4.1. CURRENT STATUS OF R&D IN MONTANA

4.1.A. State of Montana Science Infrastructure – Layout and Limitations:

Montana is a large state with a relatively small population that continues to successfully build its science and engineering infrastructure. As a result, of all EPSCoR states, Montana has demonstrated the largest improvement in terms of its percentage of NSF funding (Fig. 1). This has been accomplished by systematic implementation of a plan that emphasizes science and engineering excellence on topics that are both regionally relevant and nationally significant. The principal EPSCoR investments have been utilized to recruit and retain highly competitive faculty, develop innovative graduate and undergraduate research programs and build state-of-the art instrumentation facilities. The Montana University System (MUS) consists of two Ph.D.-granting institutions: Montana State University (MSU) and The University of Montana (UM), nine affiliated colleges (including Montana Tech with its M.S. programs), and three community colleges. It also works closely with seven tribal colleges in Montana. The total undergraduate and graduate student population in the MUS is 34,245 and 2,945, respectively, and is growing.

Montana faces significant challenges in the development of its science infrastructure and overall competitiveness. It is difficult for the individual universities to assemble the critical mass of scientists and engineers necessary to compete at a national level in many areas where an increasingly interdisciplinary approach is required. Moreover, the considerable distances between campuses reduce opportunities for communication and collaboration. However, through EPSCoR-initiated programs, a few select research clusters have overcome this barrier and now compete at the top research tier. The Montana EPSCoR (MtEPSCoR) program has learned that the most successful research clusters take advantage of unique resources (Yellowstone National Park, Glacier National Park, Flathead Lake, rivers, mountains, wildlife), address critical problems (drought, fossil fuel extraction), and create opportunities (biofilms, extremophiles, bioinspired nanotechnology) unique to Montana. Still, assembling the critical mass of scientists in strategic areas remains one of the largest barriers to the success of science and technology (S&T) in the state.

4.1.B. Montana Research & Development Enterprise – The MUS as Catalyst:

The MUS is the primary R&D engine for the state, and EPSCoR has been a central catalyst in the support of research and development (R&D) as evidenced by the significant growth in Montana’s R&D expenditures (Fig. 2). From 1990 to 2010, the MUS R&D expenditures have increased from $28.0M to $178M, exceeding the growth rate of most state public universities. MSU’s increased research activity has resulted in a Carnegie Tier I classification, and UM and...
Montana Tech have consistently risen in academic rankings. The Governor’s Office, the State Legislature and the Board of Regents of Higher Education are committed to further strategic investments that will enhance the state’s R&D enterprise. They understand the need to expand the state’s S&T talent pool through education and creation of a statewide research engine. The recently completed ten-year Science and Technology Plan (2009-2018) for Montana directs the MUS to “build partnerships with communities, businesses, and other educational entities to help align science education and research with pressing social and economic challenges.” The state’s scientific vision will be achieved with the collective skills of current and future generations. This proposal is central to the S&T priorities of the state, the MUS and Montana’s citizens (see State letters of support in Supplementary Documentation).

This EPSCoR application continues the tradition of innovative programs statewide in the sciences, engineering, and education. This proposal is focused on bridging microbiology, ecology, and climate science to understand the dynamics and linkages of processes that govern ecosystem response to climate change. As described in this proposal, we will create innovative science to address climate-change issues that are both regionally relevant and nationally significant. We propose to build on past EPSCoR investments, acquire faculty in targeted scientific areas, establish shared research facilities and build an integrated education, diversity and outreach program under a new model, a single statewide umbrella institute called the MUS Consortium for Ecosystem Research and Education (MUCERE). MIEPSCoR is committed to addressing one of the critical scientific and social issues facing the nation: the challenge of sustaining healthy ecosystems and economic growth in the face of projected climate change.

4.1.C. Strategic RII Areas and State Relevance: An ecosystems-centric climate-change theme has regional relevance, national significance, and takes advantage of the unique resources and scientific strengths found in Montana. This target was developed through a competitive statewide process to address the goals of the state’s Science and Technology Plan, contributions of national scientific experts and the selection of the State EPSCoR Committee. This proposal has the input, backing and endorsement of a broad range of stakeholders including the Governor’s Office, the Legislature, the MUS, the State EPSCoR Committee, neighboring states, federal and state partners, and non-governmental organizations (see letters of support in Supplementary Documentation). The goal is to create a fully integrated research, education, and outreach program that will be competitive for large center and program funding, such as NSF NEON and STCs. The vision of this proposal is to serve as a new model for statewide integration of research, education, and outreach in Montana and the nation.

4.1.D. Faculty Hires & Graduate Students as Key Infrastructure Building: The overall project approach is to invest in people, principally new faculty and students, as the key infrastructure building activity. There will also be investments in major instrumentation (e.g. isotope mass spectrometry facility). The MIEPSCoR program has demonstrated its ability to recruit nationally competitive faculty members, who collectively have transformed science and education in the state. We will continue these efforts to build critical mass within the MUS by focusing on climate-change research and education. The ultimate goal is to catalyze a scientific cultural change in the state and take Montana to the next level of national competitiveness in ecosystem sciences.

4.1.E. Lessons Learned from 2010 Competition: Last year’s MTEPSCoR RII proposal was not funded. As a result, the program underwent extensive internal and external review to increase effectiveness and competitiveness. The following changes have been implemented (see Management Plan for details): 1) moving the PD position to the Commissioner for Higher Education Office to elevate its stature and to reduce inter-campus issues, 2) having the PD report directly to the Deputy Commissioner, and 3) integrating planning and oversight through the Montana University System Science and Technology Advisory Committee (MUSSTAC) EPSCoR Governing Board.

4.2. RESULTS FROM PRIOR RII SUPPORT

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<thead>
<tr>
<th>KEY POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accomplishment Summary</td>
</tr>
<tr>
<td>Highlight Table</td>
</tr>
<tr>
<td>Challenges</td>
</tr>
</tbody>
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Montana has significantly developed its research capacity through strategic focus of EPSCoR resources, hiring quality faculty, and increasing overall faculty productivity. The MUS continues its upward trend during the current award. All proposed milestones of the 2007-10 Track I RII award have been met or exceeded as shown in Table 1. As an EPSCoR-funded state since
1980, Montana has used each new RII project to build upon the solid success of its predecessor, adhering to a long-term strategic plan that emphasizes Montana-centric, nationally relevant science, closely-aligned staff, strategic planning, excellent advisory committees, and strong institutional commitment and support. In Montana, EPSCoR has become more than a support mechanism for focused faculty hires; it has developed into a fulcrum for institutional leveraging. For example, a MUS faculty hire who receives EPSCoR support immediately gains additional institutional funds to build competitive startup packages. Over the past four award periods (1998-2010), Montana has made 117 NSF EPSCoR-supported, tenure-track faculty hires. MiEPSCoR also has an excellent track record of retaining faculty recruited to the MUS, with over 89% of those hired in the last twelve years still in their positions. These new faculty hires have been a driving force behind winning competitive individual and multi-investigator awards, as well as start-ups of new technology-based companies, all leading to an increased R&D base in the state. This growth in academic R&D has led to over 50 small and medium tech-based businesses. The return on EPSCoR investments in new hires has been more than 50 to 1, and EPSCoR faculty hires have garnered over $100M in external funding. EPSCoR has made a difference in Montana, seeding research centers that have been sustained after EPSCoR funding, institutionalizing workforce development programs, and fostering economic development in the form of SBIR Phase 0 and Phase 1 awards to small businesses associated with the MUS. Clearly, the investment of EPSCoR dollars has enhanced the profile and competitiveness of Montana science and technology in the nation.

4.2.A. Progress on the 2007-10 Research Core Focus Areas:
MiEPSCoR has a successful track record of achieving its proposed goals and sustaining investments in faculty and research cores with Centers grants and programs funded by the University system (Table 1). The 2007-2010 RII focused on two research areas: Hydrogen and the Environment (HE), and Large River Ecosystems (LRE). The current proposal builds on the foundation of RII investments, primarily in LRE. Both research focus areas of the 07-10 Track I award exceeded projected milestones, with 23 new faculty hires and over $55M in grant applications. This research productivity has not been possible without workforce development to support it, and at UM and MSU over 65 graduate students from 2007-2010 have been supported by MiEPSCoR. MiEPSCoR also has a strong relationship with Montana’s tribal colleges. EPSCoR funds have supported new faculty hires in STEM fields at tribal colleges, supported research projects by undergraduates and tribal college faculty, and encouraged collaborations between research faculty at the universities and tribal colleges. During the 07-10 Track I award, 13 tribal college faculty members were involved in research projects and directed

| TABLE 1: Milestones from RII Awards since 2001 (2 prior) and the most recent Track I Award |
|--------------------------------------------------------|--------------------------------------------------------|
| **Program**                                            | **2001-2007 Actual (Proposed)** | **Total Current RII Award 2007-10 Actual (Proposed)** |
| Faculty Hires                                         | 64 (40)                                | 23 (12)                                      |
| Graduate Student Stipends                              | 165 (98)                               | 67 (38)                                      |
| Undergraduate Research Stipends                        | 972 (862)                              | 354 (340)                                    |
| Single Investigator Awards                             | 256                                    | 45                                           |
| Multi-Investigator Awards                              | 48                                     | 15                                           |
| Scientific Conferences Organized                       | 37                                     | 11                                           |
| Community Outreach Partners                            | 33                                     | 24                                           |
| Native American Pre-college Students                   | 183                                    | 60                                           |

81 tribal college students. MiEPSCoR provided partial support to the Montana Technology Innovation Partnership (MTIP), an initiative of the Montana Department of Commerce to promote technology commercialization in Montana. MTIP was deemed strong enough for inclusion in the 2010 Coalition of economic-development programs funded by the State Legislature at a time when many other programs were reduced or eliminated. In 2009, 10 Montana companies received 15 Phase I awards totaling $1,438,824 and 10 Phase II awards totaling $5,032,167, for a combined total of 25 awards with a $6,470,991 value.

4.2.B. Challenges: Increasing the diversity of the S&T workforce in Montana continues to be a challenge. Efforts in recruiting underrepresented groups to STEM faculty positions are intense across the country, and competitive salary and start-up packages are requisite to attract highly qualified and sought after candidates. Successful recruitment and retention of Native Americans, Montana’s largest minority group
(7% of total population), as well as other underrepresented groups into STEM disciplines requires long-term intensive programs with multiple interactions at both student and faculty levels. Although the MUS has realized some success in the recruitment and retention of women and underrepresented groups, additional effort and funding are needed to increase the diversity of students and faculty.

4.3. RESEARCH PROGRAM ($10.8M; 45% OF GRANT)

**KEY POINTS**

| Overview | Contemporary ecosystem science is constrained by several unresolved puzzles (so-called "black boxes"), wherein vital processes are poorly understood and inadequately studied. As a result, our ability to predict ecosystem response to future climate change is limited. One such black box is the role of microbial communities in controlling C and N cycling within an ecosystem, in that general inputs and outputs are usually considered, but the microbial community dynamics are ignored. Likewise, microbial ecologists tend to focus on microbial community composition without consideration of the impact on and feedback from larger-scale ecosystem processes or patterns. Another black box concerns the lack of understanding of how broadscale changes in climate affect the hierarchy of smaller-scale physical and biotic processes that shape ecosystem dynamics at the landscape level. These black boxes are especially problematic because climate change, manifesting as warming and drying in Montana, is exerting significant consequences on regional dynamics through its impact on water availability, biodiversity, nutrient cycling, and disturbance regimes. Thus, while it is clear that climate change interacts with ecosystems over a variety of spatial and temporal scales, critical aspects of the interactions that determine ecosystem structure and function are still not understood. |

This MI-EPSCoR research program is aimed at bridging three scientific fields—microbial ecology, systems ecology, and climatology—by assembling interdisciplinary teams of scientists and students to investigate the dynamics of and linkages among multi-scale processes that govern ecosystem responses to climate change (Fig. 3). The following overarching questions motivate our research agenda:

**How do the physical and biotic processes, operating at multiple scales, interact to govern ecosystem structure and function, and how are these interactions directly and indirectly influenced by climate change?**

In the big picture, climate change will alter how hydrology, energy balance, and ecosystem composition and structure combine to influence local and large-scale controls. We will address these questions by examining hypotheses within three focal areas: 1) feedbacks between microbial dynamics and ecosystem processes; 2) linkages among landscape patterns and ecosystem processes; and 3) impacts of multi-scale interactions and specific vulnerabilities of species and ecosystems to climate change. Our examination requires integration of microbial, terrestrial, aquatic, and climate sciences, which have traditionally operated in isolation. MI-EPSCoR proposes a research agenda to link these fields through interdisciplinary experimental, observation, and modeling activities. To accomplish this, we will recruit new faculty, build multi-institutional interdisciplinary teams that include undergraduates and graduate students, invest in critical instrumentation, and create a competitive grants program. MtCERE, a new statewide institute run from the MUS Office, will coordinate all research, education activities, workforce development, external engagement, outreach, and participation in the programs outlined in this proposal.
Mountain regions occupy about one fourth of the Earth’s land surface and are a source of goods and services for about half of humanity. Montana’s landscapes include alpine and forested mountain ranges with expansive intermountain valleys of grassland, scrubland, and riparian woodland in the western half of the state and a dramatic transition from the Rocky Mountains to the High Plains in the eastern half (Fig. 4). The strong elevational gradients allow novel approaches to detect and analyze how species and their ecosystems respond to climate variability because: 1) heterogeneity in meteorological, hydrological, and ecological conditions provides highly contrasting ecosystems in close proximity for analysis; 2) boundaries along these elevational gradients are highly sensitive indicators of environmental change; 3) high-elevation areas are included in national parks and other protected environments allowing environmental impacts of climate change to be studied in the absence of confounding human influences; and 4) mountain regions like those in Montana are distributed all over the globe, from the equator to the poles and from maritime to continental climates. Thus, the proposed research for Montana has worldwide application to the understanding of climate effects on mountain ecosystems.

MtEPSCoR and Environmental Science within the MUS

MtEPSCoR will leverage current research strengths and build critical capacity to gain insights about ecosystem dynamics and climate-change impacts. The MUS will invest in climate-change research for five reasons: 1) Montana’s benchmark ecosystems, Crown of the Continent, High Plains, Upper Missouri, and Greater Yellowstone, (Fig. 4) have been studied extensively, providing a foundation upon which to build the proposed research. 2) MUS scientists are already engaged in nationally and internationally recognized climate-change initiatives and research, including: i) participation in the International Panel on Global Change, the international Mountain Research Initiative, and other National Academy of Sciences, United Nations, and International Geosphere Biosphere (IGBP) programs and committees; ii) NASA research to develop algorithms for satellite sensors to record global responses; iii) research internationally and in the western U.S. on past and future climate-change effects (e.g., NSF PIRE and numerous NSF MO, ATOL, and FIBR grants to study microbial ecology in natural settings; and iv) ongoing climate-change partnerships with federal, state, industry, and non-profit organizations relevant to the Montana and the Interior West. 3) EPSCoR and the MUS have made significant investments in faculty and resources in natural resources, ecology, earth sciences, environmental engineering, and computational sciences in the last 10 years, providing a strong foundation for the research outlined in this proposal. Currently, over 70 faculty members define their scholarly interests as focused on the environment within the MUS (see Supplementary Documentation for faculty list and expertise). Past EPSCoR-supported faculty hires bring new strengths in climate-change science, snow science, watershed modeling, biogeochemistry, land-atmosphere interactions, stream and river ecology, plant and animal ecology, genomics, remote sensing and sensor development, environmental statistics and modeling, environmental microbiology, Native American studies, and environmental education. 4) The MUS is committed to initiating programs that combine ecology, geosciences, hydrology, mathematics and social-economic science. Campus efforts will also benefit from the statewide institute outlined in this proposal. 5) The translation of regional climate-change science into decision support tools, workforce development, and outreach is a high priority for the nation, the MUS, federal and state agencies, other EPSCoR states, non-governmental...
organizations, and local communities. Coordination of MiEPSCoR activities through MtCERE, a statewide institute, will ensure timely delivery of scientific information, education, and training in this critical area.

**MtEPSCoR Research Agenda: Addressing three Focus Areas in Ecosystem Science**

Understanding the impacts of climate change requires development and testing of models that link climate, hydrologic cycling, ecosystem structure and composition, and energy balances from microbial to landscape scales to explain ecosystem processes \(^3\)\(^\text{32}\). Such models must focus on large-scale climate drivers, complex interactions among physical and biological variables at the landscape-scale, and the interconnectedness of nutrients, water, and energy and microbial dynamics at the local scale. For example, soil water and potential evapo-transpiration, which are controlled by seasonal and annual variations in precipitation and energy inputs occurring at a local scale, strongly influence land-atmosphere exchange processes of net ecosystem exchange (e.g., carbon balance of photosynthesis and respiration) at a larger scale. This variability influences actual evapo-transpiration and associated nutrient dynamics that control bioproduction via plant-animal interactions at all scales. These multi-scale relationships are further illustrated in the tight linkages between water cycling and nutrient uptake/release throughout the terrestrial and aquatic landscape. Soil microbial processing is an important component linking land-atmosphere exchange and river export via local nutrient cycling. Soil-water and ground-water redistribution, surface energy balances, and substrate at the landscape scale are key controls of 1) microbial activity (e.g., decomposition, respiration, and denitrification) and plant activity, 2) vertical transport (diffusion) and release of trace gasses, and 3) horizontal transport of dissolved constituents to other portions of the terrestrial and aquatic system. Landscape-level stores are a function of vegetation and microbial dynamics as well as climate-mediated water transport, downslope accumulation, and metabolic processes. Delivery of water and nutrients to stream networks depends on landscape hydrology and biogeochemical mobilization largely driven by landscape structure and climate \(^3\)\(^3\). The amount, composition, and timing of water and nutrients delivered to fluvial networks affect their ecological structure and their export to downstream and atmospheric environments. Superimposed on these interactions, ecological legacies (i.e., ecosystem phenomena operating on times scales ranging from minutes to millennia) influence structure and composition of the present ecosystem in significant but not necessarily obvious ways \(^3\)\(^4\)\(^3\)\(^5\).

MiEPSCoR will advance knowledge through an iterative observational, experimental, and modeling framework that utilizes four benchmark ecosystems in Montana (Fig. 4). Research will leverage on NEON activities in the Northern Rockies domain and we will work closely with U.S. Department of the Interior’s Regional Climate Science Centers, Landscape Conservation Cooperatives, NOAA Regional Integrated Science & Assessments, and Yellowstone and Glacier National Park science agendas. We will receive climate data from the NOAA Pacific Northwest Climate Decision Support Consortium, led by Oregon State University, and from the USGS Northern Rocky Mountain Science Center. Finally, we will coordinate with the research activities underway in neighboring (mostly EPSCoR) states, sharing a common focus on climate change in the western U.S. (see Supplementary Documentation.)

**Overall Resource Needs** (Table 2 and Budget Justification): Twelve new faculty positions to support the research foci are identified below. Interdisciplinary research in all three foci will be supported though a competitive grants program across MUS institutions. Team development will be further facilitated by participation of graduate students, using an IGERT-like model that will extend across the MUS for the first time (45 Ph.D. graduate students are anticipated). Undergraduates will become directly involved in interdisciplinary research teams, including students from tribal and community colleges (400 undergraduate internships will be available).

Stable-isotope geochemistry, a fundamental tool in environmental sciences, is used to study past climate, geochemical and biochemical interactions, and biological processes \(^3\)\(^6\). Use of stable isotopes is essential in addressing research questions in all foci. MSU growth in biogeochemistry, microbial ecology, and food-web ecology has led to a widely shared need for stable-isotopic techniques. A staffed MUS stable isotope mass spectrometry (SIMS) facility, the only one in Montana, will serve researchers across the MUS. Also required are the installation and augmentation of plot- and landscape-level measurements across environmental gradients to obtain fundamental, contextualizing data that will ultimately link observations and models. Budget allocations for the entire program are provided in Budget Table B.
Focus 1: Examining feedbacks between microbial metabolism and ecosystem processes (Team leaders—H.M. Valett, T. McDermott—see Biosketches)

H1: Microbial responses to climate change will strongly influence the form, abundance, and net exchange of C and N within ecosystems, because climate drivers influence how different microbial assemblages combine metabolic pathways to optimize net free energy yield and maximize growth rates.

Soil respiration (flux of carbon dioxide (CO₂) from soils to atmosphere) plays a substantive role in atmospheric CO₂ dynamics, as it constitutes a flux 10 times greater than that from fossil fuel combustion. Although CO₂ is arguably the most important of the long-lived greenhouse gasses, nitrous oxide (N₂O) and methane (CH₄) are also radiatively active and contribute significantly to global warming. Each of these gasses has microbial and anthropogenic sources, and their atmospheric concentrations have increased dramatically during the industrial era. Despite this, quantification and prediction of first-order controls on ecosystem trace gas fluxes (including CO₂, N₂O, and CH₄) to the atmosphere and export of C and N via upland hydrologic and stream network transport remain poorly understood.

The processes responsible for mediating C/N cycling and transport are largely microbiological, photosynthetic, and hydrological. Water availability is a primary control on soil organic matter (SOM) production, photosynthesis, decomposition, and SOM mineralization, and provides the linkage between the landscape and the aquatic stream network. Complex interactions among numerous watershed variables stress the interconnectedness of C, water, and energy. Difficulties in coupling water and C/N cycling (including land–atmosphere and terrestrial–aquatic transfers and internal cycling) abound due to limited spatial and temporal sampling, complexities in measuring and modeling heterogeneous systems, analytical limitations, and a lack of communication and integration across disciplines.

The natural movement of trace gasses between the Earth’s surface and the atmosphere is large, and their heterogeneity and controls through space and time are poorly understood. Similarly, the accumulation, cycling, and mobilization of dissolved and particulate C and N within terrestrial systems and their connectivity and delivery to aquatic ecosystems are central ecosystem processes, but they elude prediction within and across landscapes. At the site scale, microbial communities respond to spatial and temporal variability of water, organic substrate, nutrients, and surface energy. At the landscape scale, these variables are governed by topography, morphology, geology, vegetation and soil characteristics, hydraulics, and climate, which, in turn, determine microbial community structure and the (re)distribution of water and associated solutes over time. The full implication of spatial heterogeneity is not understood, nor is the convolution and integration of site-specific microbially- and hydrologically-mediated processes at the landscape level. Fundamental science is needed to link microbial metabolism to ecosystem processes (e.g., C/N cycling and transport) to landscape pattern. Likewise, information on hydrology, ecological legacies, and surface energy is necessary to link ecosystem processes with microbial-level metabolism and nutrient cycling. As described below, we will focus on four watersheds within our benchark ecosystems (Flathead River-Lake watershed in the Crown of the Continent Ecosystem, Gallatin River and Tenderfoot Creek watersheds in the Upper Missouri Ecosystem; the Lamar River watershed in the Greater Yellowstone Ecosystem, and Missouri River watershed in the High Plains Ecosystem; Fig. 4). These watersheds encompass broad hydrologic and elevational gradients and most are in locations where long-term hydrologic, C/N, and ecological data exist. Our research consists of observation across environmental gradients, experimental manipulations (in field and laboratory), metagenomics and transcriptomics, novel analytical and isotopic techniques, numerical simulation modeling (to test system-level conceptualizations), and perhaps most importantly, bringing disparate disciplines together in field, laboratory, and computational settings.

Tasks:

1. **Measure microbial contributions in soil and water to C/N cycling and transport.** We will establish C/N fluxes in benchmark terrestrial and aquatic settings at already instrumented watersheds. Methods for assessing C/N transformations are well established for soil and sediment samples and can be adjusted to scales appropriate for measures of microbial composition or landscape fluxes. For the C balance, we will focus on measuring rates of C fixation and release (i.e., CO₂ and O₂ budgets) along with the production, consumption, and emission of CH₄ as measured by chamber and eddy-covariance techniques at new and existing field sites. The rates of biotic (enzyme-catalyzed) transformations are sensitive to the substrate isotopic composition, while abiotic reactions are far less so. Thus, the biotic or abiotic “histories” of
carbon, nitrogen, oxygen, and other light atoms that form simple compounds in soil and aqueous environments and the atmosphere are encoded in the ratios of stable nitrogen, carbon, and oxygen isotopes. These ratios document their transformation through biochemical or abiotic reactions. Very accurate (± 0.01%) measurements in isotopic composition can be achieved by high sensitivity isotope ratio mass spectrometry. Rates of carbon and nitrogen fixation and denitrification will be related to structural measures (e.g., C:N ratio, oxidation-reduction potential, organic matter content) of the environment and to the composition and character of microbial communities. Assays of N fixation (acetylene reduction) will document rates of N inputs, and isotopic techniques will be employed to measure rates of denitrification to assess biogeochemical processes without the usual shortcomings associated with substrate enrichment. These techniques rely on adding heavy forms of nitrate (i.e., $^{15}$NO$_3$) to samples or experimental plots and quantifying the accumulation of $^{15}$N as nitrogenous gas products (i.e., N$_2$O, N$_2$).

2. **Determine temporal variability in microbial contributions to soil and water C/N cycling and transport over three to five years.** In combination with determining C/N fluxes outlined above, barcoded 16S 454-Titanium pyrosequencing will be combined with microarray platforms to monitor changes in microbial community structure and gene expression related to C/N metabolism. C/N metabolism genes will be identified by metagenomic analysis at comparative sites in the four watersheds. In combination with microbial C/N genes available in public databases, a C/N metabolism gene microarray will be designed and manufactured. Total microbial RNA will be isolated from terrestrial and aquatic study sites, and C/N gene expression will be temporally and spatially monitored using microarray platforms and verified with selective qPCR analysis. Microbial C/N metabolic activity will be compared with experimentally measured soil C/N fixation and respiration rates.

3. **Measure microbial response under natural disturbance (e.g., drought, fire, insect infestation, flood and imposed disturbance through experimental manipulations).** The consequences of altered disturbance regimes depends on geography, ecosystem structure and composition, and system feedbacks. We will examine how disturbances have affected C/N cycling and transport. For example, we will use established microarray platforms to compare C/N gene expression and outputs in microbial communities associated with soils, with and without forest insect infestations. In aquatic and terrestrial study sites, field plot experiments will be established that vary temperature, moisture, and available energy sources. In these experiments, we will examine the effects of C/N cycling and transport using measurements of direct C/N species and gene expression outlined above.

4. **Examine the flux and transformation of C/N through the system in three dimensions and in relation to microbial processing of organic C/N.** To add specific information to ecosystem models that incorporate microbial dynamics (focus 3), we will conduct a matrix of environmental change treatments (e.g., temperature, moisture, and C/N availability) in forest and grassland plots in the four watersheds. Dependent variables will include microbial composition and C/N mass balance, including N fixation rates and CO$_2$ and CH$_4$ releases. We will couple field work and experiments in both terrestrial and aquatic microcosms using soils or sediments collected at sites. We will also investigate initial changes in microbial structure and biogeochemical function and the influences of climate drivers on microbial C/N processing through experimentation and modeling. Results from these studies will improve our understanding of how ecosystem function is tied to microbial drivers.

**Resources needed:** To support Focus 1 research, critical expertise will be provided by new faculty hires, including an isotope biogeochemist, microbial biochemist, and microbial systems ecologist. In addition, Ph.D.-level staff scientists with expertise in stable-isotope chemistry, computational metagenomic-genomics, and environmental analysis are needed to support the proposed laboratory and computational activities.

**Focus 2: Linking changes in landscape pattern to ecosystem process (Team leaders: B. McGlynn, A. Wilcox)**

**H2:** Ecosystem function relates to landscape position because landscape-scale linkages between geomorphic, hydrologic, and energetic processes explain variation in biodiversity, bioproductivity, and biogeochemical patterns.
Spatial heterogeneity in ecosystem composition and structure and associated plant-animal interactions is the manifestation of site-specific geographic attributes and ecosystem processes interacting with broader controls exerted by climate, hydrology, energy balances, and ecological legacy. Understanding these linkages requires environmental data at a spatial and temporal resolution appropriate for the ecosystem processes of interest, as well as experimentation and modeling to examine pattern and process feedbacks. This will require data about past and present climate, hydrology, and geomorphic conditions, aquatic and terrestrial biodiversity, productivity, and disturbance regimes. Our four benchmark ecosystems span mesic settings in the west to drier areas in the east, and have steep elevation gradients from mountain tops to river valleys, even on the High Plains. We will research the linkages between landscape patterns and ecosystem processes by examining the importance of ecological legacies in shaping ecosystem structure and composition, improving our ability to portray climate change at regional and landscape scales, linking field and model approaches, and developing and testing models that examine the role of geomorphic, hydrologic, and climate processes.

Tasks:

1. **Understand the importance of ecological legacies on ecosystem processes, as measured by changes in ecosystem structure and composition.** Our benchmark ecosystems are vulnerable to temperature, water, and surface-energy balance changes, as well as indirect effects such as fire, drought, disease, and non-native species invasions. The particular response will depend in part on ecosystem structure and composition, which is site specific and influenced by historical legacies. Currently, there is no comprehensive compilation of current and past biotic and environmental data, nor are individual data sets fully vetted for quality control. We will develop the best possible time-series in our benchmark ecosystems, pertaining to the physical system (e.g., climate, snowpack, isotopic, stream and ground water measurements, glacial mass balance data, and mass-wasting and geomorphic changes), biotic components (e.g., vegetation inventory data, dendroecological data, phenology, genetic and species inventories) disturbance regimes (e.g., area burned measurements, fire severity and post-fire regeneration data; mountain pine beetle and blister rust inventories; avalanche frequency; flood frequencies; nonnative species invasions, human activities (e.g., historical land-cover changes, land-use and demographic changes).Datasets will span time scales of minutes in the case of continually streaming sensor arrays, to millennia in the case of paleodata, with varying spatial and temporal resolution.

2. **Create scenarios of past, present, and future landscape-level climate change by improving current down-scaled GCM and regional climate model output.** Our regional climate products come from downscaled global climate models, regional climate models, and NOAA NCEP reanalysis data, provided by USGS and NOAA. The environmental data for watershed-specific, high-resolution climate information include daily surface meteorology (historical conditions) spatially interpolated from existing weather station networks (~1km spatial resolution) and used for regional calibration, optimization and spatial downscaling of coarser scale (~0.5 degree resolution) global model reanalysis data based surface meteorology fields and relatively fine-scale numerical weather models (e.g., WRF; ~5 km resolution). Because of the relatively strong control that regional surface topography and vegetation density exerts on environmental lapse rates, modeled and historical climate data can be further downscaled for finer-scale (e.g. <1 km resolution) environmental assessments. Model simulations using statistical relations established from local surface weather station network measurements can also be verified and constrained by relatively fine-scale satellite remote sensing observations (e.g. NASA EOS MODIS based measures of land surface temperature, LST and vegetation density, NDVI).

3. **Link field and modeling approaches to fill gaps in atmospheric-terrestrial-aquatic interfaces and spatial representations of C, N, and water cycling within montane watersheds.** This work will build upon current research at the Tenderfoot Creek Experimental Forest (TCEF), a mountainous watershed with existing infrastructure including soil gas wells, soil respiration chambers, wells, groundwater piezometers, eddy-flux towers, SNOTEL sites, and stream gauges. In addition, we have 12 years of hydrology data, well-characterized vegetation coverage, IKONOS data, and ALSM bare earth topography data at ~1 m resolution that also contain substantial vegetation information including QUICKBIRD and leaf-level quantification of encroaching mountain pine beetle disturbance. This density of infrastructure, existing data, and data acquisition potential for C, N, and H2O cycle research is not widely available, especially in complex terrain. Beyond the infrastructure, TCEF is an ideal setting for the proposed research because of
its strong seasonality, elevation gradients, full range of slope, aspect, and topographic convergence/divergence; and its similarity to high-elevation mountain landscapes, which play an important role in the North American C cycle. We will integrate techniques and disciplines across microbial, plot, flux-tower footprint, landscape, and watershed scales at TCEF to understand the relationships between fine-scale process dynamics (Focus 1) and watershed ecosystem responses. Specifically, we will use observations on microbial communities and metabolic processes to inform observations of soil air CO₂ and surface efflux throughout the watershed, refine and apply a distributed simulation model of watershed respiration, net ecosystem exchange, and hydrology to determine the strength of connections between terrestrial C and N reservoirs and aquatic systems, link existing flux tower data to ground-based measurements and stream dynamics, and use remote sensing and simulation modeling to extrapolate fluxes across the larger landscapes and watersheds.

4. **Refine and develop process models for comparison of aquatic-terrestrial linkages and vegetation-climate interactions.** Montana’s large alluvial floodplains and mountain stream networks provide valuable settings to examine terrestrial-aquatic dynamics because these habitats and associated food webs reflect complex interactions between snow-driven river flows, water exchange between river and floodplain aquifers, seasonally varying sediment and nutrient transport and storage, and vegetation dynamics. These ecosystem processes produce a shifting habitat mosaic that fosters high biodiversity. We will test our understanding of ecosystem processes (water, head, C/N flux) documented and modeled at Nyack Floodplain Research Natural Area by new studies on the Gallatin River and TCEF (Upper Missouri Ecosystem); the Lamar River (Greater Yellowstone Ecosystem); and Missouri Breaks (High Plains). At each site, we will examine the consequences of changing flows, temperatures, and upland stream hydrologic connectivity on the coupling of aquatic and terrestrial components. New data will be acquired from installation of new sensor arrays and augmentation of existing ones (supported by EPSCoR Track 2) to allow better understanding of primary controls on system response. These observations will help parameterize the Nyack model and other relevant models.

Flathead Lake has been studied since 1899, and continuous data since 1977 describe the trophic structure and water, heat, sediment and nutrient (C, N, and P) flux monthly or more frequently. Declining snowpack will reduce nutrient loading, potentially reducing primary productivity and altering energy transfers in lake food webs. Climate warming is also increasing the volume of the epilimnion (warm waters above the thermocline) that provide refuge for some organisms from lake trout, mysid shrimps, and other introduced cold-water predators that dominate many western deep lakes. Introduced species have caused a 30% increase in primary production that is exacerbated by gradually increasing N loading. To better assess the trajectory of limnology and terrestrial change, sediment cores will be collected and analyzed from several locations in Flathead Lake. Multi-proxy analysis of radiocarbon-dated cores and calibration with present-day limnologic and terrestrial observations will be used to reconstruct models that describe temporal evolution of water source and evaporation rates, limnology and limnobiota, vegetation and disturbance regimes, and carbon and nitrogen inputs and storage. We will use species and community response models to interpret past changes in limnobiota and vegetation with respect to climate change and disturbance, and we will develop a mechanistic model to link climate variability, nutrient loading and state changes, as well as trophic structuring.

Novel communities, those compositionally unlike present ones, were widespread in the past as a result of the individualistic response of species to former no-analogue climates. Modern observations point to several terrestrial species and communities in our benchmark ecosystems that seem especially vulnerable to climate change. High-elevation forest (e.g., whitebark pine) and alpine communities are suffering from higher temperatures, reduced snowpack, wildland fires, insect outbreaks, non-native pathogens; and limited land area for expansion. Wetlands and riparian ecosystems are also threatened by climate change and land use. They support many of the region’s rare plant, avian, and amphibian species. We will use our understanding of past species-habitat relations and draw on existing and newly acquired paleodata to infer potential responses to future climate and land-use changes. This task requires new modeling approaches and better quantification of uncertainties. Ecological niche models are at least partially parameterized from modern observations; however, we are unable to accurately predict ecological responses to novel conditions. We will develop a unified database of ecological measurements to characterize the past and current distributions of species and communities and thereby expand our understanding of fundamental niche space. In this regard, we draw upon historical paleodata,
as well as large, spatially explicit, and newly available datasets of vegetation. Examples include: a vegetation survey of the Beartooth Plateau from low-elevation grassland to alpine zone \(^{92}\); detailed vegetation samples of Yellowstone and Glacier National parks \(^{93}\), and samples from the National Vegetation Classification database\(^{94}\). We will develop empirical species-specific autecological models that combine climate-change response with substrate specificity and test them against historical and modern observations. We will examine how species-level uncertainties in modeling accumulate at the community level owing to ecological interactions. We will employ data-driven models, such as generalized additive models (GAMs) \(^{95}^{96}^{97}\) and random forests (CART) models \(^{98,99}\).

Resources needed: Faculty positions needed in support of Focus 2 include a watershed geomorphologist to examine landscape evolution through field and modeling approaches, a hydroclimatologist and bioclimatologist to assess past and present connections between climatic, hydrologic and ecologic variation, a biophysical limnologist and a plant physiological ecologist to increase mechanistic understanding, and a vegetation modeler to explore species, community, and biome response to environmental change.

**Focus 3: Understanding impacts of climate-change through ecosystem modeling and vulnerability assessment. (Lead Scientists: S. Running, G. Poole)**

H3: Connectivity among ecosystems through hydrology, structure and composition and energy balance mediates the timing and magnitude of nutrient availability and creates localized transient opportunities for high rates of microbial activity, plant growth and consumer (food web) response.

Integration of the findings in Foci 1 and 2 is the goal of Focus 3, that is, determining how microbial processes drive larger-scale ecosystem function and how, inversely, landscape-scale dynamics govern site-specific processes, including microbial activity. Simply stated, we want to predict consequences of climate change across temporal and spatial scales in a dynamic ecosystem. How vulnerable are organisms to climate change? Can they adapt? Gaining a holistic understanding requires us to test “system-level hypotheses,” integrating mechanistic representations of microbial processes into ecosystem models (e.g. Biome BGC, CENTURY, TOPS, Ecosystem Demography)\(^{100}^{101}^{102}^{103}^{104}^{105}\). Our work in Focus 3 will examine the sensitivity and thresholds of species and communities, disturbance interactions, environmental dynamics, and ecosystem/biome responses (Fig. 5). We will develop novel soil processing algorithms for ecosystem modeling platforms using insights gained from Task 4 of Focus 1 and incorporate results from Task 3 of Focus 2 into hindcasting and forecasting scenarios used to assess the vulnerability of mountain ecosystems to climate change. Because existing models do not incorporate mechanistic representations of microbial metabolic processes, they fail to represent how the structure of microbial assemblages varies across space and time – in response to climate or land-use change – or how this structure influences ecosystem processes within heterogeneous landscapes. To integrate the microbial dynamics into existing modeling approaches, parameters describing rates of flux among pools of soil C/N will be replaced with simple but mechanistic representations of microbial response to changes in water availability, temperature, and availability of electron donors/acceptors under different climate scenarios. By integrating microbial metabolism information into applicable ecosystem models, we will: 1) simulate key linkages between terrestrial and aquatic ecosystems (on the assumption that microbial metabolism occurring along hydrologic flow paths mediates the hydrologic transport nutrients and carbon from hillslopes to river networks in significant quantities); and 2) forecast the effects of climate and land-use change on species distributions, community composition, ecosystem biogeochemistry. Data-model fusion \(^{106}\) will proceed from systems-level hypothesis generation to observation and experimentation to model conceptualization and falsification and back to new hypotheses. Nonstationarity in many of our processes necessitates considering system evolution as part of system behavior, rather than an exception \(^{107}^{33}\). Thus, Focus 3 is necessary for basic ecosystem understanding.
Climate changes expected over the next century will likely overwhelm the resilience of ecosystems and lead to major disruptions of species distributions and ecosystem processes. Such potential changes present a profound challenge for natural resource managers everywhere. Ecological forecasts, regional vulnerability assessments, and scenario modeling require understanding ecosystem processes from microbial to landscape scales, projecting changes in biotic distributions, identifying vital thresholds of change, and developing tools to convert information into actionable planning efforts. Federal and state natural resource mandates emphasize the need for ecosystem function information, strengthened observational systems, model-based projections, species-habitat linkages, risk assessment, and adaptive management plans. Outcomes of the proposed MtEPSCoR research program hold great promise for providing critical information and developing strategies to manage impacts of climate change on the region. In collaboration with federal and state agencies and non-governmental organizations, we will draw on the data and models emerging from Focus 3 to assess vulnerability of ecosystems and species to climate and land-use change, and evaluate the consequences of different management options. Ecological forecasts, vulnerability assessment, and scenario modeling will be embedded within an overarching framework for climate-change adaptation that involves identifying conservation targets, assessing vulnerability, articulating management targets; and implementing management options. Thus, Focus 3 is critical for regional assessments of where projected changes in ecosystem processes will yield dramatic, potentially irreversible, and nonstationary (no-historical analogue) ecological consequences.

Tasks:

1. *Integrate the novel microbial modeling algorithms into the ecosystem models developed above to simulate the interactive effects of climate, vegetation, land-use and disturbance on ecosystem structure and function, from microbial to landscape scale.* We will develop mechanistic modeling algorithms that represent microbial C/N processing dynamics in both unsaturated and saturated soils to be incorporated into ecosystem models including hydrology, energy balance, and biogeochemistry. Computational simulations will employ local and regional adaptations of global vegetation, landscape fire, and invasive species models to explore past and present ecological interactions at different spatial scales, as well as projected responses under future climate scenarios. Plant-animal interactions and population dynamics will be examined by refining current species population models to include no-analogue climate conditions in the future, changes in disturbance intensity and frequency, and substrate specificity to predict species distribution and abundance. Model results will be tested against current conditions and past...
environmental reconstructions. We will utilize resource selection analysis, and habitat/environmental models to test species behavior, resource, and habitat selection under different climate-change scenarios. We will conduct sensitivity experiments driven by existing environmental records and vegetation data sets to evaluate the relative merits and limitations of these approaches, and test model capabilities to recreate past and present communities. A particular focus of these activities will be environmental gradients and associated habitat distributions and change velocities under past, present, and projected future climate conditions in relation to species capacities for migration and adaptation.

2. **Assess ecosystem vulnerability focusing on the Great Northern Landscape Conservation Cooperative (GNLCC), which encompasses a wide range of federal and state-managed lands in Montana and the interior Northwest, including many underserved communities** (See Supplementary Documentation). As part of this task, we propose to: quantify temporal trends in ecological resources under projected future climate and land-use scenarios drawing on new scientific understanding; assess the vulnerability of ecosystems and illustrative species to climate and land-use change by quantifying exposure, sensitivity, adaptive capacity, and uncertainty in our benchmark ecosystems; evaluate management options for the most vulnerable ecosystems and species within these regions while considering social-economic consequences; design multi-scale management and stakeholder approaches for vulnerable ecosystems and species to illustrate adaptation strategies under climate and land-use change; and facilitate technology transfer of data, methods, and models to state and federal agencies and other regional partners to allow the decision support tools to be applied more broadly.

**Resources needed:** We seek faculty positions in resource policy and resource economics to work with scientists and managers to develop and evaluate adaptation strategies to support science-based vulnerability assessments, and in environmental science communication to disseminate the findings of Task 3 to a broad array of stakeholders.

**Overall Research Coordination - MUS Consortium for Environmental Research and Education (MtCERE)**

This ambitious research effort will be undertaken through MtCERE, a new statewide institute that will operate under the auspices of the Commissioner of Higher Education. MtCERE will coordinate research, education, diversity, workforce development, economic development, external engagement, assessment and evaluation, and cyberinfrastructure objectives across the MUS (See Management Plan). MtCERE co-directors will work closely with Focus leaders in decisions concerning research direction and investments, faculty hires, graduate and undergraduate education, outreach, and partnerships. MtCERE research responsibilities also include seminar series, workshops and regional meetings, science communication, and partnership facilitation.

**TABLE 2: Research Resource Needs, Outputs and Outcomes**

<table>
<thead>
<tr>
<th>Program Initiative</th>
<th>Year</th>
<th>Outputs</th>
<th>Outcomes</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Science/Research</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Recruit and hire new faculty</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Establish SIMS facility</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Research Team grants, seminars, annual conference</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Examine feedbacks between microbial metabolism and ecosystem processes. <em>Focus 1</em></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Study changes in landscape pattern to ecosystem process. <em>Focus 2</em></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Focus 3</td>
<td>Understand impacts of climate change through modeling and vulnerability assessment.</td>
<td>Assessments of vulnerability of ecosystem process and biodiversity to future climate change</td>
<td>Capacity to develop methods and models to decision makers and stakeholders</td>
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<td>----------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
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<tr>
<td></td>
<td>Recruit and train graduate students (total of 45)</td>
<td>Integrated graduate student training</td>
<td>Interdisciplinary training of next generation of scientists;</td>
</tr>
<tr>
<td></td>
<td>Statewide program for undergraduate research (400)</td>
<td>80/year undergraduates participating research</td>
<td></td>
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<tr>
<td>Diversity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enhance Native American graduate education opps.</td>
<td>Four Ph.D. students graduated</td>
<td>Broadly diverse workforce in STEM disciplines</td>
</tr>
<tr>
<td></td>
<td>Implement accelerated math program at Tribal Colleges</td>
<td>Enhanced math instruction at tribal colleges</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Research program on climate change at each tribal college</td>
<td>All tribal colleges engaged in collaborative research</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Women faculty recruitment and enhancement program</td>
<td>6 female faculty hires; retention of women faculty in STEM disciplines</td>
<td>More diverse STEM professoriate in MUS system</td>
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<tr>
<td>Workforce Development</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>K-12 teacher development</td>
<td>Courses in climate-change science; 2 online graduate courses; online resources</td>
<td>National dissemination of climate-change ed. and training</td>
</tr>
<tr>
<td></td>
<td>Pre-college student education</td>
<td>Collaborative networked research project; 2 online high school courses</td>
<td>Statewide pre-college collaboration and training</td>
</tr>
<tr>
<td></td>
<td>Undergrad Student training with private sector</td>
<td>Internships with small businesses; undergrad Communicating Science course</td>
<td>Increase employability of students</td>
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<tr>
<td>Cyberinfrastructure</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Hire technical support for ecosystems projects</td>
<td>Trained technical support</td>
<td>Increased capacity in state for research</td>
</tr>
<tr>
<td></td>
<td>Partnerships w/ID, NV, WY, WA</td>
<td>Regional meetings</td>
<td>Collaborations in research</td>
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<tr>
<td>External Engagement</td>
<td></td>
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<tr>
<td></td>
<td>Develop print and electronic media for National Parks</td>
<td>Media products centered around environment issues</td>
<td>Broader dissemination of information about MtEPSCoR to public, other researchers, and key stakeholders</td>
</tr>
<tr>
<td></td>
<td>Travelling exhibits and small town lecture series</td>
<td>State outreach to every Indian res. and county</td>
<td></td>
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<tr>
<td></td>
<td>Small Business Development Center training</td>
<td>Climate-change data available</td>
<td>Enhanced competitiveness of Montana companies</td>
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<tr>
<td>Evaluation and Assessment</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>External AAAS review boards</td>
<td>Assess accomplishments and progress</td>
<td>Qual. &amp; quant. assessment of MtEPSCoR effectiveness</td>
</tr>
<tr>
<td></td>
<td>External formative review</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>MUS Evaluator Development Program</td>
<td>Trained personnel</td>
<td>Statewide capacity for evaluation</td>
</tr>
</tbody>
</table>
**Sustainability**

<table>
<thead>
<tr>
<th>Small Business Development Centers. Seminars/Workshops</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>S&amp;T and SBIR consulting</th>
</tr>
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<tbody>
<tr>
<td>Education Grants for teaching</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Climate-change education courses</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Relevant courses available to all MUS interested students</td>
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</tbody>
</table>

**Research Outcomes**

The overall outcome of the proposed research will be a more complete understanding of how ecosystems function and how they are expected to be altered by climate change. The outcomes will be applicable to diverse ecosystems around the world, not just benchmark Montana ecosystems. Specifically, from Focus 1 we will provide a quantitative understanding of: a) the environmental biophysical characteristics that predict spatial distribution and microbial C/N gene activity; 2) the relative contributions of microbial community to C/N balances; and 3) how climate change affects microbial-based C/N fluxes. In Focus 2, we will produce: 1) quality-controlled databases of past climate, physical, biotic, disturbance, and land-use changes in benchmark ecosystems; 2) assessment of ecosystem change along spatial and temporal trajectories; 3) improved understanding of the biotic and physical controls of key ecosystem components; and 4) state-of-the-art projections of how important species, biotic communities, and disturbance regimes will respond under different climate-change scenarios. In Focus 3, we will provide: 1) projected changes in climate, land-use, ecosystem processes and biodiversity; 2) state-of-the-art assessments of ecosystem vulnerability; and 3) multi-scale management approaches and adaptation strategies developed in cooperation with state and federal partners. The creation of MICERE will provide a new umbrella structure for interdisciplinary collaboration in the MUS, through shared facilities and research sites, faculty and student exchange, and statewide communication, outreach, and partnerships. We predict that MICERE will be a model for other states with limited research infrastructure.

**4.4 Diversity ($4.16M; 17% of grant)**

<table>
<thead>
<tr>
<th>Key Points</th>
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<tbody>
<tr>
<td>Native American Research Lab</td>
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<tr>
<td>Tribal College Grants Program</td>
</tr>
<tr>
<td>Accelerated Math Program</td>
</tr>
<tr>
<td>Tribal College Faculty Development</td>
</tr>
<tr>
<td>Women Faculty Diversity Program</td>
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</tbody>
</table>

The EPSCoR program in Montana has a long history of partnering with other federal programs focused on building in diversity (e.g., TCUP, PACE, AIRO, MAP, BRIDGES, WRS, SPECTRUM, ADVANCE, DOC). Because Native Americans make up more than 75% of the non-white population in Montana, increasing research and education opportunities for this underrepresented group is our primary focus. Our diversity plan targets increasing science success for Native Americans and other underrepresented groups in the MUS by improving instruction in environmental sciences at tribal colleges, supporting accelerated math preparation for pre-college, tribal college, and MUS students, increasing numbers of Native American Ph.D. students in environmental sciences, and enhancing faculty diversity through strategic hires.

A second target of diversity is increasing the representation of women faculty in STEM areas within the MUS. Currently in the MUS, 42% of faculty members are women, but only 28% are in STEM disciplines. Women comprise 46% of undergraduates and 45% of graduate students in natural and physical sciences. Despite these gains, some departments still have only one or two women tenure-track faculty. To enhance university academic and research programs the MIEPSCoR Diversity Program will focus on the five components below.

**4.4.A. Native American Research Laboratory (NARL):** NARL was developed at the UM, as a pilot program, under the 2007-10 Track I RII award, and will be expanded under this funding period. The goal of NARL is to provide advanced “hands-on” research opportunities to Native American students in an interdisciplinary and intercultural training environment. NARL serves all indigenous students including those transferring from tribal colleges to four-year universities, those entering the university directly from reservation high schools, those from out-of-state urban centers, and those from multi-ethnic and multi-tribal backgrounds. This program has supported students from more than 25 tribes from across the First
Nations. We will build on this success by increasing the number of Native American students participating in NARL opportunities through MtEPSCoR-funded internships across the MUS.

4.4.B. Tribal College Grants Program: This program is designed to directly engage faculty and students at Montana’s seven tribal colleges to develop climate-change research projects appropriate for their tribes’ needs and interests. In Year 1 of the program, MtCERE, under the direction of Sara Young, a national leader in Native American STEM program development, will work with Montana’s tribal colleges to develop 4-year research projects. For example, one tribal college proposes to develop an ethnobotanical herbarium that would preserve native plants of cultural importance, many of which are threatened by climate and land-use change. Where appropriate, tribal college programs can partner with scientific and engineering experts within MtCERE.

4.4.C. Accelerated Math Program: An accelerated math program will be developed at each of the seven Montana reservations/tribal colleges. The vision of this program starts with developing the math skills of Native American high-school students and supports their math needs as they transition from high school to tribal college to four-year institutions. This program will partner with the Designing Our Communities (DOC) program at MSU, funded by the William and Flora Hewlett Foundation, which is focused on increasing the number of Native Americans in engineering and computer science. Despite DOC’s success, it has been limited by the poor preparation of incoming students from small reservation high schools where there are few opportunities for advanced math learning. Under the Accelerated Math Program, MtEPSCoR will fund new math instructors at each of the tribal colleges. These instructors will work directly with Native American high school students on their reservations to mentor their math skills and provide a math connection upon transitioning to their local tribal college. In addition, MtEPSCoR will support a math coordinator who will work with the tribal colleges to provide an intensive summer math program for high school seniors and college undergraduates. Students entering a tribal college or four-year institution will be able to begin their freshmen year of college at either the pre-calculus or calculus level. Current DOC tribal students will serve as their tutors and mentors. An incentive, including course tuition, will be provided to high school students who participate in the six-week summer math course. Additionally, a scholarship will be provided to tribal college students who earn a B or better in the pre-calculus or calculus courses upon transferring to a four-year institution and majoring in STEM disciplines that require calculus as a pre-requisite.

4.4.D. Tribal College Faculty Development: Many tribal college faculty members hold their positions without a doctoral or other terminal degree. In fact, while many have completed master’s degrees, some are teaching in the ecological/environmental sciences with only a bachelor’s degree. The lack of a doctoral degree is related to very heavy teaching loads and limited support to pursue and complete doctoral training. MtEPSCoR will address this critical need by 1) providing full tuition waivers for any tribal college faculty member in the ecological/environmental sciences seeking a doctoral degree, and 2) providing teaching internship opportunities for MSU and UM doctoral students to help relieve tribal college faculty of some or all of their teaching loads. MtEPSCoR will provide stipends for both tribal college faculty pursuing a doctoral degree and for MSU/UM doctoral students serving as instructors. The goal of this program will be to enroll 10 tribal college faculty with a research focus in ecosystem science and climate change in doctoral degree programs on the MSU or UM campus, with 4 completing their degrees by the end of the MtEPSCoR grant period.

4.4.E. Faculty Diversity: In order to increase women and Native Americans in tenure-track faculty positions in STEM disciplines, our goal is to hire women into half of the new tenure track positions that MtCERE programs will fill over the 5-year duration of the grant. We will also hire two Native American STEM faculty members. To encourage women to apply for faculty positions across the MUS, the MtEPSCoR will pilot a program of direct recruitment by identifying excellent doctoral and post-doctoral candidates, and recruiting them through personal contact. MtEPSCoR also work to recruit and retain women faculty by supporting family-friendly programs, including spousal hire accommodations; nursery, day care and after-school programs, buyout of academic activities (often teaching); and extension of the tenure clock to accommodate a broad range of family needs.
4.5 Workforce Development ($2.28M; 9.5% of grant)

<table>
<thead>
<tr>
<th>Key Points</th>
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<tbody>
<tr>
<td>Engaging the Private Sector</td>
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<tr>
<td>K-12 Teachers of Science</td>
</tr>
<tr>
<td>Pre-college students</td>
</tr>
<tr>
<td>College students &amp; faculty</td>
</tr>
</tbody>
</table>

Increasing workforce science literacy is critical for Montana’s ability to address and respond to climate change. Over the past 30 years, MTEPScoR has played a significant role in providing innovative workforce development programs that have impacted K-12 students and increased the pipeline of students entering science and engineering programs with the number of S&E grads increasing 70% since 1980 \(^{118}\). Recent programs include partnerships with private industry and small business, Montana’s universities and K-12 science programs. As examples, Expanding Your Horizons encourages middle school girls to pursue interests in science and engineering; MoSSE, a mobile science exhibition, has traveled 7,500 miles to bring programming to 14,000 Montana school children; and Science Saturdays, a community program, exposes 8-14 year-olds to the excitement of science and engineering, and has been particularly successful in Montana’s Native American communities. Despite these successes, enormous challenges remain regarding workforce development in a large rural state like Montana: 46 of Montana's 56 counties are considered "frontier," with an average of six or fewer people per square mile. MTEPScoR proposes workforce development programs that aim to overcome some of these limitations while aligning science education and research with pressing social and economic challenges. MtCERE will coordinate and manage workforce development programs that build on existing statewide initiatives, promote Montana’s connection to science, and reach the states’ rural, underrepresented and minority populations with sustained, integrated, high-quality outreach that seeks to inspire future scientists and engineers. The plan focuses on four key audiences: 1) the business community, 2) K-12 teachers, 3) pre-college students (K-12), and 4) college students and faculty.

4.5.A. Engaging the Private Sector: Technology-based start-up companies in rural states like Montana often have limited regional access to business-support personnel who are well versed in high growth and technology-based sectors. Ironically, our higher education system is providing this precise education to its students through well-established entrepreneurial and business programs, which are oftentimes lacking in practical hands-on (technology-based) opportunities as part of the educational experience. MTEPScoR will address these needs by sponsoring internships, including travel and supplies, so that students from the Entrepreneurship Center at MSU and the School of Business Administration at UM can work with companies one-on-one in efforts such as market assessments, financial modeling, sales pipeline development and competitive analyses. These efforts will make students more employable upon graduation, increase business growth in Montana, and provide for stable companies that are in turn able to hire more MUS graduates.

MTEPScoR will help develop workforce training programs related to energy and environmental issues, especially those drawing on research dealing with ecosystems and climate change, and work to educate the public and decision makers about these issues as well. Montana’s transition into a climate-friendly developing renewable energy economy will be challenging, in part due to the state’s enormous coal reserves, which the state will soon be challenged to utilize in a climate-friendly fashion. Also, climate-change legislation will alter the way energy companies conduct business. University-affiliated programs such as the Energy Research Institute and the (developing) Clean Tech Alliance are well positioned to assist in this transition with regard to both economic policy and technical issues. MtCERE workforce training efforts and communication with public and decision makers will result in open communication and advocacy at the State level regarding clean tech and green energy, thereby branding Montana as a leader in the nation’s efforts to boost energy security while sustaining the environment we depend on for our lives and livelihoods.

4.5.B. K-12 Teachers of Science: National surveys and reports show that improving teacher content knowledge remains the number-one priority for improving science education in the U.S. \(^{119}\). In order to strengthen K-12 teachers’ science content knowledge, MTEPScoR will support teachers in three ways: by providing online courses and a graduate certificate in Climate Change; non-credit online educational modules; and a Translating Research into the Classroom fellowship program.

MTEPScoR will develop and deliver four online graduate courses, which can be taken separately or as a 12-credit online graduate certificate in Climate Change. The courses and certificate will be delivered via the National Teachers Enhancement Network (NTEN), which originated in 1993 through NSF funding and
has reached more than 15,000 teachers from all 50 states and 17 countries. NTEN courses led to the development of MSU's Masters of Science in Science Education (MSSE), one of only a handful of interdisciplinary graduate programs for science teachers with a focus on science content. The new courses will become part of a permanent course catalog and establish an EPSCoR model for reaching teachers with up-to-date and accurate science content.

Additionally, and also via NTEN, MtEPSCoR will develop a non-credit online educational module that presents the scientific, economic and social issues regarding climate change via interactive inquiry-based content modules, as well as accompanying lesson plans and classroom resources, downloadable podcasts and other multimedia, and self-assessments. The module will be designed for K-12 teachers, informal educators such as museum and science center professionals, and will also be available to the public.

Lastly, MtEPSCoR will create a Translating Research into the Classroom summer fellowship program for K-12 Native American and rural teachers. Scientists, science educators and instructional designers will support teacher Fellows as they develop lesson plans, podcasts and other multimedia classroom resources in a two-week on-campus program. Materials and lessons developed by the Teacher Fellows will focus on climate change and incorporate national and Montana science standards, as well as standards for Montana's Indian Education for All initiative, the first of its kind in the country and an educational model for many other states.

All resources developed can be shared with teachers through NTEN's resource library as well as through the National Science Teachers Association (NSTA). As one of just six institutions recognized by NSTA, MSU can share courses and resources with NSTA's approximately 80,000 members and 195,000 affiliate members.

4.5. Pre-college students: MtEPSCoR will reach students in classrooms throughout Montana and beyond by partnering with the Montana Digital Academy (MTDA) to develop two online climate-change courses for high school students. The MTDA is an online high school for Montana students in a public, private, or homeschooled educational setting. Housed at The University of Montana and with support from the MUS and the Office of Public Instruction, MTDA helps students meet college admissions requirements, make up missed or failed classes, resolve scheduling conflicts, and take advanced coursework. Through the MTDA, MtEPSCoR will support rural schools and students that would have no other means of obtaining advanced interdisciplinary science courses related to current research such as climate change. Specifically, MtEPSCoR will work with MTDA to identify teams of scientists and teachers for course development and delivery, and will share the classes with other virtual high schools.

MtEPSCoR will also create CLIMB (CLimate In My Backyard), a series of classroom science modules in which students and researchers from the MUS lead middle and high school classrooms through inquiry-based hands-on experiments via a combination of videoconferences, face-to-face interaction, social networking, and tool kits. One of the main elements of CLIMB will be an interactive mapping project using GPS (Global Positioning System) units and Google Earth. Students and their teachers will be taught to use loaned GPS units and will use free software to study climate-change predictions and models using Google Earth's new climate-change-specific features. They will also develop their own local, collaborative content by sharing geodata, images and video from their own communities. Students in the Montana project will use the collaborative capacity of the Web to contribute local data such as air and water temperature, water levels, snowmelt, vegetation and other measurements, which will be combined with other data from around Montana and the region and available to the general public as a constantly growing resource on climate change in the northern Rockies. The collaborative nature of the project will allow students to meet and work with other students throughout the region. Many educational outreach programs reach a child just once, and have minimal impact and virtually no means of evaluation. Through CLIMB, we propose an alternative that offers long-term sustained, documentable contact with youth in classrooms or cohorts instead of as individuals. This project will offer extended, measurable and high-quality contact with students by targeting several classes from rural underserved communities. Special emphasis will be placed on working with underserved populations, including girls, Native Americans and rural students. Statewide and regional partners such as USGS, museum professionals or the Montana Natural History Center can participate in videoconferences and on-site visits and contribute content, kits, tools and educational modules.
4.5.D. Engaging college students and faculty: MiEPSCoR will continue its support of university students in STEM fields, primarily those related to climate change. The Undergraduate Scholars Research Program has successfully provided meaningful research experiences under the current EPSCoR award (07-10). We will build on this program by engaging 400 students within the MUS and tribal colleges in field, laboratory, and engineering research internships with an emphasis on climate change. In multiple-year experiences, students will participate in research teams (consisting of graduate student, post-docs, and faculty), receive thoughtful senior and near-peer mentoring, present results at MiCERE-organized conferences, and participate in publications.

To provide the next-generation of scientists with the skills to engage and inform the public about contemporary scientific issues, we will create a semester-long seminar series and credit course called “Communicating Science to the Public” designed for undergraduate and graduate students. The course will be available by distance learning to students at all higher education institutions in Montana and beyond. Using case studies, discussion, guest speakers and hands-on practice, the course will train future researchers in communication strategies. Participants will conduct public outreach activities, such as giving talks, working at community events, or administering educational activities. STEM students will be paired with students in the creative arts (graphic design, film, journalism, animation, etc.) to develop materials ranging from posters to sculpture to online interactive media applications, all of which interpret and communicate scientific concepts to the public. The course guide, materials, best practices and model can be shared with other EPSCoR programs and universities.

4.6. CYBERINFRASTRUCTURE ($0.90M; 4.5% of grant)

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The extraordinary amount of data needed by researchers and the public to address climate change will require access to distributed and heterogeneous data sources. To that end, enhancement of cyber-infrastructure and informatics will build on past NSF EPSCoR support which includes the creation of the Northern Tier Network Consortium, and synergies emergent from the recently funded NSF EPSCoR RII Track-2 cyberinfrastructure enhancement award. The Internet2 "US-UCAN" project, recently funded under the NTIA/Broadband program will also dramatically enhance networking connectivity along the Northern Tier, including to UM and MSU. Central to the RII Track-2, is our development of a Virtual Observatory and Ecological Informatics System (VOEIS) that will be heavily leveraged in this current proposal. VOEIS is a combination of the hardware, networking, software, and human resources to accomplish end-to-end workflow involving the following: 1) real-time data from sensors; 2) a synthesis framework for integrating data from multiple sources; 3) data management, dissemination, and on-demand performance of workflow into other applications (e.g., simulation models); and 4) data output products from modeling and visualization applications. We will build upon ongoing RII Track 2 efforts by expanding data sensor networks and expanding cyberinfomatics tools within and between MUS and Tribal colleges campuses. We will also work with MUS engineers and computer scientists on ways to improve communication between sensors in remote areas and the extraction of regional data from remote sensing. Our cyberinfrastructure efforts will focus on assembling a range of data and addressing data heterogeneity and documentation. The extraordinary amount of data needed by researchers, resource managers, the community, and the public to address climate change will require user-friendly access to distributed data resources, and multiple types of dissemination, including through web platforms and applications that run on mobile phone and tablet devices. We further propose to partner with Idaho, Nevada and Wyoming EPSCoR in ecosystems informatics development related to environmental science activities underway in the ID-NV-NM project. We have a critical need to leverage Track 2 investments with two staff positions in systems operations and environmental informatics support.

4.7. EXTERNAL ENGAGEMENT ($1.92M, 10% OF GRANT)

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Montana’s natural areas such as Yellowstone and Glacier National parks, national monuments, wilderness areas, and state and federal forest lands provide distinctive regional ecosystems that draw interest from visitors, students and scientists from around the world. However, Montanans themselves are often unaware of the quality of research happening in their own backyard. The science associated with Montana’s natural resources provides a unique platform for education and outreach with respect to climate
change. We propose to create *Science Montana*, a suite of programs within MtCERE to engage Montana’s small and large businesses, rural communities, and the public at large. Envisioned as a broad-based, multi-year, state and national outreach program, *Science Montana* is an integrated program of technical assistance, print, film, social media, traveling exhibits, public forums, and digital assets.

4.7.A. Engaging Montana’s private sector: Montana’s economy is dominated by small businesses of fewer than 10 employees. To encourage small business development, the state government recently created 12 Small Business Development Centers (SBDC) throughout the state. These centers have been instrumental in establishing new small businesses, but are unprepared to assist with development of new business with a science or engineering focus. MtEPSCoR proposes to partner with the SBDCs to provide the business expertise for helping fledgling science and engineering companies become established. Building off of the highly successful SBIR Phase 0 and 1.5 programs that MtEPSCoR initiated, organizations, such as the MUS TechLink and the Montana Community Finance Corporation, will provide on-site consulting services. In addition, this program will train SBDC staff on topics such as patent issues, financing options, cyberinfrastructure, and climate-friendly sustainable solutions.

Montana's largest industries—agriculture, mining, timber, and tourism—face significant challenges associated with climate change. These industries are exceptionally interested in understanding how climate change will affect their economic success in the future. However, these industries do not have the resources to invest in climate-change adaptation strategies. MtCERE will partner with these industries to evaluate various climate-change scenarios, their potential consequences and costs, and possible solutions. MtEPSCoR will work with industry associations, such as the Montana Wood Products Association, and Montana Renewable Energy Associations, and businesses through a one-to-one match program, designed to help the private sector adapt to the realities of climate change, including new policies and laws. The objective is to focus on specific industry needs in partnership with MUS’s research capacities. In addition, MtCERE, through *Science Montana*, will leverage its cyberinfrastructure investment to make climate science data, information products, and decision-making tools available to business partners.

4.7.B. Reaching National Park Visitors with print and digital media: Yellowstone and Glacier National parks receive approximately 5 million visitors a year, and *Science Montana* will reach out to these visitors with a blend of traditional print coupled with high-tech multimedia. Through MtCERE, we will create a series of digital assets: animations, video clips, quizzes, calculators, tips, maps, quick facts, and interactives that demonstrate concepts such as visible affects of climate change (rapidly receding glaciers) modeling predictions and uncertainties associated with climate change. The media assets will be free online but will also be directly integrated with the Parks’ printed material and signage at key tourist sites using QR codes: two-dimensional barcodes readable by cell phones. Thus, a Park visitor carrying a cell phone could aim his or her camera phone at the QR code on a sign or printed in a Park publication and connect instantly to the video clip, slide show or animation, thus engaging visitors to the Parks with electronic media that explains the science right before their eyes. Mobile applications such as iPhone, iPad or smartphone apps will be created for some of the most accessible and interesting media assets. We will work directly with the National Park Service, the private foundations of Yellowstone and Glacier, and industry and agencies surrounding the national parks.

4.7.C. Documentary films and social media: We will engage film students in the highly successful MSU Science and History Filmmaking Program to produce a series of television programs, podcasts, and other media products showcasing MtEPSCoR science and research discoveries. The media products will be distributed by local, regional, and national public television stations and produced in partnership with Montana PBS, a unified statewide television service by KUSM at MSU-Bozeman, and KUFM at UM-Missoula. The programs also will be available through social media, including YouTube, iTunesU and other sharing sites, and on the science and natural history website TERRA: *The Nature of Our World*. MSU’s TERRA has had over eight million downloads and has been listed by Apple as among the top 20 science sites on the web. One film will be an hour-length documentary focusing on climate change in the western U.S. The film will be pitched for national distribution to National Geographic and the Discovery Channel.
4.7.D. Community outreach: We will develop a pilot program in the resort community of Big Sky MT to explore how scientific discovery can effectively engage to local communities. We will host an annual Big Sky Science Summit, to bring together international/U.S. scientists, policy makers, NGO leaders, and the Big Sky community to examine climate-change issues of global and regional concern. Some of these summits will be modeled after TEDx events, in which unique talks are given by live speakers in combination with TEDTalks videos. The Big Sky partnership will serve as a test-bed to identify other platforms to spark deep conversation and connections. In addition, community forums on climate change will target the state’s smallest rural communities, those with populations under 10,000. MtCERE faculty and students will discuss the importance of climate change and its potential impact upon mainstays of the local economy, such as tourism, recreation, and agriculture. These community conversations will be coordinated by MtCERE working with the MUS county extension offices.

In support of these efforts, we will develop a mobile climate-change exhibit and laboratory that will travel to Montana’s rural communities, including tribal colleges and reservations. SpectrUM, an interactive discovery center on the UM campus, will develop the exhibit and laboratory activities. The exhibit/laboratory visits will be coordinate with the community forums. Additionally, Science Montana and the Montana Library Association will create kits that include books, resources, and supplies for libraries around the state to host climate-change information events.

4.7.D. Engaging regional partners and other EPSCoR jurisdictions (see Letters of Collaboration, Supplementary Documentation): MTEPSCoR will expand existing and build new collaborations during this funding period. For example, Montana currently partners with Kentucky in our RII Track-2 award. In this proposal we will work with partners in Washington, Wyoming, and Nevada, to coordinate and collaborate on common research, education and outreach efforts. These collaborations will include regional research meetings as well as workshops on engaging Native Americans in science, cyberinfrastructure, and science communication to the public. In addition, MTEPSCoR will partner with state and federal agencies and NGOs involved in regional climate-change initiatives, including U.S. Department of the Interior's Regional Climate Science Centers, Landscape Conservation Cooperatives, NOAA Regional Integrated Science & Assessments, Yellowstone and Glacier National Parks, NEON; The Wildlife Conservation Society, and The Nature Conservancy.

4.8. EVALUATION AND ASSESSMENT ($0.84M; 3.5% of Grant)

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<td>Collection of Metrics</td>
<td>The goal of MTEPSCoR program evaluation and assessment is to evaluate the proposed S&amp;T infrastructure improvement goals, and through constructive analysis and feedback, chart and maintain an effective course of programmatic and strategic S&amp;T development. Evaluation and assessment of the MTEPSCoR project will be both formative and summative and will involve a combination of quantitative and qualitative data collection and analysis processes. Specifically, it will include 1) ongoing tracking of performance metrics, 2) guidance by an external advisory board, 3) review by external scientific boards, and 4) formative feedback on the processes employed by EPSCoR to achieve its goals to determine if the most effective methods are being used. We will report annually to the national NSF EPSCoR Office and the state MUSSTAC on the recommendations from each of these assessments. The external evaluation of the MTEPSCoR program will be directed by Dr. Julia Meikers, Associate Professor of Public Policy at Georgia Institute of Technology.</td>
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4.8.A. Collection and Assessment of Metrics: MTEPSCoR administrative staff will track MTEPSCoR activities using a database designed specifically for the purpose of collecting data on participants and EPSCoR funding outcomes. The external evaluator will assist in the specification and content of this system. Data gathered on metrics specific to key aspects of the program will be updated monthly and accessible to NSF. Reports will be delivered to the project leadership showing involvement of underrepresented groups, including women, and other demographic measurements so that program adjustments can be made in real time. Since many of the outcomes of MTEPSCoR initiatives are long term, there will also be a longitudinal analysis produced with the data available to date. Where possible, data on EPSCoR-supported programs will be compared to programs and participants who have not received MTEPSCoR support. To measure the impact of EPSCoR support in Montana, MTEPSCoR will
use performance indicators based on the STAR METRICS (Science and Technology in America’s Reinvestment – Measuring the Effects of Research on Innovation, Competitiveness, and Science) model used to track outcomes of federal funding and provide accountability. This national effort to standardize and assess the impact of federal funding will allow EPSCoR to focus efforts on measureable outcomes that can be documented and traced to EPSCoR funding.

4.8.B. External Advisory Board: An External Advisory Board (EAB) will be used to guide all elements of MiCERE. The EAB will meet once a year to review the progress of the program and help to formulate future activities. Dr Tom Taylor (U. Kansas, Member of the National Academy, and NSF NSB), Dr. Gene Likens (Member of the National Academy, Founder and Director Emeritus, Cary Institute of Ecosystem Studies), Dr. David Schimel (Chief Executive Office, NEON), Dr Lisa Graumlich (Dean, College of the Environment, University of Washington), Dr. Anne Hershey (Julia Taylor Morton Distinguished Professor, University of North Carolina-Greensboro), and Dr. Joe McDonald (former President Salish Kootenai Tribal College) have all agreed to serve on the EAB. EAB reports will be provided to the Project Director, MiCERE Directors, MUSSTAC and the National EPSCoR Office.

4.8.C. External Review: We will contract with the AAAS Research Competitiveness Service to conduct a scientific peer review in the second and fourth years of the grant. This process will include a site visit of scientists and AAAS personnel to meet with MIEPSCoR staff, researchers, students, and other stakeholders. We recognize that these panels have been invaluable in other EPSCoR states and to Montana in the past, and view this as an important external examination of our scientific activities. We also anticipate that in Year 3 of the program that there will be a site-visit or reverse visit by NSF to evaluate the MIEPSCoR program.

4.8.D. External Evaluator: The MIEPSCoR recognizes that it is essential to have an external evaluator to track ongoing programs, personal performance, research outcomes, and success with large diversity of stakeholders. External evaluator, Dr. Julia Melkers, of the Georgia Institute of Technology, has worked with a number of other EPSCoR states, and brings extensive evaluation experience, as well as an understanding of scientific collaboration, and student engagement in research. The external evaluator will help to develop methods to address the following specific questions: To what extent is the MIEPSCoR institutional framework developing to support cross-institutional and cross disciplinary integrative research? As the program develops, what are the barriers and facilitators to interdisciplinary research? To what extent is interdisciplinary integration being advanced through the use of cyberinfrastructure tools? What have been the scientific and knowledge development outcomes of the collaborative activity? How are researchers across discipline, rank, and Montana institutions involved in the collaborative processes? Specifically, how are young researchers integral in these processes? How are students, particularly Native American students, benefiting from their EPSCoR research experience? What interdisciplinary skills, knowledge, and capacity are they gaining?

Methods: To address cross institutional and cross disciplinary integrative research, the evaluation will use a combination of 1) traditional behavioral and attitudinal survey data with detailed social network analysis to track development of collaborative patterns over time, and 2) bibliometric analysis to track the development of academic productions, and impacts on knowledge in the field. Surveys of faculty, postdoctoral researchers, and students will be conducted in each year of the project, with the first year serving as a baseline year. Many of the metrics specified in this proposal will be gathered through the survey instrumentation. In the third and final years of the project, the surveys will be limited to a core set of measures and accompanied by a bibliometric analysis, which will be conducted to address the level of interdisciplinary production on the project team. This will be accomplished through an examination of citation coupling working papers and publications and will allow a robust approach to the identification of interdisciplinary production.

4.8.E. MUS Evaluation Capacity Building: MIEPSCoR will build the capacity for program evaluation within the MUS so that we will no longer be dependent on hiring external evaluators. The milestone at the end of the five-year funding period is to have in place an internal evaluation and assessment capacity within the MUS to allow any research program to evaluate its impacts. By creating a model and resources for other researchers, MIEPSCoR will enhance the capacity of researchers, particularly in the education
and social sciences areas, and for large project grants, to conduct effective evaluation of their programs.

4.9. **Sustainability** ($0.12M; 0.5% of Grant)

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<td>Post RII Extramural Funding</td>
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MtEPSCoR is committed to ensuring that the programs initiated during this funding period are sustained into the future. MtEPSCoR has a track record of sustaining programs and research efforts it has initially seeded. For example, the Thermal Biology Institute and Center for BioInspired Nanomaterials are still thriving MUS centers years beyond receiving EPSCoR seed funding.

4.9.A. Emerging Areas Awards: In addition to the team grants programs described in Section 4.3 and the tribal college grants in Section 4.4, we will provide Emerging Areas awards to target MUS institutions and faculty not traditionally involved with NSF-supported research. These MUS institutions include MSU-Billings and UM-Western, primarily undergraduate institutions but which have begun to grow their research programs in recent years. We will particularly encourage multidisciplinary, multi-institutional activities coordinated through MtCERE.

4.9.B. Education and Human Resources Development: The overall MtEPSCoR education and human resource goal is to improve both the quantity and quality of students, professional staff, and faculty engaged in research. EPSCoR has already played a pivotal role by hiring over 117 high-quality science and engineering faculty members in the past 12 years. The milestone for this funding period is to hire an additional 12 faculty members. All faculty hires will be put into tenure-track lines supported by institutional matching funds during the five years of this grant and then the lines will be entirely supported by the university. In this funding period we have chosen to put a particular emphasis on graduate education. This is because the number of Ph.D. students involved with research as compared to the total MUS research activity (expenditures) is below the national average. One of our milestones is the recruitment of 40 new Ph.D. graduate students. To foster success of these students, we will establish a research mentoring and career development program under MtCERE. By MtEPSCoR seeding this emphasis on growth in graduate students, we hope to catalyze an institutional change in the state that supports and sustains graduate student education in the future.

The MUS has outstanding science and engineering educators principally involved with undergraduate teaching who play a critical role in training the next generation of scientists and engineers. In an effort to take advantage of their commitment to the teaching mission of the MUS, the MtEPSCoR program will pilot a new program to engage these instructors to incorporate climate-change related research and topics into their curriculum. An annual competitive Education Grants program is proposed that will support climate-change curriculum development.

4.9.C. Post RII Extramural Funding: It is expected that all faculty hires associated with this MtEPSCoR project will create and maintain active research programs fully funded by competitive external grants well beyond the five years of this EPSCoR grant. This has certainly been the expectation and history of past EPSCoR faculty hires. We expect that MtCERE will develop into a state-supported MUS School of the Environment at the end of five years and serve as a new model for other interdisciplinary consortia within the MUS and the nation.

4.10. **Management Plan** ($2.98M; 12% of Grant)

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4.10.A. Management. The management plan is designed to effectively implement and assess the programs outlined in this proposal. The MtEPSCoR program prides itself on having a track record of experienced, efficient and effective management. The overall management and governance structure is designed to provide clear lines of responsibility and encourage communication and collaboration (Fig. 7). Leadership is provided by Dr. Mark Young (PD) and the Montana University System Science and Technology Advisory Committee (MUSTSTAC). Dr. Young has 13 years experience of serving as the PD or co-PD of the MtEPSCoR program and will be responsible for all activities of the MtEPSCoR program. The MUSTSTAC governing Board is housed within the Office of the Commissioner of Higher Education, is chaired by Dr. Sylvia Moore, Deputy Commissioner, and has broad state representation (for list of
MUSSTAC members, see Supplementary Documentation). This committee has been highly active in the planning and evaluation of the programs set forth in this proposal. The MUSSTAC Governing Board has approved the programs as both appropriate and central to the state’s mission to advance Montana’s S&T infrastructure. Dr. Young reports to MUSSTAC through Dr. Moore and manages and reports the programmatic, educational and financial components of the program quarterly to MUSSTAC.

4.10.B. MUS Consortium for Ecosystem Research and Education (MtCERE): MtCERE will serve as a model for how states with small populations can create regionally effective and nationally influential research and education centers. MtCERE, is envisioned as an umbrella structure to coordinate and facilitate not only the proposed research, but also the education and outreach efforts. MtCERE will provide: 1) identity at the state and national level for environmental education and research; 2) cooperation by forming teams across disciplinary and organizational boundaries to address the questions posed above and create new research opportunities; 3) rewards and incentives to bring faculty together across traditional disciplinary boundaries and institutions in Montana and beyond; 4) integrated graduate and undergraduate education programs across the state; 5) integration of statewide programs to engage Montana’s Native American communities in climate-change science and education issues; and 6) coordinated outreach efforts across the MUS to provide Montanans with relevant information and decision-making tools that address state and national environmental topics of concern.

MtCERE will be led by co-Directors Whitlock and Stanford (see Biosketches). Drs. Whitlock and Stanford have played a critical role in designing the science outlined in this proposal and have direct management experience in running large grants, institutes or field stations. Their responsibilities include working with Dr. Young to ensure that MtEPSCoR goals are met; coordinating elements of the research subprogram and working with each of research foci leaders; providing guidance on budgetary allocation; and overseeing the Program Committee. The faculty-led MtCERE Program Committee will provide effective coordination, integration, and implementation of all MtCERE activities, and it is composed of expert faculty from MSU, UM, and the Tribal Colleges (Fig. 7, see Biosketches, Supplementary Documentation). The Program Committee provides leadership for MtEPSCoR activities and ensures wide participation in the EPSCoR process across the MUS. It is an important layer of governance that will help maintain program plasticity by keeping the projects dynamic and responsive to institutional and State needs. The Program Committee will meet with MtCERE co-Directors and the MtEPSCoR PD on a monthly basis either directly or indirectly via video conferencing to coordinate activities and solve programmatic issues as they arise. The entire management team and MUSSTAC board members will hold annual planning retreats.

4.10.C. Administrative structure: The MtEPSCoR Program Administrators (G. Allison, UM; M. Peters, MSU), under the direction of the PD, will ensure proper levels of administrative and technical assistance are available to MtCERE and its program efforts. Workshops featuring NSF program officers will be included in MtEPSCoR technical assistance activities, along with informational sessions on research opportunities at NSF and other federal agencies. These activities will ensure that EPSCoR participants within Montana and the western U.S. are aware of interdisciplinary region-wide activities. MtEPSCoR staff will assist with proposal planning and development, bring experts to Montana in a mentoring capacity, support travel by researchers to NSF and other federal funding agencies so that they can interact with program officers in order to formulate the most competitive proposals, and work with the Evaluator to design effective program assessment tools. MSU is the host institution, accepts financial responsibility for the entire project, and serves as financial hub for the project. The Associate Vice Presidents for Research (L. Schmidt, MSU; J. Fredenberg, UM) share in fiscal responsibility and will also coordinate MtCERE finances and budgets for subawards to institutions, companies, individuals and students. Quarterly meetings will be held between Associate Vice Presidents and their respective staff to ensure that the financial aspects of the project are up to date and available for NSF reporting. The PD, Associate Vice Presidents, their staff, the MtEPSCoR office staff, and MtCERE co-Directors will hold meetings twice each year to coordinate specific project finances, expenditures and projections.

4.10.D. MtEPSCoR Resource Distribution: The distribution of MtEPSCoR resources are shown in Table A. All MUS and Tribal Colleges are directly participating or have the opportunity to participate during the course of the 5-year funding period. One advantage of having the majority of the MtEPSCoR activities coordinated thorough MtCERE is that it allows flexibly in both individuals and institutions participation based on their individual needs and expertise. A detailed table describing resource
allocation and institutional matching funds to each program described in this proposal is provided in the Budget Justification.

Throughout this proposal, percentages and resources dedicated to each component of the program have been indicated. This information is provided to assure the reader that MtEPSCoR program has carefully allocated resources. However, it is also important to note that there is also significant synergy between the program components. For example, the 45% resource allocation to research is also supported by additional resources placed in diversity and workforce development, providing a much greater overall amount of resources and efforts to the research program.

Commitment of the required 20% institutional cost sharing is provided (see MUS Letter in Supplementary Documentation).
References:


118. Integrated Science and Engineering Resources Data System. 2010.