Big Sky Carbon Sequestration Partnership

Quarterly Report for period October 1, 2004 – December 31, 2004

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ABSTRACT

The Big Sky Carbon Sequestration Partnership, led by Montana State University, is comprised of research institutions, public entities and private sectors organizations, and the Confederated Salish and Kootenai Tribes and the Nez Perce Tribe. Efforts under this Partnership in Phase I fall into four areas: evaluation of sources and carbon sequestration sinks that will be used to determine the location of pilot demonstrations in Phase II; development of GIS-based reporting framework that links with national networks; designing an integrated suite of monitoring, measuring, and verification technologies and assessment frameworks; and initiating a comprehensive education and outreach program. The groundwork is in place to provide an assessment of storage capabilities for CO_2 utilizing the resources found in the Partnership region (both geological and terrestrial sinks), that would complement the ongoing DOE research. Efforts are underway to showcase the architecture of the GIS framework and initial results for sources and sinks.

The region has a diverse array of geological formations that could provide storage options for carbon in one or more of its three states. Likewise, initial estimates of terrestrial sinks indicate a vast potential for increasing and maintaining soil C on forested, agricultural, and reclaimed lands. Both options include the potential for offsetting economic benefits to industry and society. Steps have been taken to assure that the GIS-based framework is consistent among types of sinks within the Big Sky Partnership area and with the efforts of other western DOE partnerships.

The Partnership recognizes the critical importance of measurement, monitoring, and verification technologies to support not only carbon trading but all policies and programs that DOE and other agencies may want to pursue in support of GHG mitigation. The efforts in developing and implementing MMV technologies for geological sequestration reflect this concern. Research is also underway to identify and validate best management practices for soil C in the Partnership region, and to design a risk/cost effectiveness framework to make comparative assessments of each viable sink, taking into account economic costs, offsetting benefits, scale of sequestration opportunities, spatial and time dimensions, environmental risks, and long-term viability. Scientifically sound information on MMV is critical for public acceptance of these technologies.

Deliverables include the “Carbon Sequestration: A Handbook,” and planning standards, protocols, and contracting options for terrestrial sequestration in the region. The deliverables are discussed in the following sections.

The Partnership has nearly completed state-level greenhouse gas (GHG) emission inventories for South Dakota, Montana, Wyoming, and Idaho. Major point sources are being located within the project GIS in order to help assess source-sink spatial relationships. The data and methodology to conduct an assessment of agricultural GHG sources and sink potential are being finalized.

Possible rangeland terrestrial sinks throughout the Big Sky project area have been identified and a literature review to support decisions for increasing carbon sequestration for areas identified as having potential as carbon sinks has been completed. Climatic potential, MLRA, and land tenure

were selected to spatially stratify rangeland cover types into easily identifiable areas where sequestration programs could potentially be initiated.

The education and outreach efforts have resulted in a comprehensive plan which serves as a guide for implementing the outreach activities under Phase I. The public website is established (www.bigskyco2.org), along with a Partnership logo. We have made presentations to stakeholders and policy makers, and made connections to other federal and state agencies concerned with GHG emissions, climate change, and efficient and environmentally-friendly energy production. In addition, the Partnership has plans for integration of our outreach efforts with the students, especially at the tribal colleges and at the universities involved in our Partnership. This includes collaboration with MSU and with the U.S.-Norway Summer School, extended outreach efforts at LANL and INEEL, and with the student section of the ASME. Finally, the Big Sky Partnership was involved in four key meetings in the 5th Quarter: the NETL Regional Carbon Sequestration Annual Program review (November, 2004); Western Fuels Symposium (October, 2004); U.S.-China Clean Energy Initiative (October 2004); and Geological Society of America meetings (October 2004).

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INTRODUCTION

The Big Sky Regional Carbon Sequestration Partnership was initially called the Northern Rockies and Great Plains Regional Carbon Sequestration Partnership. The proposed name change was initiated in December 2003, and has received DOE/NETL approval. The Big Sky Partnership, led by Montana State University, Bozeman, MT, seeks to: identify and catalogue CO_2 sources and promising geologic and terrestrial storage sites, develop a risk assessment and decision support framework to optimize the areas' carbon-storage portfolio, enhance market-based carbon-storage methods, identify and measure advanced greenhouse gas-measurement technologies to improve verification, support voluntary trading and stimulate economic development, call upon community leaders to define carbon-sequestration strategies, and create forums that involve the public. Idaho, Montana, Wyoming, and South Dakota are currently served by this Partnership that is comprised of 23 organizations and the Confederated Salish and Kootenai Tribes and the Nez Perce Tribe. Additional collaboration is being sought with neighboring states and Canada, and with other private and non-profit entities. To date, we are in the process of discussions for Phase II for several industrial partners including Puget Sound Energy, Energy Northwest, and Sempra Generation, Ducks Unlimited, and MT Rural Electric Co-ops. Montana Tech-Montana Bureau of Mines and Geology and the Idaho Carbon Sequestration Advisory Committee/Idaho Soil Conservation Commission are new members of the Partnership. Inland Northwest Research Alliance (INRA) and Western Governors' Association (WGA) have provided support for our Partnership since the onset and are members of the Partnership.

Original Partners include

Montana State University
South Dakota School of Mines & Technology
Texas A & M University
University of Idaho
The Sampson Group
EnTech Strategies, LLC
Environmental Financial Products
Nez Perce Tribe
Idaho National Engineering and Environmental Laboratory
Los Alamos National Laboratory
Montana Governor's Carbon Sequestration Working Group
National Carbon Offset Coalition

New Partners include

Idaho Carbon Sequestration Advisory Committee/ Idaho Soil Conservation Commission
Inland Northwest Research Alliance
Montana Tech-Montana Bureau of Mines and Geology
Western Governors' Association
Wyoming Carbon Sequestration Advisory Committee
Montana Department of Environmental Quality
Univ. of Wyoming Geographic Information Science Center
Univ. of Wyoming Enhanced Oil Recovery Institute
Univ. of Wyoming Ruckelshaus Institute Environment and Natural Resources
Montana Natural Resource Information System - Montana State Library
Montana GIS Services Bureau Information Technology Services
Unifield Engineering
Jackson Hole Center for Global Affairs

New Partners (in progress) include

Puget Sound Energy, Energy Northwest, Sempra Generation, Ducks Unlimited, and MT Rural Electric Co-ops

EXECUTIVE SUMMARY

For reporting purposes, the activities and results for the Big Sky Partnership are organized into four somewhat overlapping components or efforts, with the related tasks from the workplan noted by each:

- **Evaluation of sources and potential for carbon sequestration sinks**: Tasks 1,2,4,5,6,7
- **Development of GIS-based framework and carbon cyberinfrastructure**: Task 3
- **Advanced concepts for monitoring, measuring, and verification; implementation, carbon trading, and evaluation**: Tasks 9-20
- **Education and outreach efforts.** Tasks 8, 21-25

This report summarizes the activities for the fifth quarter of the Partnership. Deliverables include the Carbon Sequestration: A Handbook, and planning standards, protocols, and contracting options for terrestrial sequestration in the region. These protocols are applicable to other regions including the NW part of the US. It is designed to assist organizations, technicians, and landowners in understanding carbon sequestration projects and their role in local, state, regional, national, and international efforts to address the issue of climate change and GHG accumulations.

A presentation was made to the Wyoming Carbon Sequestration Advisory Committee, followed up with a roundtable discussion. Substantial progress is being made on the decision support tools for assessing the location of promising sites for pilots and participation of producers and landowners in terrestrial sequestration. South Dakota School of Mines and Technology have developed a working version of C-Lock to be used in pilot trades, and National Carbon Offset Coalition is working with Chicago climate exchange on background analysis and mechanisms for pilot trades.

The Big Sky Partnership was involved in four key meetings in the 5th Quarter: the NETL Regional Carbon Sequestration Annual Program review (November, 2004); Western Fuels Symposium (October, 2004); US-China Clean Energy Initiative (October 2004); and Geological Society of America meetings (October 2004). Related presentations by partnership PIs were also made to EPA workshop on modeling terrestrial soil carbon accumulation and at an USDA Conference on Carbon Opportunities in the northern Great Plains, and

<u>Evaluation of sources and sinks (Tasks 1, 2, 4, 5, 6, 7)</u>. Activities during the fifth performance period were focused on the methodologies for characterizing the potential for geological and terrestrial sequestration sinks, compilation of data, and identifying and cataloging industrial and agricultural GHG sources. The Partnership Geologic Sequestration and Geographical Information System (GIS) support has focused on the creation of a database structure for collection of geologic sequestration data and summarizing the types of infrastructure information that are being collected in Idaho, Montana, and contiguous geologic regions of Wyoming. The Partnership has developed a uniform strategy for assessing the mineralization trapping potential across rocks types. These capabilities are being used to determine the geologic sequestration potential in the Big Sky region. We have established a geological sink assessment approach and screening criteria, and nearing completion on compiling county-level data on tillage and land use for the terrestrial component. Both the geological and terrestrial component is resulting in data layers that will allow us to assess the suitability for carbon sequestration in the Big Sky Partnership region as well as the potential for locating future energy facilities in our region. A mid-quarter report on the overall GIS efforts will be made to DOE in mid-March.

For geological sinks, the potential for subsurface formation of carbon dioxide sequestration focused on solubility and mineralization trapping, and examined the technical feasibility, the time frame until implementation, and offsetting economic benefits. For the terrestrial sinks, the methodologies have been focusing on both technical and economic feasibility. Increasing soil C levels are dependent upon both the technical capacity of the soils to sequester and utilize additional carbon, and the incentives provided for landowners to change land use management practices. Activities to identify sources and assessment of transportation infrastructure are currently focused on identifying the state and federal databases and agencies, and addressing uncertainties inherent in matching/combining data sources.

Task 1. The Partnership's and South Dakota School of Mines and Technology's responsibilities included the preparation of major GHG source inventories for SD, MT and ID. These are reported in detail in our fourth quarter report. Idaho, Montana and South Dakota emitted approximately 11.7, 3.0 and 10.1 MMTCE, respectively, in 2002, or 9, 3 and 13 MTCE per capita. Although Idaho and Montana had larger industrial emissions, these were offset by increases in forest C uptake. Because a large proportion of Idaho's energy is produced by hydroelectric power, its largest category of emissions is imported electricity; the same is true in South Dakota. In Montana, petroleum refining and other heavy industry constitutes the largest GHG source category. Livestock-related GHG emissions also comprise 15% of South Dakota's GHG emissions.

The Texas A&M University research team has contributed to the Big Sky Partnership by identifying possible rangeland terrestrial sinks throughout the Big Sky project area and by providing a literature review to support decisions for increasing carbon sequestration for areas identified as having potential as carbon sinks. The completed library search includes over 1000 references and over 150 selected articles relating to terrestrial carbon sequestration, land use change, vegetation change, restoration, remote sensing and modeling. Included in this search is a summary of Natural Resources Conservation Service (NRCS) data for each of the Major Land Resource Areas (MLRAs) in the Big Sky Partnership area (Task 4). This information can be downloaded from http://cubes.tamu.edu/bigsky.

Climatic potential, MLRA, and land tenure were selected to spatially stratify rangeland cover types into easily identifiable areas where sequestration programs could potentially be initiated. Climatic potential for carbon sequestration was classified into four categories based on annual precipitation: no potential - less than 130 mm; low potential – 130 to 230 mm; moderate potential – 230 to 460 mm; and high potential – greater than 460 mm. Since programs will not likely be implemented on Federal lands, only Indian reservations and private or other non-federal lands are discussed. For each of the Big Sky states (Idaho, South Dakota, and Montana) non-federal land areas and Indian reservations classified as rangeland have been identified according to their potential for carbon sequestration. This information can be used to target areas that will likely have the greatest return on investments in rangeland carbon sequestration projects (Task 5).

<u>GIS-based efforts (Task 3).</u> The GIS activities have involved LANL and INEEL as well as the research universities, and are focusing on completing the database to meet the immediate Big Sky Partnership needs, and on planning for multi-partnership, NATCARB, DOE, and national coordination, in the context of the emerging national cyberinfrastructure. We also have a major effort to examine the potential for using GIS-based systems in outreach/education efforts of the Partnership, and the development of complimentary efforts with the West and Southwest carbon sequestration partnerships. An interim report will be issued in mid-March.

<u>Advanced Concepts (Tasks 9-20)</u>. The Partnership recognizes the critical importance of measurement, monitoring, and verification technologies to support not only carbon trading but all policies and programs that DOE and other agencies may want to pursue in support of GHG mitigation. For terrestrial sequestration, research is validating best management practices for soil C in the Partnership region. A team of researchers from MSU have been working in the field to obtain field scale carbon estimates for ground truthing simulation models and identifying BMPs. This is reported in this progress report.

Task 16. The objective of this task is to identify and validate best management practices (BMP), including no-till and intensive cropping, for soil C sequestration within the semi-arid Northern Great Plains. To meet this objective long-term (10 yr.) field experiments were established at six wheat farms in Montana during 2002. At each farm tilled and no-till systems are compared. Within both tillage systems, 50% (i.e. fallow-wheat) and 100% (i.e. pea-wheat) cropping intensities are also compared. Initial soil organic C levels were measured in all fields to a depth of 50-cm using accepted sampling and lab analysis protocols. During 2004, nitrous oxide flux measurements were collected at two locations to learn about seasonal patterns of nitrous oxide emissions. Results from 2004 revealed periods of modest N_2O emissions during May and June. No detectable emissions were observed after July. Importantly, cumulative nitrous oxide emissions did not differ among cropping systems treatments. This indicates that there may be no GHG offset of nitrous oxide due to the adoption of soil C-sequestering practices. In collateral studies, diffuse reflectance infrared spectroscopy (DRIS) is being evaluated to determine its application for carbon determination of intact soils cores (field moist and dried), crushed soil samples, and milled soil samples. The objective is to evaluate whether DRIS methods can provide reliable and accurate estimates of soil carbon. To date, over 1000 soil samples have been scanned for this assessment. Statistical models are currently being developed that will enable the rapid determination of soil carbon levels using DRIS methods. Once in place these models will provide a low-cost alternative to expensive and labor intensive lab procedures currently being used for soil carbon analyses.

Task 19. As part of Task 19, we addressed problems in verifying changes in carbon stocks associated with the high cost and time involved with repeated sampling and analysis. The objective was to demonstrate the practicality of near infrared reflectance spectroscopy (NIR) as a technique for reducing the cost and time required for sample analysis. This section was based on our CASMGS 2003 report, which demonstrates a technique for identifying spectrally unique samples for laboratory analysis and equation development, and compares the accuracy and cost between NIR techniques and standard laboratory procedures. We also presented two general soil carbon equations built on a diverse assortment of soils collected throughout the country as well as the prediction results for several carbon fractions. This information was provided in the fourth quarter report and is also available at the Texas A&M web site: http://cubes.tamu.edu/bigsky.

Monitoring and Measurement Verification (MMV) activities, as they pertain to geological (and terrestrial) sinks, include some initial assessment of the state of the art for technologies that have a high likelihood of being mature enough to be applicable in Phase II small scale applications, and designing a risk/cost effectiveness framework to make comparative assessments of each viable sink, taking into account economic costs, offsetting benefits, scale of sequestration opportunities, spatial and time dimensions, environmental risks, and long-term viability. In conjunction with the GIS efforts and ongoing research at LANL, MSU, SDSMT, and INEEL, the Partnership is developing a well-integrated ensemble of diagnostics for MMV at each potential geological sequestration site, and a protocol for the terrestrial sequestration areas.

Regulatory and compliance research is being coordinated with the State agencies and with the IOGCC. Susan Capalbo is part of the IOGCC task force and met in Chicago in late August, 2004. A final report of the task force was issued in December 2004, and is under review. Also, the Montana Department of Environmental Quality is partnering with the Big Sky Partnership to provide detailed information on the permitting process for power plants in Montana.

Tasks 11, 13, 14. During the reporting period the National Carbon Offset Coalition (NCOC) continued to expand the number and diversity of participants in its landowner/emitter advisory committee. Meetings were held with numerous nonprofit and for-profit organizations related to energy or the environment. The final draft of the NCOC Carbon Sequestration Project Planning Handbook and key contracting and membership documents were completed. They are available by registering at http://www.ncoc.us.

The Agroforestry work being conducted by Dr. Brandle of the University of Nebraska is starting to be finalized. Initial proposals and data spread sheets covering six thousand acres of proposed reforestation and afforestation projects on the Nez Perce reservation were forwarded to Nat Source this quarter. The submission of the first data set is intended to allow NatSource to determine if the proposed data format is adequate for entry onto the market as part of a National NCOC Tribal portfolio. At the same time the Nez Perce are working with the NCOC to determine if the draft NCOC listing agreement meets the tribes contracting requirements

Education and Outreach (Tasks 8, 21-25). The primary goal of the Education and Outreach efforts is to increase awareness, understanding, and public acceptance of carbon sequestration while building support for the efforts of the Partnership. The activities this period include participation in outreach teleconference calls, updates to the website, development of handout materials for many of the conferences, and planning and designing outreach and education materials in efforts by NCOC.

EXPERIMENTAL SECTION

Task 1: GHG sources

The US EPA's Emissions Inventory Improvement Program (EIIP VIII) (USEPA 1996a and 2003a) provided the primary inventory methodology. The most recent data sources were used for each category, ranging from 1997 (most recent Census of Agriculture data) to 2002. Therefore the aggregate emissions values may be regarded as composite estimates.

CO_2, CH_4 and N_2O emissions resulting from the use of fossil energy were estimated based on the Energy Information Administration's State Energy Annual 2002 reports (USDOE-EIA, 2002a). These provide detailed state-level breakdowns of fuel consumption by sector (residential, commercial, industrial, utility and transportation) and fuel type. These reports do not provide estimates of exported electricity or bunker fuels, so these categories are not included in the inventory. Standard emission factors, as described in EIIP VIII, were applied to all fuels.

CH_4 emissions from oil production and transport were estimated based on state production statistics in the Petroleum Supply Annual (USDOE-EIA, 2002b). Only Montana has significant oil production, centered in its western oil fields, although a small amount is produced in South Dakota. Similarly, CH_4 emissions from natural gas production and transport were estimated based on processing information from the Natural Gas Annual (USDOE-EIA, 2002c) the Oil and Gas Journal (v.101[n.22-25], 2002) and pipeline statistics obtained from the Office of Pipeline Safety (USDOT-OPS, 2002). Montana has 4333 gas wells and 5 gas processing facilities, South Dakota 68 wells and Idaho has none.

<u>GHG emissions from industrial processes:</u>

Facility-level information about industrial processes that emit CO_2 and non-CO_2 GHGs was essentially unavailable from state or corporate sources. However, process information collected from permitted entities was available for some facilities through the EPA's PCS permit database for water discharges (USEPA, 2002), and the NAAQS National Emission Trends Inventory 1996 for air releases (USEPA, 1996b). The South Dakota DENR made 2001 process data available for permitted industrial facilities in South Dakota; comparable data were not available from other states.

The largest industrial sources of non-energy GHGs in the region are cement and lime manufacture. According to USGS mine and processing plant location data, South Dakota has one cement plant, Montana has 2 and Idaho has one (USGS, 1997). CO_2 emissions estimates were based on 1996 process data from the NAAQS and 2001 data from the SD DENR. An estimate of CO_2 emissions from lime calcination in the 8 lime kilns in our region was provide by Michael Miller of the USGS (personal communication).

CO_2, CH_4, N_2O and PFCs are generated during aluminum processing and manufacture. There is a single aluminum plant in the region, located in Montana. Production statistics were estimated based on information in the 2002 Aluminum Yearbook (Plunkert, 2002).

N_2O is generated during nitric acid manufacture at a single facility in Idaho; emissions were estimated based on process data from the 1996 NAAQS database. CO_2 generated by soda ash consumption and CO_2 manufacture, HFCs and PFCs generated during semiconductor manufacture, and SF_6 released from electrical transmission and distribution equipment, were all estimated using national production statistics, state population numbers from the 2000 Census and default emission factors provided in the EIIP methodology. HCFC-22, adipic acid and SF6 from magnesium production are not significant GHG sources in these states.

<u>GHGs from municipal and industrial waste:</u>

Municipal landfills that do not practice landfill gas recovery are significant aggregate sources of CH_4. Landfill emissions estimates were based on state population data since 1960, and state-level waste-in-place projections derived from default per-capita landfill waste data provided in the EIIP, along with default composition factors and fractions in large vs. small landfills were obtained from the EIIP. The EPA Landfill Methane Outreach Program (USEPA, 2003b) provides data regarding participating landfills in each state. Very small amounts of landfill methane were flared or recovered in Idaho and Montana as of 2002, and none in South Dakota. The EIIP also provides emission factors for municipal waste incineration facilities, of which there are 4 listed by the NAAQS database in Montana and 3 in South Dakota.

Anaerobic decomposition in municipal and industrial wastewater can generate CH_4 and N20. Because of uneven discharge data availability, we estimated emissions from municipal wastewater based on 2002 state population data and default factors from the EIIP. The EIIP also provided regional average protein consumption estimates, necessary for N_2O estimation.

Limited facility-level industrial wastewater discharge data are available through the EPA Permit Compliance System database of NPDES permits (USEPA, 2002.) The EIIP provides default emission factors for three major categories of industries that generate wastewater enriched in organic constituents: fruit and vegetable processing, meat and poultry, and the pulp and paper industry. Corn-based ethanol production is also an important industry in this region, particularly in South Dakota; however, the EPA has not derived default emission factors for ethanol production. Pending better guidance, we applied the default emission factors for pulp plants to those ethanol plants which had provided discharge data to the NPDES system.

<u>GHGs from land management and livestock:</u>

By far the most important source of GHGs in agriculture is livestock. In 2001 South Dakota and Montana ranked 6th and 9th, respectively, in overall cattle production among US states. Livestock-derived GHG emissions in South Dakota are exceeded only by emissions from the transportation sector. Enteric fermentation by ruminants is the largest source of agricultural CH_4, but anaerobic management of livestock and poultry manure also produces important amounts of CH_4 and N_2O.

We used county-level livestock population data from the 1997 Census of Agriculture (USDA-NASS, 1997), projected to 2001, for the various livestock commodities (cattle, poultry, hogs). Census categories were adjusted to correspond to those used in the USDA annual reports referenced in the EIIP methodology, which provided management and emission factors. County-level estimates of CH_4 and N_2O emissions for cattle, hogs, poultry, horses, mules, goats and sheep were aggregated to the state level.

Large confined feeding operations (CAFOs) have been classified as point sources of water pollution and are significant CH_4 sources. Because of limited facility data availability, weighted EIIP regional emission factors, which account for feed quality and likely manure management systems among the different livestock categories, were used to estimate CH_4 and N_2O releases from enteric fermentation and anaerobic manure management. None of the three Partnership states had any operational manure methane recovery systems in place as of 2003.

Burning of crop residues generates CO_2, CH_4 and N_2O; however, because the source is of recent biogenic origin, the CO_2 is not counted in the GHG source inventory. CH_4 and N_2O releases were estimated based on EIIP default factors and USDA crop production statistics for 2002 (USDA-NASS, 2002).

Forests can be GHG sources or sinks depending on management. We used estimates of forest stock changes from 1992-1997 and the consequent GHG fluxes derived by Birdsey and Lewis (2002). This report provides state-level estimates of forest stock changes based on USFS FIA (Forest Inventory and Analysis) data and modeling. It also includes estimates of carbon storage in persistent wood products and landfills. Methods documented in the report are consistent with those outlined for the Stock Approach in the EIIP.

Changes in soil C due to agricultural management will be estimated using soil, crop and management data compiled for the C-Lock program. Climate, soil and management files necessary for Century modeling have been developed preliminary to conducting statewide agricultural source/sink potential estimates for Idaho, Montana and South Dakota. Historical management questionnaires sent out to Montana FSA agents to help refine Century management schedules have to date resulted in a 35% response rate. Reminders have been sent in an attempt to encourage a higher rate of response.

Task 1 and 2: Geological sequestration

This section describes the efforts that have been initiated that supports the objectives of the Partnership under both Task 1 (1.2) and Task 2. Activities during the second, third, and fourth performance periods continue with the development of the methodology for characterizing the potential of subsurface formation for carbon dioxide sequestration via solubility and mineralization trapping. As noted in the first quarterly report, the approach relies upon the use of bulk whole rock chemical analyses for formation geomedia. (See references from the first report.)

The Big Sky Partnership is securing public domain information about potential geologic carbon sequestration sites, and working with industry representatives. For regional sources, we have completed the compilation of state-level aggregate data regarding emissions from fossil fuel consumption, using EIA state data. Facility-level data for energy utilities and selected industries have been compiled for South Dakota, and this will serve as a template for the other states in our Partnership. Data on CH_4 from stationary and mobile combustion sources, oil and gas production, enteric fermentation and manure management, burning of agricultural wastes, and wastewater treatment, as well as data on N_2O emissions from similar sources have been compiled for South Dakota. This information will be incorporated into the GIS database for the Big Sky Partnership.

During the third performance period the overall approach to conduct assessments of geologic carbon sequestration potential was further refined. We are using a two-phased approach for the assessment of regional geologic carbon dioxide sinks. The first phase is the identification of geologic 'plays'[1] that are screened against carbon dioxide injectability and capacity criteria. The screening eliminates plays that do meet minimum criteria. The remaining plays will be subjected to a detailed analysis to evaluate (using numerical hydrogeochemical modeling) their carbon dioxide trapping potential. In addition, an economic and regulatory feasibility analysis will be conducted. The results of the screening and analysis will be incorporated into a GIS database.

Also under the geological sequestration component of the Partnership work, we are reviewing geophysical methods for monitoring the pre-injection and injection (i.e., production) phases of subsurface carbon sequestration in deep reservoirs. We are reviewing methods that are applicable for (a) single-well testing as would occur with a pilot project of small scale and could occur in a larger production-scale project; (b) cross-hole testing including tomographic and time-lapse tomographic methods; and (c) passive and active surface seismic monitoring or testing that can track the presence and movement of supercritical carbon dioxide.

We are also continuing to review published information on basins in the Big Sky Carbon Sequestration Partnership region. As a first step in evaluation for a familiar basin, we have reviewed published information on the western Snake River Plain as a potential geologic province for carbon sequestration and we have determined that the patchy nature of both the fluvio-lacustrine environments and the potential cap rocks on them in the basin make this province quite risky for large-scale, deep-reservoir, geologic carbon sequestration.

A meeting with researchers at Los Alamos National Laboratory (LANL) was held to discuss the availability of empirically-based reaction kinetics for carbon dioxide facilitated weathering of geologic material. This meeting resulted in an a collaborative effort to advance the state of understanding regarding carbon dioxide enhanced weathering of geologic material in potential sequestration sites. The research group at Los Alamos has developed an experimental technique through which reaction kinetics can be derived for carbon dioxide facilitated weathering of geologic materials. The application of this data to field scale sequestration modeling effort currently in progress by the Big Sky Partnership could prove invaluable to a Phase II to field deployment.

[1] The fundamental geologic unit used in the 1995 National Oil and Gas Assessment was the 'play', which is defined as a set of known or postulated oil and or gas accumulations sharing similar geologic, geographic, and temporal properties, such as source rock, migration pathways, timing, trapping mechanism, and hydrocarbon type.

As stated in the last quarterly report, efforts have been continued to identify sources and databases containing pertinent information for the characterization of each of the plays and information relative to the screening criteria. There are two primary databases containing much of the information needed for Wyoming and Montana, 1) The Wyoming Oil and Gas Conservation Commission web site and 2) Montana Board of Oil and Gas Conservation web site. Screening criteria parameters expected to be collected from these agencies include depth, pressure, temperature, fluid properties, unit thickness, salinity, pH, porosity, permeability, and gas content. Efforts have begun in extracting this information and organizing it into a GIS database that will show the spatial distribution of these characteristics. Other research activities are being conducted to gather the rock type and whole rock chemistry relative to each of the geologic formations within each of the plays.

During the fourth performance period, work has continued on collecting geologic properties and characteristics for the region and entering this information into an Access data base. We have discretized the Big Sky Partnership region (including Wyoming) into 10 provinces and 111 plays in accordance with the 1995 National Assessment of United States Oil and Gas Resources conducted by the U.S. Geological Survey. The effort has included incorporating data from: 1) State of Wyoming Oil & Gas Conservation Commission, 2) Montana Board of Oil & Gas Conservation, and 3) Montana Geological Society. The data existed both as electronic databases and hard copy information. All hard copy information was entered into the data base twice, by two different individuals, the resulting files compared, and any discrepancies identified and corrected. The resultant database includes properties that will be used to calculate the size of the various reservoirs and the potential volumes of carbon dioxide that could be contained. Our data collection activities are focused on ultimately developing a database management system coordinated with GIS capabilities to support more-detailed analysis of reservoir potential based on well, stratigraphic, engineering, and production information available from state agency sources and other sources. We have also refined our assessment approach to allow consideration of the role of ferrous iron on the mineral trapping carbon dioxide and applied our assessment approach to the volcanic basins in southwest Idaho.

We are reviewing geophysical methods for monitoring the pre-injection and injection (i.e., production) phases of subsurface carbon sequestration in deep reservoirs with an eye towards methods that are applicable for (a) single-well testing as would occur with a pilot project of small scale and could occur in a larger production-scale project; (b) cross-hole testing including tomographic and time-lapse tomographic methods; and (c) passive and active surface seismic monitoring or testing that can track the presence and movement of supercritical carbon dioxide.

Geographic information system (GIS) work performed during the last quarter included developing a method for extracting formation information from the geologic properties and characteristics captured in various oil and gas databases from Wyoming and Montana. The geologic group is in the midst of compiling well log information that contains formation names, depths, temperatures and associated water chemistry into one comprehensive database for each of the states covered by the Partnership. As mentioned previously, the region has been discretized into 111 plays. The challenge for the GIS group is to connect the formation and chemistry data with the appropriate plays since the individual state databases do not make that distinction.

The method for connecting this data was accomplished by developing point layers representing well locations for each formation (see Figure 1). The point layers are then used to develop surfaces via kriging. Polygons representing the different plays were then used to clip out intersecting areas from the formations. Once the plays and formations were joined, the associated data from the database for each well was joined with the appropriate play.

As the final database for each of the states is completed, the method described above will be applied and the resulting layers will be provided to the geologists for screening. Screening at the play level and not the field (fields are smaller regions within each play) level, the amount of information that has to be collected is reduced significantly. Once the plays of interest are screened out, more detailed information at the field level will be collected and a similar method for connecting and the data will be performed. A more in depth discussion of these plays are included in the Appendix to this report.

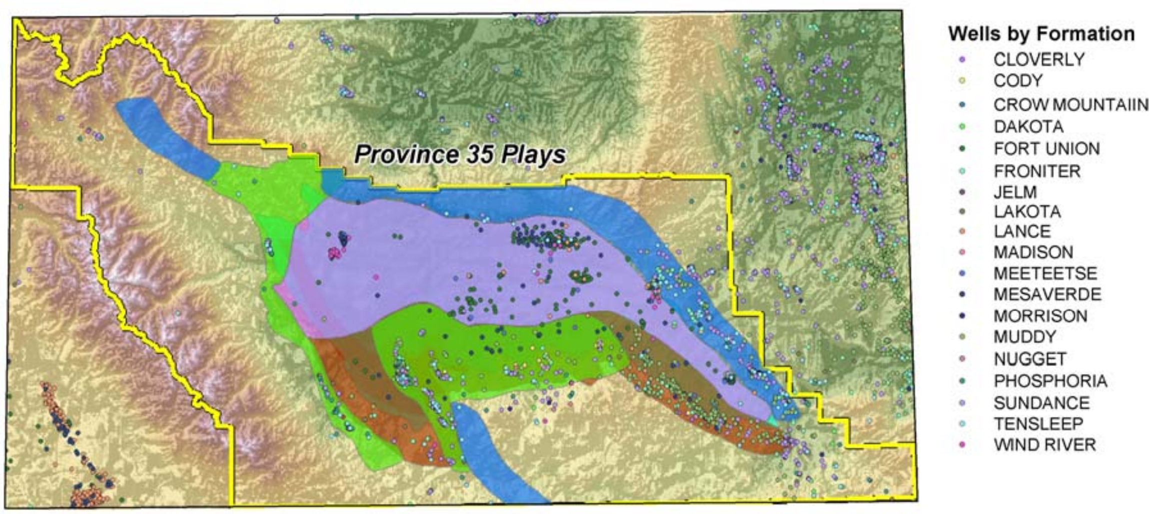


Figure 1. Well locations by formation

Tasks 4 and 5: Terrestrial sequestration

A third area of work has been to evaluate and verify the soil C potentials with the estimates forthcoming from the Century simulation model. During the second performance period, the results of the terrestrial sinks assessment for South Dakota has been completed using the SSURGO soil texture grids and is being summarized; the evaluation of soil C potential on croplands in Montana is currently underway (see related material below). We have completed the SSURGO soil texture grids for Montana and Idaho; the CLIMATE data compilation is in progress.

For forested lands, the USFS data on forest carbon stocks by state, by major species is available and ready to be incorporated into the GIS database. We have been compiling NLDC time series data to determine forest area change, for use in assessing forest sink potential.

We are integrating soil and climate databases with our econometric simulation models to estimate soil carbon trajectories at the MLRA level in Montana, and to test the impact of alternative management scenarios and carbon policy scenarios on the cost of sequestering soil C and on the size of the terrestrial sinks. During the second performance period we have developed a yield based framework for using US Ag census data to predict land use changes, soil carbon changes under alternative price and climate change scenarios. The third performance period focuses on modifying and validating these empirical results. Results were presented at the May DOE carbon sequestration meeting and will be presented at the INRA workshop in September 2004.

Rangelands comprise a sizeable portion of the land resources in our Partnership region and are of critical importance to our neighboring states. Preliminary estimates suggest that rangelands can store up to an additional 0.3 mg C/ha/yr and restores grasslands storing nearly twice that amount. Possible options that have been identified for rangeland carbon storage to date include juniper invasion control, mesquite invasion, and cheatgrass control. These options along with baseline estimates of soil C levels at the MLRA level are being compiled by Texas A&M colleagues for inclusion with the GIS terrestrial sink inventory.

In order to estimate areas of potential carbon sequestration or loss, data for use in a GIS is being acquired. This data includes 1990's Landsat TM data (30 m resolution) that identifies 21 classes of land cover types. For rangelands, land cover types designated as shrublands, grassland/ herbaceous, and pasture/hay are being considered. These classes will be intersected with MLRAs to define acres within each MLRA and linked with other datasets such as STATSGO soil and MODIS net primary productivity.

The terrestrial research component for rangeland is nearly complete. A summary of Natural Resources Conservation Service (NRCS) data for each of the Major Land Resource Areas (MLRAs) in the Big Sky Partnership area is included. The experimental plan includes a data collection and literature review and an evaluation of the terrestrial sink potential. These are discussed below.

A general library and Internet search was conducted primarily using Current Contents and Google. Relevant articles were entered into an EndNote database. The complete bibliography was exported into a word document that is linked to selected PDF articles and recorded on a CD. NRCS data for landuse, potential vegetation, soil, water, elevation, precipitation, temperature, and irrigation for each MLRA in the Partnership were summarized in an Excel spreadsheet

The results of a literature search of over 1000 entrees have already been submitted in an earlier report. A revised literature search containing over 800 references linked to over 150 selected articles is being mailed as a CD. Many of the less relevant articles were removed from the original search and selected articles were linked to the bibliography which acts as an index. A summary of NRCS data for each MLRA in the Partnership is presented in Appendix C. The results of this literature review can be used to support decisions for increasing carbon sequestration for areas identified as having potential as carbon sinks. (See http://cubes.tamu.edu/bigsky)

Climatic potential, MLRA, and land tenure were selected to spatially stratify rangeland cover types into easily identifiable areas where sequestration programs could potentially be initiated. Climatic potential for carbon sequestration was classified into four categories based on annual precipitation: no potential - less than 130 mm; low potential – 130 to 230 mm; moderate potential – 230 to 460 mm; and high potential – greater than 460 mm. Since programs will not likely be implemented on Federal lands, only Indian reservations and private or other non-federal lands are discussed. For each of the Big Sky states (Idaho, South Dakota, and Montana) non-federal land areas and Indian reservations classified as rangeland have been identified according to their potential for carbon sequestration. This information can be used to target areas that will likely have the greatest return on investments in rangeland carbon sequestration projects

A GIS approach was used to identify possible rangeland terrestrial sinks throughout the Big Sky project area. The objective was to spatially identify potential rangeland terrestrial sinks with respect to climatic potential, MLRA (as designated by the NRCS), and by land tenure (federal, private/non-federal, and Indian reservations).

Spatial cross-indexing was used to identify rangeland vegetation cover types that would have the potential for sequestration of carbon. Three major categories of cross-indexing were selected to spatially stratify rangeland cover types into easily identifiable areas where sequestration programs could be initiated. The categories of spatial cross-indexing selected included climatic potential, MLRA, and land tenure. Each of these categories and the associated spatial data used in the analysis will be described below. National land cover data from the early 1990's served as the basis for identifying rangeland land cover. This dataset and the rangeland cover types will also be described below.

Climatic Potential. To assess climatic potential for carbon sequestration, long-term precipitation was classified into the following categories:

- No Potential - Less than 130 mm (~5 inches) of annual precipitation
- Low potential – 130 to 230 mm (~5 to 9 inches) of annual precipitation
- Moderate potential – 230 to 460 mm (~9 to 18 inches) of annual precipitation
- High potential – Greater than 460 mm (18 inches) of annual precipitation

These categories were chosen in collaboration with Dr. Joel Brown of USDA/NRCS to reflect the climatic potential for carbon sequestration and/or interventions to promote carbon sequestration on rangelands. For the No Potential category, rainfall amounts of less than 130 mm would be inadequate for short-term (<10 years) sequestration goals and also inadequate for interventions such as revegetation. The remaining categories represent increasing potential with areas having annual precipitation amounts greater than 460 mm having the greatest potential for carbon sequestration on rangelands.

The Parameter-elevation Regressions on Independent Slopes Model (PRISM) (http://www.ocs.orst.edu/prism/) long-term average annual (1970 to 2000) precipitation data (SCAS 2004) was used to spatially represent the climatic potential categories. The PRISM data is a gridded data set of total annual precipitation with a spatial resolution of approximately 4 km. PRISM is currently used by NRCS for their climate mapping (http://www.ncgc.nrcs.usda.gov/branch/gdb/products/climate/index.html). Using the Spatial Analyst extension in ArcView 8.3, the gridded data were classified into the climatic categories described above and then converted to vector format (i.e., an ArcView shapefile). Converting the data to vector format allowed delineation of unique polygons of the climate potential categories. This was done for each of the three states (Idaho, Montana, and South Dakota) in the Big Sky study area (Figure 1, Figure 2, and Figure 3, respectively). (These figures can be found in Appendix C.)

Major Land Resource Areas. The NRCS defines a Major Land Resource Areas (MLRA) as "a geographic area, usually several thousand acres in extent, that is characterized by a particular pattern of soils, climate, water resources, land uses, and type of farming" (http://www.nrcs.usda.gov/ technical/land/meta/m2147.html). MLRA's form the basis of NRCS planning at national, state and regional levels. Since the NRCS will likely be a primary implementer of carbon sequestration strategies, stratification of rangelands by MLRA can provide a useful cross-index for identifying areas of high potential.

For this analysis, the MLRA boundary coverage was downloaded (ftp://fc.sc.egov.usda.gov/NHQ/pub/land/arc_export/us48mlra.e00.zip) and converted to an ArcView shapefile. Using the NRCS state boundary coverage, the MLRAs within Idaho, Montana, and South Dakota were clipped from the 48 state coverage using the clip algorithm in ArcView 8.3. The resulting state MLRA maps were saved as individual shapefiles and used in the spatial analysis (Figure 4, Figure 5, and Figure 6, respectively). (See Appendix C.)

Land Tenure. Since private or non-federal land is where the majority of carbon sequestration programs are likely to be targeted, it will be important to identify the land tenure within the study area. This will assist in identifying areas that will have the greatest potential impact in carbon sequestration. To accomplish in the spatial analysis, the Federal Lands and Indian Reservations of the United States coverage was acquired (http://nationalatlas.gov/fedlandsm.html). As was done with the MLRA coverage, the individual states in the study area were extracted from the Federal Lands and Indian Reservations coverage using the clip algorithm in ArcView 8.3. The resulting map layers for Idaho, Montana, and South Dakota were saved as shapefiles and used in the spatial analysis (Figure 7, Figure 8, and Figure 9, respectively). (See Appendix C.)

Rangeland Land Cover. The 1992 National Land Cover Data (NLCD) (Vogelmann et al. 2001) was used to identify land area as rangeland. The NLCD was derived from the early to mid-1990s Landsat Thematic Mapper satellite data. Using an unsupervised clustering algorithm, land areas were classified into a 21-class land cover scheme (http://landcover.usgs.gov/classes.asp) applied consistently over the United States. The spatial resolution of the data is 30 meters. For this analysis, the following classes were selected as rangeland land cover types:

- Shrublands
- Grasslands/Herbaceous
- Pasture/Hay

National land cover data was distributed as TIFF images for each state. Using the Spatial Analyst extension in ArcView 8.3, the TIFF images were converted to GRID format. These grids were reclassified to extract the rangeland cover types described above. The resulting map layers for Idaho, Montana, and South Dakota (Figure 10, Figure 11, and Figure 12, respectively) were then used in the cross-tabulation analysis. (See Appendix C.)

Spatial Cross Tabulation. Within the GIS, unique polygons of climatic potential, MLRA, and land tenure were generated by intersecting these layers for each of the states in the study area. The resulting map layers (Figure 13, Figure 14, and Figure 15 – see Appendix C) were then used to cross-tabulate land area for each of the rangeland cover types by unique climatic potential, MLRA, and land tenure category. This was done using the Tabulate Areas algorithm in ArcView 3.3. For the purposes of this analysis, any land that did not have a classification of Federal or Indian reservations were given the class designation of private or other non-federal land tenure designation.

Tasks 16: Terrestrial sequestration, pilot sites and simulation models

Work is also proceeding on the terrestrial sink potential for croplands in the Big Sky region, using both pilot, field-scale methods and larger simulation type models for quantifying rates of change in soil C levels. Field-scale studies were established at six farm fields in the Golden Triangle in north central Montana, and researchers have been working on a weekly basis with producers in the study sites with field management and soil carbon sampling. The purpose of these studies is to determine the effect of cropping intensity (annual vs. alternate year) and tillage (conventional vs. no-till) on soil C levels across different soil types and terrains.

Efforts have focused on carbon measurements using the following experimental plan: At each farm, a field of 32 ha was divided into four strips (8 ha) representing the following cropping/tillage systems: traditional summer-fallow – wheat; no till chemical fallow – wheat; conventional tillage pea-wheat; and no till pea-wheat. Within each strip four sites were identified for sampling/monitoring of soil carbon changes over time. The sites (total of 16 per farm) were georeferenced via GPS. Soil samples are collected on a two-year time interval beginning with the initial background sampling in the Fall of 2002. A more detailed description of the experimental plan was included in the second quarterly report.

Field-scale studies were established at 6 farm fields in the Golden Triangle in north central Montana (Figure 2). The purpose of these studies is to determine the effect of cropping intensity (annual vs. alternate year) and tillage (conventional vs. no-till) on soil C levels across different soil types and terrains. At each farm, a field of 32 ha was divided into four strips (8 ha) representing the following cropping/tillage systems: traditional summer-fallow – wheat; no till chemical fallow – wheat; conventional tillage pea-wheat; and no till pea-wheat. Within each strip four sites were identified for sampling/monitoring of soil carbon changes over time. The sites (total of 16 per farm) were georeferenced via GPS and buried metal bolts. The sampling scheme incorporates 5 cores around a center-point forming at star-shaped pattern (Figure 3). The soil sampling scheme was adapted from the Canadian Prairie Soil Carbon Balance Project, and sample preparation and C analysis procedures were adapted from (Conant and Paustian, 2002).At sampling, each core is divided into three depths of 0-10, 10-20, and 20-50 cm and the core-depths surrounding each center point are bulked into a single sample. Soil samples were collected during the Fall of 2002 and 2004. In the future samples will be collected on a two-year time interval for the duration of the study (10 years).

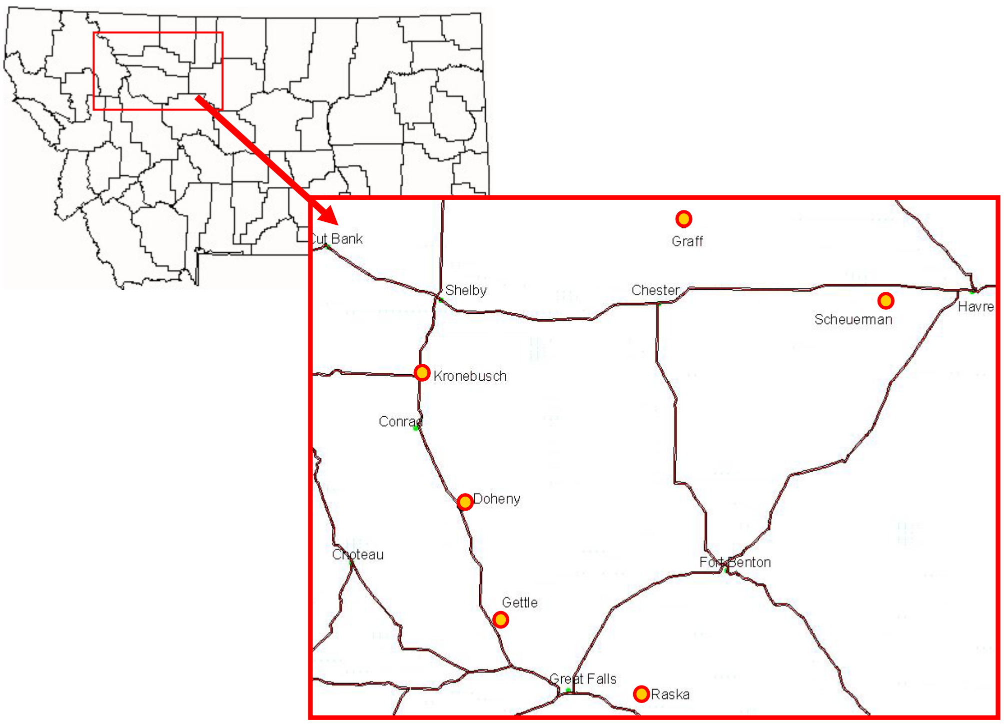


Figure 2. Locations of six farms in north central Montana for the on-farm cropping system comparisons.

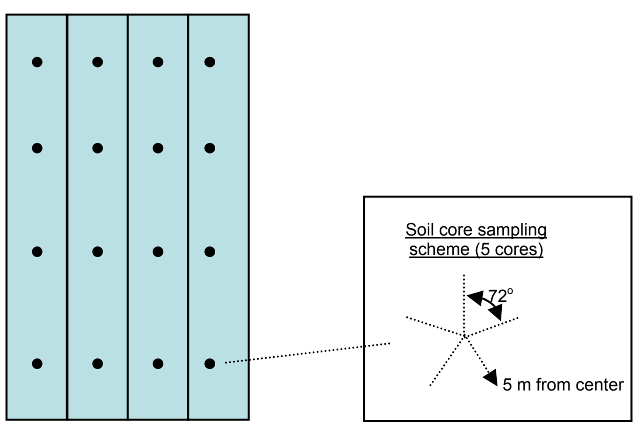


Figure 3. Hypothetical sampling scheme for long-term soil carbon studies.

Soil samples collected from this study were dried to 40^o C then ground to pass through a 2 mm sieve. Subsamples were removed and ground to a fine powder using a ball mill. Total carbon analyses were performed using an automated dry combustion analyzer or Leco CNS-2000 analyzer (Leco Corporation, Saint Joseph, MI). The inorganic carbon fraction was determined using the procedure of Sherrod, et al. (2002). Organic carbon was then calculated by difference, i.e. organic C = total C – inorganic C. Nitrous oxide samples were collected using vented chamber techniques (Figure 4). Vented soil chambers covering a 1000 cm^2 area and with a 10 cm head-space were inserted between the crop rows. The protocol used for collecting and processing the gas samples was similar to one described by Lemke et al. (1999). Nitrous oxide flux was estimated from the concentration change in the chamber headspace over a predetermined collection period (e.g. 30 minutes to 1 hr). Samples were drawn from the headspace using a 20 to 30 mL syringe and then transferred to a pre-evacuated 13 ml exetainer. The concentration of N_2O in the sample exetainer was determined using a gas chromatograph equipped with an electron capture detector.

Intact core, crushed (< 2 mm), and ball-milled soil samples were scanned using an ASD "Fieldspec Pro FR" VNIR spectroradiometer (Analytical Spectral Devices, Boulder, CO). This spectroradiometer has a spectral range of 350-2500 nm, 2 nm sampling resolution and spectral resolution of 3 nm at 700 nm and 10 nm at 1400 and 2100 nm. Soils were scanned from below with a "mug lamp" foreoptic and white light source, a borosilicate bottom glass "puck" to hold samples and a Spectralon® panel for white referencing. Four and two composite scans (consisting of 10 internally averaged scans of 100 ms each) were obtained for the crushed and milled samples respectively, with a 90^o rotation between each.

Figure 4. Nitrous oxide gas samples are collected using a vented chamber made of plexiglass. Without cover (left). With cover (right)

Efforts are nearing completion with the compilation of information relevant to point and terrestrial area sources of GHGs in MT and integration into a GIS framework as appropriate. INEEL/UI/BSU are coordinating efforts to collect spatially-referenced data for geological formations. The Partnership is assembling soil, climate, crop and land use databases and integrating these data with the C-Lock system developed by SDSMT and with economic data on land use practices and the economic frameworks developed at MSU for quantifying soil carbon sequestration potential. Furthermore, these efforts are being coordinated with the other Western partnerships.

Tasks 9-20: Advanced concepts

Task 9. Advanced concept activities this period include designing integrated measurement, monitoring, and verification for geological and terrestrial sinks, regulatory protocols, and risk assessment/tradeoff frameworks. Measurement, monitoring, and verification activities, and capture technologies, are complementing ongoing research at the labs and research institutions; to date we have assessed the focus and extent of these research efforts. The direction of the MMV research was discussed in detail the first quarterly report.

Some of the ongoing efforts at LANL on Advanced concepts include an initial examination of various mineralization concepts. These included:

1) Industrial Mineralization
2) In Situ Mineralization
3) Brine Mineralization
4) Carbonate Dissolution
5) Trona Carbonation

All these concepts fall into the category of advanced concepts and all were found to require considerable further research and development work before they could be implemented on a practical scale and/or their long-term storage capabilities could be fully understood.

The reaction rates for industrial mineralization of CO_2 are still too slow to prove to be an effective option. Although rates that can be obtained today are at the margins of becoming acceptable, achieving these rates involves still requires large (and costly) energy inputs that would prove uneconomical. New ideas and approaches are still being developed and pursued. It is believed that with further R&D, a viable approach can be found.

The reaction rates for in-situ mineralization tend to be even lower than in the industrial mineralization case as one has very limited or no ability to achieve the most favorable operating conditions. Nonetheless, given the virtually limitless source of resources available in the region, further examination of this approach is still warranted.

Brine mineralization is appealing from a conceptual point of view especially since huge quantities of brine are available deep underground. However, the brines tend to be dominated by non reactive salts and only a very small fraction of the dissolved minerals are likely to be able to be transformed into stable carbonates without the addition of other costly chemicals. The use of any reactive chemicals other than catalysts are likely to ruled out when one considers the amount of CO_2 that must be disposed of. Isolated pockets of more favorable brines could nonetheless be found.

The dissolution of calcium carbonate (limestone) in carbonic acid to form a dissolved calcium bicarbonate solution that holds down additional CO_2 has been discussed in the literature. This is a process involved in the formation of limestone caves. However, the long-term fate of the temporarily dissolved CO_2 is still uncertain and vast amounts of water would be required unless one were able to maintain high CO_2 pressure throughout the duration of the sequestration period.

Trona carbonation is a sodium-based version of the above process and would allow one to store the CO_2 in the mineral form of solid sodium bicarbonate. It has the advantage of requiring far lower CO_2 pressures if the system were damp and concentrated, and no CO_2 pressure if kept dry. Extensive deposits of trona exist in Wyoming, which would allow extensive storage for the region. At the same time, the deposits are too small to provide a long-term national solution.

Measurement, Monitoring and Verification (MMV) are essential functions of a successful Carbon Sequestration Program. MMV involves the implementation and deployment of various integrated measurement diagnostics that monitor geological and terrestrial sequestration sites and verify the veracity of the site's performance. A successful MMV program will require an ensemble of integrated diagnostics that monitor all aspects of sequestration as well as verify the accuracy of the diagnostics employed.

We are in the process of completing a gap analysis that will compare and contrast the current state of likely MMV diagnostics with the likely levels of CO2 that need to be monitored. The first step in this process is to estimate the concentration of CO2 one needs to monitor giving a generic geological or terrestrial sequestration scenario. Secondly, one needs to identify the ensemble of diagnostics that one could deploy to MMV the entire site and determine the current detection limits and sensitivity. The final step involves determining the gaps associated with the detection capabilities in the current state of the diagnostics as well as identify the technical gaps in the detection grid.

The first step involves determining the levels of CO2 one needs to monitor given a generic geological or terrestrial sequestration site. Some performance goals for the FutureGen geological sequestration project have been published and this is a good place to start. The FutureGen Program seeks to build a plant that will use coal to generate electricity and hydrogen while the CO2 produced is cleaned and permanently stored in a geological sequestration site. The goal is to annually store one million tons of CO2 and maintain a leak rate of less than 0.01% annually. This results in a total leak rate from the entire sequestration reservoir of ~2μg/sec CO2 at this maximum level. However, the CO2 that leaks will likely come from several different fractures and will follow many different paths resulting in many different point sources of CO2 at the surface. Emission from each of these point sources amounts to a small fractions of the total leak rate. The challenge is to deploy diagnostics that can detect these small point sources as the CO2 travels from the fracture to the surface.

The second goal is to identify the likely diagnostics that will be deployed to MMV a sequestration site. Our efforts to identify these diagnostics have been divided into three subgroups including Sub-Surface, Surface and Atmospheric diagnostics. The following is a list of diagnostics that we believe need to be considered at this time.

Sub-Surface MMV:
- Rock Physics
- Subsurface
- Cross-well Seismic
- Microgravity
- Downhole Sampling for Leakage, Microdrilling
- Downhole Sampling for Leakage, Isotopes

Surface MMV:
- Laser Induced Breakdown Spectroscopy (LIBS)
- Microbial Indicators
- Isotopes
- Diffuse Reflectance Infrared Imaging

Atmospheric MMV:
- Isotopes
- LIDAR
- Airborne and Satellite Remote Sensing
    - Multispectral & Hyperspectral Imaging
- Tunable Diode Laser Spectroscopy

We have started to investigate and document the current state of these diagnostics. For example, Ebinger et al. has determined that the detection limit of their current LIBS diagnostic is 300mgC/kg sample. However, it is difficult to determine, at this time, how well this compares with the performance goals associated with terrestrial or geological sequestration. Some of the question that arise include the mechanism by which terrestrial sequestration converts atmospheric CO2 into soil carbon or how well will LIBS detect increases in soil carbon that may be an indication of a geological sequestration leak.

Our current effort has focused on completing the gap analysis for the surface and atmospheric diagnostics first simply because we perceive them to be easier. We have started exploring the current state of the diagnostics that are commonly used here at LANL including LIBS, Microbial Indicators, Isotopes, and Tunable Diode Lasers. We also will begin reviewing LIDAR soon. A report that will provide the detailed results of the gap analysis is being prepared as the analysis of each diagnostic is complete.

Under Advanced Concepts, we are also exploring the possibility of coupling biomass based energy production with CO_2 separation and sequestration as a means of achieving net NEGATIVE CO_2 emissions for the Big Sky Partnership region. This possibility is attractive due to the large quantities of biomass resource available and the region's low average population density. The region's low population density and hence CO_2 production also opens the possibility of taking advantage of the large trona deposits available in Wyoming as a way to permanently sequester the CO_2 through a mineralization process. The Wyoming trona deposits are estimated to be in the 50 to 100 billion ton range, capable of sequestering 10 to 20 gigatons of CO_2, enough to account for all the region's emissions for some 100+ years. As the biomass being consumed has removed CO_2 from the atmosphere, the region would also have 10 to 20 gigatons of CO_2 credits to sell.

By using biomass, even if full CO_2 separation is not achieved during power generation, the CO_2 that escapes does not add to atmospheric CO_2 concentrations, as the biomass fuel is already carbon neutral. The proposed approach thus removes the need for very stringent performance requirements on the CO_2 separation step. Namely, any CO_2 that is not separated is not a penalty, rather it just reduces the amount of CO_2 credits that can be sold.

Trona is a hydrated sodium bicarbonate – sodium carbonate salt ($Na_3H(CO_3)_2 \cdot 2H_2O$ or $NaHCO_3 \cdot Na_2CO_3 \cdot 2H_2O$) and is found as large evaporite deposits. When trona is reacted with CO_2, the "carbonate portion" of the trona is converted to a bicarbonate, thereby sequestering CO_2, i.e.

$$NaHCO_3 \cdot Na_2CO_3 \cdot 2H_2O + CO_2 \rightarrow 3NaHCO_3 + H_2O$$

Doing this in an aqueous process will (depending on the dilution) result in precipitates, or in fully dissolved species. The resulting solution (perhaps with precipitates entrained) could be injected downhole forming a stable chemical system provided a very low CO_2 pressure (~1/1000 atmospheres). At higher CO_2 pressures it may be possible to fully carbonate the trona in place. Due to the mineralization of the trona, there is no concern about CO_2 leakage from the system.

We have obtained samples of natural trona and verified that it is readily soluble. We have examined the thermodynamics of the carbonation reaction and verified that it should move in a forward direction. The pH of the resulting solution has also been examined theoretically for equilibrium conditions and should yield nearly neutral solutions. This may impact the reaction rate and is an issue we are currently exploring.

The main future work would be in the area of building a biomass fueled gasification plant with integral CO_2 separation, and testing the trona conversion at a large scale.

Tasks 11 and 15. Market-based carbon trading research and outreach

During the reporting period the National Carbon Offset Coalition (NCOC) continued to expand the number and diversity of participants in its landowner/emitter advisory committee. Meetings were held with National Governors Association Greenhouse Gas working Group, the Intertribal Environmental Council, and the U.S, Environmental Protection Agency. NCOC contractors attended and participated in a carbon sequestration conference sponsored by the state of Wyoming. NCOC contractors and a representative of the NCOC Board of Directors met with the Congressional delegation of the states of Montana, and Idaho. NCOC contractors assisted in the development of an additional state of Montana grant designed to bring the Montana Bureau of Mines into the Partnership and expand the Partnership's geologic sequestration portion efforts. NCOC contractors worked with the Intertribal Environmental Council to develop a USDA proposal to create a 1605B Clearinghouse, conduct Greenhouse Gas workshops nationally with the tribes, and create a national Tribal Forestry Portfolio. NCOC also began discussions with a national carbon trading group to begin marketing of NCOC carbon sequestration portfolios in DOE Phase II on the CCX and other emerging markets. During the third reporting period draft planning forms, contracting options and a draft forestry portfolio were submitted to the Chicago

Climate Exchange for review. After review by CCX and a follow-up conference call between CCX staff and NCOC contactors a second draft is now under development.

Work on the Project Planning handbooks will ultimately incorporate all deliverables. The work being conducted for overall objective is design of proposed protocols planning standards, and contracting options based on input from specialists in the area greenhouse gas emission reduction policy, science and the carbon market. Dr. Brandle's work on overall objective 2, the development of volume tables relies on collection of field data from previously selected sites across Montana. Field data collection is accomplished through selecting representative samples for an identified number of key species. The field work involves actual cutting down measuring and weighing selected key species at each site. Field data is then complied into volume tables for the selected species by using existing volume tables in the region.

Task 19. Assess available Measurement Instruments that can be used to Measure, Monitor and Verify Carbon Storage in Carbon Sequestration Projects

As part of Task 19, we address problems in verifying changes in carbon stocks associated with the high cost and time involved with repeated sampling and analysis. The objective is to demonstrate the practicality of near infrared reflectance spectroscopy (NIR) as a technique for reducing the cost and time required for sample analysis. We demonstrate a technique that identifies spectrally unique samples for laboratory analysis and equation development, and compare the accuracy and cost between NIR techniques and standard laboratory procedures. Results of a general soil carbon equation built on a diverse assortment of soils collected throughout the country are presented as well as the prediction results for several carbon fractions.

Study Site and Methods. This study was conducted on a 3000 hectare ranch in North Central Texas (Throckmorton County). Samples were collected in August 2002 and January 2003 from 175 locations distributed across the entire area of the ranch in order to capture the variance around the mean at this scale (Figure 19 - see Appendix C). For sampling protocols and NIR methodology please refer to our 2003 CASMGS report at http://cnrit.tamu.edu/casmgs/.

General Soil Equation and NIR Prediction of Carbon Fractions. We have been fortunate in having a number of collaborators who were willing to send archived soil samples analyzed for a range of constituents. The collection locations, labs and collaborators associated with the samples in the first carbon/nitrogen equation are listed in Appendix II (see Appendix C). Collaborators contributing samples with carbon fraction analysis are included in our general soils database Appendix III (see Appendix C). The carbon fractions for which NIRS equations were developed include glomalin, particulate organic matter (POM), amino sugar, β-glucosaminidase, and β-glucosidase. Additionally, an attempt was made to develop an equation for predicting bulk density. Details of equation development and sample selection can be found at http://cnrit.tamu.edu/casmgs/.

Time and Cost Comparisons: NIR vs. Conventional Laboratory. In order to estimate sampling costs, records were kept of the time required for each step in the sampling process (e.g. collecting samples, soil preparation, lab analysis, and NIR scanning steps). Estimates for conventional laboratory analysis per sample time were obtained from Cathleen McFadden from the University of Nebraska laboratory where our samples were analyzed. Because samples collected at Throckmorton Ranch contained carbonates, which require acid treatment between runs, two sample runs were included in our laboratory cost estimate.

Tasks 8, 21-24: Education and Outreach

The education and outreach activities include the completion of the Education and Outreach Plan, which was revised in response to DOE and other outside review, a Partnership listserv, and the development of an internal and external website. A public website for the Big Sky Partnership was launched in the third quarter. The web site address is www.bigskyco2.org. In addition, enhanced collaboration with the University and research communities through visiting appointments, development of jointly sponsored summer schools and seminar series, presentations at international forums and at cross-departmental (USDA, EPA, DOE) conferences, and co-sponsored activities at professional meetings is underway.

RESULTS AND DISCUSSION

This material pertains only to results in the fifth quarter – see earlier quarterly reports for other results and discussions.

Task 3. LANL GISLab team leader Paul Rich continues in the role of coordination of Big Sky GIS efforts, Randy Lee (INEEL) continues as lead for geologic data, and Karen Updegraff (SDSMT) assumed the role of lead for terrestrial data. Progress includes further compilation of data for the Big Sky database, development of the data master list, plans for serving data, plans involving multi-partnership coordination, further development of links with NATCARB, and further development of links with DOE and national cyberinfrastructure efforts. The University of Wyoming, Montana Natural Resource Information System, and the Montana Geographic Information Council became Big Sky GIS partners.

The Big Sky GIS effort focuses primarily on planning and coordination, in particular 1) facilitation of GIS database implementation, 2) facilitation of multi-partner cyberinfrastructure development including links to NATCARB, 3) assistance with demonstration analyses and visualization using the database, and 4) assistance with multi-partner outreach efforts. The data master list template was updated, based on input from the partnerships GIS Working Group, and the Big Sky master list was updated to track progress. Specific GIS planning activities include 1) further discussions with NATCARB lead Tim Carr about the future of carbon cyberinfrastructure, 2) planning sessions via teleconference involving Big Sky GIS personnel, 3) coordination with the SW partnership and WGA via discussions via Dennis Goreham; 4) participation in multi-partnership GIS working group teleconferences; 5) development of a manuscript concerning data sharing with Michael Goodchild (UCSB) and a manuscript concerning enterprise GIS with Marc Witkowski and Gordon Keating (LANL); 6) participation in the Partnerships DOE Review Meeting (Nov 16-17, 2004, Pittsburgh), 7) work on national carbon cyberinfrastructure presentations for upcoming Chapman Conference "The Science and Technology of Carbon Sequestration" (January 16-20, San Diego), 8) planning for the Big Sky data server, and 9) initial planning of GIS activities for Phase II.

Plans for the Big Sky data server (IMS and SDE) were developed in conjunction with the Big Sky Institute (Lisa Graumlich, executive director), the MSU Geographic Information Analysis Center (GIAC), the Mountain Prairie Information Node (Todd Kipfer, GIS manager), and the United States Geologic Survey (USGS) Northern Rocky Mountain Science Center (Richard Jachowski, director). A new partner, the University of Wyoming Geographic Information Science Center (WyGISC) (Jeffrey D. Hamerlinck, director) will assist with preparation of Wyoming data and filling other data gaps. Two more new partners, the Montana Natural Resource Information System (MNRIS) (Jim Hill, director), and the Montana Geographic Information Council (MGIC) (Stewart Kirkpatrick, GIS coordinator) become involved in planning activities.

An interim report will be issued in March on the results of our GIS efforts and the carbon atlas for the Big Sky partnership region.

Tasks 4 and 5.
Rangeland. A GIS approach was used to spatially identify potential rangeland terrestrial sinks with respect to climatic potential, MLRA, and land tenure (federal, private/non-federal, and Indian reservations). Spatial cross-indexing was used to identify rangeland vegetation cover types that would have the potential for sequestration of carbon. Climatic potential for carbon sequestration was assessed from long-term precipitation records (PRISM: http://www.ocs.orst.edu/prism/) which were classified into the following categories:

- No Potential - Less than 130 mm (~5 inches) of annual precipitation
- Low potential – 130 to 230 mm (~5 to 9 inches) of annual precipitation
- Moderate potential – 230 to 460 mm (~9 to 18 inches) of annual precipitation
- High potential – Greater than 460 mm (18 inches) of annual precipitation

These categories were chosen in collaboration with Dr. Joel Brown of USDA/NRCS to reflect the climatic potential for carbon sequestration and/or interventions to promote carbon sequestration on rangelands.

MLRA boundary coverage was downloaded from (ftp-fc.sc.egov.usda.gov/NHQ/pub/land/arc_export/us48mlra.e00.zip)

The Federal Lands and Indian Reservations of the United States coverage was acquired from (http://nationalatlas.gov/fedlandsm.html) and the 1992 National Land Cover Data (NLCD) (Vogelmann, et al. 2001) was used to identify land area as rangeland. The spatial resolution of the data is 30 meters. For this analysis, the following classes were selected as rangeland land cover types:

- Shrublands
- Grasslands/Herbaceous
- Pasture/Hay

Within the GIS, unique polygons of climatic potential, MLRA, and land tenure were generated by intersecting these layers for each of the states in the study area. The resulting map layers were then used to cross-tabulate land area for each of the rangeland cover types by unique climatic potential, MLRA, and land tenure category. For the purposes of this analysis, any land that did not have a classification of Federal or Indian reservations were given the class designation of private or other non-federal land tenure designation.

Within the Big Sky Region study area, approximately 31.5 million hectares of rangeland occur on Indian reservations and private and other non-federal lands. The majority of this rangeland occurs under moderate climatic potential (~21 million ha). However, approximately 10 million hectares of rangeland was classified as high climatic potential across the Big Sky region which equates to approximately 12% of the total land area in the study area. This would be a large area of impact for carbon sequestration on rangelands. Of the states within the study area, South Dakota had the largest total area of land classified as high climatic potential Details of this analysis are provided in our fourth quarterly report.

Tasks 11, 13, 14. This reporting period the NCOC and its subcontractors continued to address all of the contracted tasks. Coordination with new potential participants, and key agency initiatives continued. Meetings were held with the following organizations or staff; the Executive Director of the Montana Coal Council, the Executive Director of the Montana Petroleum Association, staff from the Oregon Climate Trust, staff from the Intertribal Forestry Council, the plant manager for the Centennial power plant, and staff of the Montana Environmental Information Center. In October the NCOC presented an overview of global climate change and the role of market based carbon credit trading to the National Tribal Air Association. In November the NCOC met with the principles of the Bull Mountain companies. After the two meetings and site visits the NCOC prepared a proposal for the company to create a carbon sequestration strategy for the company using a forestry based program. The NCOC is waiting for response from the company to the proposal.

The final draft of the NCOC Carbon Sequestration Project Handbook and key contacting and membership forms are now complete. The final draft documents are ready to begin field testing in phase two. The first workshop for the tribes will be held in January 2005. Dr. Jim Brandle of the University of Nebraska finished lab analysis of the field data collected in 20004. Final volume table and yield data are now being completed.

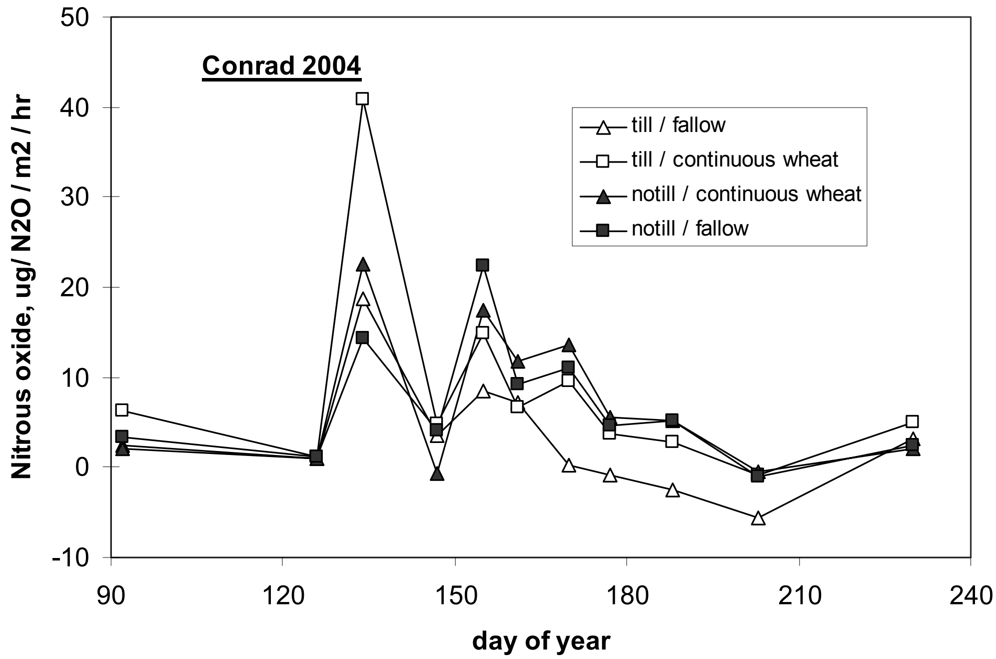
Initial proposals and data spread sheets covering six thousand acres of proposed reforestation and afforestation projects on the Nez Perce reservation were forwarded to Nat Source this quarter. The submission of the first data set is intended to allow NatSource to determine if the proposed data format is adequate for entry onto the market as part of a National NCOC Tribal portfolio. At the same time the Nez Perce are working with the NCOC to determine if the draft NCOC listing agreement meets the tribes contracting requirements

One result now evident is the need to create a carbon pool which can be marketed by aggregating a large number of landowners, and project types across a large geographical area. Portfolio design work now is focused on creating vintage credits vs. a discounted project approach. Early indications of 1605B support this approach as well as concerns about long term contracts increase of exposure and risk for landowners, aggregators, and buyers.

The NCOC has decided to reduce the number of scheduled project planning workshops in phase two and concentrate more on one-on -one meetings with landowner organizations and consultants to secure pilot projects for the private/state lands portfolio. The NCOC Web site created in Phase one has been developed with an E learning system to allow easy access to NCOC planning information and technical advisors. Workshops will continue to be used to secure tribal projects.

Task 16: Research activities, including soil carbon analysis, assessment of diffuse reflectance infrared spectroscopy and analysis of nitrous oxide emission losses are still in progress. All farmer research partners remain actively engaged in this project and we will meet in late February to review field protocols for 2005. All farmers are interviewed annually to obtain detailed economic data about the costs and returns associated with each cropping system. This information will be used to assess net greenhouse gas emissions for each cropping system and determine cost -benefit relationships for adopting alternative cropping systems. During 2004, nitrous oxide flux measurements were collected at two field sites. Highest flux measurements were observed during May (Figure 5), and were associated with wet soil moisture conditions during this month. Results from these studies reveal that nitrous oxide emissions moderate during the late June, and remain low or near background levels through the summer. If we assume a constant nitrous flux equivalent to 20 ug N/m^2 (greater than the majority of our observations), this equates to 0.14 kg of N ha^{-1}. Hence, the losses of nitrous oxide at our field sites appear nominal. Preliminary results suggest that adequate soil C estimations can be made using VNIR diffuse reflectance spectroscopy, provided 20% of a given sample set is submitted for regular laboratory analysis for model calibration (Figure 6). We have found greatly improved predictions of SOC and IC using a global spectral library together with regional calibration samples, and are currently experimenting with different weighting approaches, spectral processing techniques and smoothing algorithms.

Baseline soil carbon values (Table 1) show greater variability than soil texture and pH values (data not shown). Statistical analysis of carbon data has not been done for we are interested in the change in soil carbon values as a function of the management treatments applied to the plots; therefore, analysis of carbon change will occur once the 2004 soil samples have been analyzed for SOC. No differences in crop biomass occurred between tillage systems in 2003 (Table 2). In addition to changes in soil carbon, the agronomic effects of the treatments are also being investigated. Total biomass was measured at precisely the same locations that soil carbon is measured. Comparison of total wheat crop biomass showed that No-till was 9% greater than the tilled system and the continuous cropping system was only 72% of the alternate year fallow-wheat system (Tables 3 and 4). Importantly though, the alternate year cropping system produces crop biomass only every other year. Crop biomass differences are likely attributable to soil water status differences between treatments. Differences in crop yield and quality will also be investigated; samples have yet to be threshed for yield calculation. The amount of C and N returned to the soil will be calculated for each sampling location. Economic evaluation of the four cropping systems at each site will be completed after farm management data have been collected in November.)



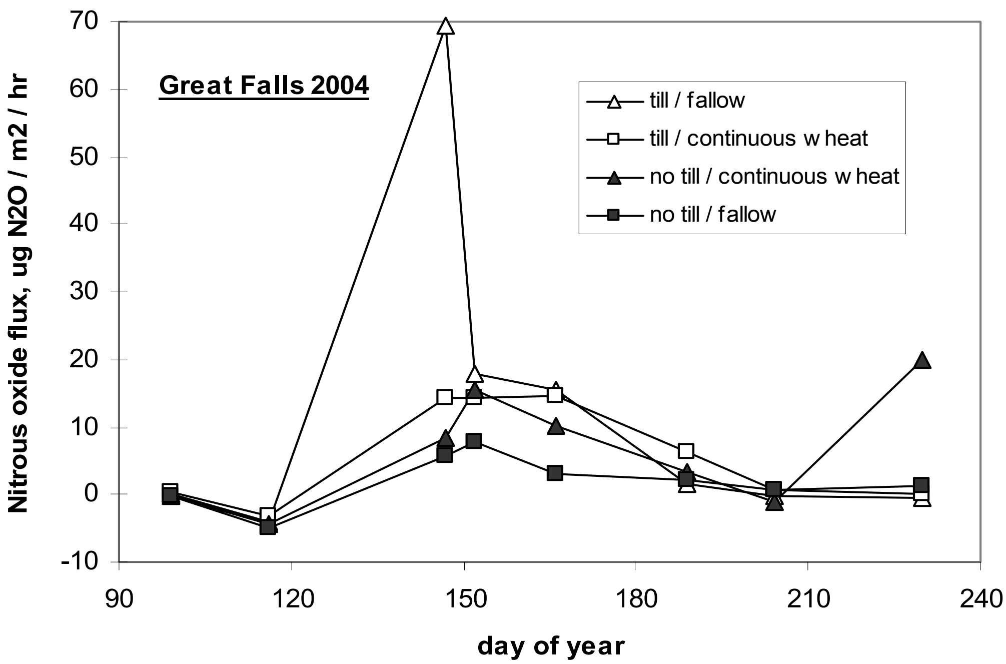


Figure 5. Seasonal distribution of N_2O emissions from Conrad and Great Falls farm sites in north central Montana.

Table 1. Soil organic carbon (t ha^{-1}) by depth for each plot at Chester, Collins, Conrad, Great Falls, Kremlin, and Power, Sept. – Oct., 2002.

Crop System	Chester	Collins	Conrad	Great Falls	Kremlin	Power
	----------	----------	----------	0-10 cm	----------	----------
Tilled F-W	10.8	12.5	15.5	17.9	10.1	15.5
No-till F-W	10.3	10.8	12.0	15.1	9.3	17.1
Tilled W-L	10.2	11.8	13.3	14.7	8.3	14.1
No-till W-L	9.9	10.7	13.3	18.5	10.8	11.8
SE	0.3	0.6	0.7	1.1	0.4	0.9
	----------	----------	----------	10-20 cm	----------	----------
Tilled F-W	10.7	8.6	12.2	11.2	7.7	12.6
No-till F-W	10.7	11.0	11.3	11.6	7.2	12.3
Tilled W-L	10.1	8.8	11.4	11.8	7.8	11.7
No-till W-L	10.2	10.3	11.6	11.8	6.9	13.6
SE	1.0	0.6	0.6	0.4	0.2	0.5
	----------	----------	----------	20-50 cm	----------	----------
Tilled F-W	7.9	7.4	9.6	9.0	7.8	7.2
No-till F-W	6.3	6.9	10.1	9.0	7.1	7.6
Tilled W-L	7.6	8.2	9.3	8.4	7.5	10.7*
No-till W-L	8.1	8.2	9.5	8.6	6.7	8.7
SE	0.6	0.4	0.5	0.5	0.3	1.3
	----------	----------	----------	50-100 cm	----------	----------
Tilled F-W	6.9	6.5	8.4	7.4	4.8	5.5
No-till F-W	6.6	6.3	7.8	7.3	3.5*	5.6
Tilled W-L	6.8	5.8	8.2	7.1	ND	5.6
No-till W-L	8.3	6.1	8.7	6.5	5.9	4.1
SE	0.5	0.2	0.7	1.2	0.5	1.2

ND = no data, samples were not able to be collected at that depth due to soil conditions.
* Values that are under review.

Table 2. Crop biomass (t ha^{-1}) for each plot at Chester, Collins, Conrad, Great Falls, Kremlin and Power, 2003

Crop System	Location and crop					
	Chester peas	Collins peas	Conrad lentils	Great Falls pea/barley	Kremlin peas	Power pea/barley
Tilled W-L	1.5	1.7	0.8	4.1	2.3	2.2
No-till W-L	1.8	1.8	0.7	4.1	2.5	1.6
Tilled F-W	----	----	----	----	----	----
No-till F-W	----	----	----	----	----	----

Table 3. Wheat crop biomass (t ha^{-1}) for each plot at Chester, Collins, Conrad, Great Falls, Kremlin and Power, 2004

Cropping System	Chester	Collins	Conrad	Great Falls	Kremlin	Power
No-till	6.3	6.5	8.2	11.3	6.9	5.9
Tilled	6.7	5.5	8.2	10.2	7.0	4.0
Alternate Yr	7.8	7.7	9.3	12.6	8.2	5.2
Continuous	5.2	4.3	7.1	8.9	6.1	4.8

Table 4. ANOVA results for total wheat biomass, 2004

Source	df	*Prob*>F	Effect
Site	5	<0.0001	
Tillage	1	0.0019	NT (7.5) >T (6.9)
Intensity	1	<0.0001	AY (8.5) > Cont (6.1)
SxT	5	0.0001	NT > T @ farms 2), 4), and 6)
SxI	5	<0.0001	AY > Cont @ all farms except 6)
TxI	1	0.6484	
SxTxI	5	0.2479	

1) Chester, 2) Collins, 3) Conrad, 4) Great Falls, 5) Kremlin, and 6) Power.

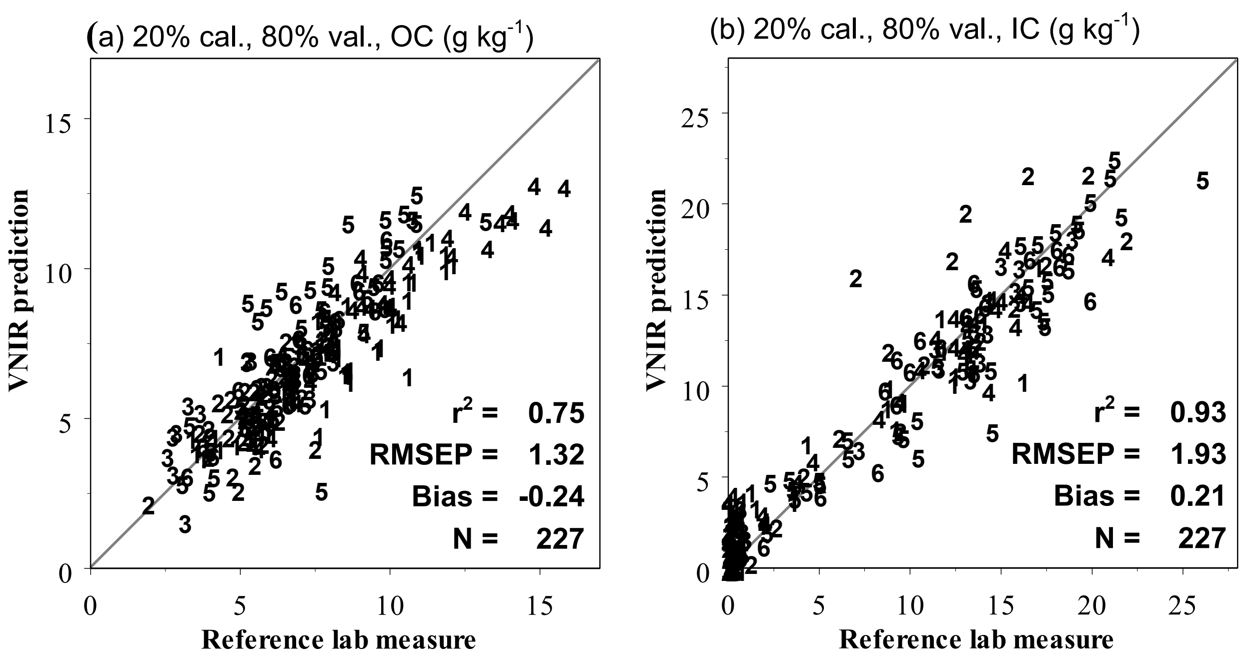


Figure 6. Predicted organic carbon (OC) and inorganic carbon (IC) using VNIR diffuse reflectance spectroscopy.

TASK 19. Assess Available Measurement Instruments that can be used to Measure, Monitor and Verify Carbon Storage in Carbon Sequestration Projects

Measurement, Monitoring and Verification is a central component of any successful geological or terrestrial carbon sequestration program. The Big Sky Regional Partnership's MMV vision involves deploying a fully integrated ensemble of diagnostics that will monitor all aspects of any geological or terrestrial site. The integration of these diagnostics will be accomplished through a world-class GIS system that will merge the MMV observations with site specific models and state-of-the-art decision making tools. Ultimately, this will provide timely information needed to assess risk or economic impact.

In order to complete a gap analysis between the capability of state-of-the-art MMV diagnostics and the needs of the sequestration community, one needs to define the performance goals for the specific geological or terrestrial site. The geological sequestration performance goals for the FutureGen Program is permanent sequestration (defined as 1000 years) with a maximum annual leak rate not to exceed 0.01%. The FutureGen Program seeks to geologically sequester one million tons of CO_2 per year, which results in maximum permissible leak rate of 100 tons of CO_2 per year (~2μg/sec). Unfortunately, we have not found any published performance goals for terrestrial sequestration.

The Big Sky Regional Partnership's vision to develop an integrated MMV system for geological sequestration will include diagnostics capable of monitoring changes at the subsurface and atmosphere. The subsurface monitoring will employ 3D seismic as a preliminary assessment of potential sites. The subsurface morphology could also be monitored periodically with ground penetrating radar to search for new fractures in the subsurface structure from the cap rock to the surface. Leaks that are below the detection capability of these subsurface diagnostics will be observed with atmospheric diagnostics that detect sequestered CO_2 that reaches the surface. Finding leaks that reach the surface will first require an MMV diagnostic that is capable of detecting CO_2 out-gassing from the surface and distinguishing between any leaking sequestered CO_2 and that from natural or other anthropogenic sources. This will be accomplished with diagnostics that are capable of measuring the carbon stable isotope ratio. The stable isotope ratios have long been known to be an indicator of the source of the material being measured. LANL is developing a deployment plan that will provide the MMV diagnostics at the level of funding required for the FutureGen Program.

Finally, the Big Sky Regional Partnership's vision to develop an integrated MMV system for terrestrial sequestration will include diagnostics capable of monitoring changes at the surface and in the atmosphere. We believe that establishing terrestrial sequestration goals needs to be a high priority for Carbon Sequestration Program. We, therefore, recommend beginning an effort early in the first year of phase II work to study the efficiency of various potential terrestrial sequestration sites. This study will include deploying LIBS, Raman LIBS, diffuse reflectance spectroscopy, and stable isotope measurements to measure changes in the total and organic soil carbon content as a function of time. Atmospheric diagnostics also need to be deployed to monitor the connection between the atmosphere and the soil. These diagnostics will also include stable isotope measurements. These diagnostics are well developed and ready to deploy. So, this effort is not a diagnostic development program, but rather is an effort to establish the performance goals needed to verify variation in sequestration potential.

Tasks 8, 23, 25: Outreach and Education.

The education and outreach efforts have resulted in a comprehensive plan which serves as a guide for implementing the outreach activities under Phase I. The primary goal of this plan is to increase awareness, understanding, and public acceptance of sequestration efforts and to build support for a constituent-based network which includes the initial Big Sky Partnership and other local and regional businesses and entities. Presentations about the Partnership have been made at the DOE Carbon Sequestration Partnership Program review in November 2005.

The public website (www.bigskyco2.org) makes available many of the presentations to stakeholders and policy makers, provides a connection to other federal and state agencies concerned with GHG emissions, climate change, and efficient and environmentally-friendly energy production. Finally, both Pam Tomski, outreach coordinator, and Susan Capalbo, PI for the Big Sky Partnership are involved in U.S.-Norway bilaterals in an effort to provide for an exchange of sequestration assessment potentials, technology, and students/faculty.

CONCLUSIONS

The Big Sky Partnership undertakes activities in four areas: evaluation of sources and carbon sequestration sinks; development of GIS-based reporting framework; designing an integrated suite of monitoring, measuring, and verification technologies; and initiating a comprehensive education and outreach program. Steps have been taken to assure that the GIS-based framework is consistent among types of sinks within the Big Sky Partnership area and with the efforts of other western DOE partnerships. The Partnership secured supplemental funding to include Wyoming in the coverage areas for both geological and terrestrial sinks and sources. This extended coverage will be the focus of the efforts in the next six months on the sources and carbon sinks. This report summarizes the activities for the fifth quarter of the Partnership. Deliverables include the Carbon Sequestration: A Handbook, and planning standards, protocols, and contracting options for terrestrial sequestration in the region. These protocols are applicable to other regions including the northwestern part of the U.S. It is designed to assist organizations, technicians, and landowners in understanding carbon sequestration projects and their role in local, state, regional, national, and international efforts to address the issue of climate change and GHG accumulations.

The Big Sky Partnership was involved in four key meetings in the 5th Quarter: the NETL Regional Carbon Sequestration Annual Program review (November, 2004); Western Fuels Symposium (October, 2004); U.S.-China Clean Energy Initiative (October 2004); and Geological Society of America meetings (October 2004). Related presentations by Partnership PIs were also made to EPA workshop on modeling terrestrial soil carbon accumulation and at a USDA Conference on Carbon Opportunities in the Northern Great Plains.

The GIS activities have involved LANL and INEEL as well as the research universities, and are focusing on completing the database to meet the immediate Big Sky Partnership needs, and on planning for multi-partnership, NATCARB, DOE, and national coordination, in the context of the emerging national cyberinfrastructure. We also have a major effort to examine the potential for using GIS-based systems in outreach/education efforts of the Partnership, and the development of complimentary efforts with the West and Southwest carbon sequestration partnerships. An interim report will be issued in Mid-March.

The Partnership recognizes the critical importance of measurement, monitoring, and verification technologies to support not only carbon trading but all policies and programs that DOE and other agencies may want to pursue in support of GHG mitigation. For terrestrial sequestration, research is validating best management practices for soil C in the Partnership region. A team of researchers from MSU have been working in the field to obtain field scale carbon estimates for ground truthing simulation models and identifying BMPs.

Monitoring and Measurement Verification (MMV) activities, as they pertain to geological (and terrestrial) sinks, include some initial assessment of the state of the art for technologies that have a high likelihood of being mature enough to be applicable in Phase II small scale applications, and designing a risk/cost effectiveness framework to make comparative assessments of each viable sink, taking into account economic costs, offsetting benefits, scale of sequestration opportunities, spatial and time dimensions, environmental risks, and long-term viability. In conjunction with the GIS efforts and ongoing research at LANL, MSU, SDSMT, and INEEL, the Partnership is developing a well-integrated ensemble of diagnostics for MMV at each potential geological sequestration site, and a protocol for the terrestrial sequestration areas.

During the reporting period the National Carbon Offset Coalition (NCOC) continued to expand the number and diversity of participants in its landowner/emitter advisory committee. Meetings were held with numerous nonprofit and for-profit organizations related to energy or the environment. The final draft of the NCOC Carbon Sequestration Project Planning Handbook and key contracting and membership documents were completed.

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APPENDICES

APPENDICES

FIGURES

Big Sky
CARBON SEQUESTRATION PARTNERSHIP

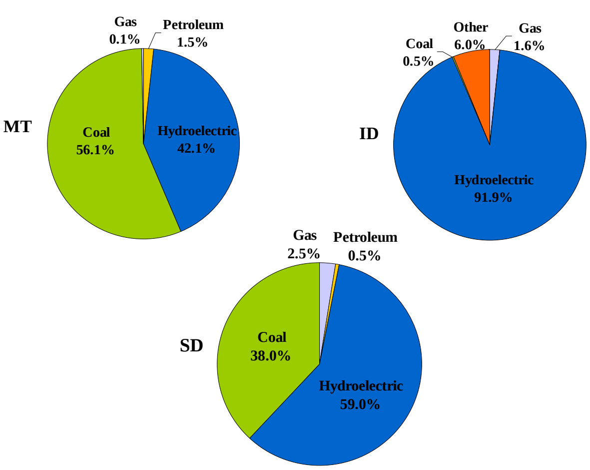
A new energy future for Montana, Idaho, South Dakota, Wyoming and the nation.

Led by Montana State University, the **Big Sky Partnership** is one of the U.S. Department of Energy's seven regional partnerships. To date, the Partnership includes Montana, Idaho and South Dakota, as well as contiguous parts of neighboring states and Canada.The Partnership is developing a framework to reduce carbon dioxide emissions that contribute to climate change and is working with stakeholders to create the vision for a new, sustainable energy future that cleanly meets the region's energy needs. Because energy is not an optional commodity, carbon sequestration will play an important role.

What is CO_2 Sequestration?

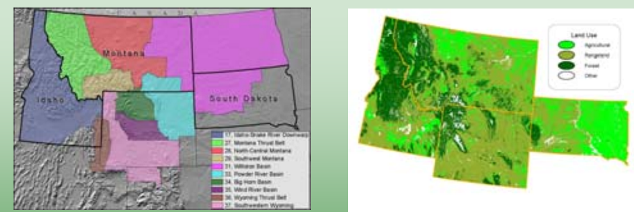
Carbon dioxide, CO_2, is a major by-product of energy use. Abundant coal and hydropower offer Montana, Idaho and South Dakota some of the lowest cost electricity in the nation. However, burning fossil fuels for transportation, electricity generation and manufacturing emits greenhouse gases (GHG) that may impact regional and global climate. "Carbon sequestration" is a family of methods for capturing and permanently isolating gases that otherwise could contribute to global climate change. Affordable and environmentally safe sequestration approaches could offer a way to stabilize atmospheric levels of carbon dioxide.

Electricity Generation & GHG Emissions in the Big Sky Region



Two Approaches To Carbon Sequestration

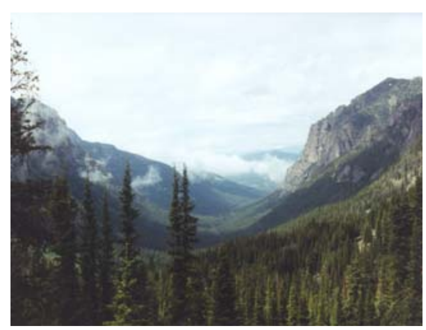
The **Big Sky Partnership** is researching two types of sequestration options: **geologic** and **terrestrial**.



Geologic and **Terrestrial** Carbon Sequestration Potential in the Big Sky Region

Geologic sequestration involves storing carbon dioxide in geologic formations including oil and gas reservoirs, deep saline reservoirs and coal seams. These are structures that have stored crude oil, natural gas, brine and CO_2 for over millions of years. Many power plants and other large emitters of CO_2 are located near geologic formations that are amenable to CO_2 storage. In many cases the injection of CO_2 into a geologic formation can enhance the recovery of hydrocarbons, providing value-added by-products that can offset the cost of CO_2 capture and sequestration.

Terrestrial sequestration relies on management practices of agricultural lands, rangelands, forests and wetlands to remove CO_2 from the atmosphere via photosynthesis and at the same time reduce CO_2 emissions. No-till or reduced till methods, increased crop rotation intensity, the use of higher residue crops, cover crops or conservation measures are all means of increasing carbon storage in agricultural soils.



Terrestrial sequestration reduces emissions while improving land and water quality, thus making soils healthier, more productive and less susceptible to large-scale CO_2 release. Enhancing the natural processes that remove CO_2 from the atmosphere is thought to be one of the most cost-effective means of reducing atmospheric levels of CO_2.

Regional Sequestration Opportunities

The objectives of the **Big Sky Partnership** fall into four areas:

- Evaluation of sources and carbon sequestration sinks with the goal of identifying viable projects;
- Development of GIS-based reporting framework;
- Designing an integrated suite of measuring, monitoring and verification technologies;
- Initiating a comprehensive education and outreach program aimed at connecting with communities and organizations within the region

The region has a diverse array of geologic formations that could provide storage options for carbon in one or more of its three states. Likewise, initial estimates of terrestrial sinks indicate a vast potential for increasing and maintaining soil C on forested, agricultural and reclaimed lands. Both options include the potential for offsetting economic benefits to industry and society.

Complementary to the efforts on evaluation of sources and sinks is the development of the **Big Sky Partnership** Carbon Cyberinfrastructure (BSP - CC) and a GIS Road Map for the Partnership. These efforts are putting in place a map-based integrated information management system or carbon atlas for our Partnership with transferability to the national carbon sequestration effort.

Measurement and Verification

The **Big Sky Partnership** recognizes the critical importance of measurement, monitoring and verification technologies to support not only carbon trading, but other policies and programs the DOE and other agencies may want to pursue in support of GHG mitigation. The efforts begun in developing and implementing MMV (measurement, monitoring and verification) technologies for geologic sequestration reflect this concern. Research is also underway to identify and validate best management practices for soil C in the Big Sky region, and to design a risk/cost effectiveness framework to make comparative assessments of each viable sink, taking into account economic costs, offsetting benefits, scale of sequestration opportunities, spatial and temporal dimensions, environmental risks and long term viability.

For More Information

Please visit our website: **www.bigskyco2.org** or contact:

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Pamela Tomski, Big Sky Outreach Director, EnTech Strategies, LLC, 1862 Mintwood Place, NW #101, Washington, DC, 20009, 202-822-6120 ex. 11, ptomski@entech-strategies.com

Marketing Carbon Credits

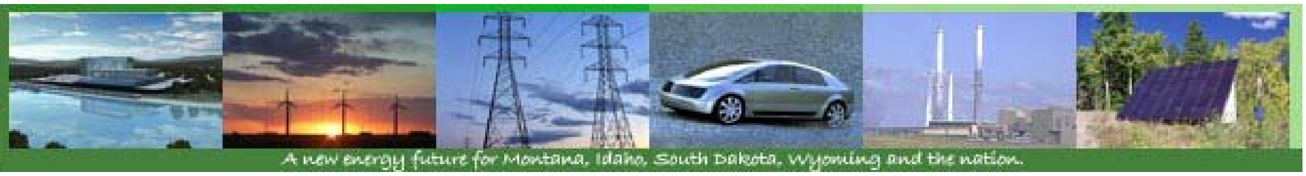
The **Big Sky Partnership** is assessing the issues surrounding the implementation of a market-based setting for soil C credits. These include the impact of existing local, state and federal permitting issues for terrestrial-based carbon sequestration projects, consistency of final protocols and planning standards with national requirements, and alignments of carbon sequestration projects with existing federal and state cost-share programs.

Connecting with the Communities and Industry

The education and outreach efforts have resulted in a comprehensive plan whose primary goal is to increase awareness, understanding, and public acceptance of sequestration efforts and build support for a constituent-based network, which includes the initial **Big Sky Partnership** and other local and regional businesses and entities.

The Big Sky Partnership Team

- **Montana State University**
- **Boise State University**
- **EnTech Strategies, LLC**
- **National Carbon Offset Coalition**
- **South Dakota School of Mines & Technology**
- **Texas A & M University**
- **University of Idaho**
- **Idaho National Engineering and Environmental Laboratory (INEEL)**
- **Los Alamos National Laboratory (LANL)**
- **Inland Northwest Research Alliance (INRA)**
- **U.S. Department of Energy**
- **Montana Governor's Carbon Sequestration Working Group**
- **The Confederated Salish and Kootenai Tribes**
- **Nez Perce Tribe**
- **The Sampson Group**
- **Environmental Financial Products, LLC**
- **Idaho Carbon Sequestration Advisory Committee (ICSAC) / Idaho Soil Conservation Commission**
- **Montana Bureau of Mines and Geology**
- **Western Governors' Association**
- **Montana Department of Environmental Quality**
- **Wyoming Carbon Sequestration Advisory Committee**
- **Wyoming Department of Environmental Quality**
- **University of Wyoming Geographic Information Science Center**
- **University of Wyoming Institute for Energy Research**
- **University of Wyoming Ruckelshaus Institute for Environment and Natural Resources**
- **Montana Natural Resource Information System - Montana State Library**
- **Montana GIS Services Bureau Information Technology Services**
- **Unifield Engineering, Inc.**
- **Jackson Hole Center for Global Affairs**



The Big Sky Carbon Sequestration Partnership
Phase II Competition

The Big Sky Carbon Sequestration Partnership is seeking industrial, government, and international partners to join its team to compete in a Phase II solicitation from the U.S. Department of Energy which would provide important insights and information regarding potential carbon reduction and sequestration scenarios for power producers and industrials within Montana, Wyoming, Idaho and South Dakota.

Background

Carbon sequestration, or carbon storage, is a suite of technologies and methods that remove carbon dioxide (CO_2) emissions resulting from power plants or large industrial facilities from the atmosphere and securely store the CO_2 in geologic formations (i.e. saline aquifers, mafic rocks, depleted oil and gas fields, deep coal seams), soils, trees and vegetation. Geographical differences in fossil fuel use and sequestration options across the United States (U.S.) dictate targeted regional approaches.

In August 2003, the U.S. Department of Energy (DOE) announced seven Phase I awards of regional carbon sequestration partnerships, including the Big Sky Partnership, led by Montana State University. The Partnership is assessing sequestration options best suited for industries and potential sequestering matrices within the region encompassing Montana, Wyoming, Idaho and South Dakota. The partnerships selected under the DOE Phase II solicitation will build upon the work of Phase I and focus on terrestrial and geologic field validation tests that demonstrate the environmental efficacy of sequestration, verify regional CO_2 sequestration capacities, and satisfy project permitting requirements. The partnerships will also conduct outreach and education activities.

DOE anticipates funding approximately seven Phase II partnerships in the range of $2-$4 million per year. Each partnership will be required to provide at least 20 percent in cost-sharing over the duration of the project. The Big Sky Carbon Sequestration Partnership is seeking industrial partners to join its team and provide direction and insight into how carbon reduction and sequestration could impact and/or provide a future competitive advantage to operating and development plans. To that end, we are extending an invitation to join the Phase II team. Proposals are required to be submitted before March 15, 2005, and awards are expected by October 2005.

The Big Sky Partnership Vision

The Big Sky region enjoys some of the lowest cost electricity in the country, produced largely through hydropower and regionally mined coal. Continued access to affordable power is critical to the region's ability to attract new businesses and jobs. Because coal is abundant in the region and because other large-scale power generation options such as hydroelectric have reached near maximum capacity, coal and gasified or liquefied products of coal will play an increasingly important role in supplying electricity to regional markets. However, given the uncertain regulatory environment regarding carbon dioxide, managers must consider planning a future energy base that supports a carbon-constrained economy. The ability to site future fossil fuel based power plants and industrial facilities could require CO_2 emissions mitigation through CO_2 capture and subsurface storage or through using carbon offsets and terrestrial carbon sequestration. Access to carbon dioxide buyers and geologic storage sites will likely become critical to the economic viability of future industrial sites.

The Big Sky Partnership's vision is to prepare its member organizations for a possible carbon-constrained economy and enable the region to cleanly utilize its abundant fossil energy resources and sequestration sinks to support future energy demand and economic growth. The Partnership will achieve this vision by demonstrating and validating the region's most promising sequestration technologies and creating the supporting infrastructure required to deploy commercial scale carbon sequestration projects. This supporting infrastructure includes a GIS-based economic and risk assessment tool to help determine optimal energy development strategies, regulatory and permitting approaches, and enhanced public understanding and acceptance. The infrastructure also includes a robust outreach program that trains scientists and engineers, and communicates the contribution carbon sequestration technologies and the Big Sky Partnership can make to the region's clean energy future.

Carbon Sequestration Opportunities: Phase II

The Partnership will propose to build on the work conducted in Phase I with a focus on geologic and terrestrial field validation tests that assess the relative efficiency of alternative sequestration options, prove the environmental efficacy and sustainability of sequestration, verify regional CO_2 sequestration capacities and satisfy project permitting and regulatory requirements. Data from validation tests will be integrated into a GIS tool that will assist industry and regional planners to optimize energy development strategies. The Partnership will also conduct extensive public outreach and education and training opportunities for students and young professionals. The following outlines the Partnership's approach to Phase II.

Geologic Sequestration

The Big Sky Partnership region has a range of geologic sites for CO_2 storage including depleted oil reservoirs, deep unminable coal seams, carbonate saline aquifers, and mafic volcanic (basalt) formations (a distinguishing feature of the region's geology). In Phase II, the Partnership will propose the following:

- Conduct two geologic demonstration projects in prominent geological formations located throughout the region - mafic rock formations and sedimentary rock hosted saline aquifers. The Partnership will characterize and test mineral trapping mechanisms in order to determine the flow and migration of CO_2 in the reservoirs and predict its long term fate. It will also determine each test site's operational needs, permitting, regulatory and monitoring requirements, and quantify economic offset opportunities such as enhanced oil recovery and coal bed methane production.

- Update and complete the region's carbon atlas, a GIS tool that visually provides spatially distributed information on CO_2 point source emissions, geologic storage sites (characterization and CO_2 storage capacity) and any supporting transportation infrastructure. Additionally, the GIS tool will incorporate economic data to optimize decision support for energy development in the region.
- Develop a national mafic rock atlas and assess the sequestration potential of these rocks through modeling studies, laboratory testing, and insights developed from mafic rock pilot projects. Of potential economic interest to Big Sky industrial partners is that the majority of this mafic formation lies relatively close to the West Coast power load.

Terrestrial Sequestration

Big Sky Partnership region has extensive land mass that provide tremendous potential for GHG offsets through terrestrial carbon sequestration in forests, range lands, and agricultural crop lands. In Phase II, the Partnership will propose to:

- Conduct pilot projects to demonstrate and validate the technical and economic feasibility of the major terrestrial carbon sinks, implement monitoring and verification protocols, and assess the impacts to existing ecosystems.
- Complete the regional GIS carbon atlas to provide spatially referenced information on terrestrial carbon sequestration potentials, land use practices, and potential co-benefits of changes in land-use management practices.
- Develop protocols for terrestrial carbon contracts that could be used in a market-based carbon emissions reductions credit market or in other government-sponsored programs.
- Implement a terrestrial offset project in conjunction with one or more coal mines and coal-fired power generator(s) to test selected monitoring, measurement and verification protocols and standards.

Outreach and Education

Public acceptance of carbon sequestration technologies and the operational capacity to deploy them is critical to the ability of (1) the Partnership to successfully implement its proposed Phase II validation tests, (2) industry to commercialize sequestration technologies and (3) the region to economically and cleanly meet future energy demand. Therefore, the Partnership will propose the following outreach and education activities:

- Establish the Big Sky Energy Future Coalition that brings together industry, academia environmental non-governmental organizations and regulatory and governmental officials bi-yearly to build dialogue on the role carbon sequestration can play in providing a technology solution to the region's energy requirements.
- Support graduate fellowships and professional development activities focused on science and engineering issues associated with carbon sequestration.
- In support of project demonstrations, organize public events that help meet regulatory, environmental and permitting requirements and build public confidence and acceptance.

- Hold Congressional forums and utilize media networks to inform policy makers and industry of carbon sequestration's potential to support regional clean energy development.

Big Sky Membership Benefits
Should the Partnership be successful in Phase II, industry will be poised to commercially deploy carbon sequestration technologies that will enable the region to cleanly meet its future energy demand. Partnership members will also receive the following benefits:

- GIS-based economic and risk assessment tool to help determine optimal energy and business development strategies
- Opportunity to influence the development of permitting and regulatory schemes
- Opportunity to influence the development of CO_2 trading and credit systems
- Inter-industrial ties between CO_2 producers and buyers
- Improved business climate through enhanced public understanding and acceptance
- Experience required to successfully compete in a possible carbon-constrained economy
- Economic and job growth associated with regional natural resource and energy development
- Local, regional and national recognition for leadership and environmental stewardship

Cost Share Commitments and Requirements: Phase II
DOE funding for each partnership is expected to be $2-$4 million per partnership per year and each partnership will be required to provide at least 20 percent in cost-sharing over the duration of the project. Cost-sharing can be both monetary and third party in-kind contributions. Examples of the latter include operating costs such as salaries, benefits, equipment etc.

Additional Information:
Information on the current partners, publications, news releases and other accomplishments can be found at the Big Sky Carbon Sequestration Partnership web site: www.bigskyco2.org

Contact:
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Director, Big Sky Regional Partnership
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406-994-5619

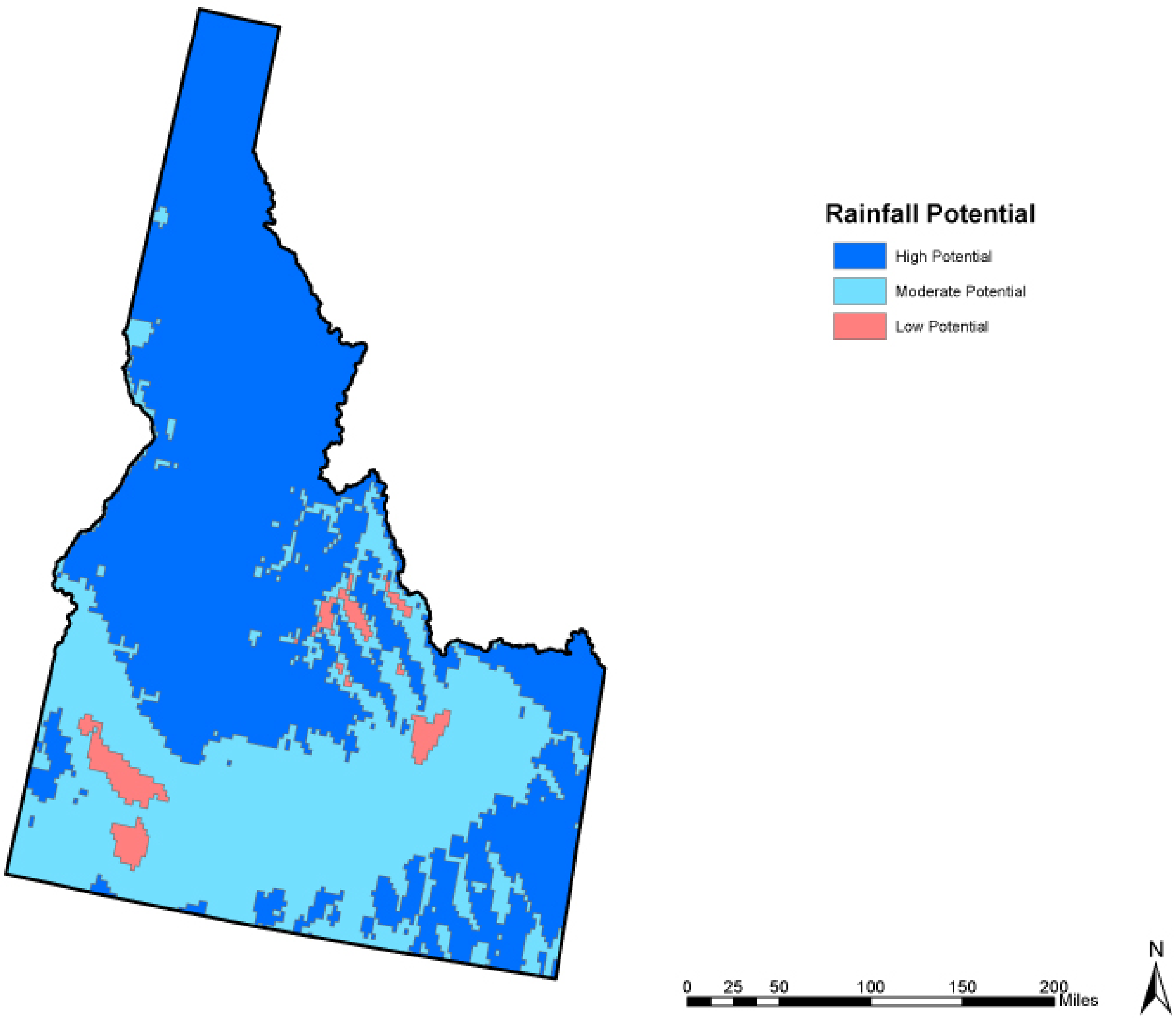

Figure 1. Spatial classification of climatic potential for Idaho. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year. Areas classified as Low Potential have between 130 and 230 mm of precipitation per year.

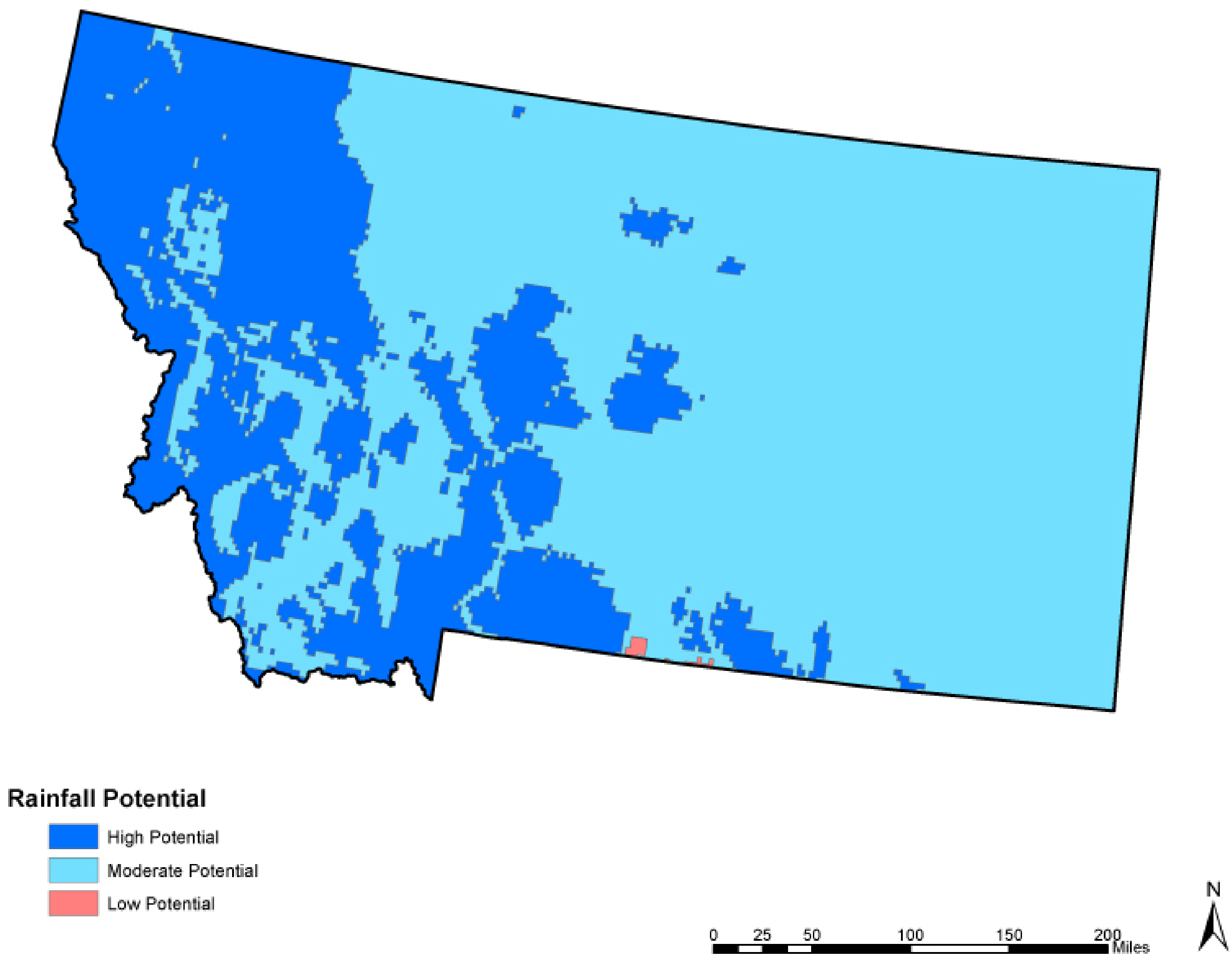

Figure 2. Spatial classification of climatic potential for Montana. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year. Areas classified as Low Potential have between 130 and 230 mm of precipitation per year.

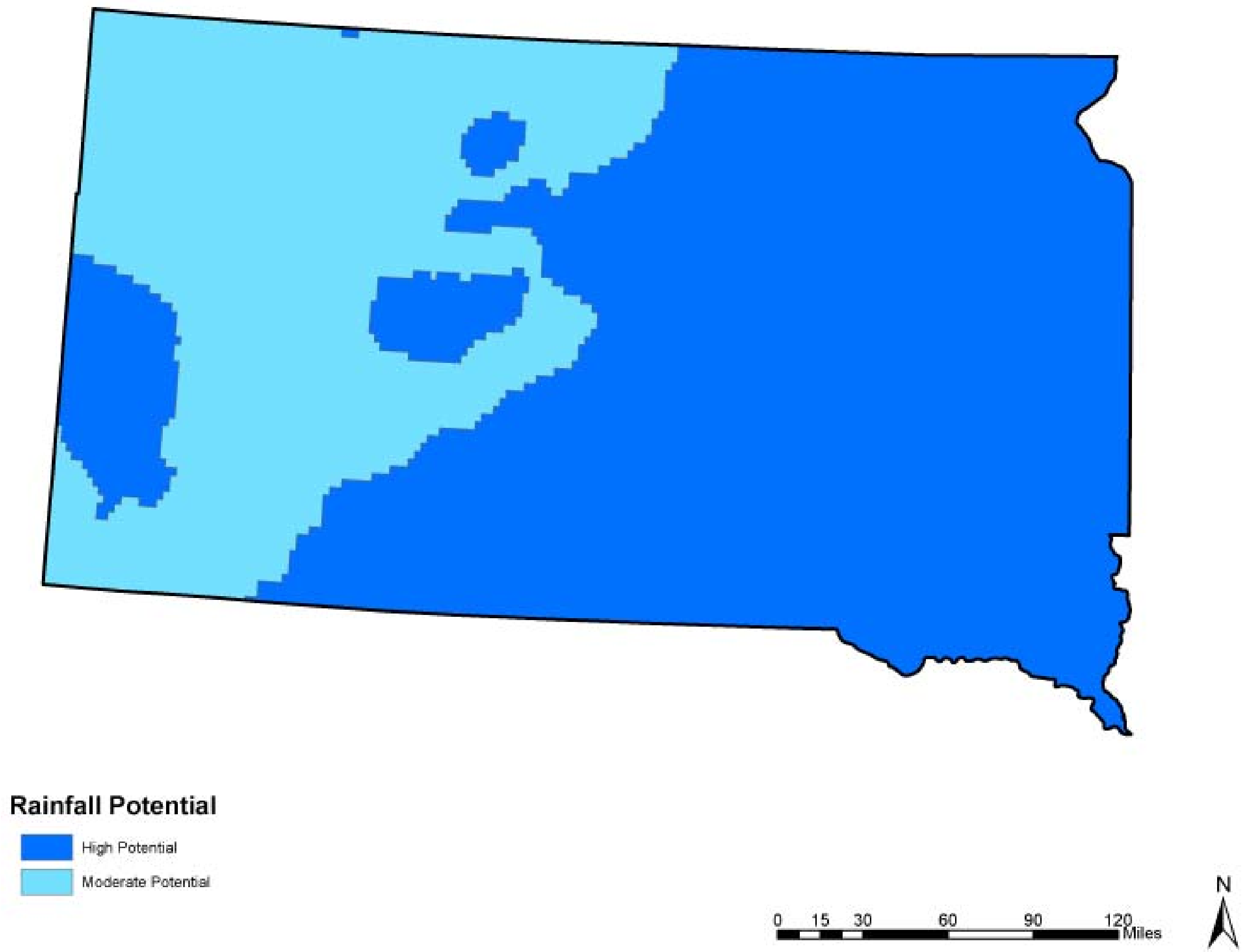

Figure 3. Spatial classification of climatic potential for South Dakota. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year.

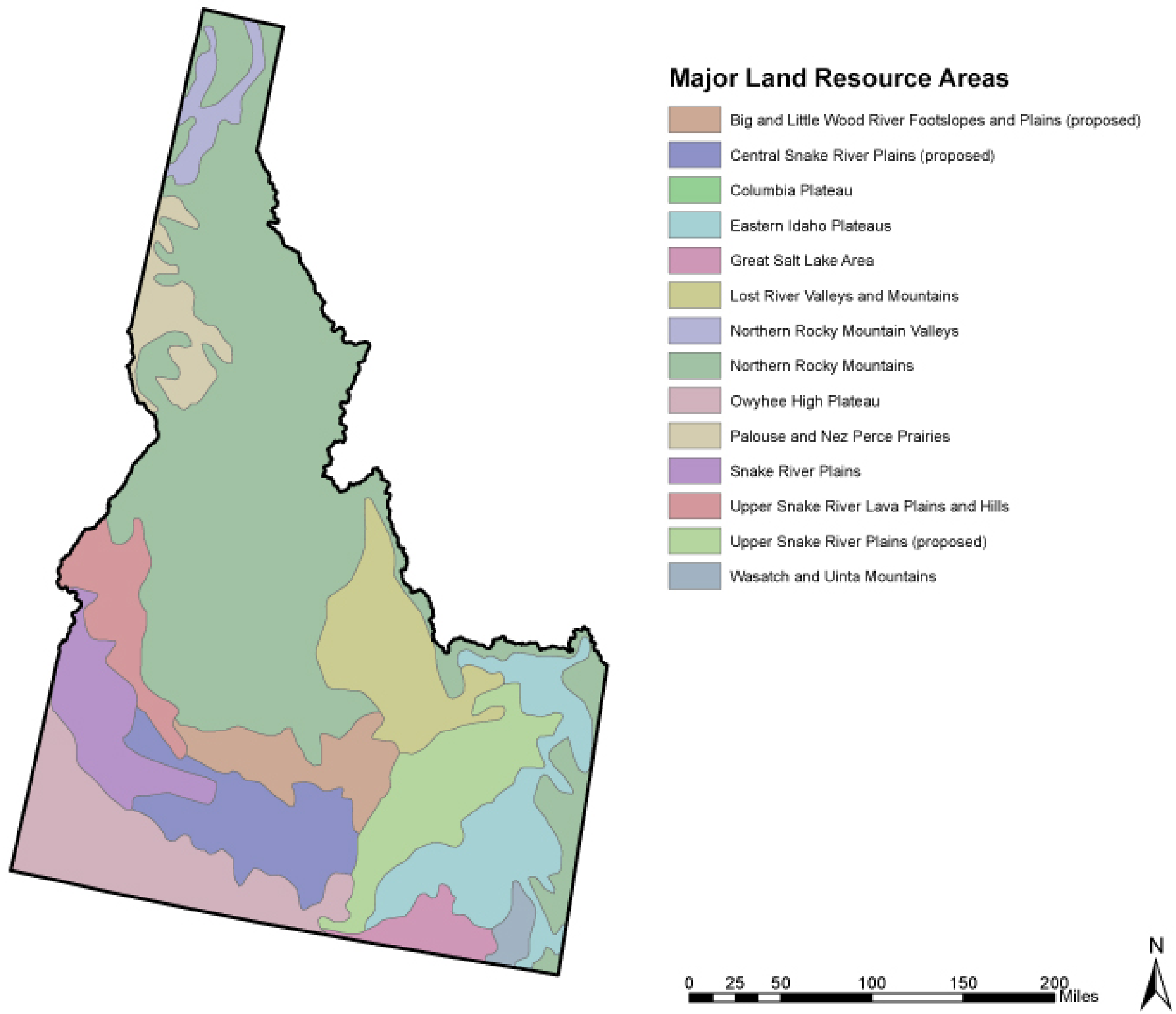

Figure 4. Major land resource areas (MLRAs) within the state of Idaho.

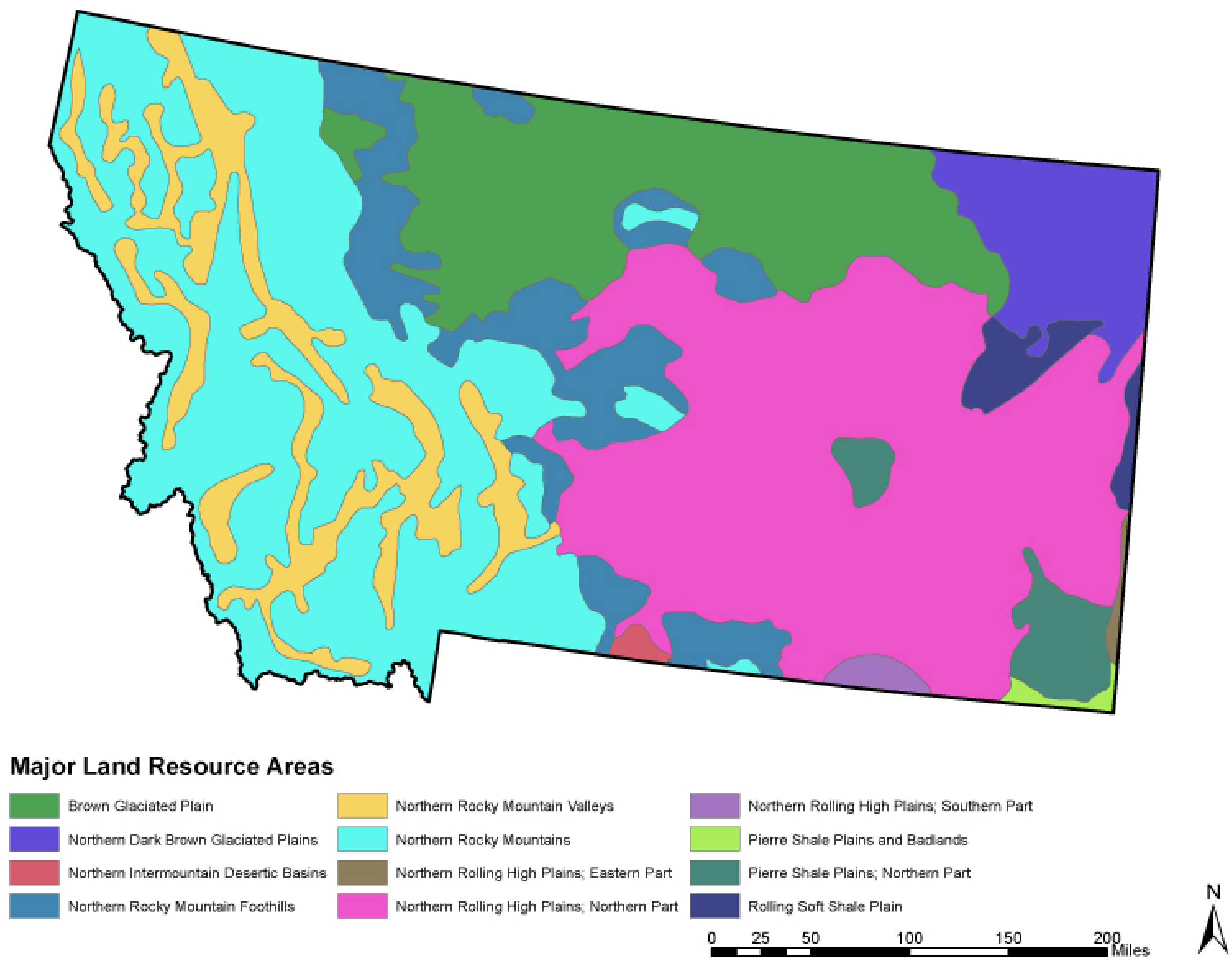

Figure 5. Major land resource areas (MLRAs) within the state of Montana.

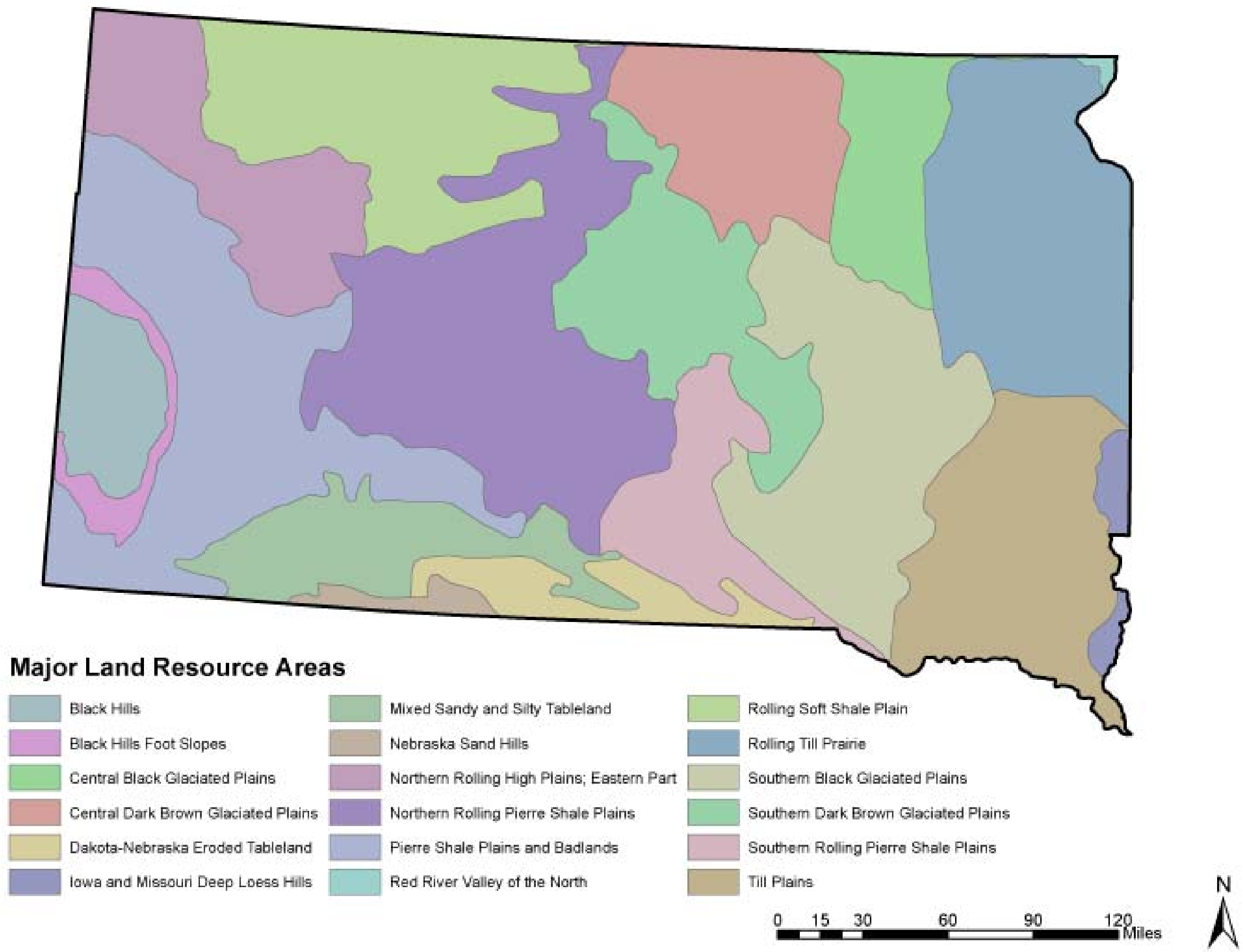

Figure 6. Major land resource areas (MLRAs) within the state of South Dakota

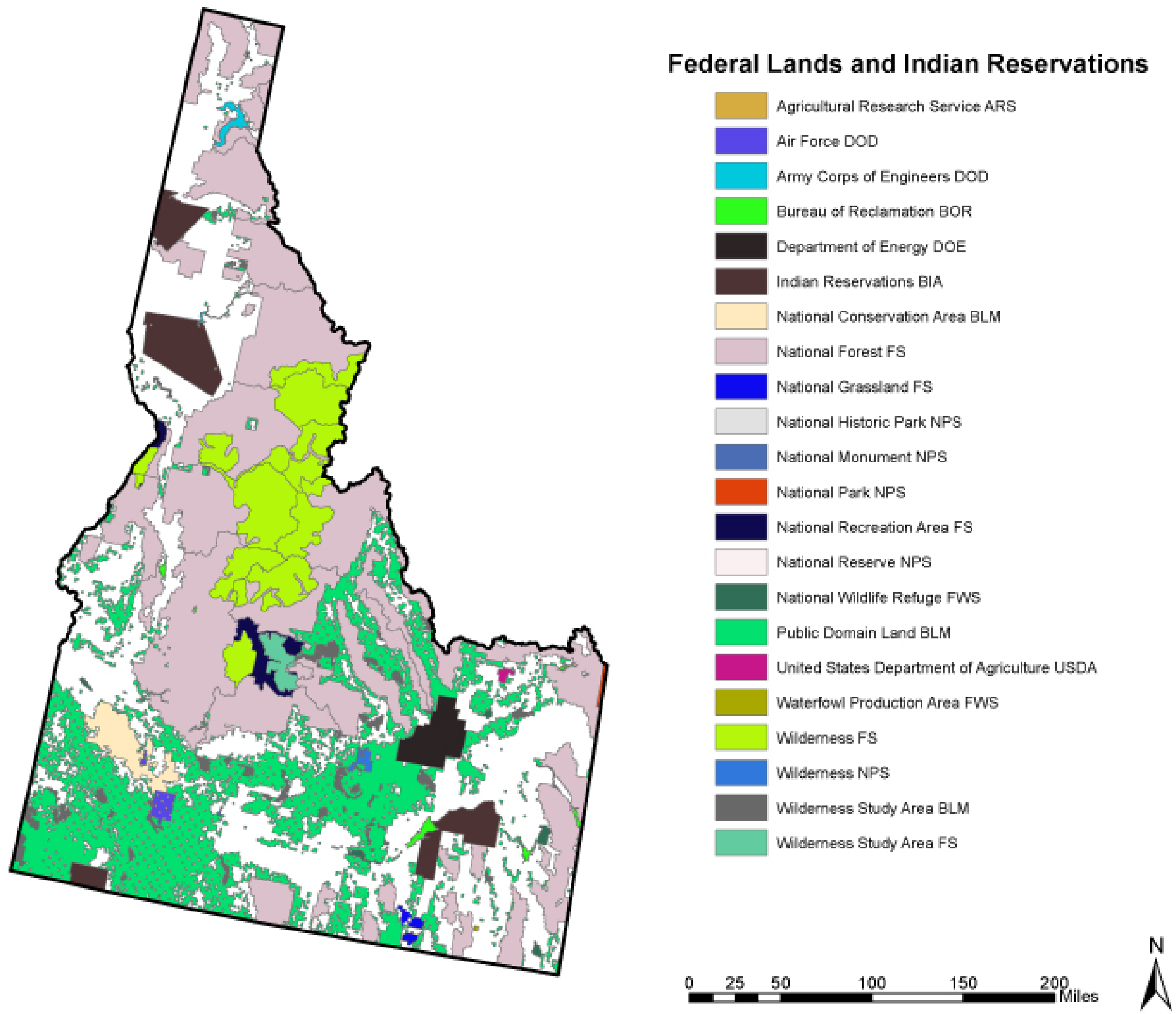

Figure 7. Federal lands and Indian reservations within the state of Idaho.

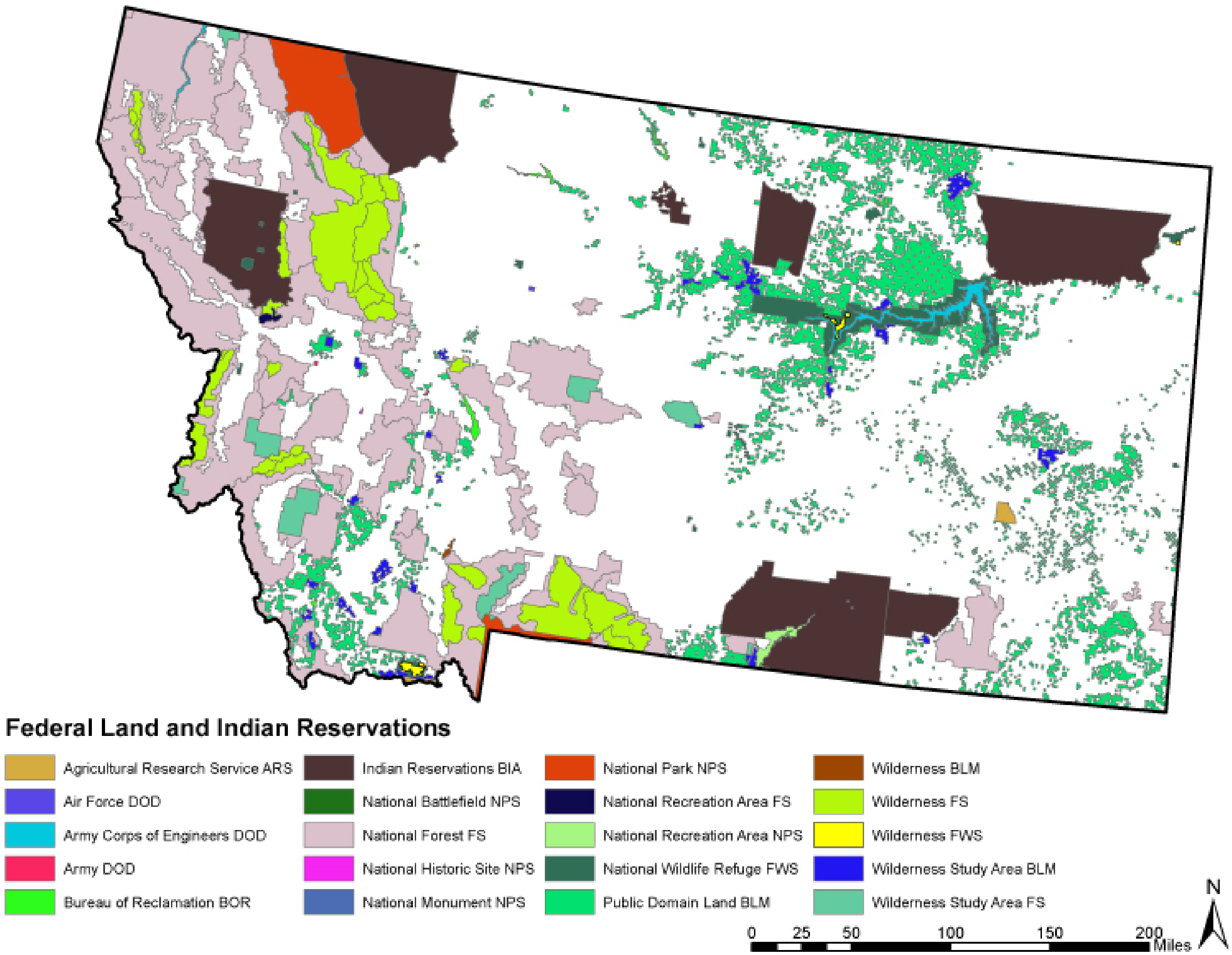

Figure 8. Federal lands and Indian reservations within the state of Montana.

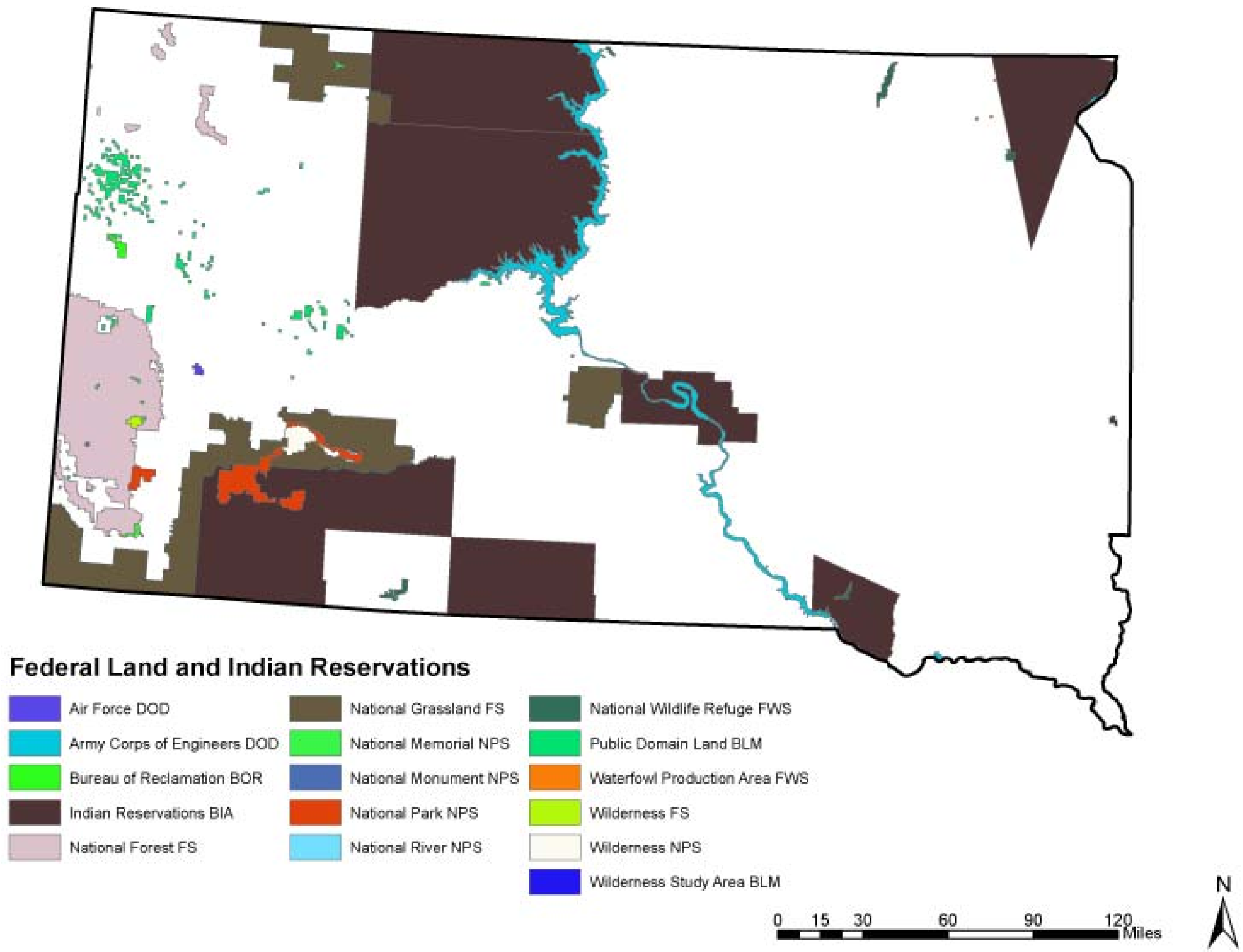

Figure 9. Federal lands and Indian reservations within the state of South Dakota

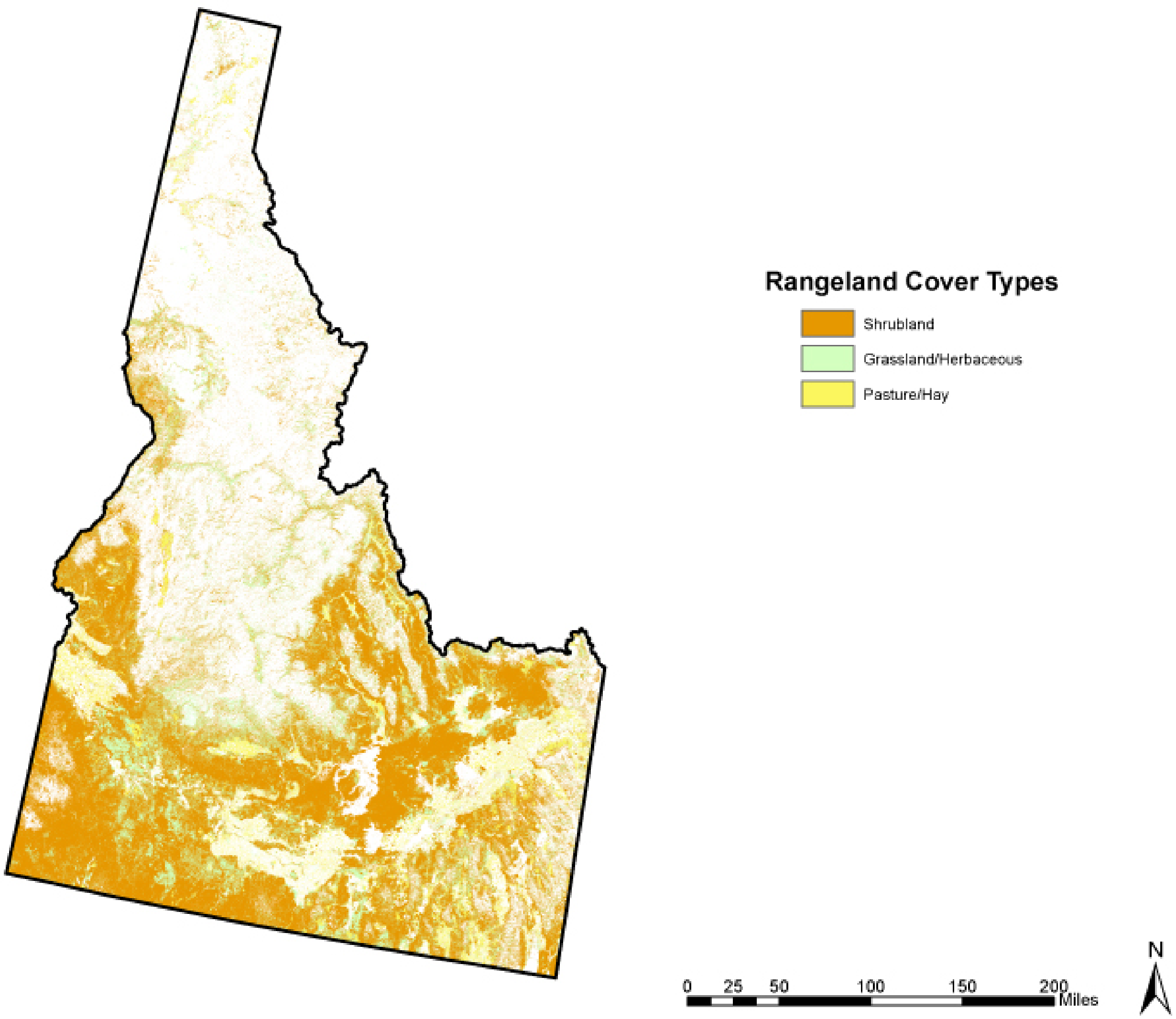

Figure10. Rangeland cover types for the state of Idaho as classified by the National Land Cover Database.

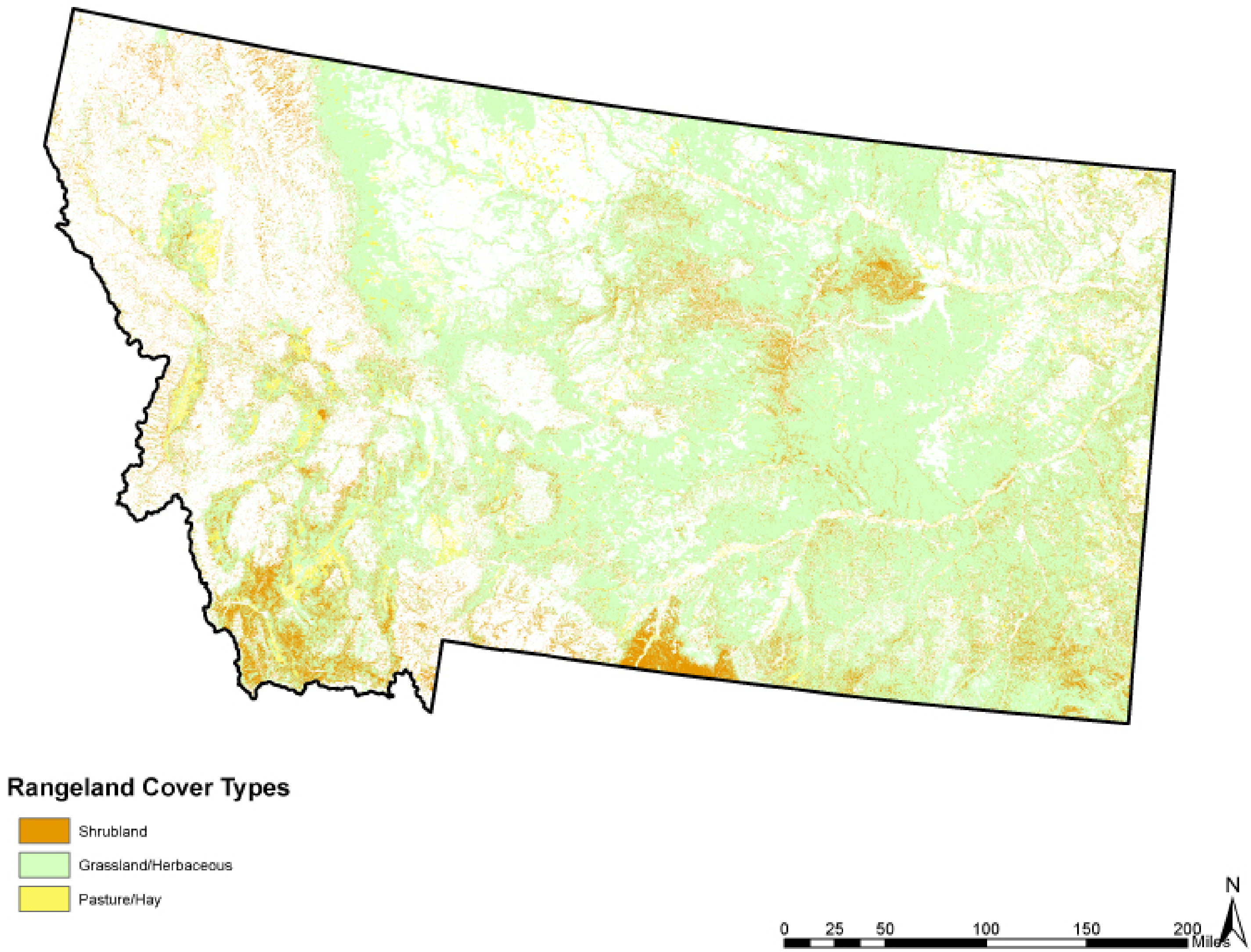

Figure 11. Rangeland cover types for the state of Montana as classified by the National Land Cover Database.

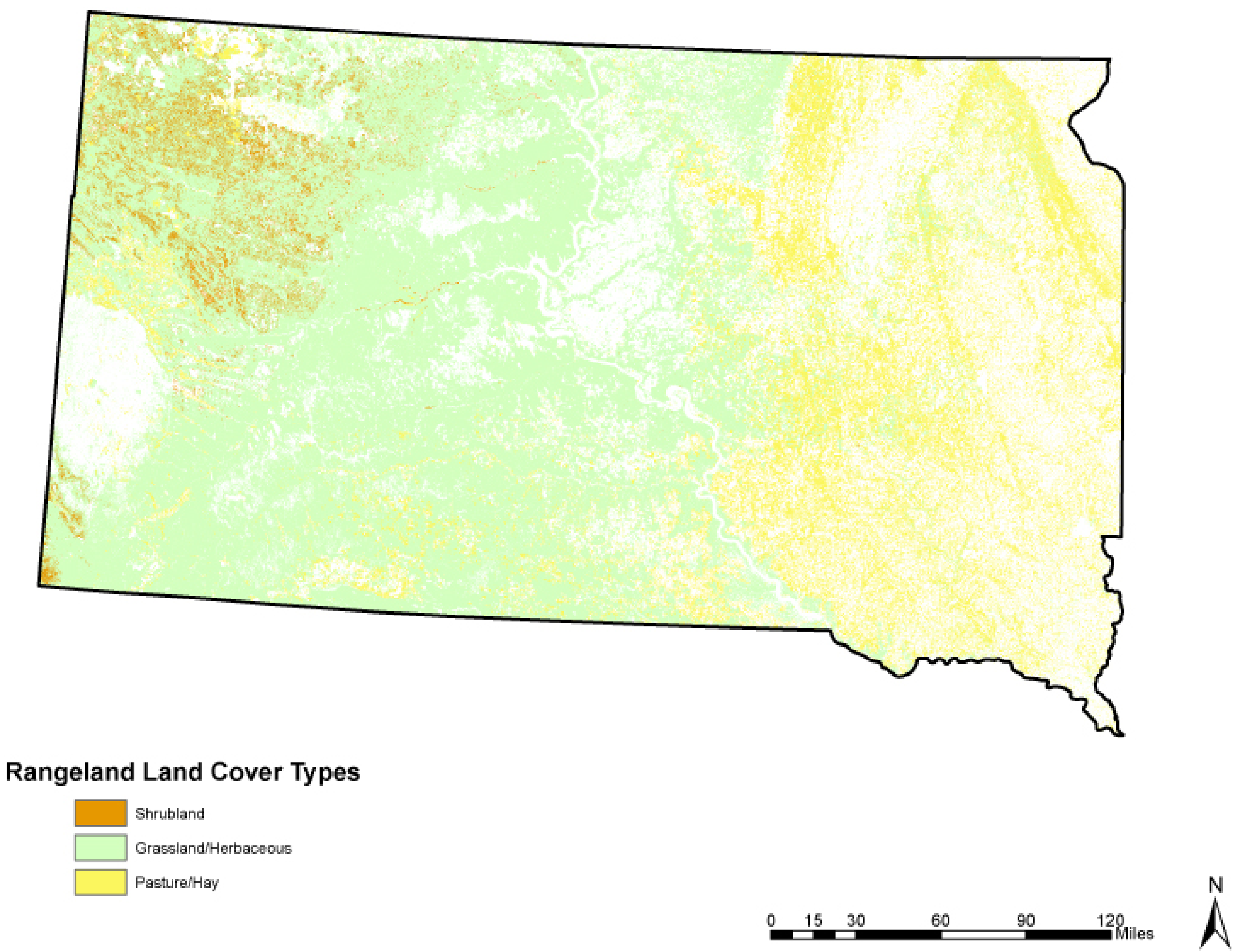

Figure 12. Rangeland cover types for the state of South Dakota as classified by the National Land Cover Database.

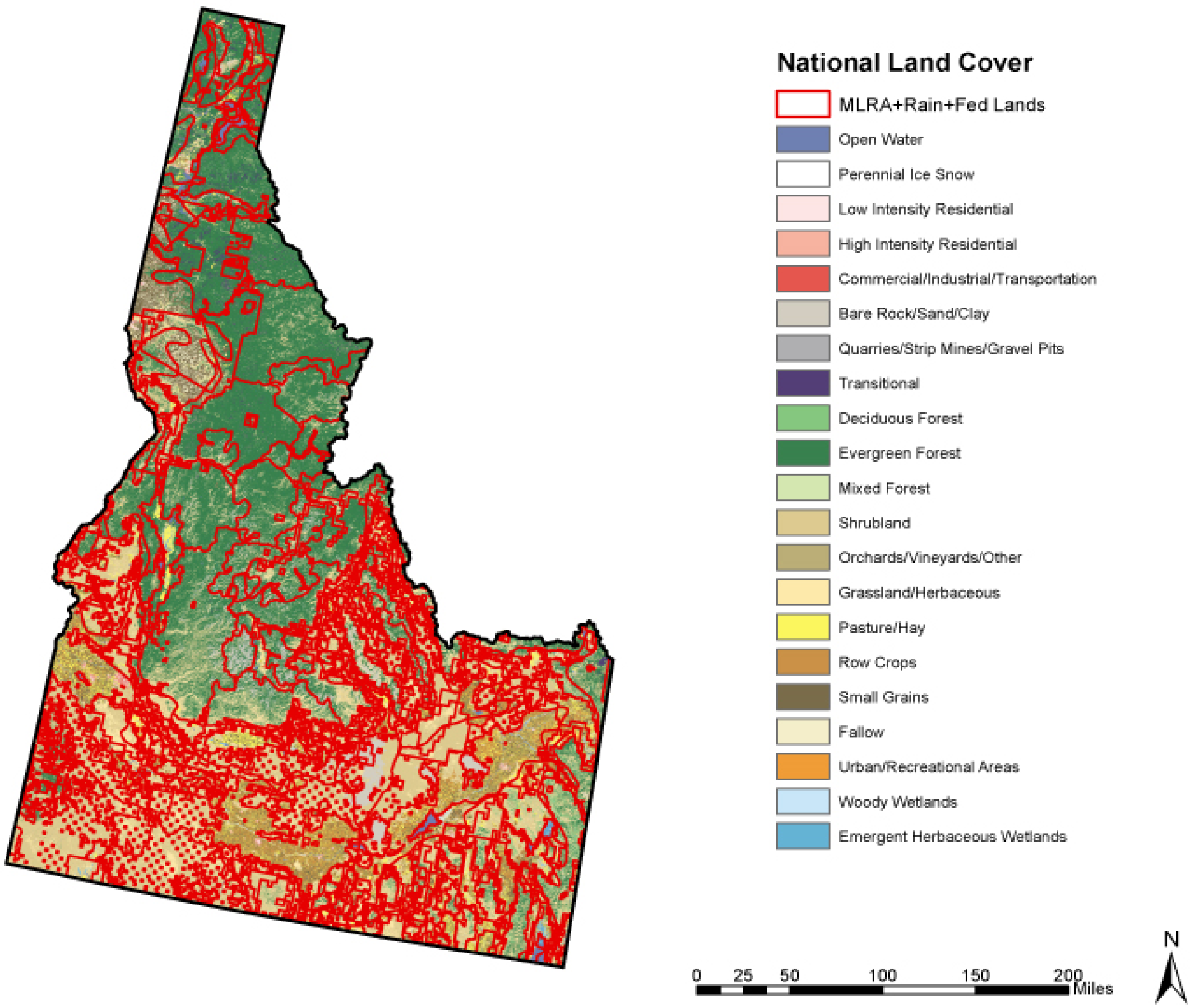

Figure 13. Sampling units (red lines) used in the spatial cross tabulation for the state of Idaho. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation analysis of the National Land Cover Database to determine area coverage of rangeland land cover classes (shrublands, grassland/herbaceous, and pasture/hay).

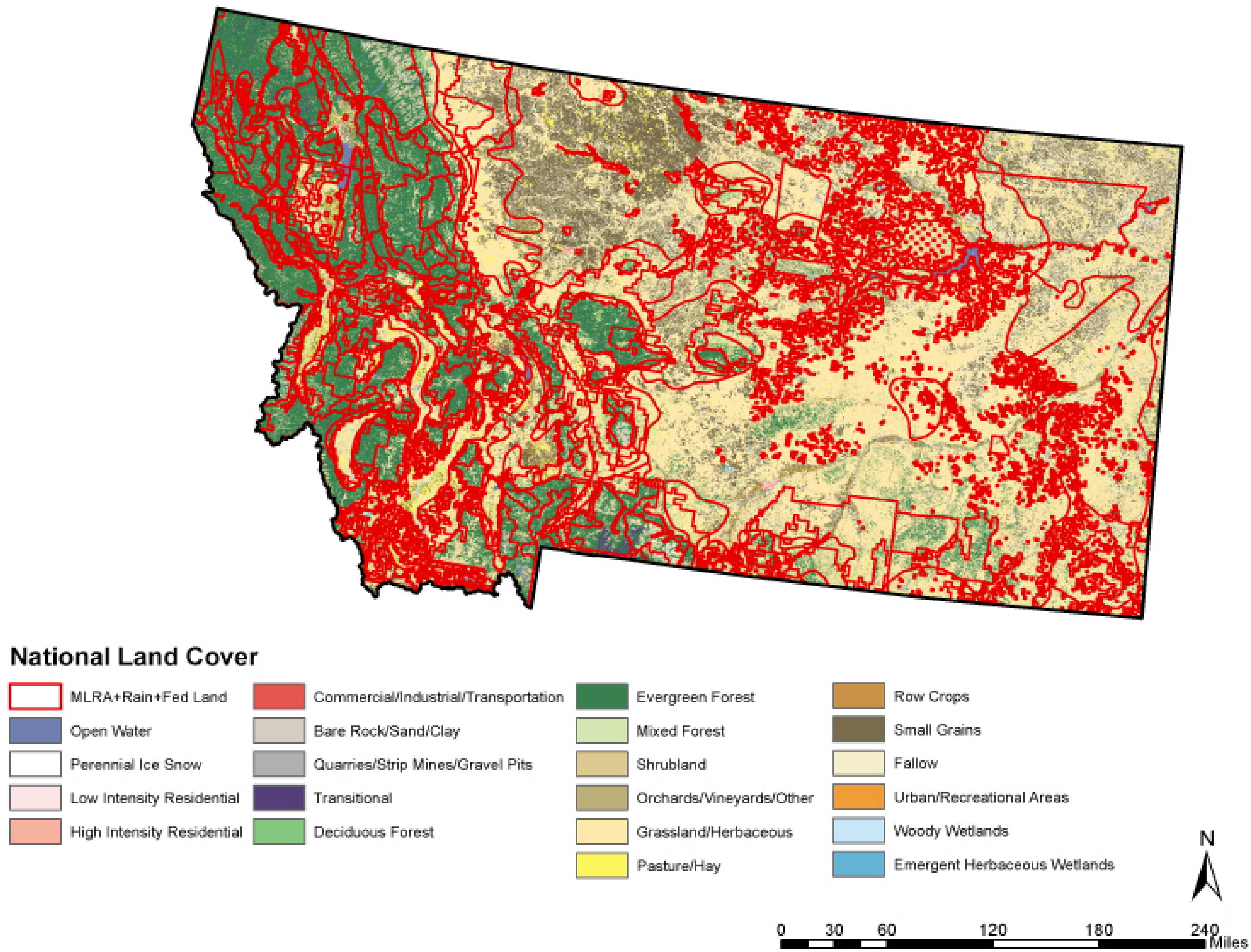

Figure 14. Sampling units (red lines) used in the spatial cross tabulation for the state of Montana. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation analysis of the National Land Cover Database to determine area coverage of rangeland land cover classes (shrublands, grassland/herbaceous, and pasture/hay).

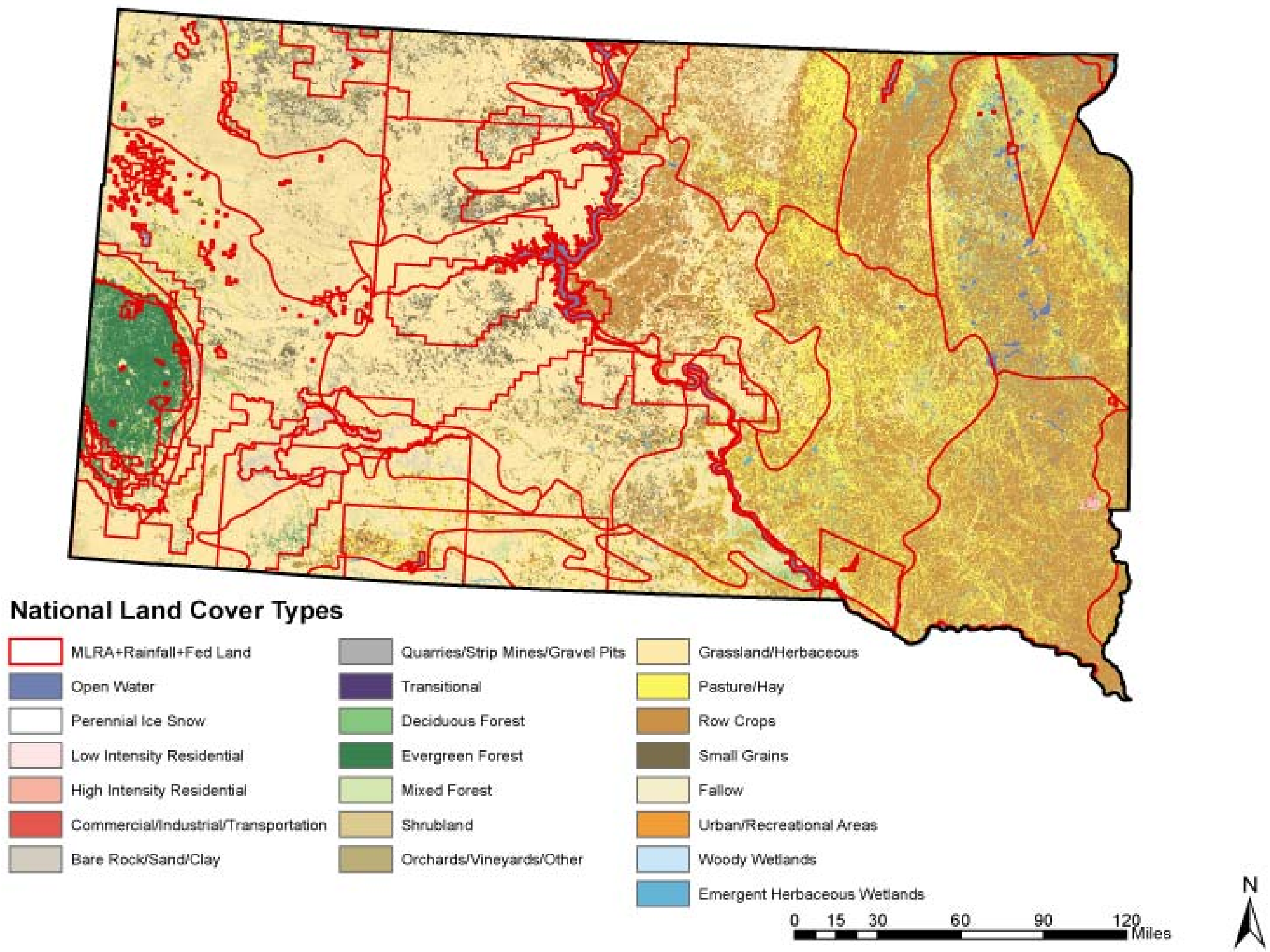

Figure 15. Sampling units (red lines) used in the spatial cross tabulation for the state of South Dakota. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation analysis of the National Land Cover Database to determine area coverage of rangeland land cover classes (shrublands, grassland/herbaceous, and pasture/hay).

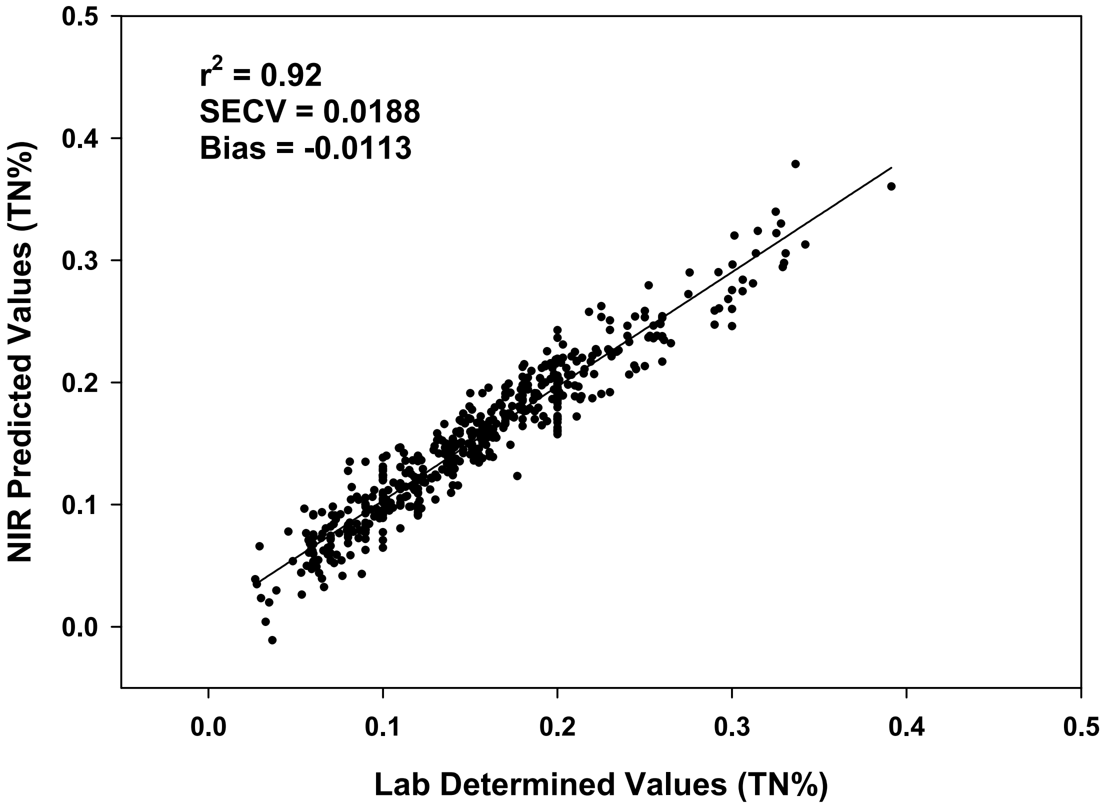

Figure 19. NIR cross validation prediction results for total nitrogen using soils from diverse locations (n = 502)

Appendix II. List of locations, sample numbers, laboratories, and contributing scientists for samples used in the first general carbon equation.

Location	No. Samples	Labs	Scientist
Akron, CO	12	USDA, Lincoln NE	Brian Wienhold
Argentina	14	Texas A&M Univ.	Wylie Harris
Blackland Prairies, TX	24	Texas A&M Univ.	R. Blaisdell
Brookings, SD	11	USDA, Lincoln NE	Brian Wienhold
Bushland, TX	22	USDA, Lincoln NE	Brian Wienhold
Fargo, ND	13	USDA, Lincoln NE	Brian Wienhold
Las Cruces, NM	24	USDA, Las Cruces, NM	Jeff Herrick
Mandan, ND	17	USDA, Lincoln NE	Brian Wienhold
Mead, NE	32	USDA, Lincoln NE	Brian Wienhold
Nebraska	138	Univ. Nebraska Lincoln	Achim Doberman
Ohio	37	Ohio State Univ.	Warren Dick
Sidney, MT	3	USDA, Lincoln NE	Brian Wienhold
Swift Current, Canada	21	USDA, Lincoln NE	Brian Wienhold
Throckmorton, TX	104	Univ. Nebraska	R. Blaisdell
Throckmorton, TX	64	Colorado State Univ.	Richard Teague and Cindy Cambardella
Vernon, TX	59	Colorado State Univ.	Richard Teague and Cindy Cambardella
Wyoming	66	Univ. of Wyoming	Jerry Schuman
Total	661	7	8

Appendix III. Soils database – listing collection locations, labs, constituents of interest and collaborators.

Location	n	Lab	Constituents of Interest	Collaborators
Big Brown Mine Fairfield, Texas	170	Univ. Delaware (FAME)	FAME	Allen Peach David Zuberer
Blackland Prairie, Central Texas	269	Texas A&M Univ. Univ. Delaware	OC,TN, IN, FAME (n=40)	Robert Blaisdell Steve Whisenant David Zuberer
Utah	26	USDA Lincoln, NE	Glomalin	Jayne Belnap
Ohio	200	Univ. Ohio	OC, enzymes	Warren Dick
Nebraska	147	Univ. Nebraska	OC, TN	Achim Doberman
Oklahoma	261	Oklahoma State Univ.	NO3, P, K OC	Sam Fuhlendorf
Argentina	16	Texas A&M Univ.	OC, TN, C13, N15	Wylie Harris
Las Cruces New Mexico	36	USDA Beltsville USDA Las Cruces	Glomalin OC, TN	Jeff Herrick
Kansas - Colorado	33	Colorado State Univ.	OC, TN, FAME	Rebecca McCulley
Wyoming	108	Univ. Wyoming	OC, TN	Jerry Schuman
Vernon, Texas	71	Colorado State Univ.	OC, IC, TN, POM	Richard Teague Cindy Cambardella
Bushland, Texas	24	USDA Lincoln, NE	OC (whole soil) glomalin (particle size)	Brian Wienhold
Fargo, North Dakota	24	USDA Lincoln, NE	OC (whole soil) glomalin (particle size	Brian Wienhold
Mead, Kansas	44	USDA Lincoln, NE	OC (whole soil) glomalin (particle size	Brian Wienhold
Swift Current, Canada	36	USDA Lincoln, NE	OC (whole soil) glomalin (particle size)	Brian Wienhold
Bushland, Texas	17	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Fargo, North Dakota	20	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Mandan, North Dakota	25	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Mead, Nebraska	28	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Sidney, Montana	22	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Swift Current, Canada	18	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Akron, Colorado	12	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Brookings, South Dakota	18	USDA Lincoln, NE	OC,TN, POM	Brian Wienhold
Throckmorton, TX	460	Univ. Nebraska (n =132) 328 predicted by NIRS	OC, IC, TN	Robert Blaisdell Jerry Stuth
Manhattan, Kansas Konza	~390	Kansas State Univ.	OC, TN	Chuck Rice Mickey Ransom Kevin Price Matt Ramspott
sum	2085	10		18