researchers will develop improved, intensive observation of orographic precipitation in test catchments. The WRF atmospheric model (*26*) will enable the introduction of controlled perturbations into boundary and surface conditions for sensitivity studies on an intermediate scale (approximately 10 km resolution). Researchers will evaluate the extent to which simple linear models (*27*) may replace more complex full-physics models like WRF and under what meteorological conditions the simpler models fail.

Large-scale climate simulations will provide lateral boundary conditions for the WRF model. Using a combination of remote sensing data analysis and field data collection, researchers will develop a distributed characterization of the Upper Rio Grande region. Within the context of regional climate

simulations, the research will explore the sensitivity of precipitation simulations (both quantitative amounts and snow/rain cover) to changes in soil moisture and temperature and to the representation of surface characteristics such as elevation, vegetation, soil and bedrock cover. By integrating the calculations with watershed scale observations, large-scale climate change scenarios will be transformed into watershed-scale projections of hydrological and socioeconomic relevance. A significant research effort will be required to downscale the output from WRF to the watershed scale resolved by process-based hydrological models such as tRIBS (*28*-*30*).

The hydrological modeling effort will use a range of techniques at different scales. At the basin scale, the choice is the SRM model (*31*) for the snowmelt producing tributaries. SRM is a semi-distributed model that employs daily satellite or aircraft snow cover extent data along with daily temperatures and precipitation data. SRM can operate in mountainous and remote portions of the Rio Grande basin, including Colorado, without direct physical access. At the river system scale, the choice is the SLURP model (*32*) to route flow through the entire Upper Rio Grande system. SLURP, a comprehensive basin model driven by existing or projected climatic conditions, allows water managers to weigh different climate scenarios and their hydrologic consequences. This model will be implemented over the entire Upper Rio Grande basin in NM and Colorado and coupled to the SRM output. Network observations will be used to test and verify the hydrological models.

Surface characterization data will provide input values to SRM, which will be implemented on all 30 sub-basins of the Rio Grande in Colorado and NM by using available climate data, intensive study basin data, and remotely sensed snow cover data (i.e., MODIS with AVHRR as a back-up and sustainable data source). Three driving variables (precipitation, max-min temperatures, and snow cover extent) will be input daily to SRM for each sub-basin.

To estimate ET for all sub-basins in the Rio Grande basin in NM and Colorado, NDVI values and thermal infrared data will be captured and used as input to the SLURP and tRIBS hydrologic models. Remote sensing using MODIS and ASTER sensors will be used during every clear MODIS pass and every relevant ASTER scene (with AVHRR and Landsat follow-on sensors as the sustainable source of data). NDVI and other spectral indices will be compared for best correlation with LAI, and efforts will continue on development of a remote sensing/ET algorithm for use as an input to SLURP (focusing on mountain basins) and on a remote sensing methodology for direct input of model parameters to both SLURP and tRIBS.

4.2.4 Climate change effects on water quality and solute fluxes. Water quality and solute fluxes are critical components of water supply and the economic and social impacts of climate-induced changes. Snowmelt mobilizes and transports dissolved solutes such as dissolved organic carbon (DOC), nitrate, phosphate, and iron that are determinants of ecosystem function and the ultimate suitability of water for human use. There is currently no program for sustained water-quality sampling in the snowpack-dominated areas of NM. Traditional chemical sampling at weekly or monthly intervals creates a bias towards low-flow conditions that underestimates riverine solute loads (*33*). We therefore propose to deploy a network of state-of-the-art, near-real-time, autonomous water quality sensors for detecting the rapid changes in surface water and groundwater characteristics associated with snowmelt events. We will take advantage of recent advances in chemical sensing technology proven successful in marine and estuarine environments and adapt the instruments for conditions encountered in low-temperature mountain environments. These instruments operate *in situ* with minimal human intervention for extended periods (*33*). The chemical sensor network will be co-located with the instruments for physical hydrologic measurements and allow for measurement of hydrological fluxes and biogeochemical fluxes at comparable time scales. Such a chemical sensor network will be unique in the mountainous regions of the western U.S. The database provided by the network will provide a platform for detailed investigations into climate controls on water chemistry and biogeochemical modeling of the impacts on ecosystems and downstream water users.

4.2.5 Evaluation of socioeconomic impacts of water management strategies. Output generated by climate models needs to be closely linked with the hydrologic models employed in this project, and output from the hydrologic models needs to be input to the economic models employed to evaluate climate change effects on the economy of the Rio Grande basin. Improving the design and facilitating the transfer of information between the hydrologic models (tRIBS, SRM, SLURP) and socio-economic models will require development of data and information to enhance the scope and improve parameterizations of

existing water management models. The results will enhance water management, allocation, and use policy development.

Several socio-economic models will be employed to develop a wide range of alternative adaptation scenarios. The Sandia Systems Dynamics model for the Rio Grande (*34*) will provide decision makers with easy access to the sectoral impacts of climate change on regional water resources. Water demand models, which consider changes in water availability, will help guide municipal growth and provide policy makers with market and non-market input. This modeling platform provides simultaneous feedback between the socioeconomic and physical drivers of water management. The NMSU Water Economics Model, RioGEM, and CROPMAN models (*35*) will enable examination of additional socio-economic adaptation strategies to the growing climate change problem along the length of the Rio Grande in NM.

Acequia systems are an integral part of the Río Chama and Río Hondo basins. The existence of these active systems was an important factor in selecting watersheds for intensive study. Remote sensing analysis of high resolution satellite data (QuickBird) will be used to map acequia channels, irrigated land areas, and riparian vegetation in the Río Hondo and Río Chama intensive study basins. Instrumentation to measure the effects of acequias on downstream flow will be installed in these basins, and modeling (Hydrus-2D and MODFLOW) will be used to synthesize field measurements to characterize acequia effects on water budgets. Detailed socio-economic (using RioGEM) and cultural evaluation of acequias will provide data to assess region-wide robustness and resilience of acequias to climate change.

4.2.6 Integration and synthesis. A well-developed research infrastructure for modeling mountain source areas will benefit the state and place the NM hydrological community at a competitive advantage for obtaining hydrologic research funding. In particular, the use of high performance computing with complex numerical models is considered as a unique contribution from our region (*30*). We are in a position to develop national recognition since several investigators in NM have conducted streamflow forecasting in mountain areas (*36*). The collaborations established in the project will strengthen mountain hydrologic forecasting using approaches ranging from semi-operational basin models to detailed, fine resolution distributed models.

Synthesis and dissemination of information to the public and operational water management stakeholders has the potential to transform public discussion of climate change in NM and is an important objective of this proposal. For example, the Dahm et al. (*37*) water budget for the middle Rio Grande (the state's most populous region) was compiled several years ago based on an anomalous wet period of time (1975-2000), yet this water budget has been used extensively in regional water planning meetings (*38*). A synthesis product of the proposed project will be the construction of scenario-based revisions to the middle Rio Grande water budget for input to future public discussions.

The tRIBS, SRM, and SLURP hydrological models will be integrated to develop climate change/hydrologic scenarios on each study basin in NM and Colorado for 2010-2110. The generated scenarios will also be used to determine effects on water rights, water use, the Rio Grande Compact, and acequia and reservoir operations in the whole Rio Grande basin. Linkages to economic models will provide quantitative data for evaluation of the scenarios and planning the future responses to climate change that water planners can use in decision-making.

An additional synthesis product will be generation of economic scenarios. Participants in this proposal have been active in disseminating water future scenarios (*25*), and it is anticipated that public discussion will move forward significantly when such scenarios are derived from more complete hydrological models.

4.3 Strategic Choice of Study Basins. The middle Rio Chama watershed and the Rio Hondo basin have been identified for intensive study (Fig. 2). Both are snowmelt-dominated rivers flowing into the Rio Grande north of the Otowi gauge, and therefore important contributors to the Rio Grande index flow involved in the interstate stream compact with Texas. The Chama is the largest tributary to the Rio Grande in NM and flows from north to south on the west side of the Rio Grande. The Rio Hondo flows roughly east to west on the east side of the Rio Grande. The summer monsoon signal is strong in this region of the state, contributing 40-50% of total annual precipitation (*39*). Additional instrumentation will be located in the Jemez River basin which has served as a research site for the SAHRA S&T Center.

4.4 Research Infrastructure Improvement Plan

The overarching goal for NM EPSCoR is to enhance research competitiveness through the acquisition of critical research infrastructure and cyberinfrastructure, and through strategic investment in human infrastructure. Secondarily, the goal is to address a critical state problem of

worldwide significance—the effects of climate change on water supply and sources in arid regions. Five specific research infrastructure improvement programs are designed to significantly benefit and enhance competitiveness of the NM academic research and education enterprise.

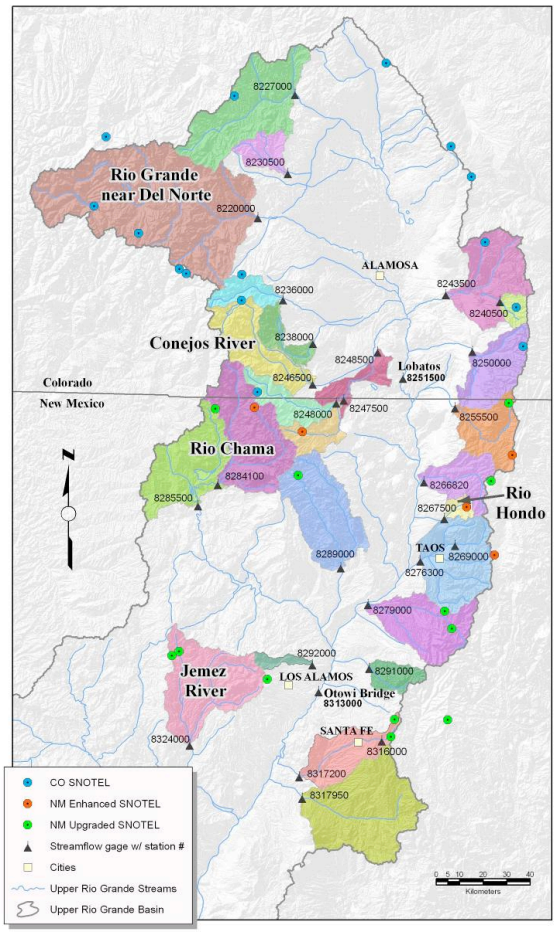


Figure 2. Map of northern NM illustrating study basins.

4.4.1 Major research infrastructure that fills critical infrastructure gaps in monitoring and analyzing climate and hydrological conditions in northern NM [Bathke and Rango NMSU; Martinez, NMHU; Pullin, NMT] This category includes: expansion and upgrades to northern NM climate station, SNOTEL, and SCAN networks, and major upgrades to the aquatic chemistry laboratories at NMT and NMHU. NM needs an improved regional climate monitoring system at high elevations to track hydrologic variability, resolve the effects of large-scale circulation changes on high elevation watersheds, and investigate land-atmosphere interactions and runoff processes in selected watersheds. At present, 18 basic SNOTEL sites provide daily values of snow water content, precipitation accumulation, and air temperature data. NM has just one enhanced SNOTEL site providing complete meteorological data along with soil moisture and soil temperature at various depths.

Funds are requested to upgrade and convert 12 existing basic SNOTEL sites in northern NM to enhanced sites. Five new sites have been selected to be instrumented with enhanced SNOTEL capability. Trained observers will continue to take manual measurements of snowpack depth and water equivalence at an additional 23 permanent snow course sites. The SNOTEL and snow course networks will provide the data needed to produce water supply forecasts and to support resource management.

The USDA-NRCS Soil Climate Analysis Network (SCAN) uses much of the same technology developed for SNOTEL, but deploys it at lower elevations with minimal snowpack. Currently, there are no SCAN sites in north-central NM. Funds are requested for SCAN instrumentation at four sites to be selected in the transition zone between high mountains and riparian valleys.

NMHU Environmental Chemistry Laboratory and NMT will be equipped with state-of-the-art instrumentation for analyzing water quality samples. Instruments proposed for NMHU include an FS3100 Automated Chemistry Analyzer, AIM500 Programmable Digestion System, Varian 280z Atomic Absorption Spectrometer, and a DS5 Water Quality Multiprobe system. This lab will supports up to 16 faculty members and their students, including four faculty members that currently send water samples to other labs for processing. Both graduate and undergraduate students will receive training on the instrumentation. Proposed instrumentation for NMT includes Sievers 900 On-Line Total Organic Carbon Analyzer, Ocean Optics Spectrometers, and a custom-designed iron flow-injection analysis system. .

4.4.2 Innovative *in situ* hydrological sensing infrastructure [Dahm and Crossey, UNM; Bowman and Pullin, NMT] This includes integrated networks of hydrometeorological stations that will measure

precipitation, soil moisture and temperature profiles, air temperature/humidity, wind speed and direction, net radiation and snow depth. Several discharge networks will be installed along the principal stream in each intensive study basin. Measurements and modeling in these basins will close the water budget at the watershed scale, providing quantitative streamflows that are coupled to large-scale climate data.

Innovative water quality sensors capable of continuous, real-time in-stream measurements of chemical constituents important for ecosystem and human health will be installed. NM researchers will take state-of-the-art technology developed for other environments and apply it to extreme environments encountered in mountainous regions of NM. A set of chemical instruments and sensors will be field deployed and co-located with the proposed hydrological instrumentation in the intensive study basins. Automated instrumentation adapted for continuous, high frequency solute analyses will be developed and deployed. The resulting sensor network will enable determination of the dynamics of solute fluxes (in particular, nutrients, soluble organics, and metals) under varying conditions. Existing sensors and chemical instrumentation will be adapted to operate in low temperature and/or low power conditions. Effort will include adapting chemical instruments and low power lab instruments.

Three sets of instruments (one set in each of the intensive study basins and one at Valles Caldera in the Jemez basin) will be deployed. Each set will include basic physiochemical parameters, automated nutrient analyzers for nitrate, phosphate, and silicate, total organic carbon, organic carbon optical properties and iron (II) and total iron. Analysis of non-stationary sensor data to infer information on the dynamics of chemical processes will be performed. This component of the proposed infrastructure will move NM to the forefront of an emerging field of freshwater science.

4.4.3 Climate change infrastructure seed grant program [Diné, SIPI, SJC, ENMU, NNMC, WNMU]. This program is designed to increase the impact of NM EPSCoR on the critical student population at NM's non-PhD granting institutions. Faculty at these colleges and regional universities will be able to apply for undergraduate institution infrastructure grants, which may be used to purchase research and teaching equipment related to climate change, hydrology, and water quality science, and to pay for student researcher salaries, research supplies, and student conference travel. A total of $350,000 will be available to faculty from the regional universities and 2-year, tribal and BIA colleges. Five-page proposals will be solicited annually and will be selected for funding through a peer-review process overseen by the EPSCoR Management Team (MT). The undergraduate institution faculty will be asked to integrate their proposed activities with the Undergraduate Research Opportunities Program (Section 4.6.3.2) through recruitment and collaborations with research institution faculty.

4.4.4 Multi-scale and multi-disciplinary model development [NMSU, NMT, UNM, LANL, SNL]. This program supports a University—National Laboratory Fellowship Program whereby at least eight PhD students will be supported for up to two years each to engage in climate, hydrological, or socioeconomic modeling. Students will be co-directed by at least one scientist from either LANL or SNL and one or more scientists from NM research universities. Students will apply to the program following prescribed guidelines and selected through a review process that will be overseen by the MT.

4.4.5 Innovation working groups (IWG) [All NM Institutions]. This program supports week-long working group activities that are modeled after those supported at the highly successful NSF-supported National Center for Ecological Analysis and Synthesis (NCEAS) at UC-Santa Barbara. Five working group meetings will be supported annually by EPSCoR funds. An IWG supports 8-12 scientists or educators who will work collaboratively to integrate and synthesize data, information, and knowledge on challenging issues. At least one IWG each year will focus on education, communication and outreach, or diversity. IWGs will provide an optimal venue for engaging a critical mass of NM scientists and educators along with key nationally and internationally recognized experts to address the grand challenges that can transform science and education. Anticipated outcomes of the IWGs include synthesis papers and proposals that target NSF cross-cutting programs.

A capstone of the program is an IWG that will be partially supported by and held each year at LANL—entitled: "Bridging Disciplines and Bridging Scales." The focus will be on how we relate changes in the physical climate to the socioeconomic impacts. Major themes will be how to institute connections across disciplines (e.g. climate change, surface hydrology, economic modeling) and how to bridge the tremendous gaps in spatial and temporal scales (e.g. from global climate change to economic impacts in NM). Scientists from around NM as well as national and international experts will be invited.

Short proposals will be solicited from NM institutions annually and IWGs will be selected through a peer-review process overseen by the MT. IWG topics will be distributed among the climatological, hydrological, and socioeconomic sciences, as well as research topics related to education, communication and outreach, and diversity. Preference will be given to topics that are transdisciplinary or have strong potential for being transformative.

Three western NSF EPSCoR states, Nevada, NM and Idaho have chosen climate change as an overall theme in the present RII competition. We propose to take advantage of this concurrence by hosting two tri-state NSF EPSCoR workshops on climate change, "Regional EPSCoR Workshop: Addressing Climate Change Research and Education Challenges in the Western United States", thereby promoting regional and inter-jurisdictional collaborations. The first workshop would occur in year 2, to encourage collaborations among the three states early in the grant period, and the second one in year 4, to promote continuation and maturation of these collaborations. Each of the three states has budgeted for these two workshops; NM EPSCoR through its IWG budget.

4.5 Cyberinfrastructure (CI) Plan

To achieve important advances in our ability to observe and simulate mountain hydrological processes and their susceptibility to climate change, NM EPSCoR will stimulate innovative use of CI including: development of efficient data acquisition, processing, and storage models; high performance computing; interoperable data discovery and delivery through interfaces based upon open standards; deployment of collaboration tools that facilitate both synchronous and asynchronous knowledge exchange; and development of a project portal that provides a single point of access for project products, services, and information.

The three research universities currently provide expertise in these areas. Proposed improvements, which will build upon previous EPSCoR investments in CI, include deployment of collaboration software; network connectivity upgrades at NMT; data acquisition/processing/management support at UNM, NMT, and NMSU; replacement data and application servers in Years 3-5; data acquisition, processing, service and client interface/portal programmers at UNM; and supercomputer code development support resources at the NMCAC. The enhancements will allow for mirrored data ingest and storage at NMT and UNM, and web and web-service-based data (ground observations, remote sensing imagery, model outputs, and synthesis products) distribution to all partner colleges and universities, state agencies, and the public. The expanded state data network will create capabilities that are competitive at a national level for scientific data delivery. Products available through the project portal will range from raw data and processed geospatial products, virtual products generated based upon user queries, basic transformation and analysis tools and services, online visualization tools, and standards-based imagery and data services. Figure 3 illustrates existing and planned CI components, while the following sections provide more specific information about each of the five emphasis areas.

4.5.1 Data Acquisition, Processing, and Storage [Benedict, UNM]. The plan for acquisition, processing, and storage of the diverse data required by the project is based on a network-centric model in which data are transferred from multiple servers or sensors (either via push or pull, depending upon the requirements of the remote system) to the central data servers housed at UNM's Earth Data Analysis Center (EDAC). The general workflow for making required data available to project partners consists of transferring data from remote systems to central data servers at EDAC, processing data files for ingest into the data management and storage system designed for the project, and storing processed data.

The protocols used to acquire data will depend on the specific data provider, but are likely to include HTTP and FTP for file-based data (e.g., remote sensing files, GCM outputs, historic meteorological and climate summaries, geospatial data). Service-based data access will most likely be accomplished through the Simple Object Access Protocol requests (SOAP, *40*) such as those supported by the CUAHSI Hydrologic Information System (*41*) and the National Weather Service National Digital Forecast Database XML Web Service (*42*), or through Open Geospatial Consortium (OGC) Web Coverage Service calls (WCS, *43*) such as those supported by Unidata's NCEP model services (*44*).

Acquired data will be in a wide variety of formats: tabular (e.g., CSV, tab-delimited ASCII, spreadsheets), GIS (e.g., shapefiles, ArcGIS Coverages, GML files), imagery (e.g., GeoTIFF's, ECW, MrSID, ArcGrid Rasters, binary rasters), databases (e.g., Access, DBF), and in some occasions as non-data oriented documents (e.g., Word or PDF documents). These data will be processed into a uniform data model within the project, with a geospatially enabled relational data model (geodatabase,

PostgreSQL/PostGIS) providing the core storage medium for tabular, vector GIS, and database-based data. Imagery data will be stored in a file-based system with individual images registered into the geodatabase for streamlined management, access and processing.

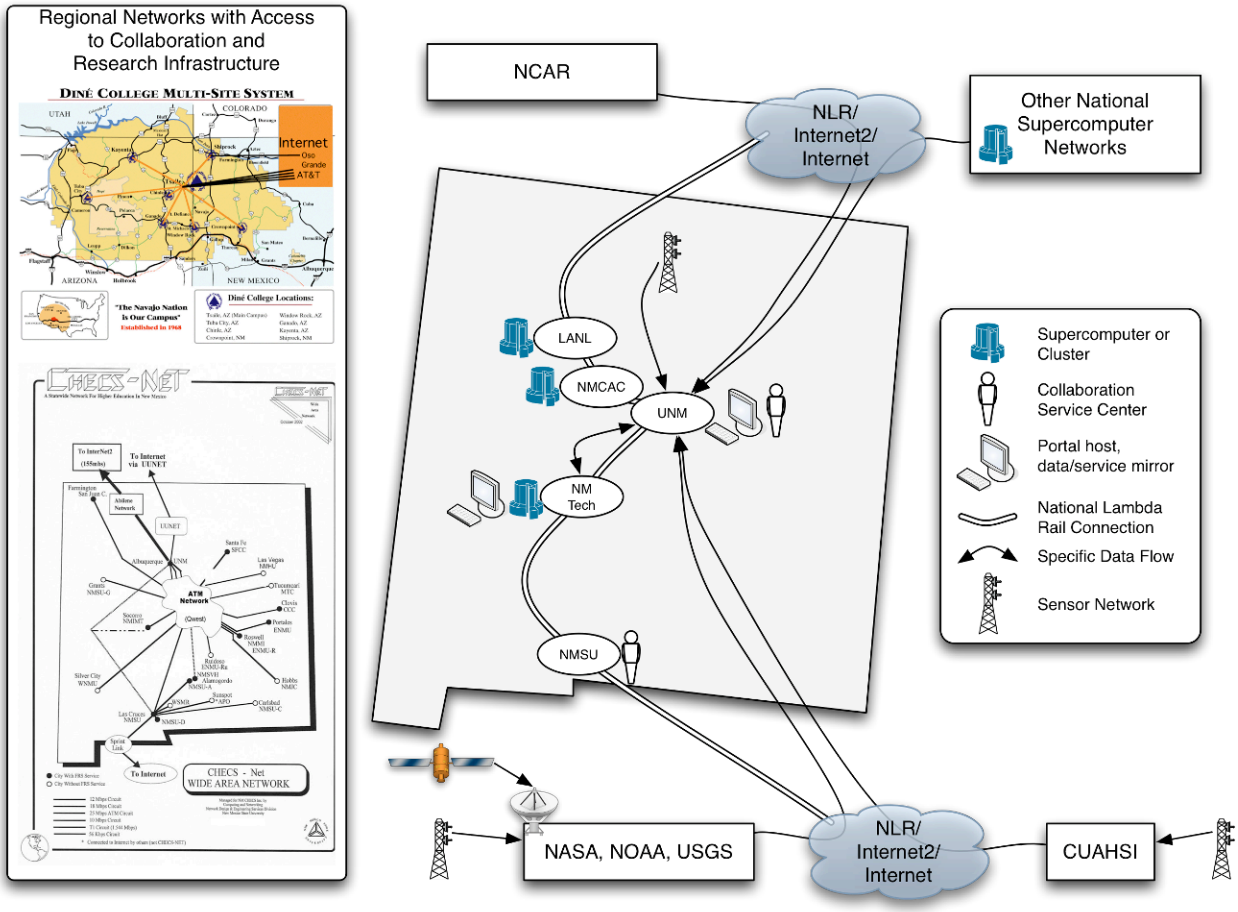


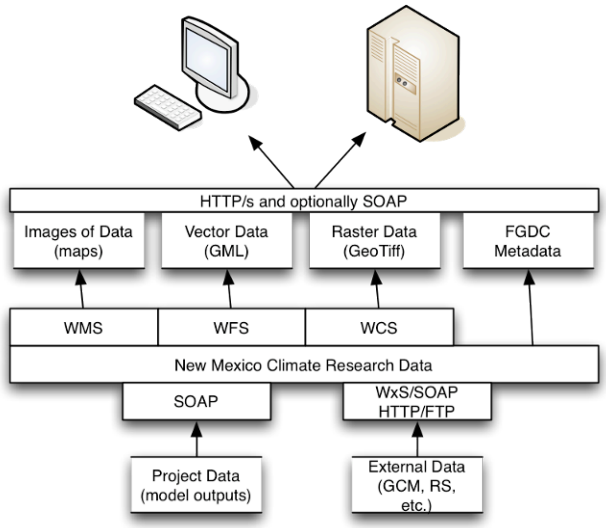
Figure 3. Existing and Planned CI Components and Key Data Flows.

4.5.2 High-Performance Computing [Galewsky, UNM; Ringler, LANL; Vivoni, NMT; Tidwell, SNL]. Detailed simulations of the headwater basins will be carried out with the recently developed parallel tRIBS model (*30*) using HPC infrastructure at NMT (a 64-node computer cluster purchased by RII2), LANL, and NMCAC. The combined capabilities are expected to meet the HPC requirements of this proposal. To optimize these resources, NMCAC will employ a part-time high-performance computing scientist to facilitate the modification and execution of hydrologic, regional climate, and economic models for the project on the NMCAC system. The investment in HPC by EPSCoR will be highly leveraged with significant support provided by the State of NM and the research universities.

4.5.3 Interoperability Through Open Standards [Benedict, UNM]. To provide maximum long-term flexibility and scalability of the data management and delivery systems developed here, a core set of open standards will be used for the delivery of data and information from the system. Specifically, existing W3C (HTTP, SOAP, XML, HTML, CSS), ECMA (Javascript), OGC (WMS [*45*], WFS [*46*], and WCS - collectively WxS), and FGDC (geospatial metadata, *47*) standards will provide the foundation for the data discovery and delivery system, developed analysis services, and developed client interfaces (including the project portal). The roles that the various standards play in the system are illustrated in Figure 4, where data ingest standards include SOAP (for internally generated data and external data) and WxS, HTTP, and FTP (for external data sources). Data delivery standards include WMS (for the delivery of maps), WFS (for the delivery of vector data and associated attributes encoded in GML [*48*]), WCS (for the delivery of imagery data), and the FGDC XML metadata standard for geospatial metadata. Client interfaces that provide access to the products served through these standard methods will be built using

the standard combination of HTML/CSS/Javascript for human interfaces (i.e. the project portal), and SOAP over HTTP for machine-to-machine communication. The OGC interfaces will be exposed for public access (as appropriate) for ad-hoc integration into other client environments such as Google Earth, uDIG (an open source desktop GIS application), and other COTS GIS applications (such as ArcGIS) that support data service access via OGC standard interfaces.

4.5.4 Collaboration Technologies [All NM Institutions]. The wide distribution of researchers, educational institutions, and decision-makers in NM requires strong remote collaboration resources for efficient multi-institution cooperative work. This need is recognized in the plan for development of major and minor NMCAC gateway centers at 40 institutions that will, among other capabilities, provide high-speed high-definition video conferencing (*4*), but this capability will only impact gateway centers, and only those users who have access to and knowledge of these fixed location resources. As a near-term complementary collaboration resource for the community of climate researchers, educators, and decision-makers in the state, a web-based synchronous/asynchronous collaboration capability is proposed for deployment as part of this project. This capability will enable web-based online meetings that include screen sharing, video and audio. The ability to record and replay these meetings will allow for asynchronous information delivery. Further asynchronous knowledge sharing will be enabled through capabilities within the project portal for document and data sharing, and threaded discussions.



4.5.5 NM Climate Change Web Portal [Benedict, UNM; Bathke, NMSU; Vivoni, NMT]. The proposed web portal will emulate the quick information access model for online content exemplified by other science portals like those developed by NCAR (*49*), CUAHSI (*50*), and the ESIP Federation's Earth Information Exchange (*51*). Each of the sites provides rapid access to its organization's diverse products: news, project/organization information, documents and publications, data and services. The portal will be developed with current web application models that make effective use of standards and modern browser support for those standards to deliver dynamic, responsive interfaces that remain operational over a range of bandwidth capabilities.

Figure 4. System Open Standards and Interfaces.

4.6 Human Infrastructure

Enhancing the human infrastructure in NM's academic and scientific research enterprise is central to NM EPSCoR. Three inter-related plans are tightly integrated with the Climate Change focus:

- Education Plan which includes: a program—The Summer Institute— focusing on middle school teacher professional development in northern NM; providing Undergraduate Research Opportunities for students at NM's regional non-PhD granting institutions; creating a Research Training Group Program that provides interdisciplinary training and develops modeling skills for MS/PhD students; developing a new class of academic leaders via Junior Faculty Leadership Training; and informing faculty throughout NM about funding opportunities via NSF Days and other NSF outreach activities.
- Outreach and Communication Plan which includes: a new Climate Change Exhibit (incorporating "Science on a Sphere") to reach 230,000 annual visitors; a Climate Change Seminar Series to bring nationally recognized experts to the large municipalities throughout the state; Science Cafés to communicate climate change science to citizens in rural northern NM; a Town Hall meeting to provide a forum for scientists, business leaders, and concerned citizens to build consensus and develop practical, actionable solutions; and a Climate Change Web Portal to provide easy access to news, project information, documents and publications, data and services.
- Diversity Plan which includes strategies for each RII component. Place-based science education will reach out to community members and provide teachers with locally relevant science for their

classrooms. Students with diverse backgrounds will be incorporated into all research opportunities through targeted recruitment. Faculty and staff will receive training on diversity inclusion in teaching and learning with a diverse student body. Diversity will be a theme of the program, addressed with workshops and through outside experts, and reflective study programs. Finally, we will partner with other diversity programs in NM and nationally.

Each plan is designed to target strategic areas where NM EPSCoR can have meaningful, significant, and measurable impact. The three plans were developed collaboratively to optimize cross-linkages and to provide specific performance metrics that are included in the Evaluation and Assessment Plan.

4.6.1 Challenges

4.6.1.1 Education. Many K-12 students in NM speak English as a second language and attend schools where teachers lack both scientific knowledge and effective teaching strategies. As a result, NM students often perform poorly on standardized tests and lack sufficient preparation for more advanced study in STEM fields. The 2005 National Assessment in Educational Progress ranks NM 49th in eighth grade mathematics and science achievement, with Hispanics and Native Americans ranking far below Caucasians in their performance. In 2004, the average composite ACT score for NM students was 41st in the nation; in math and science, the rankings were even lower—46th and 42nd respectively. Not surprisingly, NM students ranked 43rd among states in their readiness for higher education. This record of poor performance and lack of readiness to advance in STEM fields does little to promote science literacy in the adult population. As a result, many New Mexicans lack access to and the means to grasp scientific information critical to decisions about energy, water, and environmental policy.

Another set of challenges hinder education and research in NM colleges and universities. First, there have been few opportunities to provide undergraduate students at small colleges and regional universities with real research experiences using state-of-the-art instrumentation in the field and laboratory. Second, historical institutional barriers, including transfer-of-credit barriers, have hindered the undergraduate and graduate training programs at any one university from taking advantage of the expertise that exists at the other universities and the national labs. Third, junior faculty at NM colleges and universities are often ill-prepared for managing large research projects, communicating results of their research via diverse venues, educating students from diverse cultural and ethnic backgrounds, and assuming positions of leadership in their academic institutions. Fourth, faculty are often unaware of NSF funding opportunities and how best to seek funding from those sources, especially the large Foundation-wide and cross-disciplinary programs.

4.6.1.2 Outreach and Communication. NM has a rapidly growing population and is located in an extremely arid environment already subject to water shortages, fire, and forest die-off associated with prolonged and recurring droughts. Any exacerbation of these problems associated with changing climate regimes only enhances the need to communicate effectively with the State's citizenry. Specific challenges include: providing up-to-date and understandable information to citizens in the large municipalities which are located at long distances from each other; communicating climate change knowledge to citizens in rural communities; and providing access to recent and relevant data and information that can be used by scientists, educators, students, decision-makers, and the public.

4.6.1.3 Diversity. As a state rich in ethnic, cultural, linguistic, socio-economic, and geographic diversity, NM has already experienced many of the complex educational, cultural and economic changes that are increasing in other parts of the nation. The state has the highest percentage of people of Hispanic ancestry of any state (44%) as well as a large Native American population (9%), third behind Alaska and Oklahoma. Rapid population growth and mounting demand for scarce natural resources magnifies the need to include all New Mexicans in the development of the state's future.

4.6.2 The Opportunities

With its minority-as-majority population, NM has a unique opportunity and special responsibility to lead the nation in addressing the shortage in its S&T workforce by educating a new generation of STEM professionals more representative of the nation's growing minority population. At the same time, NM can develop a stronger STEM workforce and citizenry informed about climate change and its impact on natural resources and economic development.

To respond to these converging needs, NM EPSCoR will introduce a broad range of new learning and research experiences, both formal and informal, across educational levels and age groups with a

focus on Hispanic and Native American students and an emphasis on the research problems described in this proposal. NM EPSCoR will collaborate with schools, colleges, private and public organizations, and national laboratories to increase knowledge in scientific areas important to understanding the ramifications of climate change and to resolving associated energy, water, and environmental challenges.

NM EPSCoR views the state's diversity as both an asset and opportunity, and diversity is integral to the program. NM EPSCoR has infused its teaching, learning, research, and public service activities with a commitment to integrate the different ideas, talents, and cultures of its citizens. With a strong record of outreach to underrepresented groups and a broad network of partnerships, including six minority-serving institutions now participating in the program (UNM, NMSU, NMHU, SJC, Dine, SIPI), NM EPSCoR is positioned to serve the nation by becoming a laboratory for the development of effective programs that include and engage the state's diverse population in STEM research and learning activities. Through dissemination, successful programs can serve as models for replication in other states.

4.6.3 Education Plan

The principal objectives of the NM EPSCoR Education Plan are to enhance middle school teacher professional development in northern NM; engage students from community colleges and regional universities in meaningful field and laboratory climate change research; break down institutional barriers and provide inter-institutional and inter-disciplinary graduate training; develop our next generation of academic leaders; and enhance faculty competitiveness at NSF particularly with respect to large cross-cutting programs. The Education Plan describes five specific programs that will be implemented to achieve these goals. Complementary efforts to increase diversity are described in the Diversity Plan.

4.6.3.1 The Summer Institute for Teacher Professional Development [Bestelmeyer, CDNP; Brown, NMSU; Daniel, NM PED; Romero, SFIS]. This program will bring small teams of middle school teachers together with project scientists in a three-day Summer Institute held at the Valles Caldera National Preserve (VCNP) or the Santa Fe Indian School. The teachers will participate with project scientists in field activities, such as equipment deployment and data collection, and they will receive a set of prescriptive activities to take back to their classrooms. The teachers will return for two weekend workshops, one in the fall and one in the spring, to be held at the VCNP, the Sevilleta LTER, and the Jornada Basin LTER, with the spring workshop timed to coincide with snowmelt research in the northern NM study basins. The weekend workshops will strengthen the bonds within the teacher teams, provide updates and expand the scientific content delivered during the summer, and allow the teachers to share best practices for science teaching. NM EPSCoR education faculty and retired NM scientists, mathematicians, and engineers will provide mentoring and support during the school year.

The Summer Institute will host seven teacher teams each year in Years 1–4 with participants selected competitively. Teams will include three teachers (science, math and social studies) to encourage team teaching and the integration of science into geography and math. Teachers will receive a stipend, on-site housing, meal and travel allowance. Teachers completing the program will be eligible for two graduate credit hours towards professional development requirements, as mandated by the NM Three-Tiered Licensing legislation.

4.6.3.2 Undergraduate Research Opportunities Program (UROP) [Pullin, NMT; Parmenter, VCNP]. UROP will increase the exposure of students at non-PhD granting institutions in NM to high quality, relevant, hypothesis-driven research. Ten to fourteen undergraduates, recruited from institutions serving large populations of Hispanic and Native American students, will engage in four to nine weeks of summer research. Because the participants may not have sufficient preparation, the program will begin at NMT with a week of workshops and short courses on climate change, hydrology, and water quality, which will be taught by EPSCoR-supported faculty using a mixture of classroom, laboratory, and field experiences.

After completing the introductory coursework, participants will be placed with research mentors for the remainder of the program. Two students will remain at NMT and participate in an existing NSF-funded Research Experiences for Undergraduates (REU) program that focuses on environmental research. These two EPSCoR-funded students will engage in the hydrology or water quality research described in this proposal. Two additional students will work with NMSU project faculty to install and monitor equipment and interpret data at climate change study sites. The remaining six students will work with research mentors affiliated with any of the NM research universities involved in EPSCoR-funded activities at VCNP. The program will conclude with a statewide summer undergraduate environmental research conference at the Preserve where students from UROP, the NMT REU program, and other summer

environmental research endeavors within the state will be invited to present the results of their research to an audience of students, faculty, and research staff.

Participants will be selected competitively and receive a stipend, housing, meal and travel allowance, and they will be enrolled in a graded, four-credit independent study course at NMT. Non-traditional and/or tribal college students with children and/or family and tribal obligations, can choose to participate as teams in a shortened program structured to meet their needs.

4.6.3.3 Climate Change Research Training Group (RTG) [Todd Ringler, LANL]. A Climate Change RTG will be developed over the five-year project. The RTG represents a significant collaboration among the state's universities and LANL (with significant funding provided by LANL). The objectives of this activity are three-fold: (1) to promote transdisciplinary linkages across climatology, hydrology, and the socioeconomic sciences; (2) to create a cadre of scientists that are well-versed in the modeling tools and underlying frameworks used in the three scientific domains; and (3) to engage MS and PhD students and faculty from all degree granting institutions in the state as well as scientists from the national laboratories. At least two courses will serve as the initial base for the RTG. First, a Climate Change Graduate Seminar Course will be hosted at the LANL Institute for Advanced Studies (IAS) and broadcast to NM universities. The seminar course will be offered annually and will include EPSCoR scientists and recognized experts from within and outside the state that are engaged in climate, hydrology and socioeconomic studies related to climate change. Second, a five-week Graduate Summer School in Regional Climate Modeling will be offered in the summers of 2009 and 2011. LANL will provide housing, travel, and per diem for up to 10 students in each Summer School. The innovative school will include extensive hands-on training in running relevant climate, hydrologic, and economic models. These summer schools will bring together PhD students from NM institutions for an intensive study of regional climate modeling. Students will be exposed to the state-of-the-art in global climate modeling, regional climate downscaling, surface hydrological modeling, and economic modeling. The emphasis will be on how to connect these various modeling approaches in a physically realistic and computationally tractable manner.

4.6.3.4 Junior Faculty Leadership Training [Michener, EPSCoR State Office]. A week-long Junior Faculty Leadership Training workshop will be developed and held annually in early January. Training will focus on providing assistant professors from colleges and universities throughout the state with the skills they need to better communicate, manage large research projects, educate about and promote diversity, and run a research laboratory. One day will focus on communicating science to decision-makers and will be taught by a science lobbyist who has extensive experience on Capitol Hill and has taught an experiential day-long workshop for numerous professional societies. This daylong activity will include a session with one of NM's senators, congressional representatives, or one of their senior staffers. A second day will focus on communication, but from different perspectives—i.e., a print journalist, a television journalist, a documentary producer, and a professional facilitator. A third day will include sessions on diversity training and education featuring experts in informal science education, as well as K-12, undergraduate (e.g., REUs) and graduate education (e.g., IGERTs). The daylong session will include description of effective evaluation and assessment approaches by the NM EPSCoR's independent evaluator (Minnick). A fourth day will include lectures and hands-on activities associated with developing office and laboratory cyberinfrastructure (e.g., web development, metadata management, hardware alternatives). A fifth day will include lectures and exercises that focus on improving productivity (e.g., time management, personnel management, and project management).

4.6.3.5 NSF Days (Majkowski and Michener, EPSCoR State Office]. In collaboration with the NSF, NSF Days, a day and a half to two day workshop will be held during Year 2 of the project. Program Directors from all NSF Directorates will be invited to meet with faculty from all NM colleges and universities to discuss relevant funding opportunities and strategies for seeking funding from large Foundation-wide and cross-cutting programs.

4.6.4 Public Outreach and Communication Plan

The objective of NM EPSCoR Public Outreach and Communication is to create a citizenry that is informed about climate change and its impact on NM's natural resources. This objective will be achieved via five specific programs: a Climate Change Exhibit, a statewide Seminar Series, community-based Science Cafés, a Town Hall, and a Climate Change Web Portal. Programs were selected because they

optimally and cost-effectively reach a large and diverse range of the NM population, in both rural and urban areas.

New Mexico Museum of Natural History and Science (NMMNHS) will be the lead partner for Public Outreach and Communication. Uniquely positioned as the state's science museum, NMMNHS has 230,000 annual visitors to its Albuquerque facility and serves an additional 40,000 people through programs, both on-site and through outreach. NMMNHS also has capacity in communicating climate change issues to a public audience, currently leading the informal science programming for Polar-Palooza (2007-2009), and participating in the Association of Science and Technology Center's IGLO project in support of the International Polar Year.

4.6.4.1 Climate Change Exhibit – *Science on a Sphere.* To explain the local impacts of climate change on NM's most precious resource—water—NMMNHS will collaborate with NM EPSCoR to develop a climate change exhibit at the museum. The 1,000 ft^2 exhibit will feature a spherical display system showing global climate change data (based on NOAA's Science on a Sphere model), and panels or video displays of NM EPSCoR scientists demonstrating their research and explaining local impacts of climate change on NM water quality and supply. A guest curator of exhibit development will oversee the production of an effective and scientifically compelling exhibit.

4.6.4.2 Climate Change Seminar Series. This program, which targets public urban audiences, will feature NM EPSCoR scientists and nationally-recognized climate experts who will communicate current knowledge about the effects of climate change with a special focus on NM EPSCoR research and its implications for the state and world. Seminars will be held in Los Alamos/Santa Fe, Albuquerque, Socorro, and Las Cruces where the marketing for and media coverage of the series will enable NM EPSCoR to highlight its activities to the broader public. Both LANL and SNL are collaborating with NM EPSCoR to offer two to three speakers during the award period.

4.6.4.3 Science Café. Nearly one-third of NM's population lives in rural areas. To communicate information about NM EPSCoR's research in the area and the effects of climate change, Science Cafés will be held in public venues, such as restaurants, libraries, or schools in rural, northern NM where EPSCoR instruments are collecting local data. The cafés, to occur in Years 2-5, will include remarks by a science expert, followed by small group discussions. Participants in the Summer Institute (i.e., middle school teachers) will act as local disseminators and discussion leaders for these informal public forums.

4.6.4.4 Town Hall Meeting. In Year 4, NM EPSCoR in collaboration with New Mexico First, a nonprofit, nonpartisan organization that engages New Mexicans in public policy, will organize a two-day Town Hall meeting to provide a forum for scientists, economists, and business people to develop consensus on how to support businesses affected by a changing climate and decreased water supply. The meeting organizers will collaborate with NM EPSCoR researchers to develop a Background Research Paper for participants who will use it as a reference guide and learning tool. Participants will be recruited from NM citizen stakeholders, the corps of NM EPSCoR scientists and economists, and from business leaders identified by the NM SEC. During the Town Hall Meeting, participants will engage in highly structured small group discussions as well as plenary sessions and will seek consensus by the end of the two days. After the meeting, New Mexico First will produce a final report to use in presentations to community leaders, to advise policy-makers, and to inform the broader public of the Town Hall results.

4.6.4.5 NM Climate Change Web Portal. The Climate Change Web Portal (see Section 4.5.5) will provide a user-friendly single point of access to project products, services, and information.

4.6.5 Diversity Plan

Diversity is woven into the fabric of the New Mexico EPSCoR program–linking the teaching, learning, research, and public service in an integrated belief that our greatest strength is our ability to leverage the different ideas, talents, and cultures of NM citizens to help us all adapt to the challenges of climate change. But we know that without a plan our actions may not achieve the outcome we desire. NM EPSCoR will actively seek out and welcome people with diverse backgrounds to join our multidisciplinary, multicultural, and multigenerational team in an inclusive environment where ideas are freely exchanged, cultures and traditions are respected and personal and professional growth is encouraged.

A recent study (*52*) concluded that recruiting underrepresented students, reaching out to their families, offering students research opportunities, "…and then being thoughtful in the overall experience for students…" are…"ways to diversify the ecology profession now." Our Diversity Plan includes the following strategies that encompass these findings as well as our own experiences:

4.6.5.1 Placed based, locally relevant science education. The Summer Institutes and Science Cafés will take place in northern NM counties and their communities within the Rio Grande watersheds and tributaries monitored by NM EPSCoR research efforts. These counties include several pueblos and historically Spanish communities, most of which are rural and poor. Members of these communities are more likely to participate when locally relevant activities are located in their communities. Locally collected hydrological and climate data as well as global trends will be used to help families better understand the local effects of climate change and the adaptations required by these changes. The activities will focus on increasing understanding and respect between the scientific and traditional cultures. Teachers will learn how to integrate locally relevant content knowledge in mathematics, science, and social studies specific to climate change, and appropriate multicultural teaching and learning methods.

4.6.5.2 Strategic recruitment of students for research opportunities. Students will be selected from the applicant pool to maximize geographic, ethnic, cultural, physical and gender diversity in the URO and other student research programs. The URO Program will limit participants to undergraduates from the regional universities and state and tribal community colleges, all of which serve a majority Hispanic and Native American population. Students will be encouraged to pursue an advanced degree in STEM, and linkages and follow-up with faculty and support mentors at their home institution will be established. Recognizing that family is important to students from these backgrounds, the program will work with faculty mentors to equip students to help their families and communities understand climate change in their local community.

4.6.5.3 Diversity focus embedded throughout. NM EPSCoR will provide strategies for faculty on the inclusion of women, underrepresented groups and persons with disabilities in teaching, learning and research. Specifically, the program will help them understand cultural and physical differences that exist in their students, communities and the public. To ensure that diversity and inclusion are a priority, NM EPSCoR will hold diversity discussions, bring in experts, and develop workshops on diversity awareness and strategies to build an inclusive academic and social community. Program participants will be encouraged to use the self study provided by NSF, AACU, and other sponsored web sites offering self paced learning modules on diversity awareness and strategies for improving teaching, learning, and work environments for all persons. Honest, respectful communication between members of the scientific and local communities will be fostered so that each may learn from the other. Specific NM EPSCoR-sponsored conversations will include Science Cafés, New Mexico First Town Halls, the Climate Change Seminar Series, and the Junior Faculty Leadership Training.

4.6.5.4 Collaborate and network with existing programs focused on diversity. NM EPSCoR will network with other programs that encourage diversity, and seek their support, either through funding or expertise, to expand our knowledge base of successful strategies with diverse populations. These programs include: NSF AGEP, Louis Stokes AMP, ADVANCE, NIH Bridges, AISES, HACU, NM MESA, as well as programs in other EPSCoR states.

5. Project Management, Evaluation and Assessment, and Sustainability

5.1 Management Plan. The management and reporting structure, roles and responsibilities of individuals and groups, and succession plan are discussed below.

5.1.1 Management Structure. NM EPSCoR will use a broadly inclusive, team-based management structure that continues and strengthens the best practices developed in prior awards (Figure 5).

5.1.2 Council of University Presidents (CUP). The CUP, comprised of presidents of the three research and four regional universities, has overall responsibility for NM EPSCoR. The CUP oversees activities of NM SEC, appoints SEC members, promotes EPSCoR activities within the state, develops EPSCoR appropriations bills to secure additional funding from the state legislature, and approves by majority vote any changes to the bylaws. The CUP meets regularly throughout the year and will consider the EPSCoR portfolio as part of its agenda.

5.1.3 State EPSCoR Committee. The SEC serves as the primary governing body for NM EPSCoR. Members represent key constituencies in the state: the private sector (2), universities (9), national laboratories (2), the Legislature (3), Governor's Office (2), and economic development department (1); the NM EPSCoR PI/PD participates as an ex-officio member (see Appendix B). Functions of the SEC are to recommend the focus areas for NM EPSCoR; assist EPSCoR in enhancing the state's research infrastructure through partnerships with universities, national laboratories, and industry; promote research and collaboration among the NM universities; increase opportunities for K-graduate education and training in NM; help develop the workforce of scientists and engineers in the state; and promote NM economic development. The SEC meets for a half-day in February or March and in September for a full day before or after the Statewide EPSCoR meeting to consider agenda items in accordance with the duties assigned in its by-laws. At this latter meeting, members may break into sub-groups to address special challenges, such as barriers to institutional collaboration or strategies to move scientific knowledge into the policy arena. In appropriate years, the SEC will use the September meeting to select the overall focus and specific proposals for full development in the EPSCoR RII proposal to NSF.

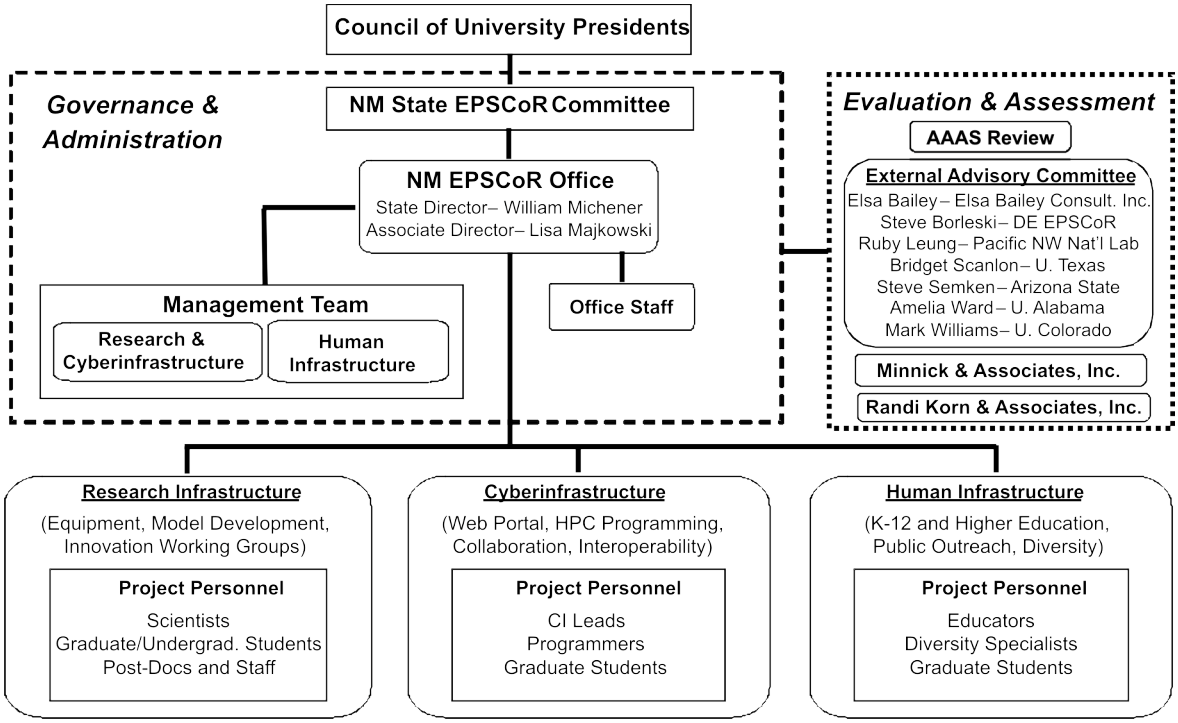


Figure 5. NM EPSCoR Management Structure (see Appendix B for more detail).

5.1.4 AAAS Review. AAAS will be contracted to hold one strategic planning in Year 1 that includes a AAAS facilitator, two scientists and one educator. Formal reviews by experts in climate change, socioeconomics, formal and informal education, and project administration will occur in Years 3 and 4. Reports of their deliberations and recommendations will be presented to the MT, SEC, EAC, and NSF.

5.1.5 External Advisory Committee (EAC). The EAC is comprised of seven nationally-recognized experts in research infrastructure, climate change science, socioeconomics, education (formal and informal science), evaluation and assessment, and project management. The EAC will meet annually for 1.5 days to advise the Project Director and make recommendations on how to improve research, education, diversity, evaluation and assessment, and management programs. A report of their deliberations and recommendations will be made available to the AAAS, MT, SEC, and NSF.

5.1.6 Management Team (MT). The MT will provide overall direction and guidance to NM EPSCoR. Its members represent the major program areas and partner universities, national laboratories, and affiliated institutions. The MT reviews applications for resources and makes recommendations for funding to the Project Director. Other MT responsibilities are to insure the integration and coordinated implementation of each focal area, identify implementation problems and recommend solutions, identify emerging

opportunities, and assist in collecting data and information for project reports. To effectively use member expertise, the MT is organized into smaller teams corresponding to: (1) research infrastructure and cyberinfrastructure; and (2) education; outreach, communications, and diversity. The smaller teams will meet monthly (via phone or video-conferencing) and the entire MT meets quarterly. Three of the MT meetings will be two-hour conference calls to review progress in each program area, and one will be a day-long meeting to review proposals and set goals for the following year.

5.1.7 NM EPSCoR Office Team. The Project Director (PD) (William Michener) serves as Principal Investigator (PI) on the NSF award and provides day-to-day management of the program from the NM EPSCoR Office at UNM, which serves as the fiduciary agent and issues subcontracts to other participating institutions. Michener has experience and training in managing complex science projects. He has served as PI on several large ($8-12.5M), multi-institutional, and multi-investigator projects since 2001, and he has been Senior Project Director for the NSF $50M Biocomplexity Program (1999-2000). To ensure that all EPSCoR funds are used to further the aims of the program, the PD will have final responsibility for reprogramming and reallocating these resources. The PD will report to the SEC, represent NM EPSCoR to federal agencies, and be responsible for submitting required reports to NSF and for preparing reports to CUP and SEC upon request. The PD will schedule and participate in MT meetings, and will work closely with the research infrastructure and cyberinfrastructure team.

The Associate Director (AD) (Lisa Majkowski) will report to and assist the PD with overall project management and communications with state and federal agencies. She had six years experience with financial reporting/planning and personnel management as a corporate executive with a large, multi-national corporation prior to returning in 2003 to academia where she has administered NMT EPSCoR funds, coordinated several other large projects in the geosciences, and managed related education programs. The AD will participate in MT meetings and work closely with the education, outreach and communications, and diversity team. The AD will supervise the NM EPSCoR Office staff, coordinate project budgets and prepare financial reports, and oversee the collection of baseline and achievement data for EPSCoR initiatives.

Minnick & Associates, Inc., an independent evaluation firm, will assist the NM EPSCoR Office in collecting and reporting evaluation and assessment information. Two additional independent firms—Randi Korn & Associates, Inc. and Elsa Bailey Consulting, Inc.—will evaluate informal science education activities. Funding is included for annual contractual work to routinely upgrade the evaluation and assessment database. A Project Administrator (PA) (Angela Gonzalez) is responsible for daily office operations, business transactions, and financial accounting associated with the overall NSF award. Additional staff includes a 0.5 FTE website manager and two students (one journalism student who will serve as a part-time public relations specialist, and one student who inputs and verifies data for the evaluation database and works closely with Minnick & Associates, Inc.).

5.1.8 Succession Plan. When the PD position becomes vacant, the NM EPSCoR by-laws require the SEC to conduct an open search for a successor. Within a few years, participants in the Junior Faculty Leadership Training program will be eligible to apply. Other vacancies among EPSCoR Office personnel are filled in accordance with UNM business procedures. Major program areas will have at least two leaders (to be determined), either of whom could lead the initiative alone or with others in the area if necessary.

5.2 Evaluation and Assessment Plan

5.2.1 Independent Evaluation and Assessment Team. Minnick & Associates, Inc. has experience as the program evaluator for numerous NSF funded projects and other endeavors including: (1) multiple NSF Rural Systemic Initiative programs (UCAN RSI, Texas RSI, Delta RSI, NNM RSI and NM Tribal RSI); (2) projects funded by the Collaborative for Excellence in Teacher Preparation (NM CETP and Texas CETP); (3) the NM EPSCoR; (4) the NM Tribal ITEST and a CDC Bridges to the Futures project at San Juan College (which introduces minority community college students to careers in biomedical research); (5) the NM PED in implementing school and district Annual Yearly Progress (AYP) reporting, as well as district and state report cards; and (6) the Santa Fe Indian School and a consortium of BIA schools to improve their data analysis capability.

The Senior Research Associate and owner, Kirk Minnick, has extensive evaluation, research, data processing, psychometrics, and statistical skills. He received his Masters in Educational Research and Statistics from UNM in 1982 and is a member of the American Educational Research Association and

National Council on Educational Measurement. The evaluation team will also include a research assistant, Kimball Sekaquaptewa, and a project assistant.

5.2.2 The Evaluation and Assessment Process. As a new EPSCoR jurisdiction, NM struggled to manage the amount of data and information generated to evaluate and assess its statewide program. NM EPSCoR has since adapted Idaho EPSCoR's web-based data collection system, which now provides NM with the ability to track goals, objectives, milestones, publications, awards and participants in the kind of interdisciplinary effort described in this proposal. The different RII3 components require different levels of assessment and evaluation, but data will be the basis for all evaluation activities.

Formative and summative evaluation will be used throughout the project and will be based on both quantitative and qualitative data collected using appropriate methodologies. Assessment and evaluation will match the type of data collected with a particular objective to determine the degree of progress toward stated outcomes. Formative evaluation will focus on project implementation, including: the policies and procedures that enable or hinder the research faculty to conduct their research; the public outreach group being able to produce an exhibit for the public that is understandable and scientifically correct; and the cyberinfrastructure group being inclusive of affected parties in the state. The formative evaluation will result in fewer missteps, better adherence to timeline, and a more successful implementation.

An evaluation team member will be assigned to each RII3 effort to gather and analyze data and report the efforts of their team. Resources allocated to collect assessment data in an area will be matched to the proposed level of effort in that area. Secondary data sources will be used as often as possible to minimize assessment efforts required by research faculty and others. When appropriate, the evaluation team will design data collection mechanisms that can be sustained and incorporated into existing institutional efforts. Specific evaluation and assessment plans are discussed below.

During RII2, NM EPSCoR used logic models and found them extremely helpful for monitoring progress and identifying gaps in activities. According to the W.K. Kellogg Foundation (*53*), "a logic model is a systematic and visual way to present and share your understanding of the relationship among the resources you have to operate your program, the activities you plan, and the changes you hope to achieve." To build capacity in the EPSCoR teams, logic models will be developed for all of the infrastructure components in RII3 during the first three months of the project. The management team and the evaluator will review the logic models before they are presented at the first meetings of the EAC and the AAAS Review. Input from the EAC and AAAS Reviews will be used to refine EPSCoR logic models.

Project milestones for key project components are illustrated in Figure 6. Each component strategy will be mapped to a logic model that will explicitly identify the problem being addressed, the audience, the activities, expected outputs, competitiveness goal and metrics to be used. A sample logic model for the Public Outreach and Communication plan strategies is included in Appendix C. The evaluation team will assess whether each strategy is: (1) being <u>implemented</u> as planned, and if not, why not; (2) <u>progressing</u> towards the stated goals and metrics; and (3) producing <u>summative</u> value by addressing the stated competitiveness goal.

Some of the evaluation questions to be addressed during the implementation evaluation will include: whether the strategy is being conducted as planned; if appropriate staff are being hired or faculty being involved; and whether the activities being conducted are those that were proposed. The progress evaluation questions begin to assess whether the strategy is resulting in progress towards its stated goals and whether some activities are working better than others. During these formative assessments, it will be critical to keep the strategy leaders informed of the evaluation results so that strategies can be modified as needed. Since a formal report may delay timely sharing of findings, information will be conveyed to strategy and project leaders through email and during project team meetings. A more formal presentation of the formative results and actions taken by strategy leaders will be provided to the EAC, AAAS, and other external review teams.

The progress and summative evaluation will be based on metrics agreed upon with each of the strategy leaders and in consultation with the project director. These metrics will include tracking outputs such as the number and type of awards, proposals submitted, publications, citations, faculty recognition awards and other metrics of faculty production. Additional tracking metrics will include the diversity of the undergraduate and graduate students involved in research and the number of teachers, students and general public reached through the outreach and communication strategies. Outcome metrics will include the assessment of teacher inclusion of scientific research in their classroom, UROP and RTG students becoming science majors and, hopefully, graduates. Although public outreach metrics will be more

difficult to address, we will measure behavioral attitudes and changes in perception of museum goers and track requests to the EPSCoR office for research presentations from community groups and newspaper coverage of activities. Dr. Bailey, who has expertise in evaluating informal science and serves on the EAC, will be a great asset in this effort. Randi Korn, an independent museum exhibit planner headquartered in Alexandria, Virginia, will conduct a baseline assessment of public perception of climate change that will serve as an initial evaluation tool and help to design displays and programs.

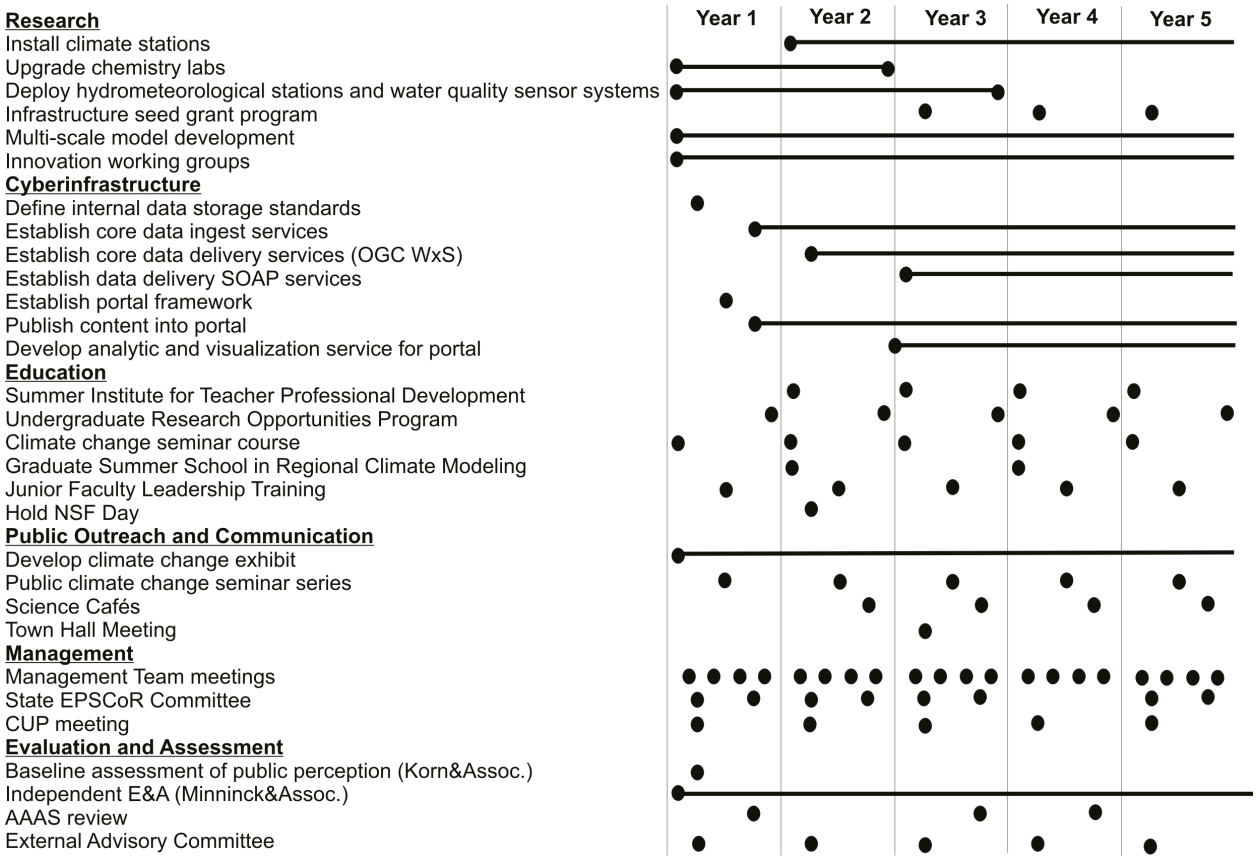


Figure 6. NM EPSCoR Project Milestones.

Another level of evaluation will occur at the macro or state level and will track the status of state educational, scientific and economic enterprises through the use of secondary data sources, such as NSF's WebCASPAR, NAEP and other sources that collect and publish data at the state level. These metrics will include the number of collaborative proposals between institutions generated by EPSCoR investment, research dollars generated, investments by state, workforce and educational diversity, and other metrics to be extracted from the secondary data sources and compared longitudinally as well as to the U.S. and similar states. Finally, we will continue to track the outcomes and impacts from RII1 and RII2, many of which can take 5-10 years to occur.

5.3 Sustainability Plan. NM EPSCoR research infrastructure, cyberinfrastructure, and human infrastructure improvement programs were strategically chosen to optimize both their immediate impact on enhancing competitiveness of NM scientists and educators as well as their ability to be sustained well beyond the lifetime of the RII3 award (see Appendix D for letters of collaboration, financial support, and commitments to long-term sustainability from Governor Richardson, the Science Advisor to the Governor, the Secretary of Higher Education, the NM Public Education Department, the NM Office of the State Engineer, the UNM Vice President for Research, LANL Institute for Advanced Studies, USDA-NRCS, SAHRA S&T Center, and others). New climate monitoring, SNOTEL, and SCAN stations will be incorporated into operational climate monitoring networks. Agreements with the USDA-NRCS are in place to maintain and operate the stations beyond the proposed award period. NM EPSCoR research infrastructure improvements and the results generated will increase the competitiveness of NM

scientists to a broad array of NSF Programs in the GEO, BIO, SBE, and EHR Directorates, as well as NASA, USDA, DOE, and other federal initiatives.

Legislative funding received by the Math and Science Bureau of the PED for teacher professional development is allocated using guidelines that match well with the structure of the proposed EPSCoR K-12 education program, including required collaborations between K-12 schools and institutions of higher education. Furthermore, the 2007 NM Legislature passed legislation creating a Cyber Academy (SB209) to provide distance learning courses to middle and high school students. The NM EPSCoR project will collaborate in developing the Cyber Academy and will provide real-time access to data collected through the research component of this grant in forms that are meaningful for students and that allow teachers to use these data for instruction that aligns with the NM Standards for Science and Mathematics in both online and real time courses. Aligning the EPSCoR educational plan with research-based statewide efforts increases the probability that the EPSCoR-initiated program will receive continued funding through future legislative allocations.

EPSCoR funding will enable NMMNHS to pilot several innovative public programs, and depending on the outcome of the programs, we will pursue alternative funding options to sustain the effort. If the climate change exhibition proves to be an effective means of communicating with the public, we will apply for NSF ISE funding for a smaller, traveling exhibition that would be deployed to local libraries and small museums across the state. After EPSCoR, the statewide seminar series will continue as part of the NMMNHS Voice in Science lecture series. Experience with conducting Science Cafés and Public Forums will enable NMMNHS to gain valuable insight into convening public groups to discuss specific issues, and increase capacity for conducting similar such programs in the future.

The service-oriented cyberinfrastructure architecture embodied in the system illustrated in Figures 3 and 4 will help sustain capabilities developed by RII3. In particular, the standard interfaces used to connect the project tiers vastly simplifies the modification and evolution of different elements (i.e. expanding data sources added to the system, the deployment of new analytic services or client interfaces) without having to make major changes throughout the system. This flexibility maximizes the potential to leverage RII3 investments into future projects and proposals. In addition, the project will maintain a working relationship with NMCAC, the state-level supercomputing resource supported by the state's on-going commitment to its success, and data products and model outputs generated for this project will be integrated, as appropriate, for public distribution through the NM Resource Geographic Information System (*54*) as a secondary distribution and access point for project products and services.

6. Conclusion: Intellectual Merit and Broader Impacts

6.1 Intellectual Merit. Climate changes affect all natural environments. In NM, climate change impacts are profound—altering processes associated with the water supply, which sustains the state's economy and determines to a great extent the quality of life. Proposed research infrastructure will enable scientists to observe processes at the watershed scale and to understand the effects of climate change on water supply and sources in arid regions. Moreover, NM EPSCoR strategically invests in building the human infrastructure required for coupled atmosphere-land surface-hydrology-socioeconomic modeling (e.g., predicting the impact of climate and hydrologic change on NM's centuries-old acequias). Such capability is needed for meaningful forecasting and decision support. New cyberinfrastructure will support multi-scale modeling and rapid delivery of climate change data and information to scientists, educators, decision-makers, and the public. NM EPSCoR targets strategic areas where there can be meaningful, significant, and measurable impact. For example, innovative education activities focus on teacher professional development, undergraduate and graduate training, and junior faculty leadership training.

6.2 Broader Impacts. NM EPSCoR research foci are of global scientific and societal importance. The investment in research, cyberinfrastructure, and human infrastructure will establish NM as a laboratory for climate change research and a model for science-based public policy that can broadly serve science and society. Education, outreach, and diversity programs will create a citizenry that is informed about climate change and its impact on natural resources. Programs targeting a large and diverse range of the NM population, in both rural and urban areas, include: (1) a new 3-D Climate Change Exhibit reaching 230,000 annual visitors; (2) a Climate Change Seminar Series; (3) Science Cafés to communicate climate change science to citizens in rural northern NM; (4) a NM First Town Hall meeting to provide a forum for scientists, business leaders, and concerned citizens to build consensus and develop solutions; and (5) a Climate Change Web Portal to provide easy public access to data and information. Innovative elements

of these programs are designed to optimally and cost-effectively reach a large and diverse range of the NM population in both rural and urban areas and, when successful, will serve as a national model.