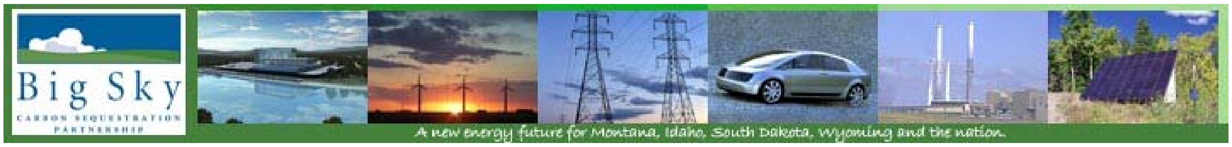

Big Sky Carbon Sequestration Partnership – Phase I

Final Technical Report

December 2005

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Big Sky Carbon Sequestration Partnership

Final Technical Report

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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 are organized 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;
- Design of an integrated suite of monitoring, measuring, and verification technologies, market-based opportunities for carbon management, and an economic/risk assessment framework; (referred to below as the Advanced Concepts component of the Phase I efforts) and
- Initiation of a comprehensive education and outreach program.

As a result of the Phase I activities, 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 complements the ongoing DOE research agenda in Carbon Sequestration.

The geology of the Big Sky Carbon Sequestration Partnership Region is favorable for the potential sequestration of enormous volume of CO_2. The United States Geological Survey (USGS 1995) identified 10 geologic provinces and 111 plays in the region. These provinces and plays include both sedimentary rock types characteristic of oil, gas, and coal productions as well as large areas of mafic volcanic rocks. Of the 10 provinces and 111 plays, 1 province and 4 plays are located within Idaho. The remaining 9 provinces and 107 plays are dominated by sedimentary rocks and located in the states of Montana and Wyoming. The potential sequestration capacity of the 9 sedimentary provinces within the region ranges from 25,000 to almost 900,000 million metric tons of CO_2. Overall every sedimentary formation investigated has significant potential to sequester large amounts of CO_2. Simulations conducted to evaluate mineral trapping potential of mafic volcanic rock formations located in the Idaho province suggest that supercritical CO_2 is converted to solid carbonate mineral within a few hundred years and permanently entombs the carbon. Although MMV for this rock type may be challenging, a carefully chosen combination of geophysical and geochemical techniques should allow assessment of the fate of CO_2 in deep basalt hosted aquifers.

Terrestrial carbon sequestration relies on land management practices and technologies to remove atmospheric CO_2 where it is stored in trees, plants, and soil. This indirect sequestration can be implemented today and is on the front line of voluntary, market-based approaches to reduce CO_2 emissions. Initial estimates of terrestrial sinks indicate a vast potential for increasing and maintaining soil Carbon (C) on rangelands, and forested, agricultural, and reclaimed lands. Rangelands can store up to an additional 0.05 mt C/ha/yr, while the croplands are on average four times that amount. Estimates of technical potential for soil sequestration within the region in cropland are in the range of 2.0 M mt C/yr over 20 year time horizon. This is equivalent to approximately 7.0 M mt CO_2e/yr. The forestry sinks are well documented, and the potential in the Big Sky region ranges from 9-15 M mt CO_2 equivalent per year. Value-added benefits

include enhanced yields, reduced erosion, and increased wildlife habitat. Thus the terrestrial sinks provide a viable, environmentally beneficial, and relatively low cost sink that is available to sequester C in the current time frame.

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 and terrestrial sequestration reflect this concern. Research in Phase I has identified and validated best management practices for soil C in the Partnership region, and outlined 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. This is the basis for the integrative analysis that will be undertaken in Phase II to work with industry, state and local governments and with the pilot demonstration projects to quantify the economic costs and risks associated with all opportunities for carbon storage in the Big Sky region. Scientifically sound MMV is critical for public acceptance of these technologies.

Key deliverables for Phase I include:

- **Geological efforts**: Three deliverables including two major reports on *Technology Needs* and *Action Plan on the Evaluation of Geological Sinks and Pilot Project Deployment* (Deliverables 2/3), and *Report on the Feasibility of Mineralization Trapping in the Snake River Plain Basin* (Deliverable 14);
- **Terrestrial efforts**: Seven key deliverables including an *Evaluation of Terrestrial Sinks* and a Report of the *Best Production Practices for Soil C Sequestration (*Deliverables 8 and 15) and the supporting documentation for terrestrial sinks.
- **GIS efforts**: the development of the on-line carbon atlas and an accompanying special report on the overall GIS activities for the Partnership which includes the documentation for the carbon atlas plus efforts on development of a data warehouse infrastructure to support Phase II activities, and linkages to other national cyberinfrastructure and outreach efforts.
- **Advanced Concepts efforts**: Seven key deliverables focusing on designing carbon market protocols, assessment of MMV technologies, assessment of geological and terrestrial sink potential as a screening tool for determining Phase II demonstration pilots, and risk assessment and decision-support methodologies. In addition the Partnership has developed a second special report on the policy implications of future economic growth in the Big Sky region.
- **Education Outreach efforts**: The Partnership developed a comprehensive plan which serves as a guide for implementing the outreach activities under Phase I, a well designed web site (www.bigskyco2.org) which has been integrated with the Carbon Atlas, and has been involved in numerous regional and national outreach efforts designed to lay the foundation for regional support of the Phase II demonstration tests.

In conclusion, in Phase I the Partnership has identified, assessed and catalogued C sources and promising geologic and terrestrial sequestration sites, developed market-based carbon trading protocols to facilitate an efficient means to sequester carbon and improve verification that is transferable to other regional, national, and international settings, designed the foundations for an economic and risk assessment decision support framework to optimize the region's C sequestration portfolio, examining means of cost effectively implementing promising MMV technologies, and developed an education and outreach program, which addresses stakeholders needs as well as develops a program for capacity building in the region incorporating the tribal colleges and at the universities involved in our Partnership.

The Phase I work clearly identified the geological similarities among Montana, Idaho, Wyoming, Washington, and Oregon. There are similar land use patterns and cropland practices among these states and South Dakota, and the Canadian provinces. At the conclusion of Phase I, we have expanded the Partnership to include the states/provinces with similar and contiguous geological and terrestrial sinks. This expansion is also justified by the common economic interests of these States, including many regional energy companies operating across States and Provincial lines. Additionally, the Partnership is working with leading research institutions in DOE's Carbon Sequestration Leadership Forum member countries including Norway, India and China who will bring unique expertise and funding commitments to leverage DOE's Big Sky Partnership investment.

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INTRODUCTION

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 area's 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 was obtained in the latter half of the Phase I efforts which expanded the Partnership to include the neighboring states of Washington and Oregon, and the neighboring provinces in Canada. We have also brought in several new industrial partners including Puget Sound Energy, Energy Northwest, Sempra Generation, Portland General Electric, and rural Cooperatives in the region. Montana Tech-Montana Bureau of Mines and Geology and the Idaho Carbon Sequestration Advisory Committee/Idaho Soil Conservation Commission, and Battelle Pacific Northwest Divison 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
Boise State University
Nez Perce Tribe
Idaho National Laboratory
Los Alamos National Laboratory
Montana Governor's Carbon Sequestration Working Group
National Carbon Offset Coalition
The Confederated Salish & Kootenai Tribes

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
Wyoming Department of Environmental Quality
Univ. of Wyoming Geographic Information Science Center
Univ. of Wyoming Enhanced Oil Recovery Institute
Idaho State University
University of Nebraska-Lincoln
Intertribal Timber Council
National Tribal Environmental Council
Univ. of Wyoming Ruckelshaus Institute for Environment and Natural Resources
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Montana Dept. of Admin., Montana GIS Services Bureau, Information Technology Services
Unifield Engineering
Jackson Hole Center for Global Affairs
Battelle Pacific Northwest Division Energy Northwest
Puget Sound Energy
Sempra Generation
Portland General Electric
Columbia University-Lamont Doherty Earth Observatory

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 statement of work 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 9-21
- **Education and outreach efforts:** Tasks 8, 22-25

This final technical report summarizes the major work performed throughout the Phase I period, and integrates the findings and conclusions from the efforts as a whole. Each of the quarterly reports has documented the research efforts in chronological manner; each of the major deliverables for the project provides greater detail on the procedures and results for the efforts in the above four components. In addition to the deliverables, the Partnership activities during Phase I included: further development of the proposed activities for the deployment and demonstration phase including both geological and terrestrial pilots; expansion of the Partnership to encompass regions and institutions that are complimentary to the geographic boundaries of the sinks and to the economic interests of the region; creation of an on-line Big Sky Carbon Atlas and associated documentation of data bases (www.bigskyco2.org); building greater collaborations with industry and stakeholders in the region; outreach efforts that spanned the other DOE partnerships; co-authorship on cross-partnership reports including the Carbon Capture and Separation report and the IOGCC report; and an assessment of the regional resources and infrastructure to address future energy opportunities in the region.

The major milestones as provided in the Phase I proposal have been accomplished. These are noted below:

Project Phase	**Milestone**
Partnership as a Whole	
• Develop a risk assessment and decision support framework for optimizing soil C sequestration portfolio • Quantify the region's contribution to meeting Bush administration's target goals of reducing GHG intensity 18% by 2012 • Identify market-based voluntary approaches to carbon sequestration	
Geological Sequestration Phase	
• Identify sources of CO_2 • Identify and assess promising geological sinks • Identify advanced concept for geological sequestration	
Terrestrial Sequestration Phase	
• Identify and assess the potential for soil C sequestration in region • Identify advanced concept for terrestrial sequestration	
Outreach	
• Web site development • Forums and workshops for engaging community leaders in the region in carbon sequestration strategies	

The primary sources of greenhouse gases (GHG) in Montana, Idaho, Wyoming and South Dakota are documented in the Big Sky Carbon Atlas and via NatCarb distributed national databases (www.natcarb.org). In 2002 the region's gross emissions of GHGs were averaging about 61 MMTCE, which translates into per capita emissions ranging from a high of 23MTCE in Wyoming to 12 MTCE in Idaho. In Montana and Wyoming, refining and other energy and heavy industries constitute the largest source of GHGs related to energy consumption source category; while in Idaho imported electricity accounts for the largest category of energy-related emissions. Potential emissions from future development of the vast fossil-fuel resources are conservatively estimated to be an order of magnitude higher, depending on transmission lines and other energy demand factors. GHG emissions from agriculture, principally CH_4 from livestock and N_2O from soil management, account for nearly 27% of South Dakota emissions.

The geology of the Big Sky Carbon Sequestration Partnership Region is favorable for the potential sequestration of enormous volume of CO_2. The United States Geological Survey (USGS 1995) identified 10 geologic provinces and 111 plays in the region. These provinces and plays include both sedimentary rock types characteristic of oil, gas, and coal productions as well as large areas of mafic volcanic rocks. Of the 10 provinces and 111 plays, 1 province and 4 plays are located within Idaho. The remaining 9 provinces and 107 plays are dominated by sedimentary rocks and located in the states of Montana and Wyoming. The potential sequestration capacity of the 9 sedimentary provinces within the region ranges from 25,000 to almost 900,000 million metric tons of CO_2. Overall every sedimentary formation investigated has significant potential to sequester large amounts of CO_2. Simulations conducted to evaluate mineral trapping potential of mafic volcanic rock formations located in the Idaho province suggest that supercritical CO_2 is converted to solid carbonate mineral within a few hundred years and permanently entombs the carbon. Although MMV for this rock type may be challenging, a carefully chosen combination of geophysical and geochemical techniques should allow assessment of the fate of CO_2 in deep basalt hosted aquifers.

For terrestrial sequestration estimates, the Partnership has developed a county level land use data base on management practices, climate, and land use history. Simulation programs developed in conjunction with USDA, and Century models are used to compile the large scale terrestrial sink estimates. Coverage includes Indian reservations and private lands, and reflects potential changes in carbon on rangelands, croplands, and forested areas. Rangelands can store up to an additional 0.05 mt C/ha/yr, while the croplands are on average four times that amount. Estimates of technical potential for soil sequestration within the region (ID, MT, WY, and SD) in cropland are in the range of 2.0 M mt C/yr over 20 year time horizon. This is equivalent to approximately 7.0 M mt CO_2e/yr. The forestry sinks are well documented, and the potential in the Big Sky region ranges from 9-15 M mt CO_2 equivalent per year. Value-added benefits include enhanced yields, reduced erosion, and increased wildlife habitat.

The Big Sky geographic information system (GIS) phase I accomplishments included the following three major areas of effort: (i) Big Sky Carbon Atlas: compilation of geologic and terrestrial sequestration data for the states of Montana, South Dakota, Idaho, and Wyoming and sources data; (ii) Big Sky Data Warehouse: planning and initial implementation of online access via IMS and SDE; and (iii) interpartnership coordination and links with NATCARB, DOE, and national cyberinfrastructure efforts. Expansion of these efforts in the first year of Phase II will include the sink data for eastern Washington and Oregon.

The advanced concept component has integrated the activities of the partnership by focusing on needed efforts for pending large scale deployment of the sequestration opportunities. The key efforts include examining the feasibility for market-based sequestration options; exploring mineralization trapping feasibility in the Snake River Plain Basin; defining measurement, monitoring, and verification requirements for all sinks; and developing a common (economic) framework for evaluating the tradeoffs among alternative carbon sinks at both the project and regional levels. The MMV efforts summarized the current state of capabilities for geological and terrestrial sinks, and evaluated the systems for public credibility, cost effectiveness, and timeliness of detection of leakages. The economic framework provides a means to quantify regional C supply curves, showing at each price of C, the total amount of C that could be sequestered in the region. This framework has become a valuable tool to enable the Partnership, its industry members and the region to begin to assess the economic potential of all its sequestration options on a common basis. The MMV procedures are an integral part of the geological pilots that will be done in Phase II, the carbon markets, and the terrestrial pilots. They are also critical in terms of examining the costs of sequestering carbon, and will be incorporated into the economic and risk assessment analysis.

Furthermore, with the largest and most comprehensive terrestrial program in the nation, the Partnership has taken a lead in enhancing market-based C storage methods and improving verification protocols. Throughout Phase I the National Carbon Offset Coalition (NCOC) has successfully expanded the number and diversity of participants in its landowner/emitter advisory committee, and held meetings with the National Governors Association Greenhouse Gas working Group, the Intertribal Environmental Council, and the U.S, Environmental Protection Agency. The Partnership, through the NCOC, has 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 had extensive 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. Planning forms, contracting options and forestry portfolios, and Project Planning Handbooks were developed and have been reviewed by the Chicago Climate Exchange.

The focus of the Partnership's Phase I education and outreach activities was to lay the foundation for regional support of Phase II field validation tests. An Education and Outreach Action Plan was developed to identify key stakeholder groups and targeted messages and guide Phase I activities. Focus was given to communicating the opportunities and risks associated with carbon sequestration and working with decision makers to determine possible issues associated with field validation test implementation and ultimately commercial deployment. Outreach activities were conducted in a number of ways and venues ranging from individual meetings, legislative briefings, workshops, and symposia, to poster sessions, presentations, web networks and the news. Feedback from education and outreach activities indicate that given potential energy resource development in the region and the need for economic growth, there is considerable interest in carbon sequestration. Regional environmental management and stewardship is also of considerable interest; therefore, the Partnership's primary conclusion from its outreach activities is that the region as a whole is cautiously optimistic about sequestration's potential, supportive of Phase II field validation tests and would like to learn more.

In summarizing the Phase I results and activities, the following major cross-cutting and integrative themes emerge:

- The Big Sky region is a relatively low emitter of GHG and in particular CO_2 emissions, with only a few point sources that account for a large share of these emissions. However, the region contains extensive fossil-fuel based resources, having more than 25% of the coal resources in the US. As a result the Big Sky partnership region can play a unique role in designing and meeting future energy production in a way that addresses energy security, cost efficiency, reliability, and environmental stewardship. The potential for providing clean coal technologies and regional carbon sequestration opportunities that complement the future energy development objectives of the region, including FutureGen, and the demands for long term, safe storage of carbon is real and, through the selection and design of our Phase II pilots and with the collaboration of research partners, industry, state agencies, and landowners, achievable in the near future.
- The region is a wealth of sinks. Geological and terrestrial carbon sinks provide a myriad of sequestration options that span both temporal and spatial dimensions, and are similar to large sequestration sinks that exist in other parts of the developing and developed world. The current terrestrial sinks, including cropland, rangelands, and forestry/agroforestry, combined with the opportunities to continue to expand EOR in the Big Sky region, offer an answer to near-term carbon sequestration needs at a cost that is competitive with other national and international alternatives. In the longer term, the potential sequestration capacity of the sedimentary provinces within the region are almost 900,000 million metric tons of CO_2 with the characteristic to permanently entomb the carbon.
- In addressing future carbon sequestration opportunities, the Partnership has invested in efforts designed to help insure that the opportunities and programs are cost-effective and competitive with other sequestration alternatives. The attention to the economic potential of these sinks, i.e., the 'opportunity cost" of changing land use patterns, of using energy to capture, separate, and sequester CO_2, of combining energy production in a manner that optimizes a joint energy production and CO_2 mitigation plans, is a key strength of the partnership. Equally important and recognized nationally and internationally is the extensive efforts on designing protocols and verification procedures for enhanced market-based carbon trading, carbon offsets, and carbon-storage methods.
- The Partnership has conducted public education and outreach to build a dialogue with key decision makers, regulatory officials, industry, environmental groups, tribal nations, and the public on the region's energy future and the opportunities and risks associated with advanced coal technologies and C sequestration.

The Phase I work clearly identified the geological similarities among Montana, Idaho, Wyoming, eastern Washington and Oregon. There are also similar land use patterns and cropland practices among these states and South Dakota, and the Canadian provinces. Thus as we proceed into Phase II, we have expanded the Partnership to include the states/provinces with similar and contiguous geological and terrestrial sinks. This expansion is also justified by the common economic interests of these States, including many regional energy companies operating across States and Provincial lines. Additionally, the Partnership is working with leading research institutions in DOE's Carbon Sequestration Leadership Forum member countries including Norway, India and China who will bring unique expertise and funding commitments to leverage DOE's Big Sky Partnership investment.

Key contributors to this final technical report are listed in Appendix E.

EXPERIMENTAL SECTION

This section presents a summary overview of the design and approach the partnership used in Phase I to address the sources and potential sinks in the region, the development of the GIS-based carbon atlas, the advanced concepts, and the outreach and education. Greater detail is provided in the quarterly reports.

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.

GHG Emissions from Industrial Processes

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 provided 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.

GHGs from Municipal and Industrial Waste

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.

GHGs from Land Management and Livestock

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 U.S. 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). The estimates of forest stock changes are 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.

Geological Sequestration

Geologic sequestration is the storage or entombment of CO_2 in subsurface geologic formations. Because approximately one third of the CO_2 emitted annually in the United States is from point sources, capture at the source coupled with geologic entombment has high potential to limit emissions to the atmosphere. Potential geologic formations that may be conducive to sequestration include: deep saline aquifers, depleted oil/gas reservoirs, deep unmineable coal beds, and mafic/ultramafic rocks. Because many of these natural reservoirs are known to have stored fossil fuels and other fluids over geologic time frames, they can be expected to have high potential for the long-term sequestration of CO_2.

Geologic sequestration occurs via three interrelated processes. The first is hydrodynamic trapping where CO_2 is physically isolated by trapping beneath impermeable geological barriers such as a shale bed. This is the primary sequestering process in the short-term and is largely a function of the storage capacity of the deep system and its degree of isolation from the Earth's surface. The second process is solubility trapping in which CO_2 dissolves in subsurface fluids such as brines, petroleum, or deep aquifer waters. Solubility trapping is slower than hydrodynamic trapping and depends on the CO_2 dissolution rate in the fluid of interest. The third process is trapping due to mineralization in which CO_2 is entombed by increased diagenesis of the geochemically reactive base cations (primarily Ca^{2+}, Mg^{2+}, and Fe^{2+}) in subsurface minerals. The weathering reactions result in the conversion of CO_2 into carbonate alkalinity and ultimately carbonate minerals. The time frame for mineralization trapping is primarily a function of the weathering rate and is much slower that the other two trapping processes. In developing the assessment of sequestration potential the partnership considered each of the three trapping processes as appropriate for a given reservoir or rock type.

The Big Sky Partnership region is characterized by a host of major geological terrains with high potential for geologic sequestration, including the volcanic rocks of the Snake River Plain and Columbia River Plateau (ID, WA), the Williston Basin (MT) the Powder River Basin (WY, MT), and other sedimentary basins such as the Wind River (WY) and other associated basins. Together these sedimentary basins cover more than 400,000 km^2 of Wyoming, South Dakota, and Montana. These basins range from 1,500 to 3,000 meters thick and are comprised of bedded sandstones, shales, thick coal beds, dolomites and limestone. In addition to the sedimentary basins, the region also contains over 220,000 km^2 of mafic volcanic rocks in the Columbia Plateau/Snake River Plain and Columbia River Basalts (ID, WA) with maximum thickness of 2,100 to 3000 meters.

In describing the Partnership's region the 1995 National Assessment of United States Oil and Gas Resources conducted by the United States Geological Survey (USGS 1995) was used to define manageable parcels of like geology referred to as plays. The National Assessment identified 10 provinces (Figure 1) and 111 plays in the region. Of the 111 plays 84 are conventional plays or plays with oil and gas deposits that can be extracted using traditional methods. The remaining 27 are unconventional plays which are generally characterized as continuous geologic formations that because of rock type, geologic timing or seal failure do not contain hydrocarbons. Of the 111 plays 4 are located within Idaho. The remaining 107 plays are in the states of Montana and Wyoming.

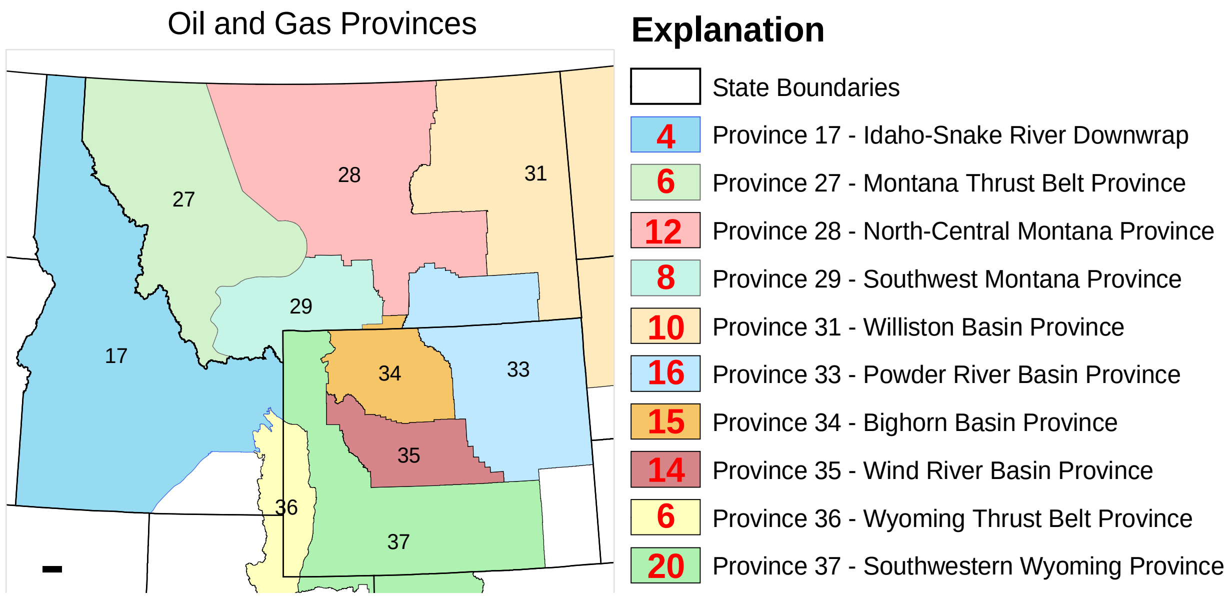

Figure 1. Location map showing the geologic provinces as identified in the 1995 National Assessment of United States Oil and Gas Resources. The red numbers in the "Explanation" indicates the number of plays within each province.

Each of the 107 plays located in Montana and Wyoming had one or more geologic formations that were identified, the needed properties for each formation were collected based on availability of data in readily assessable data bases. Because both Montana and Wyoming have significant production of energy resources significant amount of data exist in state managed databases which are available to the general public and were used in the assessment. The collected data as well as tools developed to process the data were prepared for inclusion in the regions carbon atlas which is planned for early in Phase II. Because state managed databases were not available for fossil fuel poor Idaho, the assessment approach for the 4 plays located in Idaho were lumped and relied on a set of "advance concept" example (Smith et al., 2004) calculations that focused on the role of mineral trapping in mafic volcanic rocks located within the state. A more detailed analysis of the sequestration potential of Idaho is planned in Phase II as part of the National Mafic Rock Atlas Activity.

Sedimentary Rocks in Montana and Wyoming

The evaluation of sequestration potential for sedimentary basins required the collected of specific parameters for each play. The parameters of interest for each play included the properties that describe the rock chemistry, brine chemistry, and hydraulic conditions, depth to play, etc. Data for Wyoming was downloaded from the Wyoming Oil and Gas Conservation Commission website (http://wogcc.state.wy.us/). Data for Montana's was downloaded from the Montana Board of Oil and Gas Conservation website (http://bogc.dnrc.state.mt.us/). The formation properties were available in hard copy from the Montana Geological Society (Tonnsen 1985) and were converted to electronic form and checked. The total number of well locations downloaded was 117,304 and 38,588 for Wyoming and Montana, respectively. The total number of formations depths recorded was 311,023 and 190,800 for Wyoming and Montana, respectively. In addition, 3,385 water analysis, 1,959 pressure and temperature measurements and 1,433 porosity and water saturation measurements were identified and recorded. All information was entered into a Microsoft Access database and converted into a GIS format for the assessment. Because of the nature of the available data the results are skewed by the formation that produce or have produced energy resources.

For each of the 107 plays the theoretical capacity to sequester CO_2 was calculated based on the volumetric properties of the reservoirs and nature of the existing formation fluids (i.e., brines, oil, etc.) derived from the constructed database. These calculations provide an upper bound on the *potential capacity* for sequestration rather than an estimate of the *practical capacity* as no consideration was made of reservoir characteristics that control injectability (e.g., permeability) or the costs associated with sequestration. A more detailed assessment of costs will be conducted in Phase II. The *potential capacity* calculations were extremely sensitive to temperature, pressure, salinity, reservoir thickness, reservoir area, porosity, and water saturation; subtle changes in these values could result in a significant change of calculated *potential capacity*. The details of the calculation are described in Nathan (in review, Geologic Carbon Sequestration: Assessed Potential for Montana and Wyoming, MS thesis, University of Idaho, Idaho Falls, ID.)

Mafic Volcanic Rocks in Idaho

The evaluation of mafic volcanic rocks in Idaho was conducted as an "advanced concept" and is documented in a separate report (Smith et al., 2004). The approach used in the assessment was to consider a cubic meter of hypothetical basalt with a composition based on the averages of Idaho basalts and normative mineralogy calculated from this average. A generalize rate expression that describe the time dependent dissolution of the basalt minerals was also developed. Using this rate expression, the normalized 'rock,' a representative of Snake River Plain groundwater, and a commercially available geochemical reaction path computer code was parameterized and 500 year simulation conducted. This modeling provided an estimate of the relative importance of hydrodynamic, solubility, and mineral trapping as a function of time for the regional basalts.

MMV Approaches for a Mafic Volcanic Rock Pilot Test

In addition, an evaluation of potential monitor and verification technologies that would be applicable to a planned Phase II pilot scale injection of CO_2 in a basalt host aquifer was conducted. This assessment included both geophysical and geochemical approaches.

Terrestrial Sequestration

Terrestrial sequestration activities in forestry and agriculture (including cropland and rangelands) can reduce and divert the atmospheric buildup of CO_2. Adoption of recommended management practices can enhance soil carbon, and improve soil quality and productivity. The opportunities to enhance soil carbon include: increasing the soil organic carbon concentration, improving water and nutrient use efficiencies and improving biomass productivity. Moreover, soils provide a significant reservoir for organic carbon, storing twice as much as the atmosphere and three times as much as plants.

Many U.S. cropland soils have lost as much as 50% of their original organic carbon due to the effects of land clearing and tillage. It is estimated that U.S. cropland and grazing lands alone have the potential to store 150-380 million metric tons of carbon per year or 9.4-23.8% of total U.S. emissions. Some management practices that sequester carbon are: reducing tillage intensity, diversifying crop rotations, reducing summer fallow, planting higher residue crops, converting marginal agricultural land to grassland or forest, restoring wetlands and using vegetation buffers and conservation measures that reduce soil erosion. Grazing lands, comprised of pasture and rangelands, represent the largest most diverse single land resource in Big Sky region, which is also characteristic of the United States and in the world. As with croplands, the magnitude of the carbon input to the soil in grazing lands depends on several management approaches such as residue management, improving the use of fertilizers, application of organic manure, planting improved species, improved forage quality, regular use of prescribed burns to increase forage productivity, reducing overgrazing and improving grazing practices.

Forests cover about one-third of the United States, totaling about 750 million acres. The growth of forests and their management offers one of the most promising sources of carbon sequestration in the biosphere. The concept of offsetting carbon dioxide emissions by sequestering the CO_2 in forests is not new. IPCC reviews concluded that globally, changes in forest management could induce future carbon sequestration adequate to offset an additional 15-20% of CO_2 emissions. Reforestation and afforestation present many opportunities to sequester carbon. Among these opportunities are increasing in situ tree growth, increasing the area planted to forests, increasing use and permanence of forest products and decreasing the loss of current forests.

Terrestrial carbon sequestration also provides the opportunity to trade carbon credits and reduce emissions voluntarily. Carbon sequestered by one party could offset emissions produced by another. The U.S. Department of Agriculture (USDA) and the U.S. Department of Energy are currently developing accounting rules for sequestration projects and improving the voluntary GHG registry (1605b) and crediting system. Furthermore, USDA is giving consideration to management practices that store carbon and reduce GHGs in setting priorities and implementing conservation programs. Private sector groups such as the National Carbon Offset Coalition and the Chicago Climate Exchange, both Big Sky Partnership members, have initiated pilot market-based systems to trade CO_2.

In the following sections we briefly describe the procedures used to estimate the potential for terrestrial sequestration in the region. For the terrestrial sinks, what is considered sink potential is the additional amount of carbon that can be stored; the “additional” carbon measurement requires that a baseline level of carbon is established from which the changes in carbon storage that have or can occur be quantified and verified. These changes can either be measured empirically, or estimated using a variety of methods and models, or some combination of approaches. Specifically we employed a three-part approach for terrestrial carbon sequestration in Phase I that combines the need to examine soil C sequestration potential at farm/field scale as well as at a more regional scale and to address the important question of whether terrestrial sequestration is an efficient and viable means of mitigating GHG intensities relative to alternative methods. The key components are: to determine the technical and economic potential for soil C sequestration in the region; to overlay the technical potential with an assessment of the opportunity costs and economic benefits of sequestering additional soil C in these terrestrial ecosystems; and to provide analysis of advanced concepts within the terrestrial sequestration arena that will identify and validate, using field test plots, best production practices using soil C sequestration potentials as the common metric, and the potential development of voluntary carbon markets.

Forested Lands: Technical Potential

The Big Sky region is 40% federal land (Figure 2). These lands are included in the federal Greenhouse Gas Inventory (USDA 2004) but are excluded from the estimates of potential opportunity for the creation of additional GHG reductions through state or market programs for carbon sequestration. The exception to this was in the analysis of potential for biomass fuels, where the federal forest land was included as a potential source of woody biomass. The assessment focuses on the 161 million acres of rural, non-federal land in the region, estimating the potential for increasing carbon sequestration through forestry, agroforestry, and bioenergy strategies.

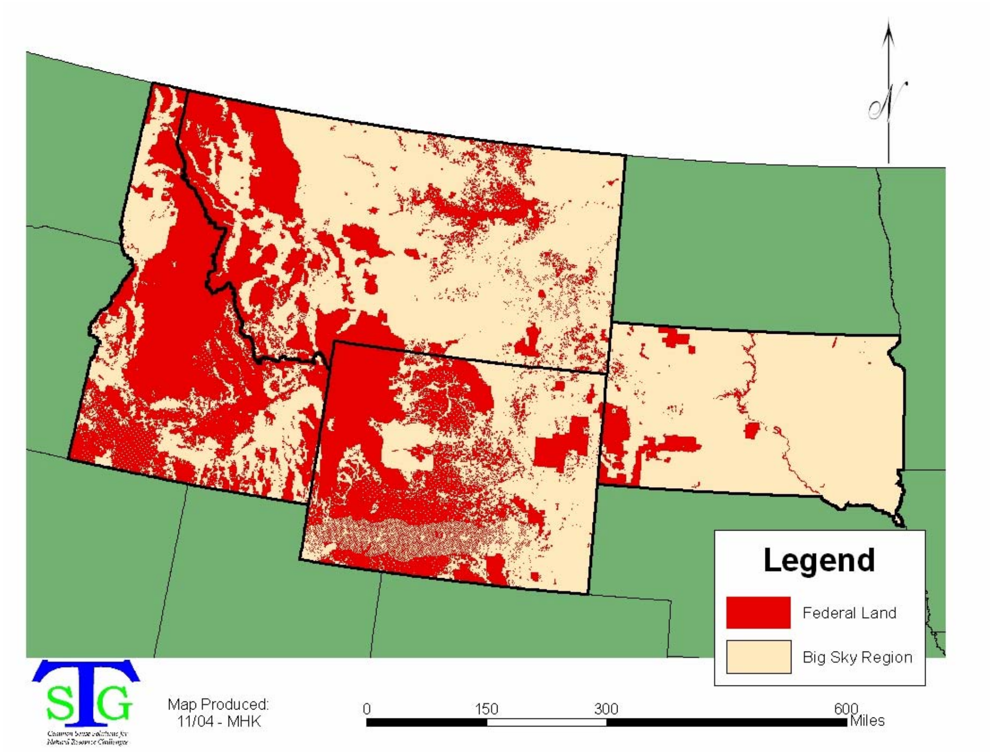

Figure 2. Federal land in the Big Sky Region.

Much of the cropland (19%) in the region is irrigated. The opportunities for converting marginal crop and pasture land to forest are limited to non-irrigated cultivated cropland where soils and climate conditions could support forest growth.

Afforestation. We define the biological opportunity for afforestation as all non-federal, non-forest land (primarily cropland and grassland) identified in the 1992 NLCD data in areas where the STATSGO soil survey (USDA-NRCS 2004) identifies woodland as being the native vegetation (Figure 3). That estimate may overstate the real biological opportunity, since some of those sites have been degraded by soil erosion to the point where an ecological type change has occurred that may prevent successful re-establishment of trees. That overestimation has been taken into account by discounting the estimates of feasible afforestation from the estimate of total suitable land. The amount of discount was based on the current land use and the forest type suitability.

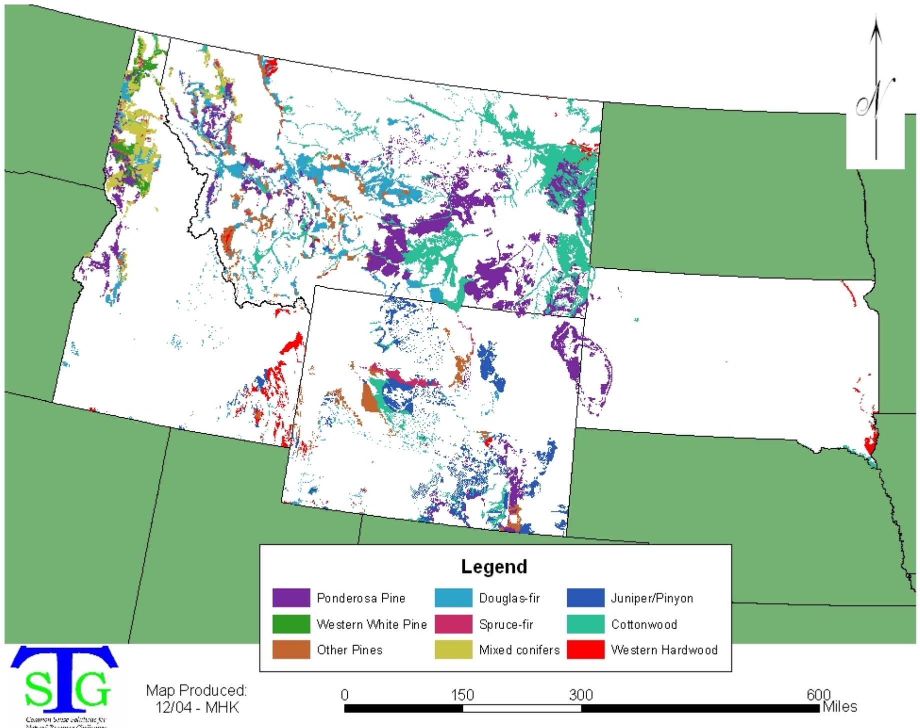

Figure 3. Potential forest types on non-federal lands, as indicated by general soil type (STATSGO).

To develop estimates of the impact of afforestation, tables were developed by state indicating the current non-forest area that coincided with a native forest type. These were then combined in a regional table. Average annual forest growth estimates were developed from Birdsey (1996). Estimates of potential timber volume growth were developed by multiplying the acreage of land available to be afforested times the average annual growth rate of the appropriate forest type.

Forest management. The analysis for forest management opportunity is based on data from the 1997 National Resources Inventory (NRI) that, for the first time, included an attribute for woodland species on the non-federal lands (USDA-NRCS 2000). Here, the land that was forest in 1997 was tabulated by forest type. There are no data on forest age or condition, how intensively these forests are currently being managed, or what opportunities might exist to improve that management through practices like enrichment planting (to fill understocked stands), thinning to improve health and growth in overstocked stands, or fertilization. The carbon dynamics in these forests can also be changed by lengthening the growing rotation on managed forests to provide larger trees, and larger wood products that last longer in use (Row 1996). Table 1 contains 1997 estimates of non-federal forest by species groups as one basis for understanding the potential for carbon sequestration through improved forest management.

Table 1. Forest species groups on non-federal land, by state, 1997.

Group	Species	Idaho	Montana	S Dakota	Wyoming	Total
				1,000 acres		
1	Ponderosa Pine	462.0	1,116.7	346.5	660.7	2,585.9
2	Lodgepole Pine	47.0	662.7		49.3	759.0
3	Douglas Fir	1,272.5	2,335.0		23.8	3,631.3
4	Fir; Spruce	122.0	439.6		98.2	659.8
4	Hemlock; Sitka Spruce	658.0	-			658.0
4	Spruce; Fir		8.2			8.2
5	Larch	946.1	296.1			1,242.2
5	Western White Pine	60.7	16.2			76.9
6	Pinyon; Juniper	5.4	-			5.4
7	Elm; Ash; Cottonwood		40.6	89.4	3.2	133.2
8	Aspen; Birch		54.4	10.1	15.9	80.4
8	Oak; Pine			40.1	10.7	50.8
8	Western hardwoods	248.4	192.6	26.6	107.4	575.0
9	Noncommercial	3.6	90.5	5.0	32.9	132.0
9	Non-stocked	122.1	178.2	0.6	2.0	302.9
	Total non-federal forest	3,947.8	5,430.8	518.3	1,004.1	10,901.0

Source: 1997 NRI (USDA-NRCS 2000)

The next question that arises is the extent to which the existing forests can be managed differently to increase carbon sequestration. The forest types were divided into three classes on the probability that state or regional carbon sequestration programs would be likely to impact forest management (Table 2). As a general rule, the average annual carbon sequestration impact from changing forest management is quite low. Lengthening harvest rotations, thinning and weeding for improved species adaptation and forest health, inter-planting to achieve optimum stand density, and fertilization all can change forest growth dynamics, but the region’s forest types are fairly slow-growing, and changing management does not impact the annual change in standing biomass rapidly. The result is fairly low estimates of potential annual impact from forest management. The large area involved, almost 10 million acres in the “high” and “medium” categories, result in fairly significant estimates of potential impact.

Table 2. Non-federal forest land, Big Sky Region, with estimates of the management opportunities for increasing carbon sequestration.

		Management Opportunity*		
Species Group	1000 Acres	High	Medium	Low
Ponderosa Pine	2,585.9	2,585.9		
Other Pines	759.0		759.0	
Douglas-fir	3,631.3	3,631.3		
Fir-spruce	1,326.0		1,326.0	
Mixed conifers	1,319.1		1,319.1	
Pinyon/juniper	5.4			5.4
Cottonwood	133.2			133.2
Western Hardwood	706.2			706.2
Non-stocked	434.9			434.9
Total	10,901.0	6,217.2	3,404.1	1,279.7
* Rated by authors on the basis of the likelihood that landowners will Manage them for long-term timber or carbon sequestration goals.				
tCO_2e/acre/year		0.25	0.1	0
Sequestration Opportunity		1,554.3	340.4	-
Total Annual Sequestration Opportunity (1000 tCO_2e)				1,894.7

Agroforestry opportunities. The analysis for field windbreak needs and opportunities is based on data from the 1997 NRI (USDA-NRCS 2000). We used the NRI to identify all non-irrigated cropland with an erosion index (EI) of 5 or higher that did not have windbreaks or cross-wind stripcropping established in 1997. No credit was given for the emissions reductions inherent in the soil conservation effect of windbreaks, or the reduction in cultivated area and associated fuel and fertilizer use, etc. Field windbreaks offer significant ancillary environmental benefits in addition to their impact on carbon sequestration (Brandle et al., 1992b).

Rangeland Sequestration: Technical Potential

Rangelands comprise a sizeable portion of the land resources in our Partnership region. 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 have been compiled by Texas A&M colleagues for inclusion with the GIS terrestrial sink inventory.

The data used to estimate the rangeland potential includes 1990's Landsat TM data (30 m resolution) that identifies 21 classes of land cover types, including shrublands, grassland/ herbaceous, and pasture/hay. These classes are intersected with MLRAs to define acres within each MLRA and linked with other datasets such as STATSGO soil and MODIS net primary productivity.

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 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.

Cropland: Technical and Economic Potential

The carbon sequestration potential for croplands in the Big Sky region is estimated using field-scale methods, GIS methods for larger scale estimates, and integrated simulation type models for quantifying rates of change in soil C levels.

Field-scale analysis. Field-scale studies were established at six farm fields in the Golden Triangle in north central Montana (see Figure 4). 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 a well-prescribed 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. 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. The procedures for estimating the soil C levels are described in earlier quarterly reports and deliverables.

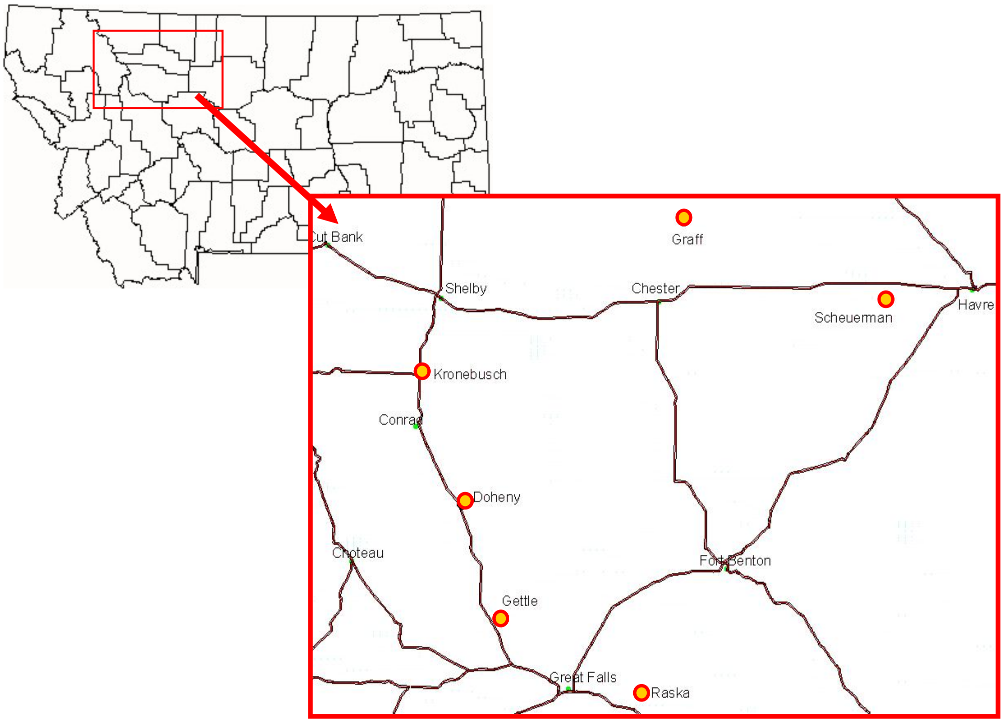

Figure 4. Locations of six farms in north central Montana for the on-farm cropping system comparisons.

GIS-based analysis. GIS components of the terrestrial sink evaluation include climate, soil and land use databases. One hundred years of climate data from National Climate Data Center station records were averaged for each of up to 10 climate zones in each state, to produce zone-average files containing monthly max/min temperatures and precipitation since 1895. In addition, zone-specific statistical data on climate variability were provided to Century's stochastic climate generation subroutine, which we used to simulate climate after 2003.

Soil texture grids derived from SSURGO or STATSGO soil databases were developed for each state, then statistically aggregated to approximately 20 representative soil texture classes. Century simulations are highly sensitive to soil texture, so although it was impractical to model every actual soil map unit in the state, the classes we use represented the range of soil textures found in the state. Each class was weighted by the actual area of land to which it applied in each county.

Land management data were extracted from the 1997 Census of Agriculture (USDA 1997). Land in Farms data, for total areas of harvested cropland and grazing (pasture) land, and from the Conservation Technology Information Center (CTIC 2004) data for 2002 on land enrolled in the CRP and cropland under no-till management. These data were compiled on a county basis and are summarized in Table 3.

Table 3. Agricultural land areas, in km^2.

State	*Crop-Conv Till*	*Crop-No till*	*Grazing*	*CRP*	*Total*
Idaho	19,479	1,087	23,325	3,244	47,135
Montana	39,801	4,226	141,882	10,884	196,793
South Dakota	51,986	14,664	105,440	5,752	177,842
Wyoming	8,881	142	127,357	1,134	137,514

Five different management scenarios, ranging from continuous grassland to continuous conventionally-tilled cropland, were applied to spatial "cells" developed by intersecting climate and soil texture grids at the county level. The management types applied in our default (business-as-usual, or BAU) scenario were based on current agricultural land use statistics. The results of CENTURY modeling for each soil-climate-land use combination were applied to the appropriate cell, and the cells (up to 20 per county) were summed to obtain county-level estimates of current soil carbon flux rates. These were further summed to obtain state estimates (Figure 5).

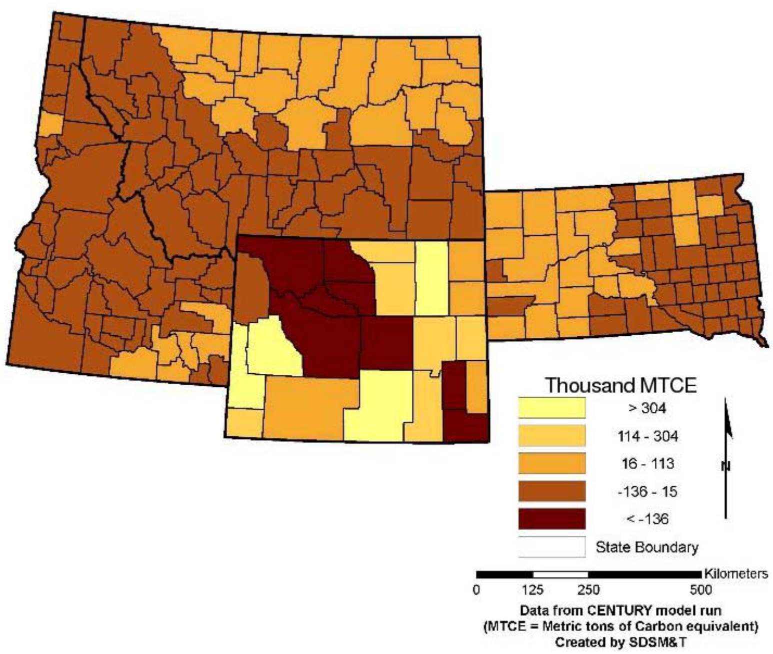

Figure 5. Current estimated annual soil carbon fluxes in ID, MT, WY, and SD, by county.

The cellular nature of the data enables us to explore the effect of changes in the status quo, for example, an increase in the rate of no-till adoption or CRP enrollment, or a decline in CRP enrollment. Estimates for a limited suite of scenarios are included in the GIS database. Montana has the largest agricultural land base, but South Dakota has by far the largest area of harvested cropland. As a result, South Dakota offers the largest potential for terrestrial sink enhancement due to agricultural land management, particularly through conversion to no-till. GIS-based modeling has enabled the iterative exploration of effects from changes to the status quo in land use/management such as altered rates of no-till adoption or CRP enrollment. The CENTURY model has already afforded significant insights into the spatially-variable prospects for terrestrial sequestration. Estimates of sequestration potential for a limited suite of scenarios are currently included in the GIS database of the Big Sky Carbon Warehouse.

Integrated simulation models: In a market for greenhouse gases, the competitiveness of US agricultural producers as suppliers of carbon-credits depends on the marginal costs and quantities of soil carbon (C) that can be sequestered. The technical potential of the terrestrial sinks providing an upper bound are the amount of carbon that could be sequestered at very high prices offered for carbon. The economic potential provides a means to address how much carbon would actually be sequestered at different prices offered for carbon to landowners.

The integrated approach to the analysis of the technical and economic potential to sequester soil C links biophysical information with economic information on a site-specific basis. The analysis can account for the spatial heterogeneity of biophysical conditions (soil C sequestration rates) and economic decisions (land use) and how these conditions interact to determine the marginal cost of sequestering C in soil. More specifically, this integrated assessment approach to assess the cost of agricultural soil C sequestration involves linking the output of two disciplinary models—an econometric-process simulation model and a crop ecosystem model—to simulate the responses of farmers to economic incentives to sequester soil C. This simulation model utilizes the stochastic properties of the economic production models and sample data, so its output can be interpreted as providing a statistical representation of the population of land units in a given region. The crop ecosystem model provides estimates of the levels of soil C and productivity (yields) associated with each production system. Following the marginal cost presentation, simulated changes in production systems are combined with simulated changes in soil C to compute the implied marginal costs, government costs, and producer surplus associated with policies in given regions. Thus, the integrated assessment model provides answers to policy questions about the effects of different payment schemes on the quantity of carbon sequestered and the marginal cost of sequestering soil C, and how the costs vary spatially. This approach also provides a basis for estimating the value of using government-based carbon payments as a part of the policy options to offset greenhouse gas emissions.

We apply an integrated assessment approach to quantify the costs of sequestering C from changes in land use and management practices in the dryland grain production systems of the Northern Plains region of the United States which encompasses the Big Sky region. A formal model of the decision process and the resulting supply curves for carbon is presented in Deliverable 8.

Advanced Concepts

The advanced concepts phase of our efforts was designed as a means to integrate these key elements into coherent threads that would provide a foundation and network for our Phase II demonstration pilots and deployment activities. The specific tasks revolve around designing market-based sequestration options; exploring mineralization trapping feasibility for geological sequestration; assessing measurement, monitoring, and verification requirements for all sinks;

and developing a framework or common metric for evaluating the tradeoffs among alternative carbon sinks.

Carbon Market Trading and Decision Support Frameworks.

The motivation for these efforts reached beyond the many technical advancements in terrestrial sequestration and into the next steps of carbon credit trading: how would a market for carbon credits function, and understanding the decision support framework for assessing terrestrial carbon sequestration opportunities. In establishing carbon credits for trading there are several issues that must be addressed including the following: additionally and baselines, leakage, duration, monitoring and verification, and transparency and credibility. Additionally and baselines is the amount of net carbon sequestered when comparing the amount of net carbon measured and calculated when one compares the carbon after specific activates as compared to the baseline measurements of carbon which are measured and calculated before the activity commences. There are several ways proposed to make these calculations but there are no universal guidelines as such.

Leakage is the term applied to off-site impacts caused by a project. There have been many studies on these areas in terrestrial sequestration but there are few established programs for including leakage estimates. Another critical area to understand is duration or permanence. Carbon stored in trees, vegetation, soil, or even in underground reservoirs presents a risk of dissipating through management actions or natural events. Many liability rules have been suggested in order to account for non-permanence of carbon credits generated through land based sequestration activities. Designing proper monitoring, measurement and verification systems is a pathway to minimize these concerns. Monitoring and verification is essential to determine that sequestered carbon or emission reductions attains a market value for example a "creditable" ton if it is to become a commodity. Carbon credits unlike other commodities that are bought and sold in markets do not physically move from the control of the seller to control of the buyer. Instead, what moves is a certificate or statement proclaiming the existence, stability and legitimacy of the claim subject to monitoring ad verification. Transparency and credibility are influenced by project reports that feature fully transparent measurements and calculations. Acceptability of these reports will be influenced and more readily accepted than those accept where calculations of reported amounts of carbon cannot be readily determined from available material and information. A project plan, measured pools, reported GHG's and locations can influence credibility.

The Partnership currently has the most comprehensive terrestrial sequestration program in the nation, and has designed the protocols and needed verification for a trading market to develop. The National Carbon Offset Coalition (NCOC) has been the key partner in designing the market-based carbon trading efforts. They have held numerous public meetings to gain landowners' input, worked with the Intertribal Environmental Council to develop a USDA proposal to create a 1605B Clearinghouse, conducted workshops nationally with the tribes, and create a national Tribal Forestry Portfolio. NCOC also will begin marketing of NCOC carbon sequestration portfolios in DOE Phase II on the Chicago Climate Exchange and other emerging markets. Planning forms, contracting options and a draft forestry portfolio were developed and submitted to the Chicago Climate Exchange for review.

The market trading efforts under the advanced concepts have been successful. In Phase II, the Partnership will build upon this investment and will work closely with Sempra Generation, its Tribal members and other landowners to design and implement cropland, rangeland, and forestland field test sites and carbon portfolios, advance the Partnership's Phase I market-based C storage methods and verification protocols and demonstrate the marketability of one of the nation's emerging, cutting-edge pilot C markets. The results of this activity will be one of the largest market-based C trades in the country that is nationally recognized and in compliance with the reporting requirements of the 1605(b) National Greenhouse Gas Registry.

Mineralization

The Partnership's primary geologic effort will be to demonstrate C storage in mafic/basalt rock formations, a geology not yet well characterized but with significant long-term storage potential in the region and other parts of the world including China and India. For instance, the region's Columbia River Basalt Group covers approximately 164,000 km^2 in OR, WA, and ID; conservative estimates of the CO_2 storage capacity are over 100 $GtCO_2$, enough capacity for 20 years storage of all U.S. coal-fueled power plant emissions (McGrail et al. 2003). Additionally, the Columbia River basalt group and the Snake River Plain in ID represent another 60,000 km^2 of sequestration capacity. Preliminary calculations done during the Phase I period show that basalt formations can rapidly convert injected CO_2 to carbonate minerals and complete conversion of fluid phase CO_2 to solid phase carbonate minerals in a few hundred years. If these laboratory-based estimates can be verified in the field, basalt formations may offer a unique geologic medium for long-term, zero leakage C sequestration.

Additionally, the Partnership will assess long-term CO_2 mineralization rates in the Madison Formation, a large carbonate aquifer in WY and MT. Like mafic rocks, carbonates are highly reactive with CO_2 and represent a significant opportunity for C sequestration. In collaboration with industry, the Partnership will utilize an on-going, long-term enhanced oil recovery (EOR) site at Lost Soldier and Wertz oil fields in WY to conduct a pilot on the consequences of the long-term exposure of carbonate rocks to CO_2-rich fluids. Specifically, the Partnership will model and match pre-injection conditions to assess changes in water chemistry and indirectly changes in the rocks to assess C sequestration potential.

Part of the advanced concepts focus in Phase I has been to design a phased approach to other sequestration opportunities in the region and develop technology networks that will continue to assess and characterize deep carbonate (limestone and dolomite) hosted aquifers and deep unminable coal beds.

Economics as an Integrating Factor

The economic and risk assessment framework is a means to assist the region to understand the economic impacts of terrestrial and geologic C sequestration at both the project and regional levels. In phase I we have designed the key parameters that would need to be quantified in order to find a common metric for evaluating the different sequestration options in terms of relative efficiency and magnitude as well as other desirable characteristics such as environmental stability and long term storage.   Combining results provides a regional C supply curve that shows, at each price of C, the total amount of C that could be sequestered in the region (see prototype curve shown in Figure 6). The analysis of each sequestration technology is linked to the large-scale deployment assessment to show which technologies would be viable at alternative C prices, their location, and how much C can be sequestered. The development of the C supply curve(s) will be of significant value in assessing carbon potential across options.

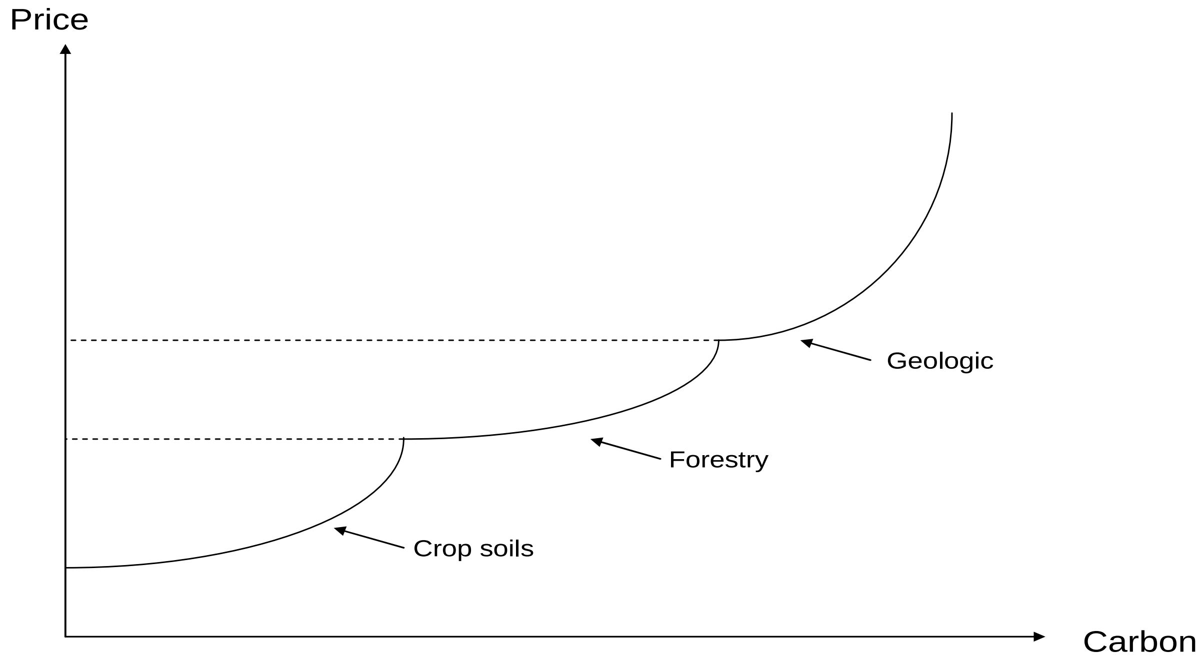

Figure 6. Prototype Regional Carbon supply curve.

MMV Activities

Monitoring and measuring of CO_2 storage is critical in ensuring that CO_2 storage systems and projects are both safe and predictable. Building on industrial experience in current industrial storage programs and a strong base R&D program, Los Alamos National Laboratory led the Phase I effort in examining the needs for monitoring, measurement and verification (MMV) of CO_2 land based storage options in the Big Sky Region. Montana State University and LANL worked together to review many types of diagnostics which could be ready for Phase II deployment.   Although deploying the portfolio of possible technologies is scientifically valuable, the focus was on three technologies: Laser Induced Breakdown Spectroscopy (LIBS), Visible and Near Infrared (VNIR) and Stable Isotope analysis. All three of these diagnostic systems will be integrated into the terrestrial program led by MSU. In addition, an MMV program for the mafic rock experiment was designed.

Regional Energy Assessments

As part of the advanced concepts, the Partnership has also been involved in regional assessment of future energy growth. The region holds high potential for future energy growth due to significant energy resources (e.g., coal reserves, wind) and central proximity to western energy markets. This region is also characterized by small populations, limited industry, and low greenhouse gas emissions. There are significant policy implications associated with energy development that would result in changes to the regional energy mix, water resource demands, energy transmission systems, and from the implementation of new energy technologies including carbon sequestration. Part of the experimental design efforts was to identify key factors influencing energy development, including population demographics, climate change, land and water availability, energy transmission and transportation infrastructure, energy market supplies and demands, environmental/regulatory constraints, and the availability of raw energy resources.

Climate change can have a direct impact on water availability, market demands, economics of power systems (e.g., carbon taxes, carbon capture, and sequestration), preference for renewable vs. fossil energy systems, and siting fossil plants near carbon sequestration sinks. The Big Sky Regional Carbon Sequestration Partnership is examining regional carbon sequestration resources that could be used to reduce or offset the carbon emissions from fossil power energy production and other industrials. The Big Sky Partnership is using this study to gain insight into the issues driving regional energy demand and facilitate the development of a regional infrastructure that can support future energy development with carbon sequestration resources.

Education and Outreach

Phase I activities were guided by an Education and Outreach Plan which identified key stakeholder groups and targeted messages. 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 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 and is continuing in Phase II.

Stakeholder groups included: industry, state government representatives and energy and environment agencies, environmental NGOs, Tribal Councils, economic development groups, and the public. Primary activities included the development of Partnership outreach materials (i.e. web site, poster, handouts, etc.) and the overarching message to each group was the opportunities and risks associated with carbon sequestration. Various groups and individuals were engaged in dialogue through individual meetings, legislative briefings, workshops, and symposia, to poster sessions, presentations, web networks and the news. (Table 4)

Table 4. Education and Outreach Activities and Exposure

Activity	Number
Stakeholder Meetings	21
Legislative Briefings	6
Workshops/Symposia	8
Poster Sessions	5
Presentations	Over 25
Web Networks	800 + individuals
News Articles	15

These various dialogues helped the Partnership identify key individuals who would be involved in actual project demonstration or deployment and gain understanding on how to design a path forward to support field tests and ultimately commercial deployment.

Regulatory and compliance research is being coordinated with the State agencies and with the IOGCC. Susan Capalbo is part of the IOGCC task force which issued a final report in December 2004, and has been revised. A copy is available on the IOGCC website http://www.iogcc.state.ok.us/.

RESULTS AND DISCUSSION

GIS Overview and Sources/Infrastructure Profile

During Phase I, the Big Sky geographic information system (GIS) effort focused primarily on characterization of regional carbon sources, sinks, and infrastructure. The Big Sky geographic region was defined to include land area encompassing the states of Montana (MT), South Dakota (SD), Idaho (ID), and Wyoming (WY). During Phase II this will be expanded to include contiguous areas in eastern Washington, Oregon, and Canadian provinces. Data are being made available via the Big Sky Carbon Atlas (Table 5). The Big Sky Carbon Atlas can be viewed via the Big Sky Partnership website (http://www.bigskyco2.org), and via the NatCarb distributed national databases (http://www.natcarb.org).

Table 5. Data layers of the Big Sky Carbon Atlas (ID, MT, SD, and WY) during Phase I.

Data Type	Description	Served by Big Sky
GHG Sources	Emission point locations	Yes
GHG Inventory	State-level source & sink emission summaries	Yes
GHG Livestock	County-level livestock emission summaries	Yes
Terrestrial Sinks	Actual/potential soil sink estimates (CENTURY)	Yes
Soil	SSURGO/STATSGO & Soil Texture Grids	Yes
Climate	Monthly precipitation/temperature 1900–present	Yes
Climate Divisions	NCDC climate division boundaries	Yes
Ag Management	Cropland areas (various tillage/rangeland)	Yes
Political	State/County Boundaries	Yes
Infrastructure	Transportation/Pipelines/Powerlines	No[a]
Geologic Sinks	Oil/Gas Provinces & Plays	Yes
Wells	Oil & Gas wells	Yes

[a.] Infrastructure data layers such as gas pipelines are not served due to homeland security issues.

GHG Sources

The primary sources of greenhouse gases in Montana, Idaho, Wyoming and South Dakota are compared in Figure 7. In 2002 the region's gross emissions of GHGs were averaging about 61 MMTCE, which translates into per capita emissions ranging from a high of 23MTCE in Wyoming to 12 MTCE in Idaho. In Montana and Wyoming, refining and other energy and heavy industries constitute the largest source of GHGs related to energy consumption source category; while in Idaho imported electricity accounts for the largest category of energy-related emissions. Potential emissions from future development of the vast fossil-fuel resources are conservatively estimated to be an order of magnitude higher, depending on transmission lines and other energy demand factors. GHG emissions from agriculture, principally CH_4 from livestock and N_2O from soil management, account for nearly 27% of South Dakota emissions.

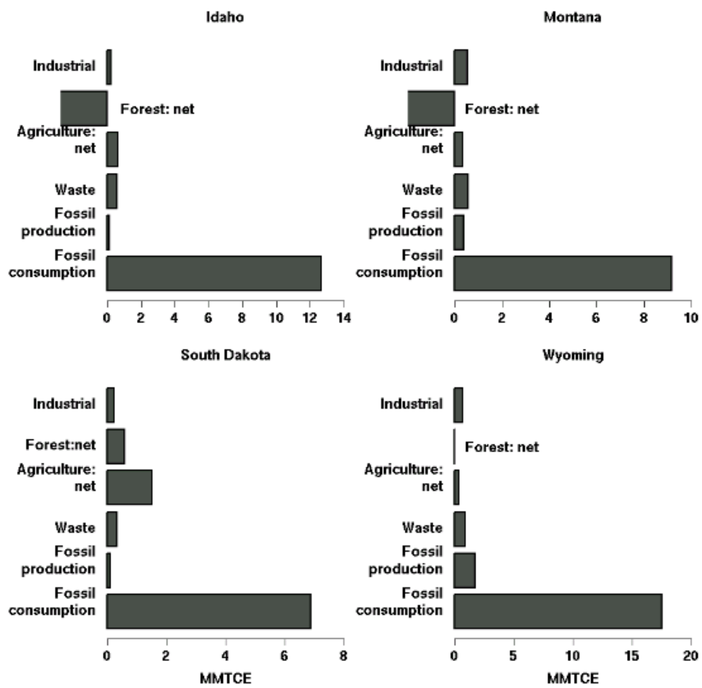

Figure 7. Primary Greenhouse gas emission sources in ID, MT, SD, and WY.

Infrastructure Data

Infrastructure data was compiled for the states of MT, WY, ID, and SD. Road and railroad data for the four states were derived from the SDC Feature Classes "highways.sdc" and "rail100k.sdc", respectively, supplied with ESRI ArcInfo Workstation 9.0. Only road and railroad data are made available through the Big Sky Data Warehouse. Pipeline data for the four states were extracted from the Office of Pipeline Safety's National Pipeline Mapping System, to which LANL has a license. These data is considered to be “Official Use Only” (OUO).

Big Sky Data Warehouse and Data Coordination

The Big Sky Carbon Sequestration Partnership Data Warehouse was established at the Big Sky Institute at MSU, and staff were hired to administer the system and manage data. Initial efforts have focused on establishing a base architecture for managing Big Sky Partnership data and providing access to that data via an ESRI ArcIMS interactive mapping application and a live data link to NatCarb (Figure 8).

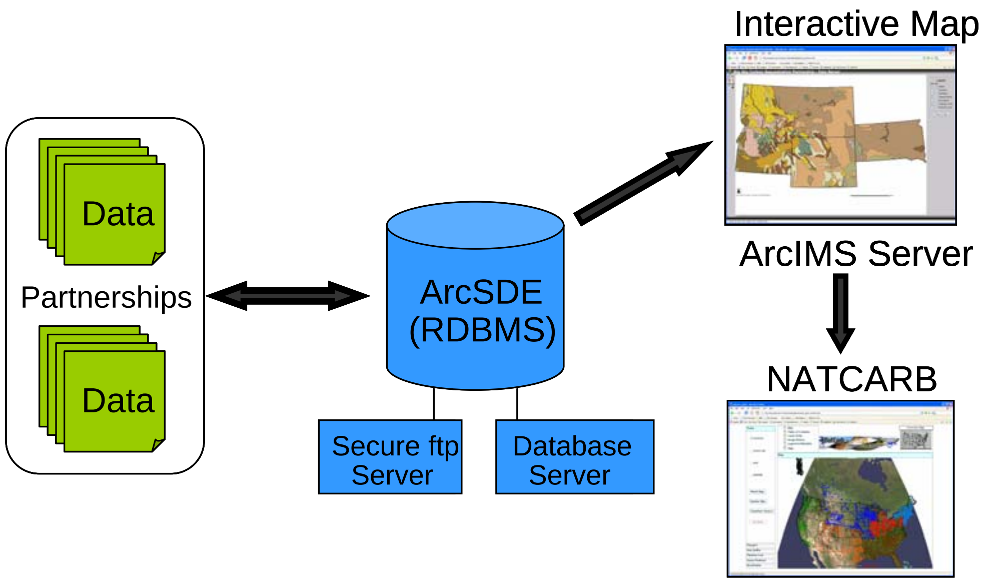

Figure 8. Web-based access to Big Sky data and integration with other partnerships and NatCarb is provided via ArcSDE and ArcIMS.

Witkowski et al. (2003) provided a key reference for determining the initial data architecture in the geodatabase and in anticipating how work flow will occur via ArcSDE. In addition, ESRI's Modeling our World and Building a Geodatabase have each proven instructive in envisioning how the Big Sky Data Warehouse might best be construed once data holdings have progressed to a point where we can expect to support site-specific decisions concerning CO_2 transfer and storage.

For the Big Sky Partnership, we established a new application/database server with ArcIMS 9, MS SQL Server 2000 SP3, and ArcSDE 9 running on Windows 2003 Server with Apache and Tomcat. The server hardware consists of a dual Xeon server with a redundant SCSI disk array. Backup is maintained by tape and server to server backup strategies. The initial setup was slowed by configuration issues. We arrived at a stable installation and configuration of all IMS Server components and gained an in depth understanding of the latest iteration of ArcIMS/ArcSDE/MS SQL Server architecture.

A secure FTP site was established as a vehicle for harvesting large datasets (e.g., STATSGO data) from collaborators. Geologic and terrestrial data were relayed to MSU and integrated into the Data Warehouse at Big Sky Institute and are now accessible through the Carbon Atlas ArcIMS service. Performance of the IMS-SDE-SQL configuration was optimized in terms of the speed and reliability of data transfer. Where possible, FGDC-compliant metadata were provided and field aliases were created for tabular data to provide greater intelligibility to end-users of the Carbon Atlas ArcIMS interface. We worked to fill data gaps by working with Partnership collaborators and by directly obtaining the data from other sources.

We integrated and standardized a composite master data list (Appendix A1) for the Data Warehouse holdings in support of current and future Partnership activities.

Interpartnership Coordination and Links with NatCarb, DOE, and National Cyberinfrastructure Efforts

Big Sky GIS personnel participated in period GIS Working Group teleconferences, which provided the primary means of communication with counterparts in other partnerships. In addition Big Sky GIS personnel from LANL (Paul Rich), MSU (Todd Kipfer and Aaron Jones), and UWy (Jeffrey Hamerlinck) attended an Interpartnership/NatCarb meeting in Lawrence, KS (February 1-2, 2005). The meeting focused on building partnership links with NatCarb and on GIS coordination during Phase II. The following goals were formulated for GIS coordination during Phase II:

- Participate in inter-partnership planning and ongoing communication to ensure that key carbon sequestration data layers and tools are consistent, complete, and available (methodology, quality…).
- Contribute to building the national carbon cyberinfrastructure, an integrated computing environment that provides access to information, models, problem solving capabilities, and communication concerning carbon science and technology.
- Coordinate with key federal and DOE GIS efforts.

GIS coordination during Phase II will be implemented through the following activities:

- Participate in formulation of a **national carbon cyberinfrastructure plan** with input from diverse stakeholders and based on sound design.
- Participate in **GIS coordination meetings** and regular **GIS teleconferences**.
- Make data available via the **NatCarb** distributed network of carbon sequestration databases (http://www.natcarb.org).
- **Share key GIS resources** (methods, design, data sources, tools…) with other partnerships and NatCarb via the partnership/NatCarb e-mail list, web posting, and other effective means of communication.
- Resolve issues (gaps, overlaps, errors, inconsistencies…) required to produce a complete **regional carbon sequestration atlas** for each partnership.
- Follow **federal requirements** concerning geospatial data documentation, in particular by producing Federal Geographic Data Committee (FGDC) compliant metadata (http://www.fgdc.gov/metadata/metadata.html).
- Register geospatial data with the **Geospatial One-Stop** (GOS), the primary U.S. geoportal (http://www.geodata.gov/gos), mandated as part of the president's E-Government agenda.
- Contribute to building a department-wide **DOE Geospatial Science Program** in conjunction with the DOE Office of the Chief Information Officer (contact Rosita Parkes, rose.parkes@hq.doe.gov) DOE Geospatial Science Steering Committee (contact David

Morehouse, dmorehou@eia.doe.gov) and the DOE GIS User Group (contact James Bollinger, james02.bollinger@srs.gov).

An oral presentation and posters concerning carbon cyberinfrastructure were presented at the American Geophysical Union Chapman Conference on "The Science and Technology of Carbon Sequestration", January 16-20, 2005, San Diego, CA (Rich et al. 2005, Keating et al. 2005A). Under separate funding, presentations were made concerning complex-wide GIS efforts (Bollinger et al. 2004, Rich et al. 2004), and a proposal was submitted to the DOE Office of the Chief Information Officer (Bollinger et al. 2005), which resulted in designation of a new DOE Geospatial Science program in August 2005.

Geological Sink Potential

Sedimentary Rocks in Montana and Wyoming

A total of 260 oil and gas or saline aquifer units (formations within a play) were identified within the 9 Montana and Wyoming provinces. Of these units, 22 were identified as being most favorable for sequestration, 40 as favorable, and 28 as unfavorable. There was insufficient information to categorize the remaining 160 units. In addition, there was insufficient information to categorize the 15 coal bearing units in the region. The *potential capacity* calculations were conducted at the unit level. These calculations were then screened and any unit that had *potential capacity* less that 400 million metric tons of CO_2 (approximate 50 year output of 1,000 megawatt coal fired power plant) were removed and the resulting units were summed at the province level. At the province level, the results are insensitive to the screening. The estimated *potential capacities* are presented in Table 6 in terms of million metric tons of CO_2 and gigawatts of coal fired electrical output. As may be seen from the Table, the regions potential for sequestration is enormous. However, the results presented only consider the potential for sequestration and do not include consideration (beyond depth and physical size) of engineering (e.g., permeability and injectability) or economic factors (e.g., infrastructure and transportation costs). Future work considering economic criteria to be carried out in Phase II will likely result in reduction of the values presented here.

Table 6. Total potential sequestration capacity for Montana and Wyoming provinces considered in this study.

Potential Sequestration Capacity		
Province	MMT CO_2	Equivalent Gigawatts
27	47,000	6,000
28	890,000	112,000
29	25,000	3,000
31	895,000	113,000
33	244,000	31,000
34	141,000	18,000
35	222,000	28,000
36	646,000	81,000
37	493,000	62,000

Mafic Volcanic Rocks in Idaho

The geochemical model developed for the Mafic Volcanic rocks advanced concept calculations was 'calibrated' by adjusting the surface area to yield an estimated basalt reaction rate of 150 mg L^{-1} yr^{-1} (Roback et al., 2001). Using the calibrated model a 500 year simulation for 200 bars CO_2 pressure and 40°C was conducted. In this simulation, 50% of the porosity was instantaneously flooded with supercritical liquid (SCL) CO_2 (with a density of 821 kg m^{-3}) to simulate the rapid injection phase. Under these P-T conditions a total of 15.4 kg m^{-3} of carbon is sequestered with hydrodynamic trapping accounting for approximately 14 kg m^{-3} of carbon and solubility trapping accounting for the remaining 1.4 kg m^{-3} of carbon. Because the simulation considered is for a single injection of CO_2, the total carbon sequestered is a constant 15.4 kg m^{-3} with time.

As a result of mineralization reactions, sequestered CO_2 dissolved the original minerals in the basalts and precipitated secondary minerals (Figure 9). Within 350 years the SCL CO_2 phase disappeared, ending the period in which hydrodynamic trapping contributed to sequestration. Figure 9 shows that during the period that SCL CO_2 is present (first 350 years); secondary minerals formed included zeolites and Ca, Fe, and mixed Ca-Mg carbonates. Following the loss of the SCL CO_2, dissolved aqueous CO_2 continued to react with the basalt for another 30 years. At approximately 380 years all the CO_2 is consumed, zeolites began to dissolve, and clay minerals formed.

Alteration reactions resulted in a steady decrease in porosity from 12.5% to 8.5% during the first 380 years. Following this period, the porosity remained essentially constant for the remainder of the simulation. At later times, mineralization reactions with their associated reduction in porosity may serve to seal and isolate formation fluids. Figure 10 shows the relative importance of hydrodynamic, solubility, and mineral trapping over time of 1 m^3 of basalt geomedia.

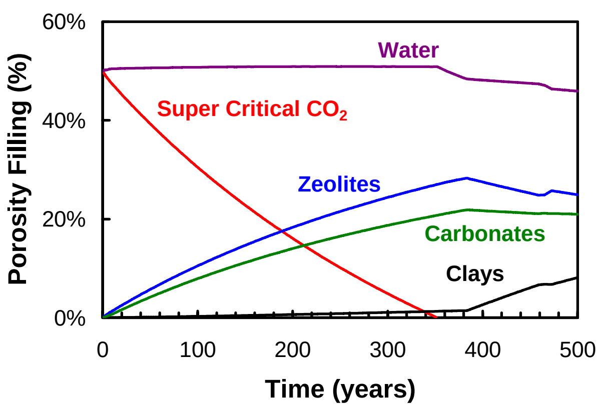

Figure 9. Relative filling of porosity (origninal porosity plus new porosity created by dissolution of primary minerals) as a function of time.

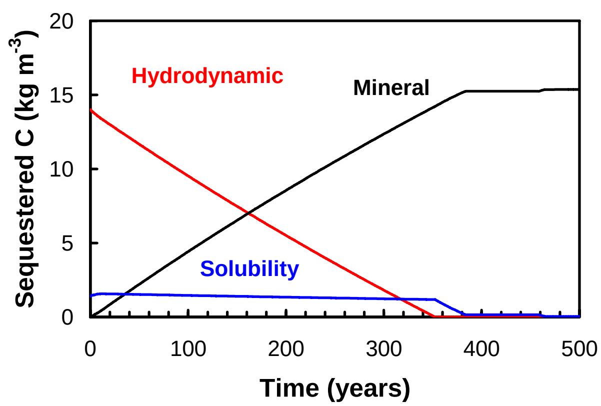

Figure 10. Carbon sequestration potential of basalt by different mechanism as a function of time. The nature of the simulation fixed the total carbon sequestered at 15.4 kg m^{-3} (see text).

MMV Approaches for a Mafic Volcanic Rock Pilot Test

Measurement, Monitoring, and Verification are a central aspect of any sequestration effort. First and foremost, MMV is needed to establish public credibility by verifying the viability of the approach. Sequestration will work only if economic incentives exist and MMV is needed to quantify the effectiveness of the sequestration. Perhaps most importantly, MMV is required to safeguard the public and determine the existence of local threats to the public before these threats emerge. An integrated ensemble of tools is needed to complete these tasks. These tools need to be deployed at the basalt sequestration site to quantitatively demonstrate their capabilities. Only an integrated ensemble of diagnostics will provide the data required. A GIS system is capable of serving as this integrating platform. The GIS system will integrate the data to provide a larger picture of the site's performance. This information will be uploaded into various modeling and decision making tools so that additional measurements can be taken as the situation demands. Finally, in order manage and limit MMV costs while protecting the site's workers and general public, an automated system of MMV capabilities is required. Decision making tools could use these data sets to initiate actions needed to preserve the sites integrity.

Geophysical methods. Surface seismic reflection is the method of choice for monitoring changes in reservoir characteristics. Unfortunately, surface seismic reflection methods have a poor history of imaging beneath flood basalt terranes (Pujol et al., 1989). In basalt environments such as in the Columbia River Plateau and the Snake River Plain, geophysical monitoring is likely to focus on cross-well imaging, coda wave interferometry, and passive seismic monitoring. Pre-injection measurements will establish baseline conditions for comparison to post-injection measurements. Cross-well seismic methods will have higher spatial resolution of the injection volume than surface-based methods. Cross-well analysis methods provide an image of subsurface structure in the vicinity of the wells, as well as a tomographic view of the velocities between the wells (Dong et al., 2005). Another method for characterizing the reservoir is the vertical seismic profile (VSP). The geophones are placed down the well and record surface sources to image the subsurface. VSP has great potential for accurately monitoring of CO_2 sequestration. Unfortunately, VSPs will have a similar, though less severe ringing problem compared to the surface reflection data (Pujol et al., 1989).

These active source seismic methods, when they work, provide the highest resolution images. Unfortunately, these methods are very costly. Active source time lapse imaging is a potential method to provide subsurface images (Roberts et al., 1992). Seismometers are placed on the surface or in shallow holes to record seismic energy. The method relies on repeatable measurements to remove the noise from the signal. This method is still in the research stage, but its potential to monitor changes in the subsurface at the basalt sequestration site is great.

To obtain high-resolution results using passive seismic to monitor CO_2 injection, geophones should be placed in boreholes, as close to reservoirs as possible. The geophones will record signals from micro-seismicity induced by CO_2 injection. The signals can be used to locate where the induced micro-seismicity occur. Passive seismic monitoring has a long history in reservoir monitoring (e. g. Rutledge et al., 2004).

An increase in measured activity could indicate that more thorough MMV of the sequestered CO_2 is necessary. Other monitoring methods could be deployed to better characterize the sequestration site and detect potential CO_2 leaks.

Electromagnetic induction and electrical resistivity methods are also capable of MMV (LaBrecque et al., 1999; Kirkendall and Roberts, 2004). These methods are not commonly used in MMV, but their potential is great, so a number of researchers are studying these techniques (Hoversten et al., 2003). Electromagnetic methods are sensitive to the pore fluids in the subsurface (Kirkendall and Roberts, 2004), thus EM imaging has great potential to directly image the injected and sequestered CO_2.

Geological/geochemical methods. Chemical tracers will be a key aspect of planned MMV activities. Although limited to a single injection well in this pilot, similar tracer tests are known to be effective in the characterization of several subsurface flow and reactive transport properties, including kinematic porosity, permeability, phase volume fractions, kinetics of sorption, dissolution, microbial transformations, ion exchange phenomena, dispersion and formation damage (Bachmat et al., 1998; Haggerty et al., 2001; Davis et al., 2002). A suite of tracers will be designed to: 1) interact with the CO_2, water, and mineral phases of the reservoir, 2) limit the problem of interference from naturally occurring CO_2 background concentrations, and 3) provide a statistically superior monitoring and characterization method due to the redundancy built in by using multiple tracers**.** Pre-injection tracer tests will be performed using conservative tracers (such as bromide, PFBA, tritium) to establish the basic hydrologic properties such as porosity, hydraulic conductivity and dispersion. During the CO_2 injection phase, pulses of different tracers will be added to the CO_2 stream. The succession of break through curves (BTCs) for each tracer during this phase, when analyzed together and in comparison with the pre-injection BTCs, will reveal information about the fate and transport of injected CO_2 as a function of time. The injected tracers will also serve as sensitive markers for vadose zone gas monitoring will allow us to recognize if leakage occurs during or following the pilot test.

Collection of fluid and core samples from the target injection zone is a key post-injection characterization task to verify and assess in situ mineralization rates. The core samples will be obtained from the CO_2 injection horizon but in the aqueous phase underneath the supercritical CO_2 bubble.

Terrestrial Sequestration Potential

The U.S. Department of Agriculture has conducted a comprehensive assessment of greenhouse gas emissions and sinks in U.S. agriculture and forests (USDA 2004). Estimates are provided at State, regional, and national scales, categorized by management practices where possible. The estimates are consistent with those published by EPA in the official Inventory of U.S. Greenhouse Gas Emissions and Sinks that was submitted to the United Nations Framework Convention on Climate Change in April 2003. For the Big Sky Region, cropland soils were estimated to be an annual sink of 5.4 $TgCO_2e$ (Table 7), while forests (not counting soils or forest products) were estimated to be a sink of 40.8 $TgCO_2e$ per year (Table 8). (Tg stands for teragrams, or million metric tons.)

Table 7. State estimates of soil carbon changes in cropland and grazing land in 1997 by major activity categories.

State	Plowout of Grassland to Annual Cropland[1]	Cropland Manage-Ment	Other Crop-land[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land man-agement	CRP	Manure applica-tion	Cultiva-tion of organic Soils	Net soil carbon Emissions[4]
						Tg CO_2e					
Idaho	1.1	-0.07	0	-1.03	-0.04	-0.26	-0.04	-0.59	-0.34	0.07	-1.19
Montana	1.91	-0.59	0	-1.28	-0.07	-0.48	0	-1.8	-0.08	0.11	-2.28
South Dakota	4.07	-0.18	0	-2.9	-0.04	-0.44	0.07	-1.39	-0.31	0.07	-1.04
Wyoming	0.51	-0.07	0	-0.62	-0.04	-0.29	0	-0.37	-0.04	0	-0.92
Big Sky Totals	7.59	-0.91	0	-5.83	-0.19	-1.47	0.03	-4.15	-0.77	0.25	-5.43

Negative numbers indicate net sequestration.

[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).

[2] Perennial/horticultural cropland and rice cultivation.

[3] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.

[4] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

Source: Appendix Table B-11, USDA 2004.

Tg = terragrams = million metric tones

Table 8. State summaries of forest area, total area, forest non-soil stocks (2002), forest non-soil stock change (2001), and forest products stock change (2001).

State	Forest Area	Total Area	Forest non-soil stocks	Forest non-soil stock change	Products stock change
	1,000 ha		*Tg CO_2 e*	*Tg CO_2 e/yr*	
Idaho	8,760.0	21,646.0	4,145.0	-12.1	-3.4
Montana	9,426.0	23,291.6	3,938.0	-21.5	-2.3
South Dakota	655.0	1,618.5	192.0	0.6	-0.2
Wyoming	4,449.0	10,993.5	1,897.0	-7.8	-0.2
Big Sky Totals	23,290.0	57,549.6	10,172.0	-40.8	-6.1

Source: Appendix Table C-1, USDA 2004

Forestry Potential

The technical potential related to agroforestry practices and biomass production on agricultural lands, as well as afforestation of marginal agricultural soils and changing the management of existing private forests are not overwhelmingly large, as one would expect in a region characterized by a high proportion of federal land, vast areas of arid and semi-arid ecosystems, and widely scattered production areas. But they could be important contributors to state, regional, and national efforts to mitigate greenhouse gas emissions in the near term, as these management practices are available immediately, with mature technologies that are widely known to landowners and technical agents in the region. In the event that carbon sequestration were to gain some market value, these opportunities could become a badly-needed supplement to income in a region dependent on agriculture and forestry for much of its rural economy.

Table 9 illustrates the estimates produced by the Phase I study. These estimates have a high degree of uncertainty, in that while most of the practices are well established, the policies and incentives to implement them are not. An example is found in the agroforestry practice of field windbreaks. The values of field windbreaks for soil erosion reduction, soil moisture retention, fuel use reduction, and farm yield protection have been known for decades, and there have been federal cost-sharing incentives since the 1930's. But there are still thousands of acres where windbreak protection would be beneficial, but remains undone. Farmers have resisted the existing incentives, and it is not yet clear how an added incentive tied to carbon sequestration would make a significant difference.

Table 9 contains estimates that reflect the total physical area in the region that is suitable for each practice. While these lands are available in the physical sense, they do not reflect actual implementation. The "potential area" is an author's estimate of what is most likely to be realized over the next 5-10 years unless much additional work is done to produce the policy, economic, and institutional support needed to assure increased success.

Table 9. Summary of carbon sequestration potential in agroforestry, biomass, and forestry, Big Sky Region.

Practice	Available Area (1,000 Ac)	Potential Area (1,000 Ac)	Potential Mitigation ($TgCO_2e/yr$)*
Afforestation	34,000	3,400	4 – 6
Forest Management	10,900	6,200	1.5 – 2
Field Windbreaks	594	300	1.0 – 1.5
Riparian Forest Planting	1,500	750	2.0 – 2.5
Biomass for co-firing	10,500	330	0.25 – 3

* Tg = terragrams = million metric tonnes

Table 9 suggests a total agroforestry, biomass, and forest opportunity in the range of 9 – 15 $TgCO_2e$ per year on the non-federal lands of the region. In comparison, USDA currently estimates that the forests of the region (including federal forests) are sequestering around 41 $TgCO_2e$ per year (Table 8). Thus, while 9-15 will not represent a huge national or global impact, it would mean that activities on private lands could increase regional sequestration by 25 to 35 percent. That, accompanied by the many other environmental values associated with improved carbon sequestration practices, would seem substantial.

Rangeland Potential

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

Within the Big Sky Region study area, including WY, approximately 40 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 (~25 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. Preliminary estimates suggest that rangelands can store up to an additional 0.05-0.075 t C/ha/yr, providing an aggregate technical potential in the range of 2-4Mmt C/yr. Details of this analysis are provided in our fourth quarterly report.

Cropland Potential

The cropland assessments are done in terms of both technical potential and economic potential. Technical potential provides the most optimistic estimate of the size of the terrestrial sinks, assuming that all land use management was changes to the management regime that sequestered the maximum amount of soil carbon. The economic potential examines the amount of carbon that would be sequestered from land use changes taking into account the "cost' of changing the existing land use management to a management regime that would sequester larger amounts of carbon. In theory, the economic assessment is a realistic means of capturing both the potential size of the sinks and the opportunity cost of sequestering carbon.

GIS components of the terrestrial sink evaluation include climate, soil and land use databases. One hundred years of climate data from National Climate Data Center station records were averaged for each of up to 10 climate zones in each state, to produce zone-average files containing monthly max/min temperatures and precipitation since 1895. In addition, zone-specific statistical data on climate variability were provided to Century's stochastic climate generation subroutine, which we used to simulate climate after 2003.

Soil texture grids derived from SSURGO or STATSGO soil databases were developed for each state, then statistically aggregated to approximately 20 representative soil texture classes. Century simulations are highly sensitive to soil texture, so although it was impractical to model every actual soil map unit in the state, the classes we use represented the range of soil textures found in the state. Each class was weighted by the actual area of land to which it applied in each county. Land management data were extracted from the 1997 Census of Agriculture (USDA 1997). Land in farms data, for total areas of harvested cropland and grazing (pasture) land, and from the Conservation Technology Information Center (CTIC 2004) data for 2002 on land enrolled in the CRP and cropland under no-till management. These data were compiled on a county basis and are summarized in Table 10.

Table 10. Agricultural land areas, in km^2.

State	Crop-Conv Till	Crop-No Till	Grazing	CRP	Total
Idaho	19,479	1,087	23,325	3,244	47,135
Montana	39,801	4,226	141,882	10,884	196,793
South Dakota	51,986	14,664	105,440	5,752	177,842
Wyoming	8,881	142	127,357	1,134	137,514

Five different management scenarios, ranging from continuous grassland to continuous conventionally-tilled cropland, were applied to spatial "cells" developed by intersecting climate and soil texture grids at the county level. The management types applied in our default (business-as-usual, or BAU) scenario were based on current agricultural land use statistics. The results of CENTURY modeling for each soil-climate-land use combination were applied to the appropriate cell, and the cells (up to 20 per county) were summed to obtain county-level estimates of current soil carbon flux rates (Figure 11). These were further summed to obtain state estimates.

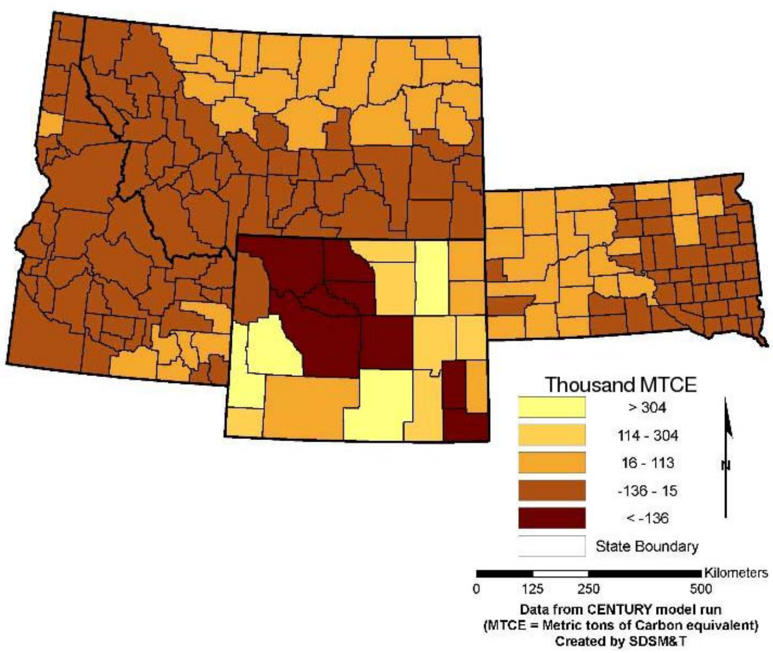

Figure 11. Current estimated annual soil carbon fluxes in ID, MT, WY, and SD, by county.

The cellular nature of the data enables us to explore the effect of changes in the status quo, for example, an increase in the rate of no-till adoption or CRP enrollment, or a decline in CRP enrollment. GIS-based modeling has enabled the iterative exploration of effects from changes to the status quo in land use/management such as altered rates of no-till adoption or CRP enrollment. The CENTURY model has already afforded significant insights into the spatially-variable prospects for terrestrial sequestration; as one general example, results have confirmed that South Dakota (the state with by far the largest area of harvested cropland) offers the largest potential for terrestrial sink enhancement due to improved agricultural land management, particularly through conversion to no-till. Estimates of sequestration potential for a limited suite of scenarios are currently included in the GIS database of the Big Sky Carbon Warehouse.

Statewide simulation preliminary results for current and potential agricultural management scenarios are summarized in Table 11. Increasing CRP areas by 25% at the expense of conventionally tilled lands enhances agricultural sinks by 4-9% over 40 years of simulation. An increase in no-till area appears to offer the greatest potential for enhancing agricultural sinks in South Dakota, which has more cropland than the other states. The much lower gains resulting from increased no-till in Montana, Idaho and Wyoming are due in part to the very small areas currently classified as no-till. On the other hand, Wyoming and South Dakota realize the largest gains from a hypothetical 50% reduction in grazing pressure across all grazing lands. It is not clear why Montana, with a larger rangeland area than SD, does not realize at least a comparable benefit. Literature indicates that forage condition responds in a complex way to the interaction of grazing pressure and climate (under wetter conditions pasturelands can sustain more intensive grazing without losing productivity); however, it is unlikely that Century is capable of simulating this interaction effectively, therefore grazing results should be treated as preliminary.

Table 11. Predicted 40-year average annual C stock change (MTCE) for different scenarios. Percent change from current in parentheses.

State	***Current***	***+25% CRP[1]***	***-50% Grazing[2]***	***+25% No-Till[3]***
Idaho	287,124	312,968 (9%)	283,087(-1%)	289,071 (1%)
Montana	788,544	818,251 (4%)	883,797 (12%)	801,317 (2%)
South Dakota	706,193	748,105 (6%)	846,748 (20%)	931,406 (32%)
Wyoming	43,050	46,742 (9%)	104,093 (142%)	43,323 (1%)

1. 25% increase in current CRP area, deducted from current conv till land.
2. Grazing intensity reduced by about 50% on all grazing land.
25% increase based on *current* no-till area, deducted from current conv. till land (i.e. 0% current no-till resulted in 0% increase).

The integrated approach to the analysis of the technical and economic potential to sequester soil C which links biophysical information with economic information on a site-specific basis provided estimates for Montana non-irrigated croplands which are consistent with the measures reported earlier by USDA (2004). We apply an integrated assessment approach to quantify the amount of C and the costs of sequestering C from changes in land use and management practices in the dryland grain production systems of Montana. Our analysis indicates that at high prices, the economic potential is basically approximating the technical potential of these croplands. Over a twenty-year time horizon, this area has the technical potential to sequester approximately 18-20 M mt C or approximately 1.0 M mtC/yr. This is equivalent to approximately 70 M mt CO_2equivalent over the 20 yr time horizon.

Extrapolating these results to the larger Big Sky region using the cropland acreage reported by the USDA for conservation and no-tillage, the major cropland sinks in the region would provide carbon storage ranging from 1.7-2.4 M mt C/yr (Antle et al, 2005) using an average carbon sequestration rate of 0.2 mt C/ha/yr. This is equivalent to 6.2-8.5 M mt CO_2e/yr. The reported amounts by USDA for dryland cropping in the Big Sky region was approximately 5.4 M mt CO_2e/yr.

The integrated analysis also provided estimates of the magnitude of the potential cropland sinks for the Central US region which includes the Big Sky region and the Central plains, from Minnesota down through Texas. Simulations for the central United States show that reduction in fallow and conservation tillage adoption in the wheat-pasture system could generate up to about 1.7 M mt C/yr, whereas increased adoption of conservation tillage in the corn-soy-feed system could generate up to about 6.2 M mt C/yr. At least half of this technical potential could be achieved at relatively low carbon prices (less than $100 per mt).

Market-Based Carbon Efforts

The NCOC continued to address all of the needs for establishing a viable market for carbon trading. 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 II. 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 at the end of Phase I. 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 II 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 I and linked to the Big Sky Partnership website 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.

Regional Energy Analysis

The Partnership has assessed future energy growth in this region. There are significant policy implications associated with energy development that would result in changes to the regional energy mix, water resource demands, energy transmission systems, and from the implementation of new energy technologies including carbon sequestration. The Big Sky partnership has identified key factors influencing energy development. The Conference proceedings “Policy Implications from Regional Energy Growth” (Appendix A2) examines some of these factors including population demographics, land and water availability, energy transmission and transportation infrastructure, energy market supplies and demands, environmental/regulatory constraints, and the availability of raw energy resources. The Big Sky Regional Carbon Sequestration Partnership is examining regional carbon sequestration opportunities that could be used to reduce or offset the carbon emissions from fossil power energy production and other industrials.

Outreach and Education

The main result of lesson learned from the education and outreach component is that carbon sequestration is not well known and very few individuals in the region – even those with energy and environmental backgrounds – were familiar with the topic. If there was any familiarity, people were inclined to associate carbon sequestration with terrestrial opportunities and potential benefits to farmers, ranchers and foresters. Therefore, Phase I required more of an emphasis on identifying key stakeholders and building individual relationships to communicate the range of sequestration technology options and issues than anticipated. For the most part, activities associated with building regional networks were largely delayed until Phase II.

Other lessons learned include:

- *Global climate change is the 1000 lb. gorilla*. The region has abundant natural beauty and there are many local and regional environmental groups concerned and engaged on a range of environmental issues from various endangered species to water quality and smart forest growth. Many also recognize the impact global climate change has on the local environment but in essence, the region is very locally oriented. Messages that focus on the multiple benefits of terrestrial sequestration and potential reductions in local particulates haze through carbon capture and geologic storage resonate with individuals from environmental groups. These individuals are cautiously optimistic and willing to help engage their groups to help the Partnership deliver these messages in Phase II.
- *Economic development matters a lot*. It is a key issue in all of the Partnership's states, in which many have the opportunity for energy resource development. Messages that highlight the economic development potential energy development coupled with carbon sequestration resonate. In Phase I, the Partnership engaged various individuals from economic development groups throughout the region who are willing to become an integral part of Phase II education and outreach efforts.
- *Engaging state leadership is key*. At the end of Phase I, governors of multiple states in the region launched major energy initiatives. Based on Phase I outreach efforts, the Partnership is poised to further engage state leadership to elevate the profile of carbon sequestration's potential throughout Phase II.

CONCLUSIONS

This final technical report summarizes the major work performed throughout the Phase I period, and integrates the findings and conclusions from the efforts as a whole.

The primary sources of greenhouse gases (GHG) in Montana, Idaho, Wyoming and South Dakota are documented in the Big Sky Carbon Atlas and via NatCarb distributed national databases (www.natcarb.org). In 2002 the region's gross emissions profile for GHGs were averaging about 61 MMTCE, which translates into per capita emissions ranging from a high of 23 MTCE in Wyoming to 12 MTCE in Idaho. In Montana and Wyoming, refining and other energy and heavy industries constitute the largest source of GHGs related to energy consumption source category.

Geologic formations in Big Sky Carbon Sequestration Partnership Region have the potential to sequester enormous volume of CO_2. These formations include both sedimentary rock types characteristic of oil, gas, and coal productions as well as large areas of mafic volcanic rocks. The potential sequestration capacity of the nine sedimentary provinces within the region ranges from 25,000 to almost 900,000 million metric tons of CO_2. Overall every sedimentary formation investigated in the region has significant potential to sequester large amounts of CO_2. In addition, a full evaluation of the potential of geologic sequences for carbon sequestration potential needs to consider the relative contributions of hydrodynamic, solubility, and mineralization trapping. The relative contribution to sequestration of these 3 processes will vary with rock type and time. In sequences that include basalts, such as those located in southern Idaho, all 3 processes contribute to sequestration, with hydrodynamic trapping import at early time and mineralization trapping dominating at later time. The results of Phase I suggest that mineral trapping in mafic volcanic rock has significant potential to permanently entomb CO_2. Although MMV for this rock type may be challenging, a carefully chosen combination of geophysical and geochemical techniques should allow assessment of the fate of CO_2 in deep basalt hosted aquifers. The efficacy of mineral trapping will be investigated at the pilot scale in mafic volcanic rock as a key Phase II activity.

For terrestrial sequestration estimates, the Partnership has identified three major sinks: rangelands, croplands, and forested areas. Coverage includes Indian reservations and private lands, and reflects potential changes in carbon. Rangelands can store up to an additional 0.05 mt C/ha/yr, while the croplands are on average four times that amount. Estimates of technical potential for soil sequestration within the region in cropland are in the range of 2.0 M mt C/yr over 20 year time horizon. This is equivalent to approximately 7.0 M mt CO_2e/yr. The forestry sinks are well documented, and the potential in the Big Sky region ranges from 9-15 M mt CO_2 equivalent per year. Value-added benefits include enhanced yields, reduced erosion, and increased wildlife habitat.

The Big Sky geographic information system (GIS) Phase I accomplishments included the following three major areas of effort: (i) Big Sky Carbon Atlas: compilation of geologic and terrestrial sequestration data for the states of Montana, South Dakota, Idaho, and Wyoming and sources data; (ii) Big Sky Data Warehouse: planning and initial implementation of online access via IMS and SDE; and (iii) interpartnership coordination and links with NATCARB, DOE, and national cyberinfrastructure efforts. Expansion of these efforts in the first year of Phase II will include the sink data for eastern Washington and Oregon.

The advanced concept component has integrated the activities of the partnership by focusing on needed efforts for pending large scale deployment of the sequestration opportunities. The key efforts include examining the feasibility for market-based sequestration options; exploring mineralization trapping feasibility in the Snake River Plain Basin; defining measurement, monitoring, and verification requirements for all sinks; and developing a common (economic) framework for evaluating the tradeoffs among alternative carbon sinks at both the project and regional levels. The MMV efforts summarized the current state of capabilities for geological and terrestrial sinks, and evaluated the systems for public credibility, cost effectiveness, and timeliness of detection of leakages. The economic framework provides a means to quantify regional C supply curves, showing at each price of C, the total amount of C that could be sequestered in the region. This framework has become a valuable tool to enable the Partnership, its industry members and the region to begin to assess the economic potential of all its sequestration options on a common basis. The MMV procedures are an integral part of the geological pilots that will be done in Phase II, the carbon markets, and the terrestrial pilots. They are also critical in terms of examining the costs of sequestering carbon, and will be incorporated into the economic and risk assessment analysis.

Furthermore, with the largest and most comprehensive terrestrial program in the nation, the Partnership has taken a lead in enhancing market-based C storage methods and improving verification protocols. Throughout Phase I the National Carbon Offset Coalition (NCOC) has successfully expanded the number and diversity of participants in its landowner/emitter advisory committee, held meetings were held with National Governors Association Greenhouse Gas working Group, the Intertribal Environmental Council, and the U.S, Environmental Protection Agency. The Partnership, through the NCOC, has 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 had extensive 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. Planning forms, contracting options and forestry portfolios, and Project Planning Handbooks were developed and have been reviewed by the Chicago Climate Exchange.

The focus of the Partnership's Phase I education and outreach activities was to lay the foundation for regional support of Phase II field validation tests. An Education and Outreach Action Plan was developed to identify key stakeholder groups and targeted messages and guide Phase I activities. Focus was given to communicating the opportunities and risks associated with carbon sequestration and working with decision makers to determine possible issues associated with field validation test implementation and ultimately commercial deployment. Outreach activities were conducted in a number of ways and venues ranging from individual meetings, legislative briefings, workshops, and symposia, to poster sessions, presentations, web networks and the news. Feedback from education and outreach activities indicate that given potential energy resource development in the region and the need for economic growth, there is considerable interest in carbon sequestration. Regional environmental management and stewardship is also of considerable interest; therefore, the Partnership's primary conclusion from its outreach activities is that the region as a whole is cautiously optimistic about sequestration's potential, supportive of Phase II field validation tests and would like to learn more. The Partnership's primary conclusion from its outreach activities is that the region as a whole is cautiously optimistic about sequestration's potential, supportive of Phase II field validation tests and would like to learn more. This conclusion is driven by the fact that a high value is placed on potential energy resource development for regional economic growth as well as environmental management and stewardship.

In summarizing Phase I results and activities, the following major cross-cutting and integrative themes emerge:

- The Big Sky region is a relatively low emitter of GHG and in particular CO_2 emissions, with only a few point sources that account for a large share of these emissions. However, the region contains extensive fossil-fuel based resources, having more than 25% of the coal resources in the US. As a result the Big Sky partnership region can play a unique role in designing and meeting future energy production in a way that addresses energy security, cost efficiency, reliability, and environmental stewardship. The potential for providing clean coal technologies and regional carbon sequestration opportunities that complement the future energy development objectives of the region and the demands for long term, safe storage of carbon is real and, through the selection and design of our Phase II pilots and with the collaboration of research partners, industry, state agencies, and landowners, achievable in the near future.
- Geological and terrestrial carbon sinks provide a myriad of sequestration options that span both temporal and spatial dimensions, and are similar to large sequestration sinks that exist in other parts of the developing and developed world. The current terrestrial sinks, including cropland, rangelands, and forestry/agroforestry, combined with the opportunities to continue to expand EOR in the Big Sky region, offer an answer to near-term carbon sequestration needs at a cost that is competitive with other national and international alternatives. In the longer term, the potential sequestration capacity of the sedimentary provinces within the region are nearly almost 900,000 million metric tons of CO_2 with the characteristic to permanently entomb the carbon.
- In addressing future carbon sequestration opportunities, the Partnership has invested in efforts designed to help insure that the opportunities and programs are cost-effective and competitive with other sequestration alternatives. The attention to the economic potential of these sinks, i.e., the ‘opportunity cost” of changing land use patterns, of using energy to capture, separate, and sequester CO_2, of combining energy production in a manner that optimizes a joint energy production and CO_2 mitigation plans, is a key strength of the partnership. Equally important and recognized nationally and internationally is the extensive efforts on designing protocols and verification procedures for enhanced market-based carbon trading, carbon offsets, and carbon-storage methods.
- The Partnership has conducted extensive public education and outreach to build a dialogue with key decision makers, regulatory officials, industry, environmental groups, tribal nations, and the public on the region’s energy future and the opportunities and risks associated with advanced coal technologies and C sequestration.

The Phase I work clearly identified the geological similarities among Montana, Idaho, Wyoming, eastern Washington and Oregon. There are also similar land use patterns and cropland practices among these states and South Dakota, and the Canadian provinces. Thus as we proceed into Phase II, we have expanded the Partnership to include the states/provinces with similar and contiguous geological and terrestrial sinks. This expansion is also justified by the common economic interests of these States, including many regional energy companies operating across

States and Provincial lines. Additionally, the Partnership is working with leading research institutions in DOE's Carbon Sequestration Leadership Forum member countries including Norway, India and China who will bring unique expertise and funding commitments to leverage DOE's Big Sky Partnership investment.

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APPENDICES to Final Report

A. Special reports:

1. Final Report on GIS Activities for the Big Sky Carbon Sequestration Regional Partnership Phase 1 through September 2005
2. Conference proceedings "Policy Implications from Regional Energy Growth." Shropshire, D. and S. Capalbo. Presented at the Fourth Annual Conference on Carbon Capture and Sequestration, Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date, Alexandria, VA, May 2-5, 2005. (PPT available at http://www.bigskyco2.org/presentations/CarbonSequestrationConfFile19Shropshire.ppt)

B. Deliverables attached to this Final Technical Report

Deliverable 9. Report on Evaluation of Terrestrial Sinks

Deliverable 13. Measurement, Monitoring and Verification Technology Assessment Report

Deliverable 16. Report on Common Methodology for assessing tradeoffs among carbon sinks

Deliverable 17. Overall Assessment and Evaluation Report and workshop proceedings on advanced concepts for geological and terrestrial sequestration

Deliverable 20. Summary of innovation sessions/workshop, seminars, roundtables

C. Listing of all Phase I Deliverables

D. Statement of Work

E. Partnership Principals and Contributors to Final Report

F. Deliverables Previously Submitted to DOE as Topical Reports

Deliverable 2. Report on Technology Needs.

Deliverable 3. Report and Action Plan on the Evaluation of Geologic Sinks and Pilot Project Deployment

Deliverable 5. Action Plan Report and infrastructure needs for enhancing terrestrial sequestration sinks

Deliverable 6. Manuscript on Carbon Budget and Analyses/GIS database

Deliverable 8. Report on Evaluation of Terrestrial Sinks

Deliverable 12. Contracting and Project Implementation Handbook

Deliverable 14. Report on the feasibility of mineralization trapping in the Snake River Plain Basin

Deliverable 15. Report on the results of best production practice for soil C sequestration

Deliverable 18. Action Plan for Carbon Sequestration Implementation

Final Report on GIS Activities for the Big Sky Carbon Sequestration Regional Partnership Phase 1 through September 2005

Randy Lee (randy.lee@inl.gov), Ecological and Cultural Resources, Idaho National Laboratory; role: geologic database lead

Karen Updegraff (karen.updegraff@sdsmt.edu), Institute of Atmospheric Sciences, South Dakota School of Mines and Technology; role: terrestrial database lead

Todd Kipfer (tkipfer@montana.edu) and Aaron Jones (aaronjones@montana.edu), Big Sky Institute, Montana State University; role: data warehouse lead

Paul Rich (pmr@lanl.gov), Earth and Environmental Sciences, Los Alamos National Laboratory; role: GIS coordination

Jeff Hamerlinck (itasca@uwyo.edu), Wyoming Geographic Information Science Center, University of Wyoming; role: assistance with terrestrial and geologic databases

Stewart Kirkpatrick (skirkpatrick@mt.gov), Montana State GIS Coordinator, MT Dept of Administration/Information Technology Services Division; role: state GIS planning

Executive Summary

The Big Sky geographic information system (GIS) phase one accomplishments included five major areas of effort:

- **Big Sky Carbon Atlas:** compilation of geologic and terrestrial sequestration data for the states of Montana, South Dakota, Idaho, and Wyoming;
- **Big Sky Data Warehouse:** planning and initial implementation of online access via IMS and SDE;
- **Interpartnership coordination and links with NATCARB, DOE, and national cyberinfrastructure efforts:** planning, communication, and establishment of links to NATCARB;
- **Outreach:** contributions highlighting GIS and key data; and
- **Big Sky Phase 2 planning:** development of the GIS component.

Big Sky GIS Overview

During phase 1, the Big Sky geographic information system (GIS) effort focused primarily on characterization of regional carbon sources, sinks, and infrastructure. The Big Sky geographic region was defined to include land area encompassing the states of Montana (MT), South Dakota (SD), Idaho (ID), and Wyoming (WY). During phase 2 this will be expanded to include contiguous areas in eastern Washington, Oregon, and Canadian provinces. Data are being made available via the Big Sky Carbon Atlas (Table 1). The Big Sky Carbon Atlas can be viewed via the Big Sky Partnership website (http://www.bigskyco2.org), and via the NatCarb distributed national databases (http://www.natcarb.org).

Table 1. Data layers of the Big Sky Carbon Atlas (ID, MT, SD, and WY) during Phase I.

Data Type	Description	Served by Big Sky
GHG Sources	Emission point locations	Yes
GHG Inventory	State-level source & sink emission summaries	Yes
GHG Livestock	County-level livestock emission summaries	Yes
Terrestrial Sinks	Actual/potential soil sink estimates (CENTURY)	Yes
Soil	SSURGO/STATSGO & Soil Texture Grids	Yes
Climate	Monthly precipitation/temperature 1900–present	Yes
Climate Divisions	NCDC climate division boundaries	Yes
Ag Management	Cropland areas (various tillage/rangeland)	Yes
Political	State/County Boundaries	Yes
Infrastructure	Transportation/Pipelines/Powerlines	No[a]
Geologic Sinks	Oil/Gas Provinces & Plays	Yes
Wells	Oil & Gas wells	Yes

[a.] Infrastructure data layers such as gas pipelines are not served due to homeland security issues.

GIS Support for Geological Sequestration Efforts

The region of interest for geological sequestration efforts includes Idaho, Montana, South Dakota, and geologically contiguous areas in North Dakota and Wyoming. The geologic sequestration potential is being assessed in sedimentary and volcanic basins including deep saline aquifers, depleted oil/gas reservoirs, deep unminable coal beds, and mafic/rock hosted fresh aquifers. During the first year of a two-year program, we developed a GIS database structure, identified the sources, and collected data that now populate the database. During this second year, specific geologic data are being evaluated to determine the sequestration potential for geologic sites within the Big Sky region.

We focused on assessing the sequestration potential of the large traditional hydrocarbon basins located in Montana, Wyoming and South Dakota (Figure 1); and additionally developed a procedure to evaluate the non-traditional volcanic basins plays found in southern Idaho.

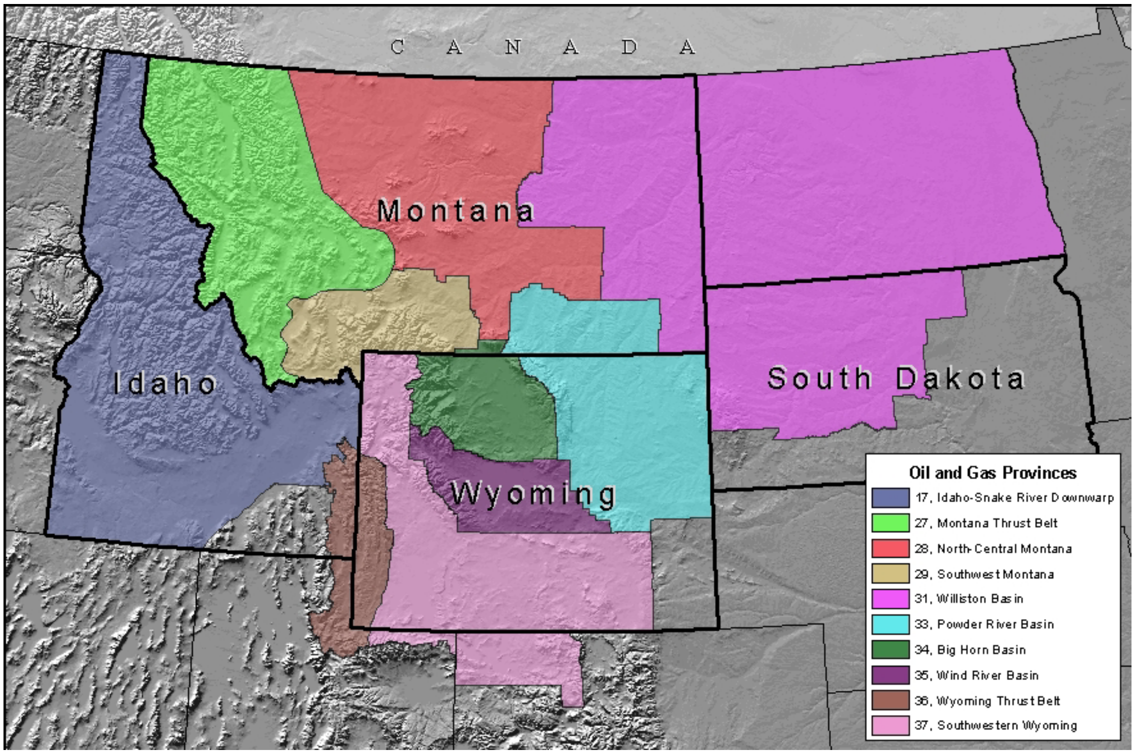


Figure 1. Big Sky region oil and gas provinces.

An overall approach to assess geologic carbon sequestration potential was developed. This assessment was based on geospatial and tabular data being collected and fed into a GIS based database. This database is structured to feed critical information into the geochemical and reservoir modeling activities (see Figure 2). During this performance period, modeling of the oil and gas regions of WY and MT to characterize the suitability of each candidate site with respect to its carbon dioxide sequestration potential has been completed. The modeling approach includes isolating individual oil and gas wells first by *play* area, then by formation within each *play*. Then calculations were performed in the model, using data from the well tables, resulting in either surfaces or tables for pressure, temperature, density, and thickness. From this new information, sequestration volumes were established for each formation within each *play*. To date, sequestration volumes have been calculated for 283 formations in 57 *plays* using data from 117,304 active wells in WY and approximately 50,000 wells in MT. A view of the model can be seen in Figure 3 and an example of the resulting information in tabular form can be seen in Figure 4.

Along with the modeling efforts during this period, additional GIS layers have been collected, cataloged and delivered to MSU for inclusion into the Big Sky Carbon Atlas. A complete list of geologic data is provided in Appendix A: GIS Master List.

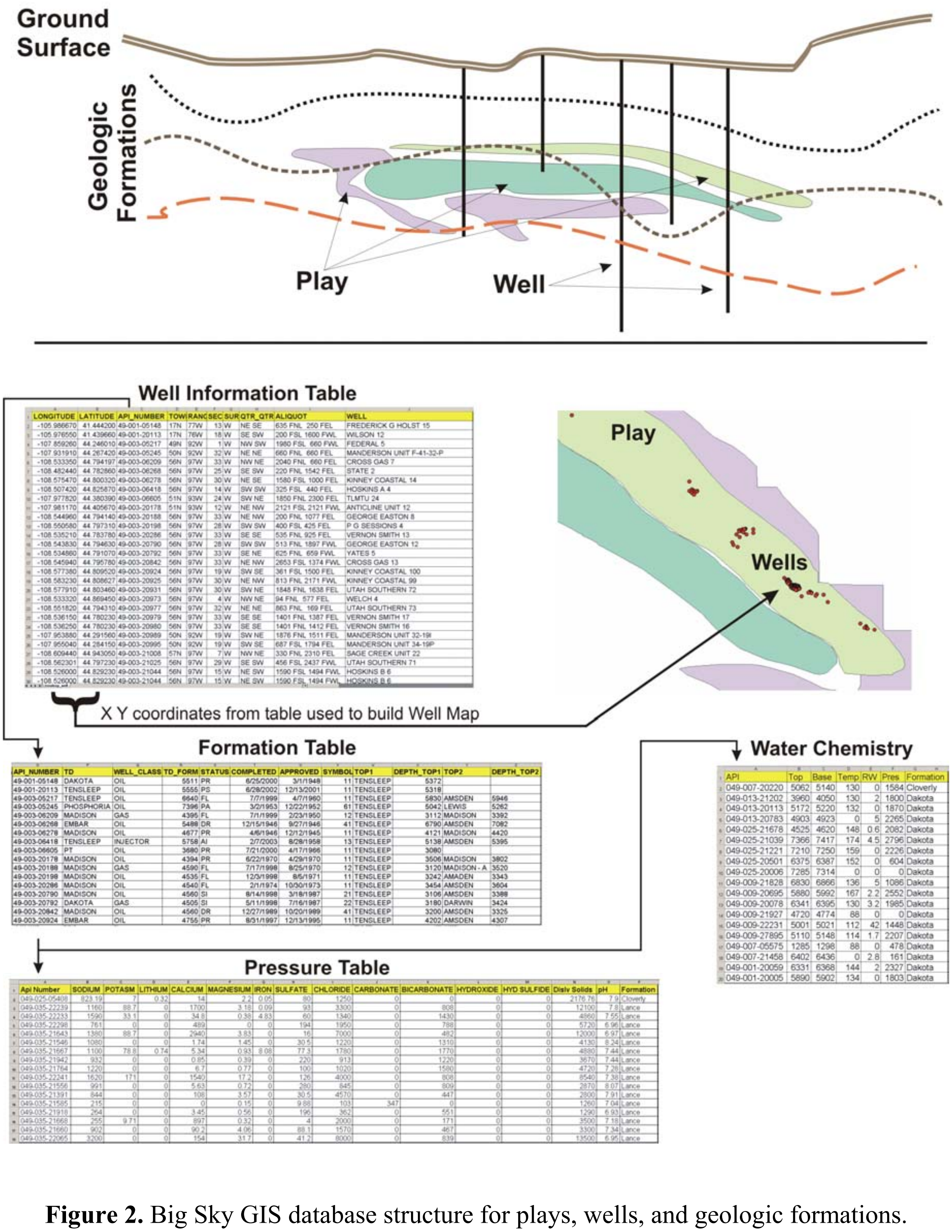


Figure 2. Big Sky GIS database structure for plays, wells, and geologic formations.

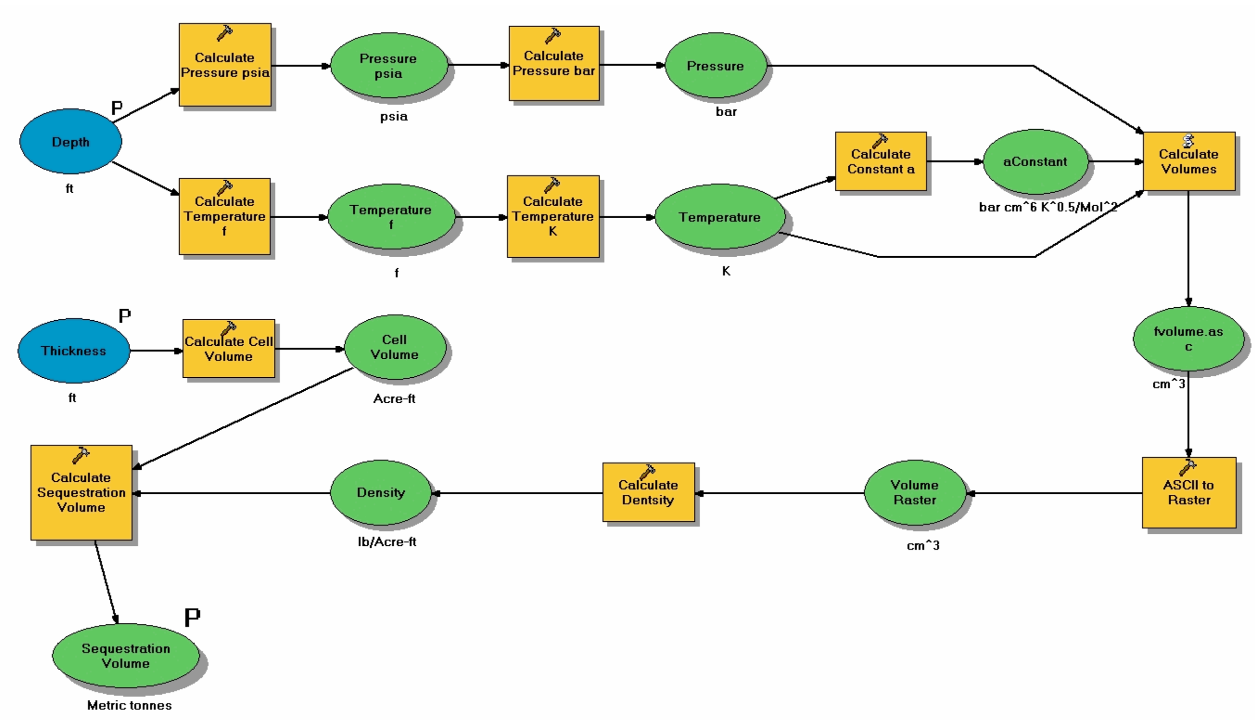
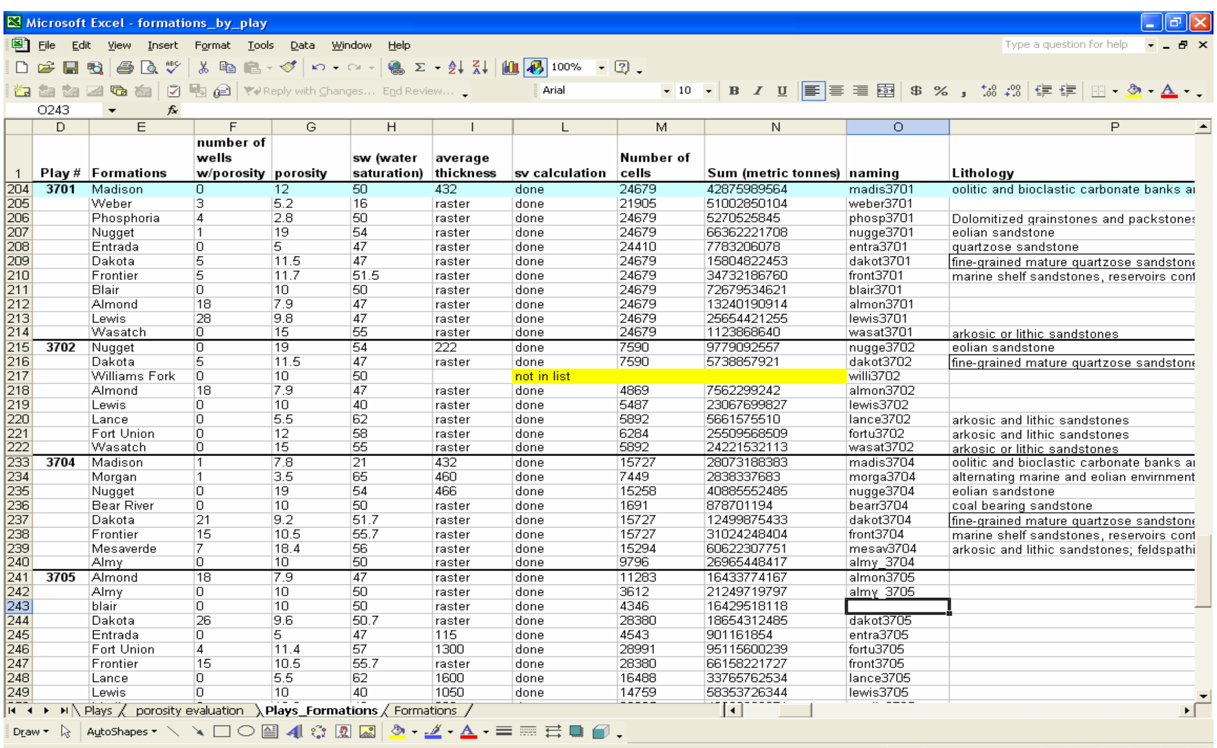


Figure 3. Big Sky carbon sequestration volume model.



1	Play #	Formations	number of wells w/porosity	porosity	sw (water saturation)	average thickness	sv calculation	Number of cells	Sum (metric tonnes)	naming	Lithology
204	3701	Madison	0	12	50	432	done	24679	42875989564	madis3701	oolitic and bioclastic carbonate banks ai
205		Weber	3	5.2	16	raster	done	21905	51002850104	weber3701	
206		Phosphoria	4	2.8	50	raster	done	24679	5270525845	phosp3701	Dolomitized grainstones and packstones
207		Nugget	1	19	54	raster	done	24679	66362221708	nugge3701	eolian sandstone
208		Entrada	0	5	47	raster	done	24410	7783206078	entra3701	quartzose sandstone
209		Dakota	5	11.5	47	raster	done	24679	15804822453	dakot3701	fine-grained mature quartzose sandstone
210		Frontier	5	11.7	51.5	raster	done	24679	34732186760	front3701	marine shelf sandstones, reservoirs cont
211		Blair	0	10	50	raster	done	24679	72679534621	blair3701	
212		Almond	18	7.9	47	raster	done	24679	13240190914	almon3701	
213		Lewis	28	9.8	47	raster	done	24679	25654421255	lewis3701	
214		Wasatch	0	15	55	raster	done	24679	1123868640	wasat3701	arkosic or lithic sandstones
215	3702	Nugget	0	19	54	222	done	7590	9779092557	nugge3702	eolian sandstone
216		Dakota	5	11.5	47	raster	done	7590	5738857921	dakot3702	fine-grained mature quartzose sandstone
217		Williams Fork	0	10	50		not in list			willi3702	
218		Almond	18	7.9	47	raster	done	4869	7562299242	almon3702	
219		Lewis	0	10	40	raster	done	5487	23067699827	lewis3702	
220		Lance	0	5.5	62	raster	done	5892	5661575510	lance3702	arkosic and lithic sandstones
221		Fort Union	0	12	58	raster	done	6284	25509568509	fortu3702	arkosic and lithic sandstones
222		Wasatch	0	15	55	raster	done	5892	24221532113	wasat3702	arkosic or lithic sandstones
233	3704	Madison	1	7.8	21	432	done	15727	28073188383	madis3704	oolitic and bioclastic carbonate banks ai
234		Morgan	1	3.5	65	460	done	7449	2838337683	morga3704	alternating marine and eolian envirnment
235		Nugget	0	19	54	466	done	15258	40885552485	nugge3704	eolian sandstone
236		Bear River	0	10	50	raster	done	1691	878701194	bearr3704	coal bearing sandstone
237		Dakota	21	9.2	51.7	raster	done	15727	12499875433	dakot3704	fine-grained mature quartzose sandstone
238		Frontier	15	10.5	55.7	raster	done	15727	31024248404	front3704	marine shelf sandstones, reservoirs cont
239		Mesaverde	7	18.4	56	raster	done	15294	60622307751	mesav3704	arkosic and lithic sandstones; feldspathi
240		Almy	0	10	50	raster	done	9796	26965448417	almy_3704	
241	3705	Almond	18	7.9	47	raster	done	11283	16433774167	almon3705	
242		Almy	0	10	50	raster	done	3612	21249719797	almy_3705	
243		blair	0	10	50	raster	done	4346	16429518118		
244		Dakota	26	9.6	50.7	raster	done	28380	18654312485	dakot3705	
245		Entrada	0	5	47	115	done	4543	901161854	entra3705	
246		Fort Union	4	11.4	57	1300	done	28991	95115600239	fortu3705	
247		Frontier	15	10.5	55.7	raster	done	28380	66158221727	front3705	
248		Lance	0	5.5	62	1600	done	16488	33765762534	lance3705	
249		Lewis	0	10	40	1050	done	14759	58353726344	lewis3705	

Figure 4. Results from Carbon Sequestration Volume modeling.

GIS Support for Terrestrial Sequestration Efforts

Characterization of MT, ID, WY, and SD with respect to major GHG sources and agricultural carbon sequestration potential has been completed.

GHG sources: The primary sources of greenhouse gases in Montana, Idaho, Wyoming and South Dakota are compared in Figure 5. In 2002 the region's gross emissions of GHGs were averaging about 61 MMTCE, which translates into per capita emissions ranging from a high of 23MTCE in Wyoming to 12 MTCE in Idaho. In Montana and Wyoming, refining and other energy and heavy industries constitute the largest source of GHGs related to energy consumption source category; while in Idaho imported electricity accounts for the largest category of energy-related emissions. Potential emissions from future development of the vast fossil-fuel resources are conservatively estimated to be an order of magnitude higher, depending on transmission lines and other energy demand factors. GHG emissions from agriculture, principally CH_4 from livestock and N_2O from soil management, account for nearly 27% of South Dakota emissions.

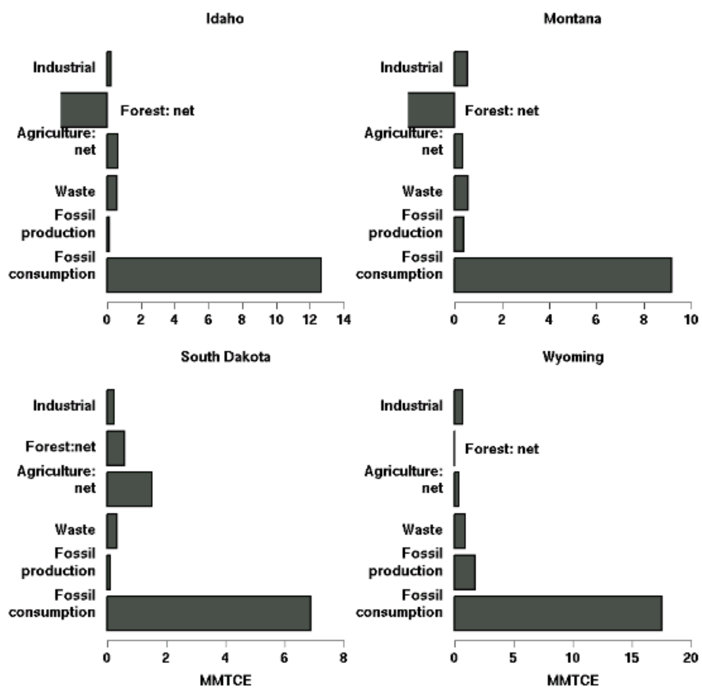


Figure 5. Primary Greenhouse gas emission sources in ID, MT, SD, and WY.

GHG Sinks: GIS components of the terrestrial sink evaluation include climate, soil and land use databases. One hundred years of climate data from National Climate Data Center station records were averaged for each of up to 10 climate zones in each state, to produce zone-average files containing monthly max/min temperatures and precipitation since 1895. In addition, zone-specific statistical data on climate variability were provided to Century's stochastic climate generation subroutine, which we used to simulate climate after 2003.

Soil texture grids derived from SSURGO or STATSGO soil databases were developed for each state, then statistically aggregated to approximately 20 representative soil texture classes. Century simulations are highly sensitive to soil texture, so although it was impractical to model every actual soil map unit in the state, the classes we use represented the range of soil textures found in the state. Each class was weighted by the actual area of land to which it applied in each county.

Land management data were extracted from the 1997 Census of Agriculture (USDA 1997). Land in Farms data, for total areas of harvested cropland and grazing (pasture) land, and from the Conservation Technology Information Center (CTIC 2004) data for 2002 on land enrolled in the CRP and cropland under no-till management. These data were compiled on a county basis and are summarized in Table 2.

Table 2. Agricultural land areas, in km^2.

State	*Crop-Conv Till*	*Crop-No till*	*Grazing*	*CRP*	*Total*
Idaho	19,479	1,087	23,325	3,244	47,135
Montana	39,801	4,226	141,882	10,884	196,793
South Dakota	51,986	14,664	105,440	5,752	177,842
Wyoming	8,881	142	127,357	1,134	137,514

Five different management scenarios, ranging from continuous grassland to continuous conventionally-tilled cropland, were applied to spatial "cells" developed by intersecting climate and soil texture grids at the county level. The management types applied in our default (business-as-usual, or BAU) scenario were based on current agricultural land use statistics. The results of CENTURY modeling for each soil-climate-land use combination were applied to the appropriate cell, and the cells (up to 20 per county) were summed to obtain county-level estimates of current soil carbon flux rates. These were further summed to obtain state estimates (Figure 6).

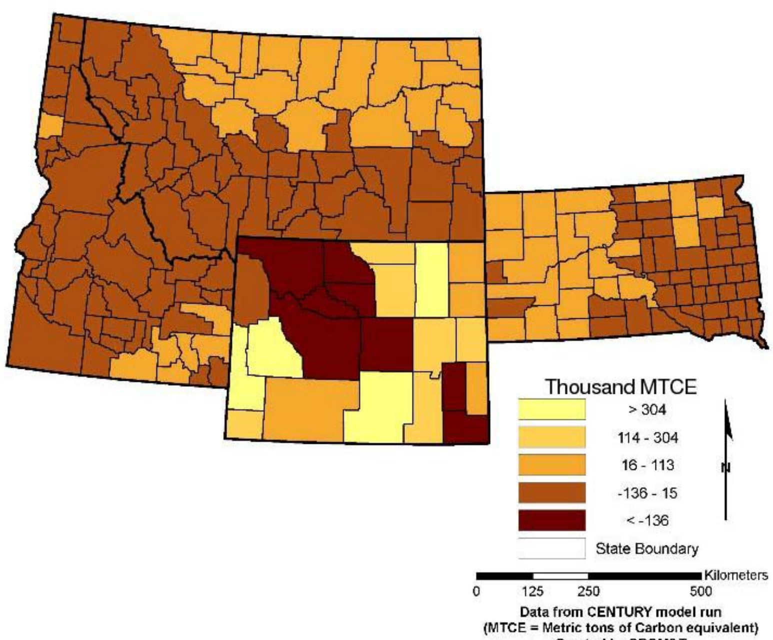


Figure 6. Current estimated annual soil carbon fluxes in ID, MT, WY, and SD, by county.

The cellular nature of the data enables us to explore the effect of changes in the status quo, for example, an increase in the rate of no-till adoption or CRP enrollment, or a decline in CRP enrollment. Estimates for a limited suite of scenarios are included in the GIS database. Montana has the largest agricultural land base, but South Dakota has by far the largest area of harvested cropland. As a result, South Dakota offers the largest potential for terrestrial sink enhancement due to agricultural land management, particularly through conversion to no-till.

Infrastructure Data

Infrastructure data was compiled for the states of MT, WY, ID, and SD. Road and railroad data for the four states were derived from the SDC Feature Classes "highways.sdc" and "rail100k.sdc", respectively, supplied with ESRI ArcInfo Workstation 9.0. Only road and railroad data are made available through the Big Sky Data Warehouse. Pipeline data for the four states were extracted from the Office of Pipeline Safety's National Pipeline Mapping System, to which LANL has a license. These data is considered to be "Official Use Only" (OUO), and come with the following disclaimer:

> *"I understand that any and all data/information obtained from the Office of Pipeline Safety's National Pipeline Mapping System is sensitive security information and I agree that it will be treated as DOT proprietary information. I agree to: restrict disclosure of and access to this data/information to persons with official state and local government responsibility; to not redistribute the data/information; and to refer requests by other persons for such information to the Associate Administrator for Pipeline Safety. I also agree to maintain a list of those persons that have been provided access to this information."*

Big Sky Data Warehouse and Data Coordination

Planning and Initial Implementation: The Big Sky Carbon Sequestration Partnership Data Warehouse was established at the Big Sky Institute at MSU, and staff were hired to administer the system and manage data. Initial efforts have focused on establishing a base architecture for managing Big Sky Partnership data and providing access to that data via an ESRI ArcIMS interactive mapping application and a live data link to NatCarb (Figure 6).

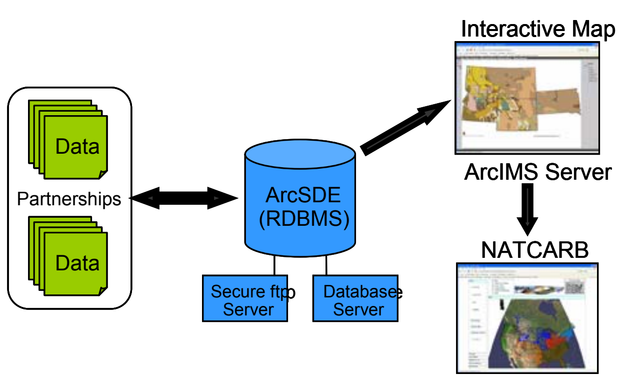


Figure 6. Web-based access to Big Sky data and integration with other partnerships and NatCarb is provided via ArcSDE and ArcIMS.

Witkowski et al. (2003) provided a key reference for determining the initial data architecture in the geodatabase and in anticipating how work flow will occur via ArcSDE. In addition, ESRI's Modeling our World and Building a Geodatabase have each proven instructive in envisioning how the Big Sky Data Warehouse might best be construed once data holdings have progressed to a point where we can expect to support site-specific decisions concerning CO2 transfer and storage.

For the Big Sky Partnership, we established a new application/database server with ArcIMS 9, MS SQL Server 2000 SP3, and ArcSDE 9 running on Windows 2003 Server with Apache and Tomcat. The server hardware consists of a dual Xeon server with a redundant SCSI disk array. Backup is maintained by tape and server to server backup strategies. The initial setup was slowed by configuration issues. We arrived at a stable installation and configuration of all IMS Server components and gained an in depth understanding of the latest iteration of ArcIMS/ArcSDE/MS SQL Server architecture.

Data Coordination: A secure FTP site was established as a vehicle for harvesting large datasets (e.g., STATSGO data) from collaborators. Geologic and terrestrial data were relayed to MSU and integrated into the Data Warehouse at Big Sky Institute and are now accessible through the Carbon Atlas ArcIMS service. Performance of the IMS-SDE-SQL configuration was optimized in terms of the speed and reliability of data transfer. Where possible, FGDC-compliant metadata were provided and field aliases were created for tabular data to provide greater intelligibility to end-users of the Carbon Atlas ArcIMS interface. We worked to fill data gaps by working with Partnership collaborators and by directly obtaining the data from other sources.

We integrated and standardized a composite master data list (Appendix A) for the Data Warehouse holdings in support of current and future Partnership activities.

Interpartnership Coordination and Links with NatCarb, DOE, and National Cyberinfrastructure Efforts

Interpartnership Coordination and Links with NatCarb: Big Sky GIS personnel participated in period GIS Working Group teleconferences, which provided the primary means of communication with counterparts in other partnerships. In addition Big Sky GIS personnel from LANL (Paul Rich), MSU (Todd Kipfer and Aaron Jones), and UWy (Jeffrey Hamerlinck) attended an Interpartnership/NatCarb meeting in Lawrence, KS (February 1-2, 2005). The meeting focused on building partnership links with NatCarb and on GIS coordination during phase 2. The following goals were formulated for GIS coordination during phase 2:

- Participate in inter-partnership planning and ongoing communication to ensure that key carbon sequestration data layers and tools are consistent, complete, and available (methodology, quality…).
- Contribute to building the national carbon cyberinfrastructure, an integrated computing environment that provides access to information, models, problem solving capabilities, and communication concerning carbon science and technology.
- Coordinate with key federal and DOE GIS efforts.

GIS coordination during phase 2 will be implemented through the following activities:

- Participate in formulation of a **national carbon cyberinfrastructure plan** with input from diverse stakeholders and based on sound design.
- Participate in **GIS coordination meetings** and regular **GIS teleconferences**.
- Make data available via the **NatCarb** distributed network of carbon sequestration databases (http://www.natcarb.org).
- **Share key GIS resources** (methods, design, data sources, tools…) with other partnerships and NatCarb via the partnership/NatCarb e-mail list, web posting, and other effective means of communication.
- Resolve issues (gaps, overlaps, errors, inconsistencies…) required to produce a complete **regional carbon sequestration atlas** for each partnership.
- Follow **federal requirements** concerning geospatial data documentation, in particular by producing Federal Geographic Data Committee (FGDC) compliant metadata (http://www.fgdc.gov/metadata/metadata.html).
- Register geospatial data with the **Geospatial One-Stop** (GOS), the primary U.S. geoportal (http://www.geodata.gov/gos), mandated as part of the president's E-Government agenda.
- Contribute to building a department-wide **DOE Geospatial Science Program** in conjunction with the DOE Office of the Chief Information Officer (contact Rosita Parkes, rose.parkes@hq.doe.gov) DOE Geospatial Science Steering Committee (contact David Morehouse, dmorehou@eia.doe.gov) and the DOE GIS User Group (contact James Bollinger, james02.bollinger@srs.gov).

Links with DOE and National Efforts: An oral presentation and posters concerning carbon cyberinfrastructure were presented at the American Geophysical Union Chapman Conference on "The Science and Technology of Carbon Sequestration", January 16-20, 2005, San Diego, CA (Rich et al. 2005, Keating et al. 2005A). Under separate funding, presentations were made concerning complex-wide GIS efforts (Bollinger et al. 2004, Rich et al. 2004), and a proposal was submitted to the DOE Office of the Chief Information Officer (Bollinger et al. 2005), which resulted in designation of a new DOE Geospatial Science program in August 2005. Also under separate funding several manuscripts concerning data sharing and and cyberinfrastructure were and are currently under peer review (Witkowski et al. 2005, Goodchild et al. 2005). We also presented a poster for the NETL-sponsored Fourth Annual Conference on Carbon Capture and Sequestration (Keating et al. 2005B).

Outreach

Outreach efforts focused primarily on ongoing contributions to the Big Sky website (http://www.bigskyco2.org), including basics of GIS and synopses of major findings.

References Cited

Conservation Technology Information Center. 2004. National Crop Residue Management Survey; Conservation Tillage Data. (http://www.ctic.purdue.edu/CTIC/CRM.html . Verified 11 Jan. 05.)

USDA. 1997. Census of Agriculture. National Agricultural Statistics Service. (http://www.nass.usda.gov/census/index1997.htm. Verified 17 Aug 04.)

Witkowski, M.S., P.M. Rich, and G.N. Keating. 2003. A prototype for enterprise GIS. Los Alamos National Laboratory Report, LA-14027, Los Alamos, NM.

Presentations, Publications, and Proposals

<u>Presentations at National Meetings:</u>

Keating, G.N., T.L. Riggs, P.M. Rich, M.S. Witkowski, and H.S. Viswanathan. 2005A. GIS-Based Decision Support for Carbon Sequestration. Chapman Conference on The Science and Technology of Carbon Sequestration, January 16-20, 2005, San Diego, CA. LA-UR-04-7595.

Keating, G.N., P.M. Rich, M.S. Witkowski, and H.S.Viswanathan. 2005B. GIS knowledge integration for carbon sequestration: the cyberinfrastructure approach. to be presented at the Fourth Annual Conference on Carbon Capture and Sequestration, May 2-5, 2005, Alexandria, VA.

Rich, P.M., G.N. Keating, T.L. Riggs, and M.S. Witkowski. 2005. A vision for carbon cyberinfrastructure. Chapman Conference, The Science and Technology of Carbon Sequestration, January 16-20, 2005, San Diego, CA. LA-UR-04-7594.

Rich, P.M., T.L. Riggs, M.S. Witkowski, and G.N. Keating 2004. Toward enterprise GIS design for DOE. Invited talk for DOE GIS User Group Meeting. at ESRI International User Conference, San Diego.

Bollinger, J.S., S.M. Hargrove, Rich, P.M., L. Brady-Sabeff, D. Collette, A. Guber, M. Klein, J. Kuiper, J. Lee, R. Lee, K. Mickus, D. Morehouse, K. Moore, A. Ramsdell, S. Rush, J. Stewart, H. Walker, R. Wells. 2004. The DOE GIS Core Team. DOE Annual Information Management Conference, Columbus, OH.

<u>Publications Submitted and In Manuscript:</u>

Goodchild, M.F., P. Fu, and P.M. Rich. 2005. Geographic information sharing: the case of the Geospatial One-Stop portal. manuscript to be submitted for peer review.

Witkowski, M.S., P.M. Rich, and G.N. Keating. 2005. Enterprise GIS: definition, requirements, and metrics of success. submitted for peer review.

<u>Proposals Submitted:</u>

Department of Energy, Office of the Chief Information Officer. submitted February 2005. $3M requested for FY05. "DOE Geospatial Science Program". Draft plan for ramp-up funding for new DOE Geospatial Science program, goal $20-30M/yr across DOE complex. J. Bollinger, P. Rich, D. Morehouse, and S. Hargrove (Co-PIs). pending.

Department of Energy, NETL. submitted March 2005. $17.97M requested for FY06 to FY09. "Big Sky Regional Carbon Sequestration Partnership - Phase II", S. Capablo (PI). funded.

Appendix A. Big Sky database master list, page 1 of 6

IDAHO Filename	Data model	LAYER NAME	Description	Source
bid_bndclip	vector	**ID - State Boundary**	State boundary	ESRI
bid_counties	vector	**ID - Counties**	County boundaries	ESRI
bid_fedlands	vector	**ID - Federal Lands**	Federal lands	ESRI
bid_indlands	vector	**ID - Tribal Lands**	Tribal lands	ESRI
bid_mjwater	vector	**ID - Major Water Bodies**	Major water bodies	ESRI
bid_rds	vector	**ID - Major Roads**	Major Roads (including US and state hwys)	ESRI
bid_rivers	vector	**ID - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bidshdrlf	raster	**ID - Shaded Relief**	Shaded relief (1km res.)	ESRI
gid_pr1700g	vector	**ID - Play 1700**	Idaho-Snake River Downwarp Province (17) Boundary	NOGA
gid_pr1701g	vector	**ID - Play 1701**	Miocene Lacustrine (Lake Bruneau)	NOGA
gid_pr1702g	vector	**ID - Play 1702**	Pliocene Lacustrine (Lake Idaho)	NOGA
gid_pr1703g	vector	**ID - Play 1703**	Pre-Miocene	NOGA
gid_pr1704g	vector	**ID - Play 1704**	Older Tertiary	NOGA
gid_provinces	vector	**ID - NOGA Provinces**	Oil and gas province boundaries	NOGA
gid_regions	vector	**ID - NOGA Regions**	Oil and gas region boundaries	NOGA
tid_aveprecip1895-2003	vector	**ID - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	…
tid_climdivs	vector	**ID - Climatic Divisions**	Climatic divisions	EPA
tid_co2sources	vector	**ID - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
tid_countydc	vector	**ID - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**ID - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**ID - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**ID - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
tid_cropland	vector	**ID - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**ID - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**ID - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**ID - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
tid_livestock	vector	**ID - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**ID - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**ID - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
tid_bd	raster	**ID - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
tid_cl	raster	**ID - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
tid_sa	raster	**ID - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
tid_si	raster	**ID - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…

MONTANA Filename	Data model	LAYER NAME	Description	Source
bmt_bndclip	vector	**MT - State Boundary**	State boundary	ESRI
bmt_counties	vector	**MT - Counties**	County boundaries	ESRI
bmt_fedlands	vector	**MT - Federal Lands**	Federal lands	ESRI
bmt_indlands	vector	**MT - Tribal Lands**	Tribal lands	ESRI
bmt_mjwater	vector	**MT - Major Water Bodies**	Major water bodies	ESRI
bmt_rds	vector	**MT - Major Roads**	Major Roads (including US and state hwys)	ESRI
bmt_rivers	vector	**MT - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bmtshdrlf	raster	**MT - Shaded Relief**	Shaded relief (1km res.)	ESRI
gmt_pr2700g	vector	**MT - Play 2700**	Montana Thrust Belt Province (27) Boundary	NOGA
gmt_pr2701g	vector	**MT - Play 2701**	Imbricate Thrust Gas	NOGA
gmt_pr2800g	vector	**MT - Play 2800**	North-Central Montana	NOGA
gmt_pr2805g	vector	**MT - Play 2805**	Devonian-Mississippian Carbonates	NOGA
gmt_pr8806g	vector	**MT - Play 2806**	Tyler Sandstones	NOGA
gmt_pr8807g	vector	**MT - Play 2807**	Fractured-Faulted Carbonates in Anticlines	NOGA
gmt_pr8808g	vector	**MT - Play 2808**	Jurassic-Cretaceous Sandstones	NOGA
gmt_pr2809g	vector	**MT - Play 2809**	Shallow Cretaceous Biogenic Gas	NOGA
gmt_pr2900g	vector	**MT - Play 2900**	Southwest Montana	NOGA
gmt_pr2901g	vector	**MT - Play 2901**	Crazy Mountains and Lake Basins Cretaceous Gas	NOGA
gmt_pr2903g	vector	**MT - Play 2903**	Nye-Bowler Wrench Zone Oil and Gas	NOGA
gmt_pr3100g	vector	**MT - Play 3100**	Williston Basin	NOGA
gmt_pr3101g	vector	**MT - Play 3101**	Madison (Mississippian)	NOGA
gmt_pr3102g	vector	**MT - Play 3102**	Red River (Ordovician)	NOGA
gmt_pr3103g	vector	**MT - Play 3103**	Middle and Upper Devonian (Pre-Bakken-Post Prairie Salt)	NOGA
gmt_pr3105g	vector	**MT - Play 3105**	Pre-Prairie Middle Devonian and Silurian	NOGA
gmt_pr3106g	vector	**MT - Play 3106**	Post-Madison trhough Triassic Clastics	NOGA
gmt_pr3107g	vector	**MT - Play 3107**	Pre-Red River Gas	NOGA
gmt_pr3110g	vector	**MT - Play 3110**	Bakken Fairway	NOGA
gmt_pr3300g	vector	**MT - Play 3300**	Powder River Basin	NOGA
gmt_pr3302g	vector	**MT - Play3302**	Basin Magin Anticline	NOGA
gmt_pr3303g	vector	**MT - Play3303**	Leo Sandstone	NOGA
gmt_pr3304g	vector	**MT - Play 3304**	Upper Minnelusa Sandstone	NOGA
gmt_pr3305g	vector	**MT - Play 3305**	Lakota Sandstone	NOGA
gmt_pr3306g	vector	**MT - Play 3306**	Fall River Sandstone	NOGA
gmt_pr3307g	vector	**MT - Play 3307**	Muddy Sandstone	NOGA
gmt_pr3308g	vector	**MT - Play 3308**	Mowry Fractured Shale	NOGA
gmt_pr3309g	vector	**MT - Play 3309**	Deep Frontier Sandstone	NOGA
gmt_pr3310g	vector	**MT - Play 3310**	Turner Sandstone	NOGA
gmt_pr3311g	vector	**MT - Play 3311**	Niobrara Fractured Shale	NOGA
gmt_pr3312g	vector	**MT - Play 3312**	Sussex-Shannon Sandstone	NOGA
gmt_pr3313g	vector	**MT - Play 3313**	Mesaverde-Lewis	NOGA
gmt_pr3315g	vector	**MT - Play 3315**	Biogenic Gas	NOGA
gmt_pr3350g	vector	**MT - Play 3350**	Powder River Basin - Shallow Mining-Related	NOGA
gmt_pr3351g	vector	**MT - Play 3351**	Powder River Basin - Central Basin	NOGA
gmt_pr3400g	vector	**MT - Play 3400**	Bighorn Basin	NOGA
gmt_pr3402g	vector	**MT - Play 3402**	Basin Margin Anticline	NOGA
gmt_pr3403g	vector	**MT - Play 3403**	Deep Basin Structure	NOGA
gmt_pr3405g	vector	**MT - Play 3405**	Sub-Absaroka	NOGA
gmt_pr3406g	vector	**MT - Play 3406**	Phosphoria Stratigraphic	NOGA
gmt_pr3417g	vector	**MT - Play 3417**	Shallow Tertiary-Upper Cretaceous Stratigraphic	NOGA
gmt_provinces	vector	**MT - NOGA Provinces**	Oil and gas province boundaries	NOGA
gmt_regions	vector	**MT - NOGA Regions**	Oil and gas region boundaries	NOGA

MONTANA Filename	Data model	LAYER NAME	Description	Source
tmt_aveprecip1895-2003	vector	**MT - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	…
tmt_climdivs	vector	**MT - Climatic Divisions**	Climatic divisions	EPA
tmt_co2sources	vector	**MT - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
tmt_countydc	vector	**MT - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**MT - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**MT - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**MT - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
tmt_cropland	vector	**MT - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**MT - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**MT - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**MT - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
tmt_livestock	vector	**MT - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**MT - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**MT - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
tmt_bd	raster	**MT - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
tmt_cl	raster	**MT - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
tmt_sa	raster	**MT - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
tmt_si	raster	**MT - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…

S. DAKOTA Filename	Data model	LAYER NAME	Description	Source
bsd_bndclip	vector	**SD - State Boundary**	State boundary	ESRI
bsd_counties	vector	**SD - Counties**	County boundaries	ESRI
bsd_fedlands	vector	**SD - Federal Lands**	Federal lands	ESRI
bsd_indlands	vector	**SD - Tribal Lands**	Tribal lands	ESRI
bsd_mjwater	vector	**SD - Major Water Bodies**	Major water bodies	ESRI
bsd_rds	vector	**SD - Major Roads**	Major Roads (including US and state hwys)	ESRI
bsd_rivers	vector	**SD - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bsdshdrlf	raster	**SD - Shaded Relief**	Shaded relief (1km res.)	ESRI
gsd_pr3100g	vector	**SD - Play 3100**	Williston Basin	NOGA
gsd_pr3101g	vector	**SD - Play 3101**	Madison (Mississippian)	NOGA
gsd_pr3102g	vector	**SD - Play 3102**	Red River (Ordovician)	NOGA
gsd_pr3103g	vector	**SD - Play 3103**	Middle and Upper Devonian (Pre-Bakken-Post Prairie Salt)	NOGA
gsd_pr3302g	vector	**SD - Play 3302**	Basin Magin Anticline	NOGA
gsd_provinces	vector	**SD - NOGA Provinces**	Oil and gas province boundaries	NOGA
gsd_regions	vector	**SD - NOGA Regions**	Oil and gas region boundaries	NOGA

S. DAKOTA Filename	Data model	LAYER NAME	Description	Source
tsd_aveprecip1895-2003	vector	**SD - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	
tsd_climdivs	vector	**SD - Climatic Divisions**	Climatic divisions	EPA
tsd_co2sources	vector	**SD - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
tsd_countydc	vector	**SD - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**SD - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**SD - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**SD - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
tsd_cropland	vector	**SD - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**SD - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**SD - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**SD - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
tsd_livestock	vector	**SD - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**SD - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**SD - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
tsd_bd	raster	**SD - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
tsd_cl	raster	**SD - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
tsd_sa	raster	**SD - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
tsd_si	raster	**SD - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…

WYOMING Filename	Data model	LAYER NAME	Description	Source
bwy_bndclip	vector	**WY - State Boundary**	State boundary	ESRI
bwy_counties	vector	**WY - Counties**	County boundaries	ESRI
bwy_fedlands	vector	**WY - Federal Lands**	Federal lands	ESRI
bwy_indlands	vector	**WY - Tribal Lands**	Tribal lands	ESRI
bwy_mjwater	vector	**WY - Major Water Bodies**	Major water bodies	ESRI
bwy_rds	vector	**WY - Major Roads**	Major Roads (including US and state hwys)	ESRI
bwy_rivers	vector	**WY - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bwyshdrlf	raster	**WY - Shaded Relief**	Shaded relief (1km res.)	ESRI
gwy_pr3300g	vector	**WY - Play 3300**	Powder River Basin	NOGA
gwy_pr3302g	vector	**WY - Play 3302**	Basin Magin Anticline	NOGA
gwy_pr3303g	vector	**WY - Play 3303**	Leo Sandstone	NOGA
gwy_pr3304g	vector	**WY - Play 3304**	Upper Minnelusa Sandstone	NOGA
gwy_pr3305g	vector	**WY - Play 3305**	Lakota Sandstone	NOGA

WYOMING Filename	Data model	LAYER NAME	Description	Source
gwy_pr3306g	vector	**WY - Play 3306**	Fall River Sandstone	NOGA
gwy_pr3307g	vector	**WY - Play 3307**	Muddy Sandstone	NOGA
gwy_pr3308g	vector	**WY - Play 3308**	Mowry Fractured Shale	NOGA
gwy_pr3309g	vector	**WY - Play 3309**	Deep Frontier Sandstone	NOGA
gwy_pr3310g	vector	**WY - Play 3310**	Turner Sandstone	NOGA
gwy_pr3311g	vector	**WY - Play 3311**	Niobrara Fractured Shale	NOGA
gwy_pr3312g	vector	**WY - Play 3312**	Sussex-Shannon Sandstone	NOGA
gwy_pr3313g	vector	**WY - Play 3313**	Mesaverde-Lewis	NOGA
gwy_pr3315g	vector	**WY - Play 3315**	Biogenic Gas	NOGA
gwy_pr3350g	vector	**WY - Play 3350**	Powder River Basin - Shallow Mining-Related	NOGA
gwy_pr3351g	vector	**WY - Play 3351**	Powder River Basin - Central Basin	NOGA
gwy_pr3400g	vector	**WY - Play 3400**	Bighorn Basin	NOGA
gwy_pr3402g	vector	**WY - Play 3402**	Basin Margin Anticline	NOGA
gwy_pr3403g	vector	**WY - Play 3403**	Deep Basin Structure	NOGA
gwy_pr3405g	vector	**WY - Play 3405**	Sub-Absaroka	NOGA
gwy_pr3406g	vector	**WY - Play 3406**	Phosphoria Stratigraphic	NOGA
gwy_pr3417g	vector	**WY - Play 3417**	Shallow Tertiary-Upper Cretaceous Stratigraphic	NOGA
gwy_pr3500g	vector	**WY - Play 3500**	Wind River Basin	NOGA
gwy_pr3501g	vector	**WY - Play 3501**	Basin Margin Subtrhrust	NOGA
gwy_pr3502g	vector	**WY - Play 3502**	Basin Margin Anticline	NOGA
gwy_pr3503g	vector	**WY - Play 3503**	Deep Basin Structure	NOGA
gwy_pr3504g	vector	**WY - Play 3504**	Muddy Sandstone Stratigraphic	NOGA
gwy_pr3515g	vector	**WY - Play 3515**	Shallow Tertiary-Upper Cretaceous Stratigraphic	NOGA
gwy_pr3518g	vector	**WY - Play 3518**	Cody and Frontier Stratigraphic	NOGA
gwy_pr3550g	vector	**WY - Play 3550**	Wind River Basin-Mesaverde	NOGA
gwy_pr3600g	vector	**WY - Play 3600**	Wyoming Thrust Belt	NOGA
gwy_pr3601g	vector	**WY - Play 3601**	Moxa Arch Extentsion	NOGA
gwy_pr3604g	vector	**WY - Play 3604**	Absaroka Thrust	NOGA
gwy_pr3606g	vector	**WY - Play 3606**	Hogsback Thrust	NOGA
gwy_pr3607g	vector	**WY - Play 3607**	Cretaceous Stratigraphic	NOGA
gwy_pr3700g	vector	**WY - Play 3700**	Southwestern Wyoming	NOGA
gwy_pr3701g	vector	**WY - Play 3701**	Rock Springs Uplift	NOGA
gwy_pr3702g	vector	**WY - Play 3702**	Cherokee Arch	NOGA
gwy_pr3703g	vector	**WY - Play 3703**	Axial Uplift	NOGA
gwy_pr3704g	vector	**WY - Play 3704**	Moxa Arch-LaBarge	NOGA
gwy_pr3705g	vector	**WY - Play 3705**	Basin Margin Anticline	NOGA
gwy_pr3707g	vector	**WY - Play 3707**	Platform	NOGA
gwy_pr3750g	vector	**WY - Play 3750**	Greater Green River Basin-Rock Springs	NOGA
gwy_pr3751g	vector	**WY - Play 3751**	Greater Green River Basin-Iles	NOGA
gwy_pr3752g	vector	**WY - Play 3752**	Greater Green River Basin-Williams Fork	NOGA
gwy_pr3753g	vector	**WY - Play 3753**	Greater Green River Basin-Almond	NOGA

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WYOMING Filename	Data model	LAYER NAME	Description	Source
gwy_pr3754g	vector	**WY - Play 3754**	Greater Green River Basin-Lance	NOGA
gwy_pr3755g	vector	**WY - Play 3755**	Greater Green River Basin-Fort Union	NOGA
gwy_provinces	vector	**WY - NOGA Provinces**	Oil and gas province boundaries	NOGA
gwy_regions	vector	**WY - NOGA Regions**	Oil and gas region boundaries	NOGA
gwy_CO2OilGasArealFields	vector	**WY - Oil and gas fields**	Wyoming Oil and Gas fields	…
gwy_refineries	vector	**WY - Refineries**	Refineries	…
gwy_CMBArealFields	vector	**WY - Coalbed-methane fields**	Coalbed-methane fields	…
twy_aveprecip1895-2003	vector	**WY - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	…
twy_climdivs	vector	**WY - Climatic Divisions**	Climatic divisions	EPA
twy_co2sources	vector	**WY - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
twy_countydc	vector	**WY - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**WY - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**WY - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**WY - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
twy_cropland	vector	**WY - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**WY - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**WY - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**WY - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
twy_livestock	vector	**WY - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**WY - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**WY - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
twy_bd	raster	**WY - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
twy_cl	raster	**WY - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
twy_sa	raster	**WY - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
twy_si	raster	**WY - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…

Policy Implications from Regional Energy Growth

David Shropshire, Idaho National Laboratory
Susan Capalbo, Montana State University

Abstract

The Big Sky region consisting of Idaho, Montana, and Wyoming holds high potential for future energy growth due to significant energy resources (e.g., coal reserves, wind) and central proximity to western energy markets. This region is also characterized by small populations, limited industry, and low greenhouse gas emissions. There are significant policy implications associated with energy development that would result in changes to the regional energy mix, water resource demands, energy transmission systems, and from the implementation of new energy technologies including carbon sequestration. The Big Sky partnership has identified key factors influencing energy development. This paper examines some of these factors including population demographics, land and water availability, energy transmission and transportation infrastructure, energy market supplies and demands, environmental/regulatory constraints, and the availability of raw energy resources. This paper also considers the potential influence of regional climate change on energy growth. Climate change can have a direct impact on water availability, market demands, economics of power systems (e.g., carbon taxes, carbon capture, and sequestration), preference for renewable vs. fossil energy systems, and siting fossil plants near carbon sequestration sinks. The Big Sky Regional Carbon Sequestration Partnership is examining regional carbon sequestration resources that could be used to reduce or offset the carbon emissions from fossil power energy production and other industrials. The Big Sky Partnership is using this study to gain insight into the issues driving regional energy demand and facilitate the development of a regional infrastructure that can support future energy development with carbon sequestration resources. The methodologies created through this activity will be applicable to other regional applications. This methodology can be used to evaluate the economic and policy ramifications from regional energy growth.

1. Introduction

Energy growth assessment is a complex, dynamic process with many factors and drivers. The assessment of the Big Sky region was considered within the broader context of the resources and demands of the eleven Western states. A regional perspective provides a comprehensive view that considers combined geopolitical boundaries (e.g., Western Governors Association), energy transmission corridors (electricity, pipelines), transportation routes (railroad, highways), contiguous geologic characteristics, socio-economic regions, shared water resources, and other overlapping regional features.

The key factors included in this evaluation were selected for their potential to positively or negatively influence future energy growth in the Big Sky region. We have included population demographics, land and water availability, transmission and transportation infrastructure, regional energy market supplies and demands, environmental/regulatory constraints, raw energy resource availability, energy technology resources, and regional climate change. These factors are illustrated in Figure 1 to show how each factor could positively (green lines) or negatively (red lines) influence future energy growth. Additionally, some links (purple lines) between factors were drawn to show some of the complexity that can drive system behavior. For example, climate change can influence where businesses locate and where people live, but it can also influence energy demands for heating and cooling, and drive energy market demands. It is also important to consider that energy growth is not a static process, but a dynamic process where the importance of the dynamic factors may change over time, as well as the relative influence that they may assert on energy growth.

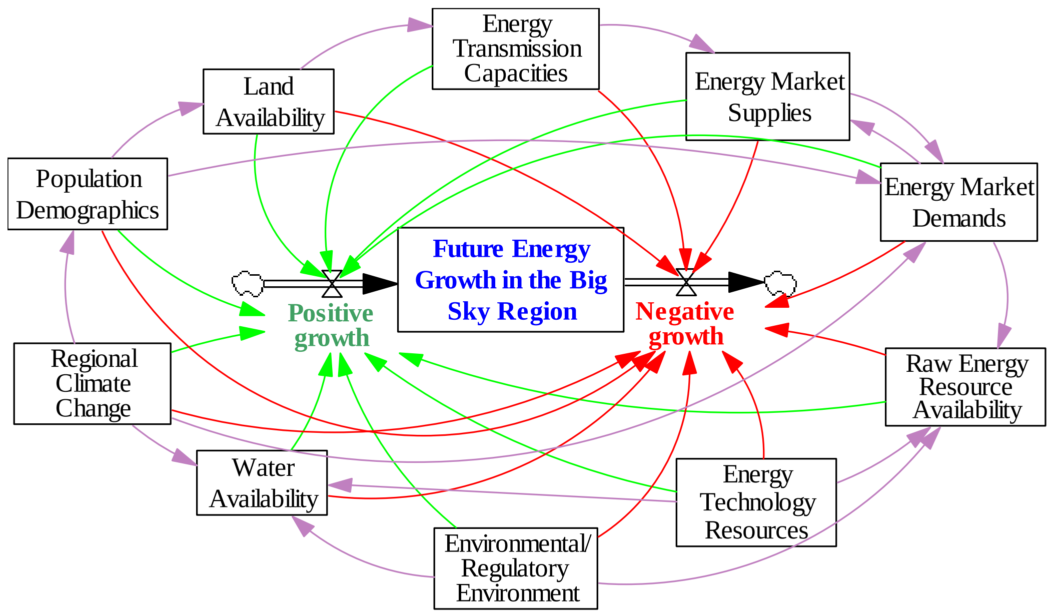


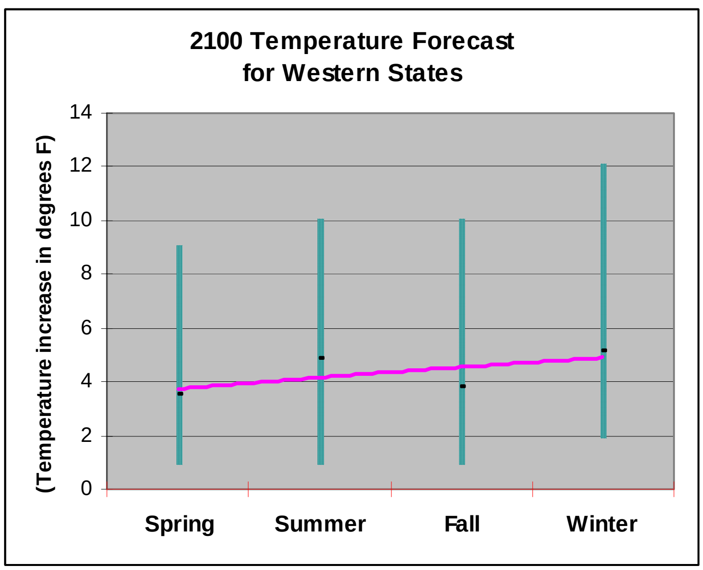
Figure 1. Causal relationships between the key dynamic factors affecting future energy growth in the Big Sky Region.

2. Factors Affecting Energy Growth

The following sections describe each of the key dynamic factors and their potential influences (positive and negative) on energy growth as they relate to the Big Sky region. In many cases, perspectives are provided for the Western U.S., with an emphasis on the Big Sky region.

2.1 Regional Climate Change

According to the Intergovernmental Panel on Climate Change (IPCC) and the United Kingdom's Hadley Centre's climate model (HadCM2), the Western states are predicted to experience warming trends of 4–5°F over the next century, with the greatest temperature increases during winter. Figures 2 and 3 show precipitation trend lines (in red) and their range of potential variation (vertical blue line). The trends indicate wetter spring, fall, and winter seasons; but potentially dryer summers. [1,2] The data reflects a high degree of variability in the precipitation and temperature trends.



Figures 2. 2100 Temperature trends for Western states. [EPA data]

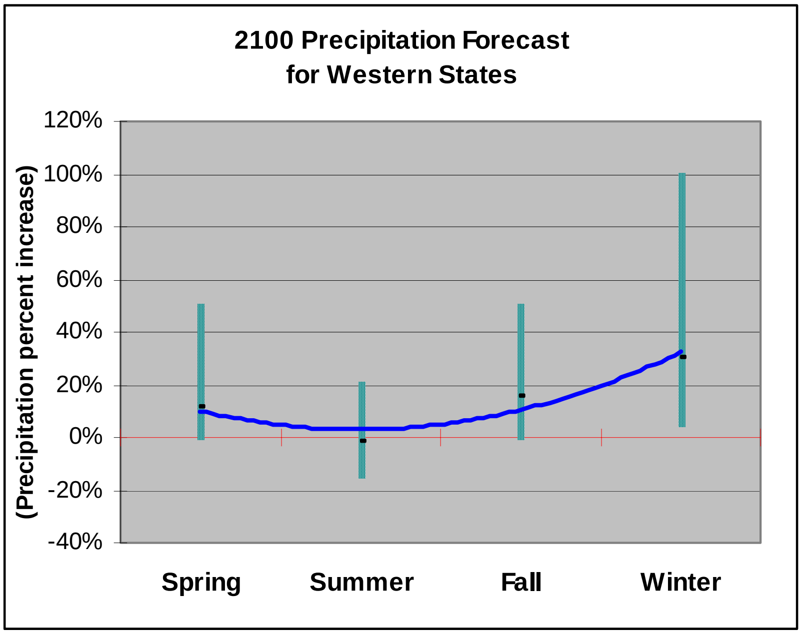


Figure 3. 2100 Precipitation Trends for Western States. [EPA data]

Over the past century, the average temperatures in the Big Sky region have increased between 1 and 1.6°F. Precipitation has increased by 20% in some parts of Idaho, while decreasing by 20% in most of Montana and Wyoming. Figure 4 shows the United States precipitation trends for 1900 to 1994. Climate models predict that the Big Sky regional weather during the next century will continue warming (1 to 11°F) and turn toward wetter (5% to 100% increases) spring, fall, and winter seasons. Summers may have up to 20% less precipitation. [3]

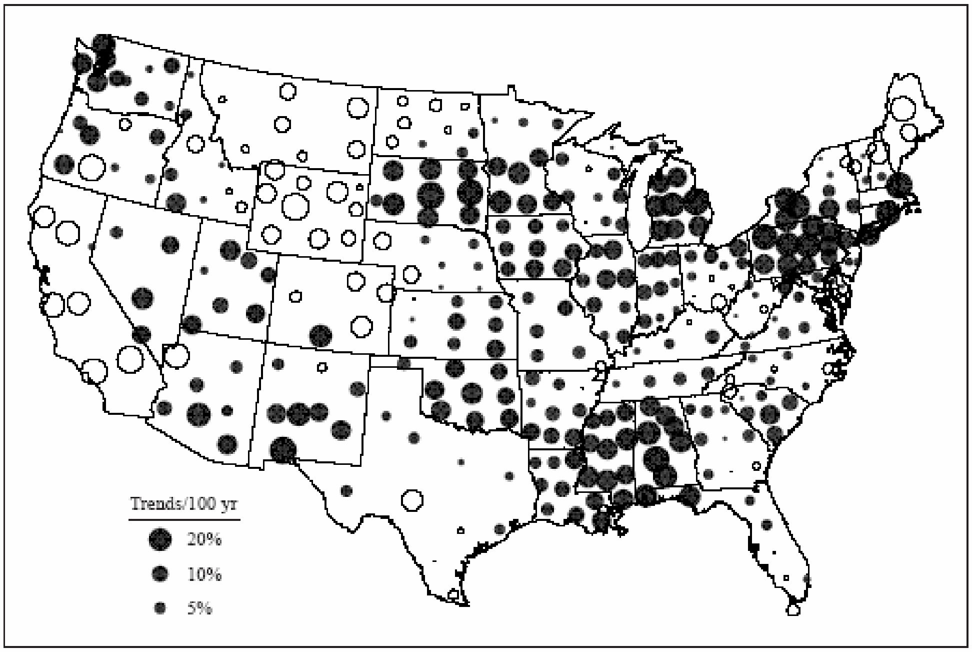


Figure 4. U.S. precipitation trends for 1900-1994 (converted to %/century), the black circles indicate an increase in precipitation while the hollow white circles indicate a decrease. [IPCC]

There are various potential implications from the changing weather patterns. Wetter conditions could benefit hydropower production, but could also increase flooding in some areas. In mountainous regions, warming could lead to a long-term reduction in peak snow-water equivalent, with the snowpack building later and melting sooner.

Ironically, wetter weather could result in streams without significant summer flows and lower reservoirs and water supplies to support hydropower electricity production.

In the Western U.S., the upper Colorado River is predicted to experience a -33 to +12% change in annual discharge. Reduced river flows and dry hot summer conditions in the Western states dependent on the Colorado River (e.g., California) could place a premium on water availability. Climate change may cause some areas to switch from a winter peaking regime to a summer peaking regime. If peak demand occurs in the winter, maximum energy demand is likely to fall, whereas if there is a summer peak, maximum demand will rise. Additional investments would be needed to supply electricity demands if the peak occurs in the summer.

Drier summer conditions would intensify competition for water among the diverse interests (e.g., power production, recreation, tribal rights, salmon, agriculture, etc.) and demands from growing populations in the West. Changes in water availability could complicate the complex water rights and allocations issues in Western states. Climate changes in the Pacific Northwest could result in dryer conditions and less water available to produce electricity for markets in the Intermountain and Rocky Mountain region.

Hydropower electrical output is subject to fluctuations reflecting year-to-year variation in precipitation. Idaho Power reports that in 1998, the share of electricity from hydropower exceeded 50%, but in recent years the proportion has lowered to 37%, due to customer growth plus below normal precipitation.

Groundwater supplies may also be affected by regional climate change. Unless precipitation increases, the increased evaporation that would accompany warmer temperatures probably would reduce groundwater supplies. Lower stream flows and runoff could reduce rates of groundwater recharge and exacerbate water supply problems.

Within the Big Sky region and the Northwest, high hydropower usage could be vulnerable to climate change impacts. Additional sources of energy may be needed to offset hydro reductions due to limited summer water supplies, support summer peaking loads, and increasing demands for water from growing regional population. Power companies, like Idaho Power, have an obligation to serve customer loads regardless of the water conditions that may occur. If hydropower is not available due to water shortages, then other non renewable sources may be tapped.

Weather conditions are the primary factor affecting load forecasts on the weekly, monthly, and seasonal time horizon. Economic and demographic conditions affect the load forecast in the long-term horizon.

Conclusions regarding the affects from climate change: 1) there is potential for a switch to summer peaking energy demands which could require additional energy resources, 2) less dependence should be placed on hydroelectricity, due to restricted summer flows and multiple conflicting demands, 3) future energy sources need to conserve water usage and be located in areas less likely to experience major variations in water availability, 4) hydropower dam reserves need to be sufficient to hold early runoff for use during the summer, and 5) existing less efficient power plants should be replaced by more efficient systems that require less cooling water.

2.2 Water Availability

Availability of cooling water is critical to the siting of future power plants. Thermoelectric power has been the largest water user in the U.S., accounting for 48 percent of total withdrawals (195 Bgal/day in 2000). Most of this water is derived from surface water and is used for once through cooling at power plants. In the West, California has the largest withdrawals for irrigation and thermoelectric power, as seen in Figure 5. In the Pacific Northwest, hydroelectric-power generation is used to supply a substantial part of the regional demand for electricity; therefore relatively small water withdrawals from fresh or saline-water sources are required. Idaho reports no withdrawals for thermoelectric power, due to the abundance of in-state hydroelectric-power generation. [4]

The headwaters of several rivers originate in the Big Sky region and flow in all directions to the Missouri, Snake, Colorado, Yellowstone, and Colombia. Changing water supplies in the Big Sky will directly impact down stream water users throughout the West.

Groundwater withdrawals also impact the water availability for power production. In the West, the Eastern Snake River Plain aquifer (shown in Figure 6) stretching across Southern Idaho, is one of the least tapped, but largest (1 billion acre-feet) water resources in the Western U.S. The aquifer annually supplies approximately 40,000 acre-feet (about 642 billion gallons) of water for drinking and nearly 2 million acre feed of water for irrigation and industry. In the West, Idaho has one of the highest intensity of freshwater withdrawals, in terms of gallons per day per square mile. Over the past 50 years, water levels in the Snake River aquifer have been impacted by increased pumpage from the groundwater, changes in irrigation practices (to sprinklers that do not replenish the groundwater), and prolonged droughts (1987–1994). Lower stream flows and runoff could reduce rates of groundwater recharge and exacerbate water supply problems. [5,6]

Future energy development should consider sustainable uses of water supplies. Tradeoffs between storing water for hydropower and expending water for thermal cooling should be considered. Thermal technologies using closed-loop cooling systems or air-cooled systems reduce the water requirements at the power plant, resulting in reduced water withdrawals. Renewable technologies, such as wind power, require no cooling water and are also being considered in future energy portfolios.

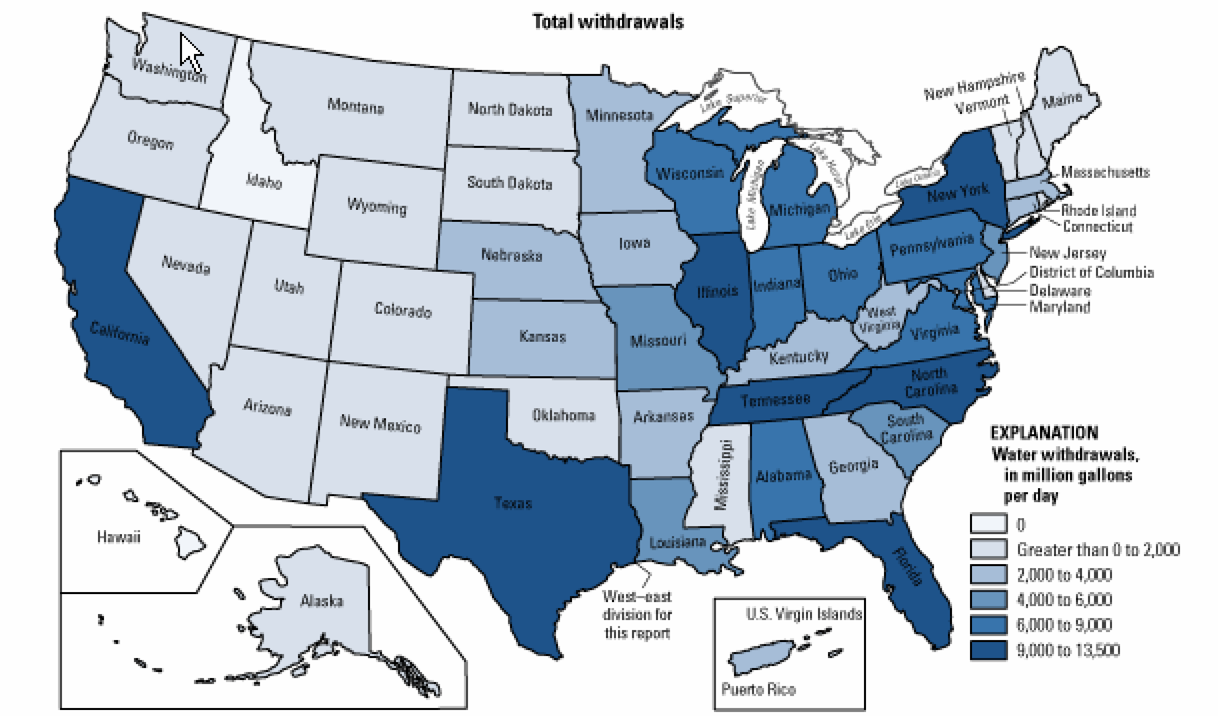


Figure 5. Thermoelectric-power withdrawals by water quality and state, 2000. [USGS]

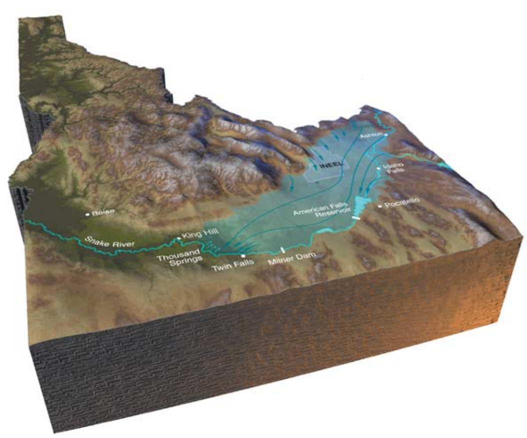


Figure 6. The Snake River Plain aquifer in Southern Idaho. [USGS, INEEL]

Conclusions regarding water availability: 1) the addition of thermoelectric power will put additional demands on surface and groundwater supplies, 2) the importance of the water resources produced in the Big Sky region will grow in step with energy demands and population expansion in the region, 3) climate change can impact groundwater and surface water supplies, which can directly influence the availability of water needed for power production from hydro or thermal energy systems, and 4) efficient thermal technologies can reduce the load on water supplies.

2.3 Population Demographics

The Western states are the fastest growing region in the United States. Population growth in six Western states has averaged more than twice the U.S. average of 16% percent, from 1990–2003, as indicated in Figure 7 and Figure 8 during the period of 1995 to 2025, the West is projected to grow at ~1.4-1.8% per year, versus the national average of ~0.9%. Growth is projected from factors including the base population, fertility, mortality, international migration, and domestic migration. Seven of the ten highest projected growth states in the U.S. are in the West (see Figure 9). Expanding populations, if coupled to growing economies, will drive the demand for electricity. In Idaho, the energy growth is estimated to expand at 80% of GDP growth. [7]

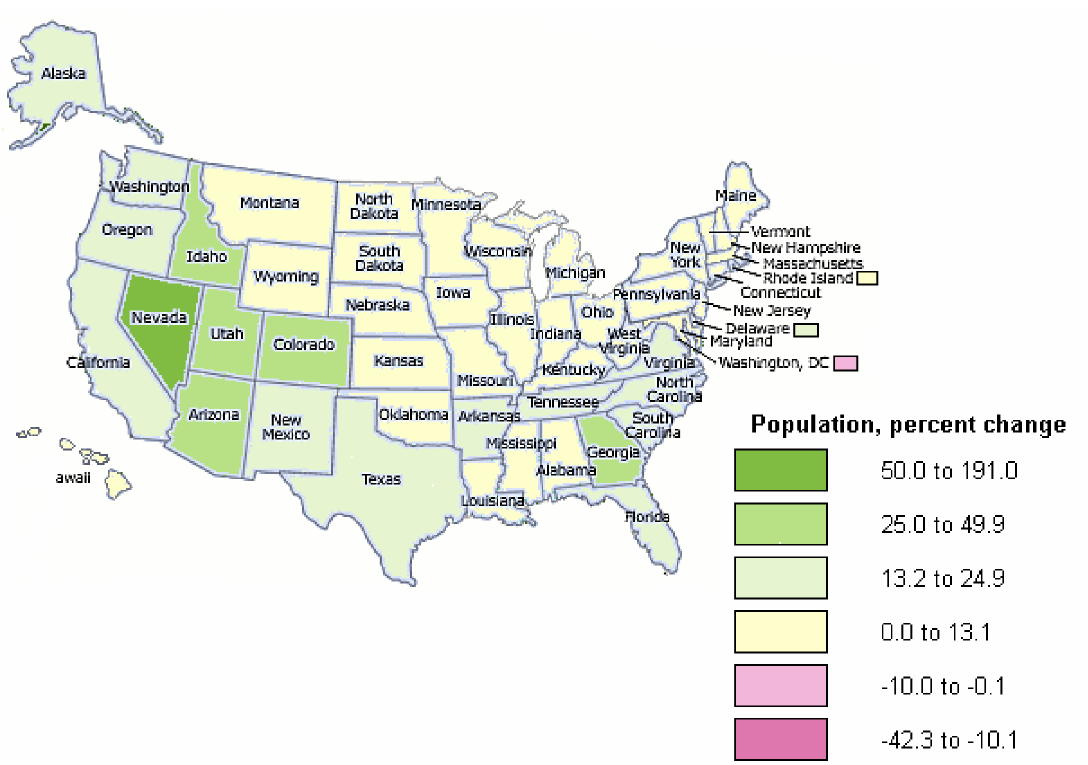


Figure 7. U.S. population change from 1990 to 2000. [US Census Bureau]

Within the Big Sky region, Idaho has seen the highest rate of population change from 1990–2000, at 49.5%; with Wyoming and Montana growing at slower rates (44.6% and 28.8%, respectively). These states combined, represent only 1% of the total US population (281 million in 2000) while occupying over 9% of the land area, hence resulting in a low population density.

Conclusions regarding population demographics: 1) expanding populations in the West, if coupled to growing economies, will drive demands for electricity, and 2) population migration to the intermountain West can cause greater interregional demands in addition to energy exports to the West Coast and Southwestern states, and 3) regional climate change can affect the desirability of the Big Sky region for businesses and individuals relative to other regions of the U.S.

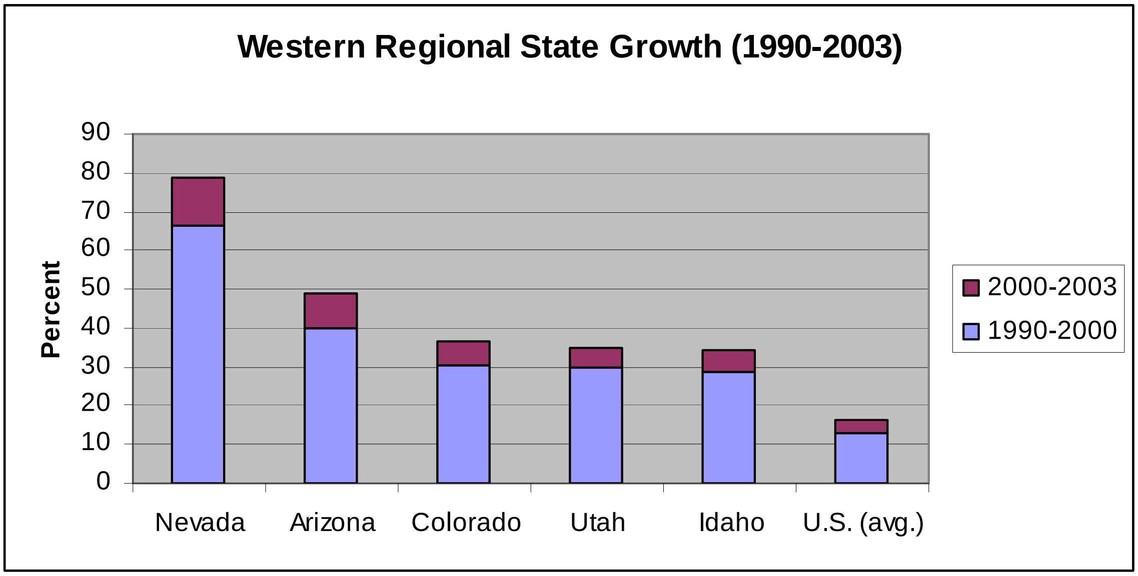


Figure 8. Western regional state growth from 1990 to 2003. [US Census Bureau]

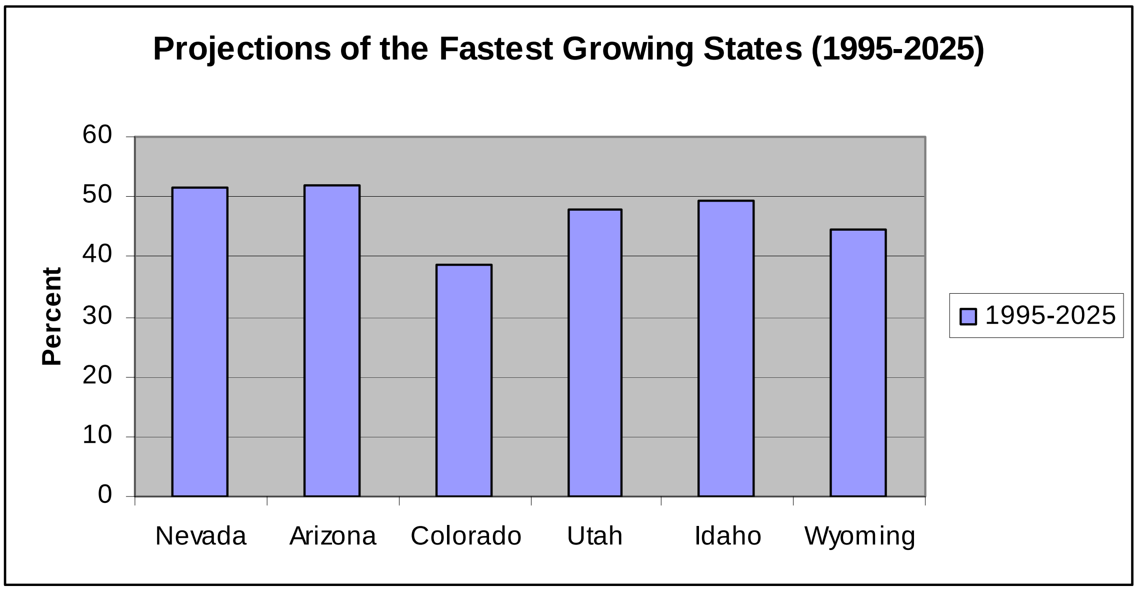


Figure 9. Projected fastest growing Western states from 1995–2025. [U.S. Census Bureau]

2.4 Energy Resource Availability

The Big Sky region contains abundant raw energy resources (i.e., water for hydropower, mineable coal, natural gas, wind, and geothermal resources) relative to the small population of the region. New energy resources (described below) are being planned to support the energy demands from population growth in the Big Sky region (e.g., Treasure Valley in Southwestern Idaho) as well as demands from expanding populations in the West. The Rocky Mountain States include Idaho, Montana, and Wyoming, as well as Colorado, Utah, and New Mexico.

COAL: According to the Organization for Economic Cooperation and Development (OECD), coal is expected to play a key role in the world energy mix, with demand projected to grow for steam coal, which is used for generating electricity and process heat, by 1.5% per year over the period of 2002–2030. The assumed 2008 generation capacity located within the Rocky Mountain States is 29,121 MW. The distribution of generation among the Rocky Mountain States is shown in Figure 10. [8]

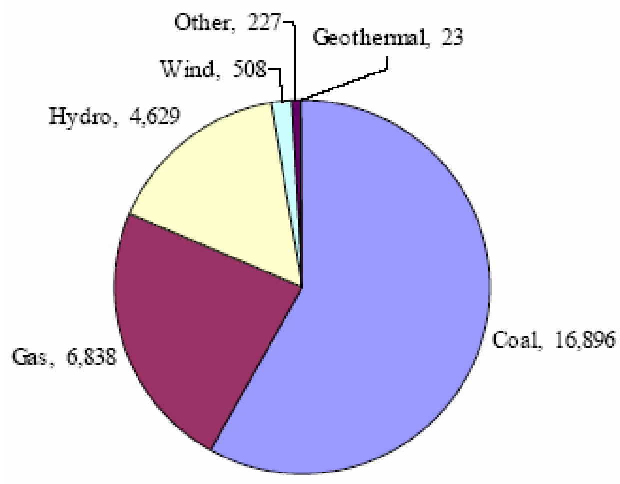


Figure 10. 2008 Rocky Mountain area total resources by type (MW) [OECD]

Significant reserves of coal are available in Wyoming and Montana. The Energy Information Agency (EIA) reports that Montana and Wyoming hold nearly 40% of the total U.S. coal reserves. Montana is ranked number one in reserves with 120.1 billion tons and Wyoming, ranked as number three, has 68.7 billion tons. In 2000, coal production in the Western Region (as well as in the entire United States) was dominated by Wyoming, which accounted for two thirds of the regional production and nearly one third of U.S. production of 1,073 million tons in 2000, as shown in Figure 11. Overall U.S. coal production in 2000 dropped 2.4 percent (26.8 million short tons) from 1999, but the Western region declined at a slower rate of only 0.3 percent. The decline in production was attributable to (1) a substantial draw down in total coal stocks, (2) a lack of excess production capacity at some mines, and (3) a reluctance on the part of some producers to expand production to meet increasing demands in the latter part of the year. Wyoming produced 338.9 million short tons of coal—only 7 percent less than the next three largest coal-producing states combined. In 2000, Wyoming continued an 8-year trend of increasing coal production, growing by 1.8 million short tons (0.5 percent). The continued penetration of the Powder River Basin coal into the eastern electric power markets has helped to drive Wyoming production to record levels for another year, although the level of growth dropped substantially in 2000. The slowdown in growth in Wyoming was a reflection of the decision by some producers to limit production expansion and by the constraints of the coal transportation (or railroad loadout) capacity in the Powder River Basin. [9,10]

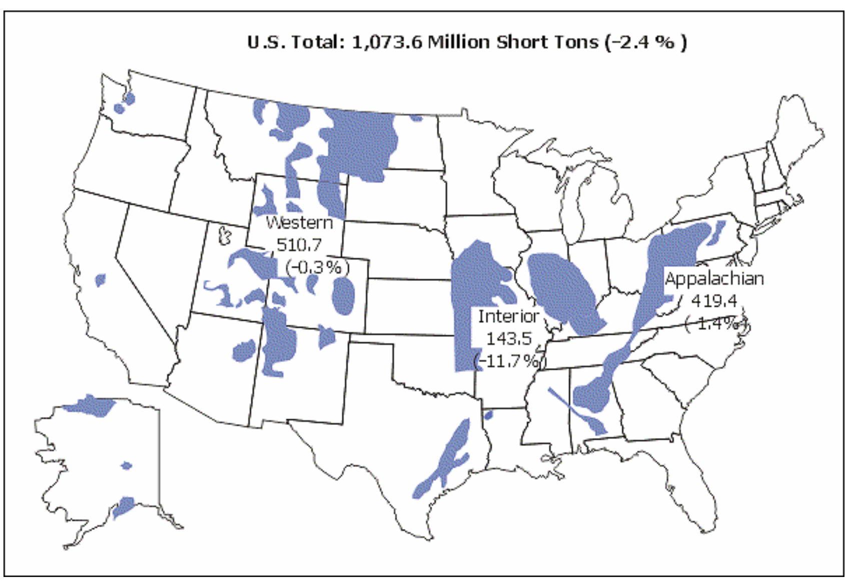


Figure 11. Coal Production by Coal Producing Region, 2000. [EIA]

WIND: Renewable energy from wind may also be tapped in the Big Sky region. Interest in wind power has grown considerably in the Big Sky region over the last several years. Several outstanding wind resource locations are available in Eastern Idaho, Montana, and Wyoming for large-scale wind development. The foothills of the Rocky Mountains are particularly attractive locations, as shown in Figure 12 by the brightly colored areas flowing from Northwest Montana diagonally traversing through Montana and across Wyoming. The region has excellent wind resources that could be tapped to support small- and large-scale wind turbine installations on farms, ranches and tribal lands. Wind is an intermittent seasonal resource, with the greatest production of wind electricity generated in the winter. The estimate used for annual energy output is a 35 percent capacity factor. The 35 percent factor means that a wind project with a nameplate capacity of 100 MW will produce and average of 35 MW over the course of a year.

Where the transmission grid is accessible, small-scale wind turbines can connect directly to existing power lines and provide economic benefits for rural landowners by allowing them to sell their extra power back to the utility. Larger-scale wind production will in some cases (e.g., Treasure Valley) require significant upgrades to the transmission paths. [11]

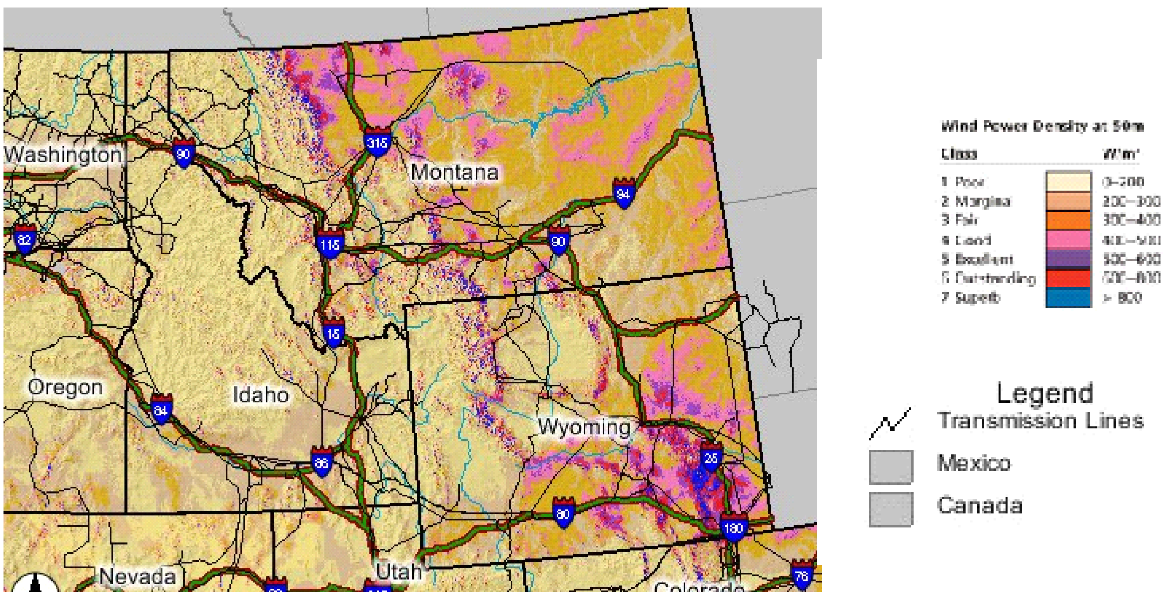
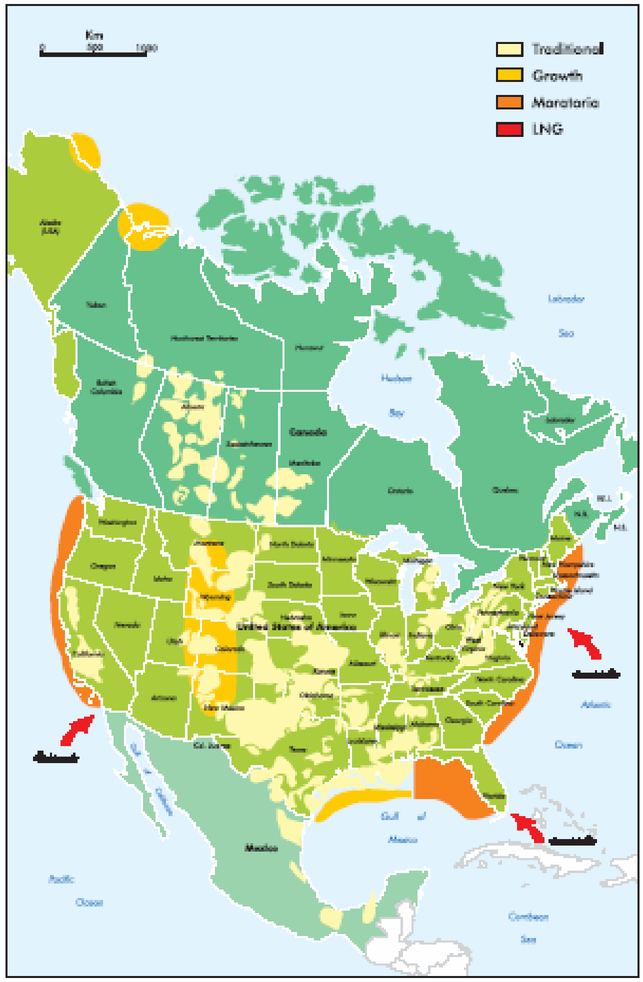


Figure 12. Wind power density in the Big Sky region. [Hewlett Foundation]

NATURAL GAS: Comparative supplies of domestic natural gas are significantly limited. Non-conventional reserves—coal-bed methane, tight gas and shale gas—mostly found in the Rocky Mountains could provide a major source of new supply. However, much of the gas is effectively stranded because of public access and environmental restrictions on drilling on federal lands. (Figure 13) About 5.5 Tcm are in the Rocky Mountains and mid-continent regions. [8,12]

Conclusions regarding energy resource availability: 1) the Big Sky region contains significant U.S. coal reserves which could be used to fuel thermoelectric power production in the region for many years, 2) the region also hosts regions with high potential to support wind generated power, 3) natural gas reserves may also be tapped in the future, if desired, and 4) abundant tracks of land are available to site new energy systems.



Source: IEA based on NPC (2003).

Figure 13. North American and Rocky Mountain growth of natural gas supplies. [OECD]

2.5 Energy Transmission Infrastructure

There are tradeoffs between shipping coal from mines to power plants versus shipping the electricity (wheeling the power) from a mine-mouth power plant to regional markets. Coal is commonly shipped by rail to power plants located near population centers, and then the electricity is transferred through the electric transmission and distribution system to end consumers. The railroad infrastructure has supported transport of coal from mines in Montana and Wyoming to coal power plants throughout the U.S. Some coal transportation capacity constraints have been associated with the Powder River Basin in Wyoming and Montana. [13]

The existing electricity transmission system in the Big Sky region is currently limited for new capacity growth. However, bottlenecks are known and solutions available to increase regional capacity and expand transmission corridors to surrounding Western markets. Plans have been drawn up in the Integrated Resource Plans of utilities in the West to expand capacity in selected bottlenecks to enable higher energy throughput in the region. The Rocky Mountain Area Transmission Study (RMATS) has developed two recommendations to expand energy transmission. Recommendation 1 includes three projects involving upgrades to the Montana system (tan oval), Bridger expansion (green oval), and Wyoming to Colorado Project (yellow oval) as shown in Figure 14. The expansion provided by these upgrades would provide for construction of 2,205 MW of wind power, and 1,884 MW of coal-fired generation capacity at the cost of $970 million. These upgrades would support new energy generation additions that are expected to meet expected load growth in the Rocky Mountain region for the 2013 timeframe. [13]

In addition to the export projects in Recommendation 1, Recommendation 2 provides expansions that extend beyond the Big Sky region that will substantially enable exports of generation. This longer-term proposal would 1) include the additional generation defined in Recommendation 1; 2) provide for construction of 3,900 MW of coal generation and remote wind generation; and, 3) build export paths to the West Coast, Nevada, and Arizona markets. This expansion would provide 7,800 total MW at the cost of $4.3 billion. Figure 15 shows the transmission expansion extending beyond the Big Sky region. Figure 16 shows the assumed generation additions provided by this upgrade. Figure 17 shows load centers and projected peak growth with existing transmission capacity, 1999 and 2010.

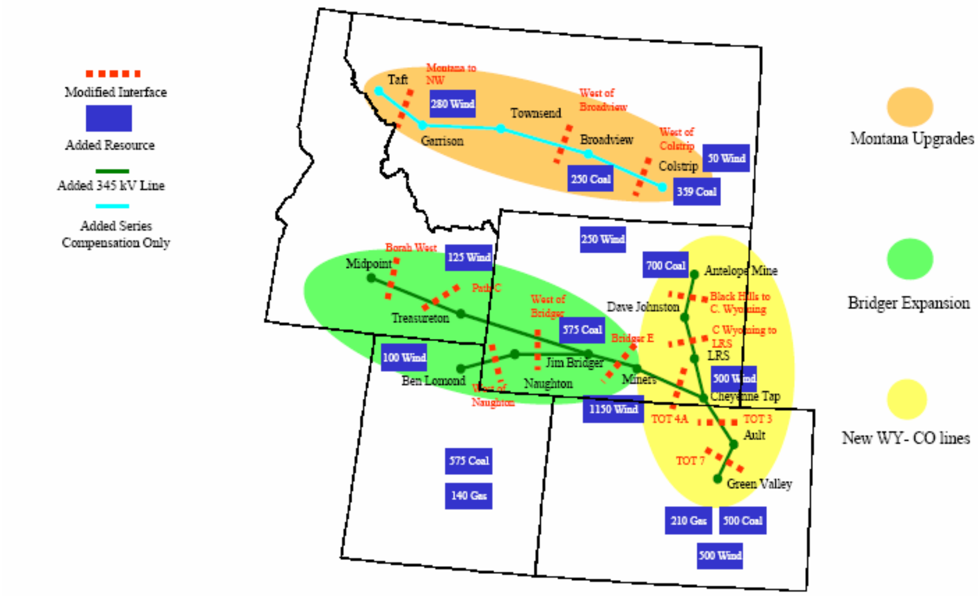


Figure 14. Recommended distribution upgrade projects in RMATS Recommendation 1. [RMATS]

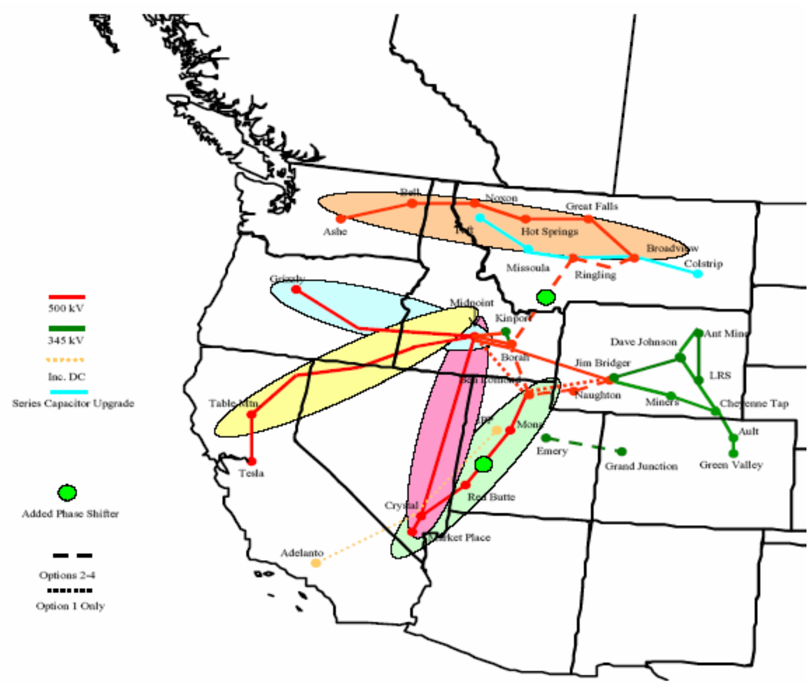


Figure 15. Transmission expansion extending beyond the Big Sky region. [RMATS]

Added transmission capacity acts as a “hedge” against the risk of upward swings in the forward price of power from natural gas and any other fuel source. The construction of new transmission capacity allows customers to pay a known amount now to lessen or lower the risk later of high dependency on a single fuel source, whose future price is vulnerable to fluctuations in regional and global market conditions.

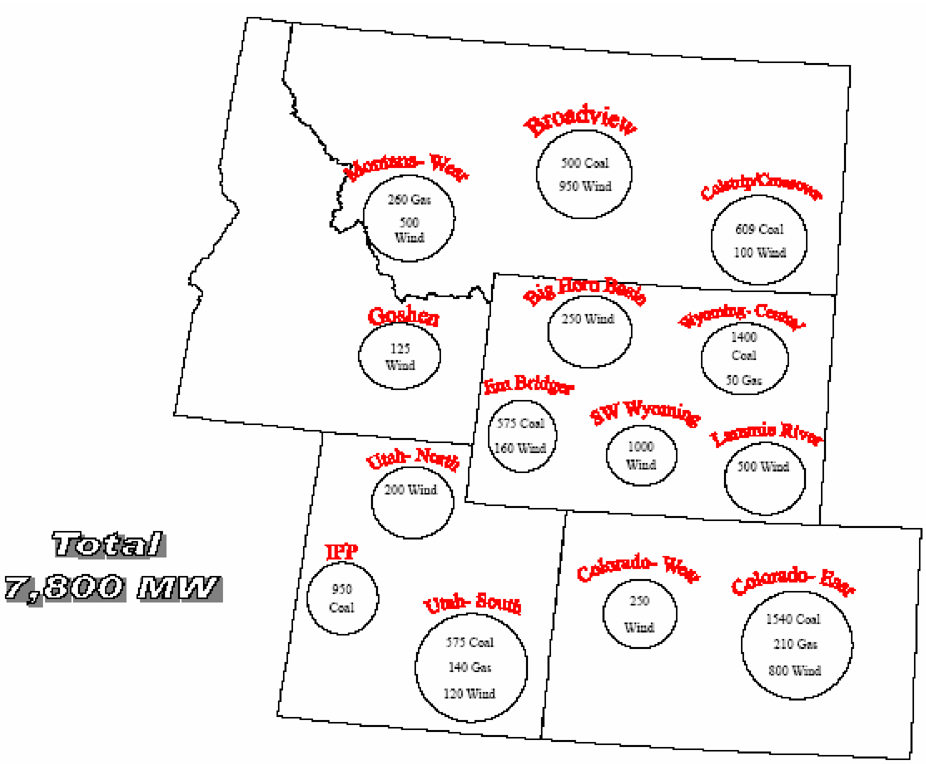


Figure 16. Generation additions assumed in Recommendation 2. [RMATS]

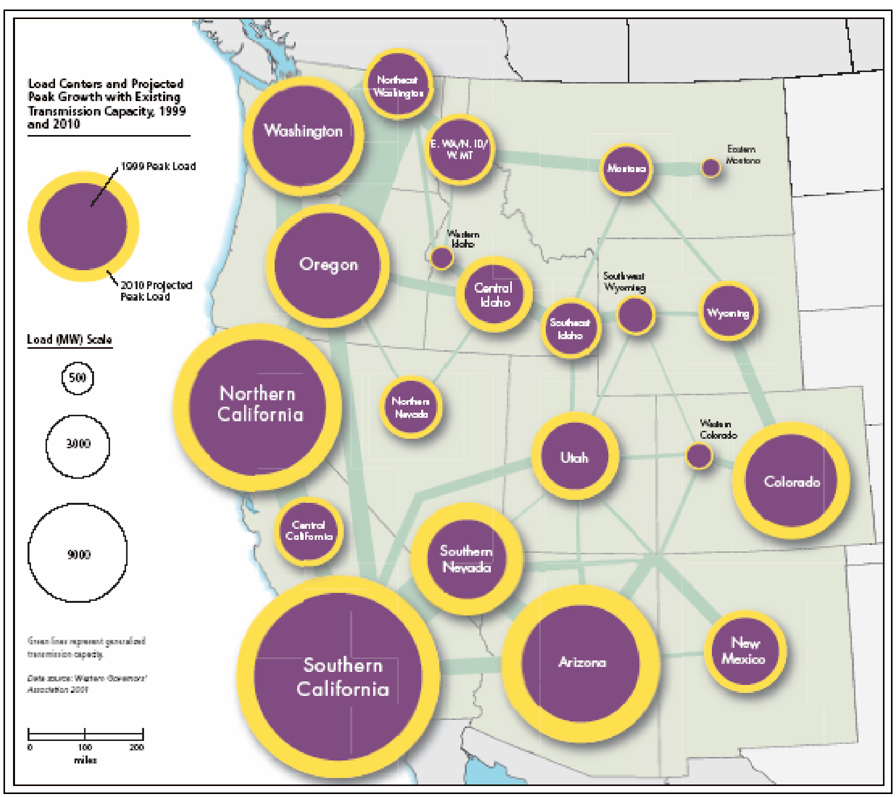


Figure 17. Load centers and projected peak growth with existing transmission capacity, 1999 and 2010. [Hewlett Foundation]

Open transmission access has facilitated the transfer of power within the West, but has also increased the competition for transmission resources. Since 1996, Idaho Power has been providing transmission service to qualified wholesale customers under its Open Access Transmission Tariff. Because of the geographic location of the Big Sky region, there are many requests to transport power between the Pacific Northwest and the desert U.S. Southwest. Idaho Power cannot deny service to qualified wholesale customers when there is sufficient transmission capacity available to satisfy the customer's request. The Open Access Transmission Tariff policy also provides that additional transmission facilities will be constructed if the party seeking the increased capacity pays the cost of adding the capacity.

Additionally, transmission-planning reserves have been increased as a hedge against unexpected loss due to natural or man-caused events. Natural events include low water years when peak-hour deficiencies are being met by energy purchases from the Pacific Northwest at the same time that system is delivering power to local users. Man-caused events include terrorist strikes to the national energy infrastructure, which could result in planning reserves to be widened, demands for increased system redundancy, and demands for additional power plants.

Conclusions regarding energy resource availability: 1) rail infrastructure is in place to transport coal to markets across the U.S., 2) increasing competition for electrical transmission compounds current bottlenecks within the system, and 3) transmission reserves may be widened to support contingencies for low water years and natural and man-caused disruptions.

2.6 Land Availability

Land is required to support the siting of new power plants and upgrades and additions to energy transmission. Transmission upgrade projects will, in some cases, require limited siting requirements (e.g., upgrades to existing substations sites). Alternatively, acquisition of sufficient land for substations and new transmission corridors are more serious issues. Land availability and transmission corridors will be important to implement large capacity upgrades. Land may also be required to obtain the water rights needed for power plant cooling water. Additionally, large tracks of lands would be required to support renewable sources like wind or solar power.

The Big Sky region is located geographically central to the West coast, the Rocky Mountains, and the Southwestern energy markets. The Big Sky region has large tracks of privately owned agricultural and range lands that could be reclassified for commercial uses, as has historically happened near population centers. However, a large percentage of the Big Sky region consists of federal lands, which historically have been challenging to secure the necessary easements for transmission corridors.

Conclusions on land availability: 1) suitable lands are necessary for energy production and transmission, and 2) lands are available in the Big Sky region but may require access to public lands.

2.7 Regional Energy Market Demands

Load forecasts are developed by the power companies to provide the most probable projection of service territory load growth during a planning period (generally 10 years). The forecast for the total load growth is determined by summing the load forecasts for residential, commercial, irrigation, industrial, and additional firm load growth. The projections of energy growth from selected Western Integrated Resource Plans (IRPs) as of July 2004 are shown in Figure 18. The projected annual growth rate ranges from 1.0% to over 3.5%. The expected load growth forecast for the Idaho Power service territory is 2.2% per year over the ten-year planning period. The peak loads for the West range from around 1,000 MW for Avista Corporation and NorthWestern Energy Corporation to as high as 9,000 MW for Pacificorp. [13, 16]

Energy suppliers are seeking a balance between renewable resources, demand-side measures, and thermal generation. In the recent past, fast growing energy markets have been meeting base load demand with low capital cost gas plants.

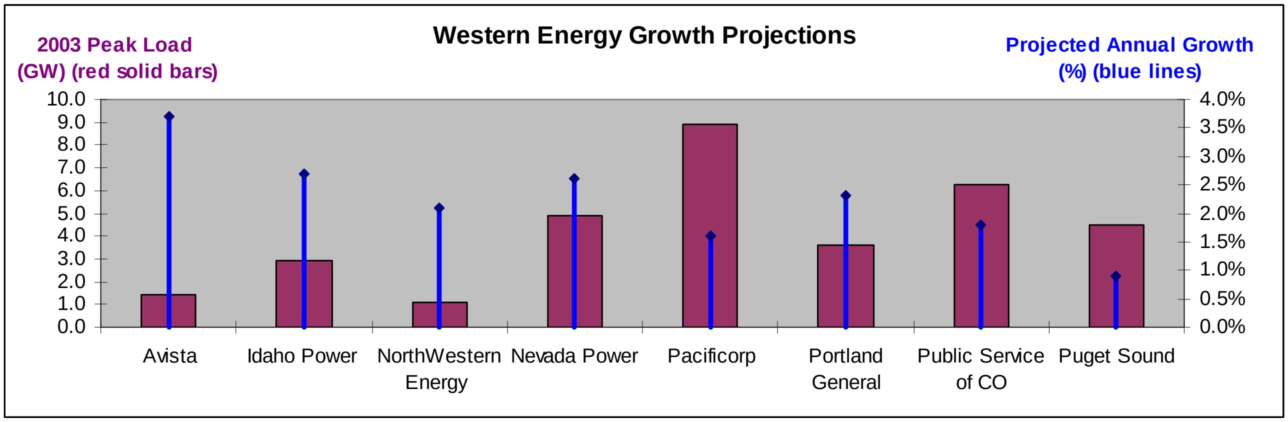


Figure 18. Growth projections for selected Western energy companies. [Western Governors Association]

Consequently, natural gas sets the price of electricity in the Western states more than 70% of the time. More than 90% of the interconnection is becoming increasingly dependent on gas-fired generation. But recent price spikes of natural gas (over $6/Mcf), which have been driven by increased demand, have cooled the interest in gas. Gas and oil, heavily imported from the middle-east, have seen historical price swings. Electricity costs over the past thirty years have shown increases in-step with the costs of imported oil and natural gas. The price stability of coal vs. the volatility of natural gas will be a factor in the selection of fuels for new power plants. By diversifying fuels, generators can mitigate gas price risks. Coal (lowest black line) has historically has been the lowest cost of energy on an equivalent cost of energy basis, as shown in Figure 19. Long-term coal resources in the Big Sky region are available to support long-term base load capacity. [17, 20]

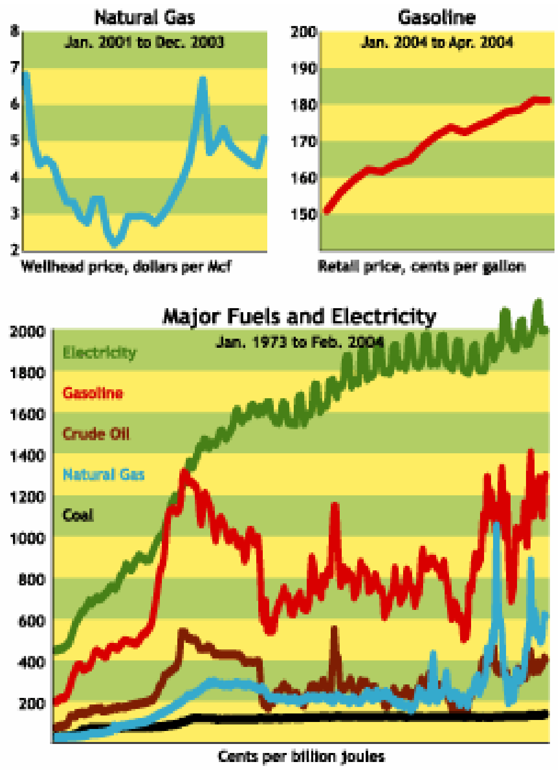


Figure 19. Comparison of Major Fuels and Electricity. [Power & Energy]

Conclusions regarding regional energy market demands: 1) the West has created a dependency on gas-fired generation to support peaking loads, 2) the price stability of coal vs. the volatility of natural gas will be a factor in the selection of fuels for new power plants, and 3) diversification of energy sources and expansion of transmission capacity can help reduce price spikes.

2.8 Environmental/Regulatory Constraints

There are increasing restrictions associated with the emissions from fossil power plants in Washington State and Oregon. Examples include:

• In the State of Washington, House Bill 3141 (signed in March 2004) requires that fossil fueled power plants with a generating capacity of 25 MW or more to mitigate 20% of the carbon dioxide emissions the plant produces over 30 years. This requirement also applies to new power plants seeking site certification and existing plants that increase production of carbon dioxide by 15%. [14]

• In 1997, the Oregon legislature gave the Energy Facility Siting Council authority to set carbon dioxide emissions standards for new energy facilities. The standard requires new power plants to emit 17% less carbon dioxide than the most energy-efficient plant available. The standard can be met by offsetting emissions through energy efficiency or carbon sequestration projects. Energy facility operators may implement offset projects directly, or by payment to the Climate Trust, which encourages and funds projects to reduce or offset CO_2. New energy facilities can meet the standard in four ways: 1) building high-efficiency plants; 2) cogeneration projects; 3) invest directly in CO_2 offset projects; 4) pay a fee (raised in October 2001 from $.57 per ton to $.85 per ton) for excess CO_2 emissions. Plants constructed or planned since passage of the standard will double the generating capacity within Oregon. [15]

There is reasonable likelihood that carbon emissions will be regulated within the operational timeframe of any power plant built in the future. The other Western states could adopt carbon emission restrictions similar to Washington State and Oregon, or federal laws could be passed that restrict carbon emissions or require mandated cap and trade programs. Current regulations in the Big Sky region are not restrictive on carbon emissions. Fossil energy produced in the Big Sky may become more competitive as further emission restrictions are placed on other energy producers in the region. Longer term, the regulation of carbon capture, transportation, and geologic sequestration is another area of uncertainty. Future regulations may decide if geologically stored carbon dioxide is classified as a product or waste.

Conclusions regarding environmental/ regulatory constraints: 1) the Big Sky region currently allows unrestricted carbon emissions, 2) carbon restrictions within the West may provide a short-term competitive advantage for electricity produced in the Big Sky region, and 3) the regulatory issues associated with geologic sequestration are important to future fossil energy development in carbon constrained environments.

2.9 Energy Technology Resources

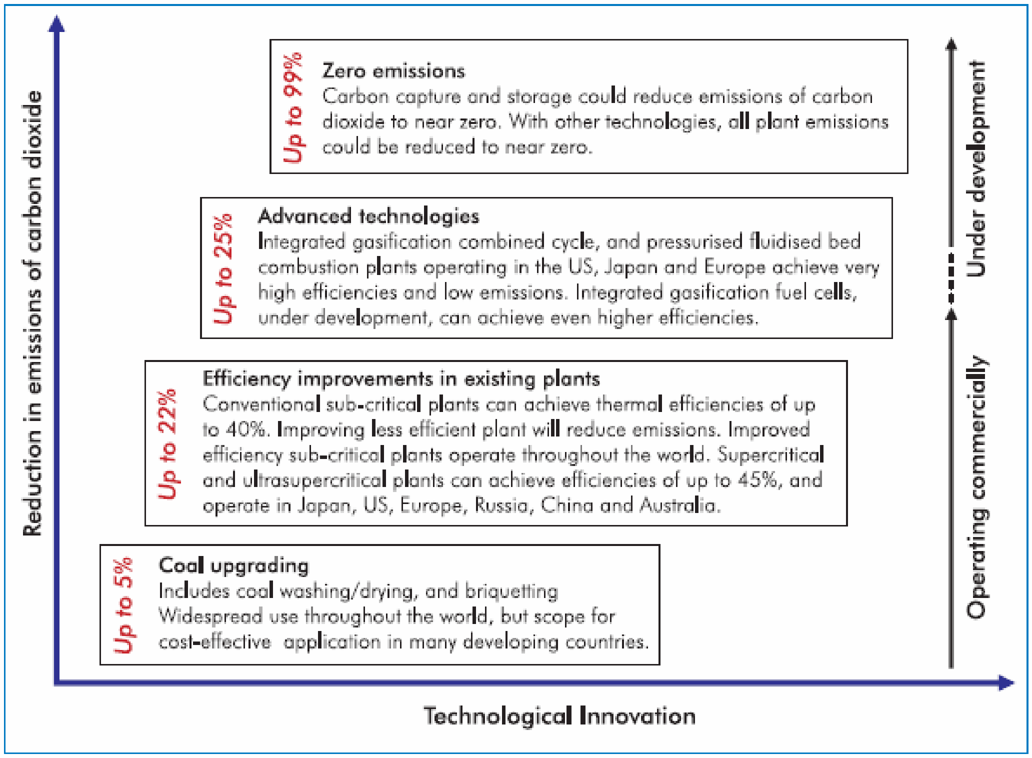
Implementation of clean coal technologies, which would improve the thermal efficiency of coal production and use and reduce emissions, could minimize investment risk and give a major boost to prospects for coal demand. New techniques have been developed for coal mining and the preparation of coal for use in power stations, as well as for coal combustion, emissions-control and the disposal of solid waste. Technologies on the horizon such as carbon capture and storage could achieve near-zero emissions of all pollutants from coal-fired power plants. Technology innovations are expected to reduce the emissions of carbon dioxide as shown in Figure 20. [8]

Future energy concepts, including FutureGen, would include the production of hydrogen and sequestration of carbon dioxide. Siting of these future power plants would need to consider market opportunities for hydrogen and new fossil energy products (e.g., syngas), and sequestration locations for storage of carbon emissions.

The Big Sky region has several unique characteristics relative to the production and storage of carbon. First, the region is very near zero-net carbon emissions resulting from a small but growing industrial base, low populations, and large areas of forest and agricultural lands which hold the capacity to store carbon. [19]

The Big Sky region has diverse geologic formations, as shown in Figure 21, which could take carbon captured from power plants and permanently store it in geologic reservoirs in a solid carbonate form.

Carbon offsets could be also achieved through terrestrial sequestration in the rich agricultural and forested areas of the Big Sky region. Processes are being developed to increase soil organic carbon and store carbon in biomass. The Big Sky region has diverse agricultural, timber, and grasslands that could be used to store carbon, as shown in Figure 22.



Source: Based on World Coal Institute (2003).

Figure 20. Reductions in emissions of CO2 through technology innovation. [OECD, World Coal Institute]

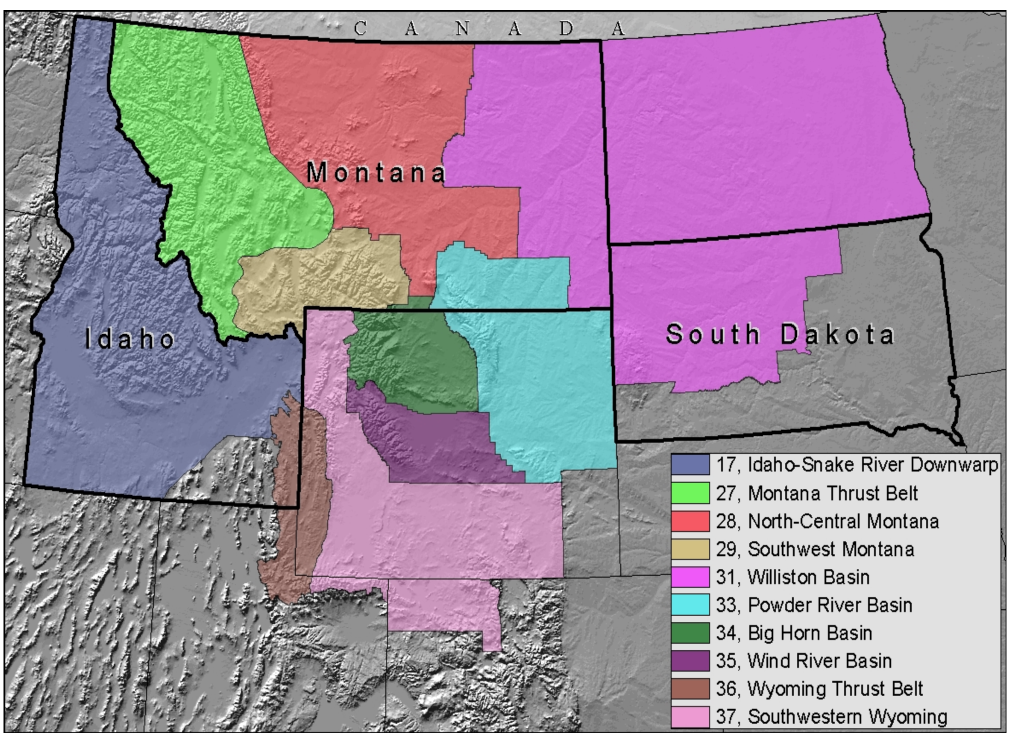


Figure 21. Diversity of geologic sequestration locations in the Big Sky region. [Big Sky Regional Carbon Sequestration Partnership]

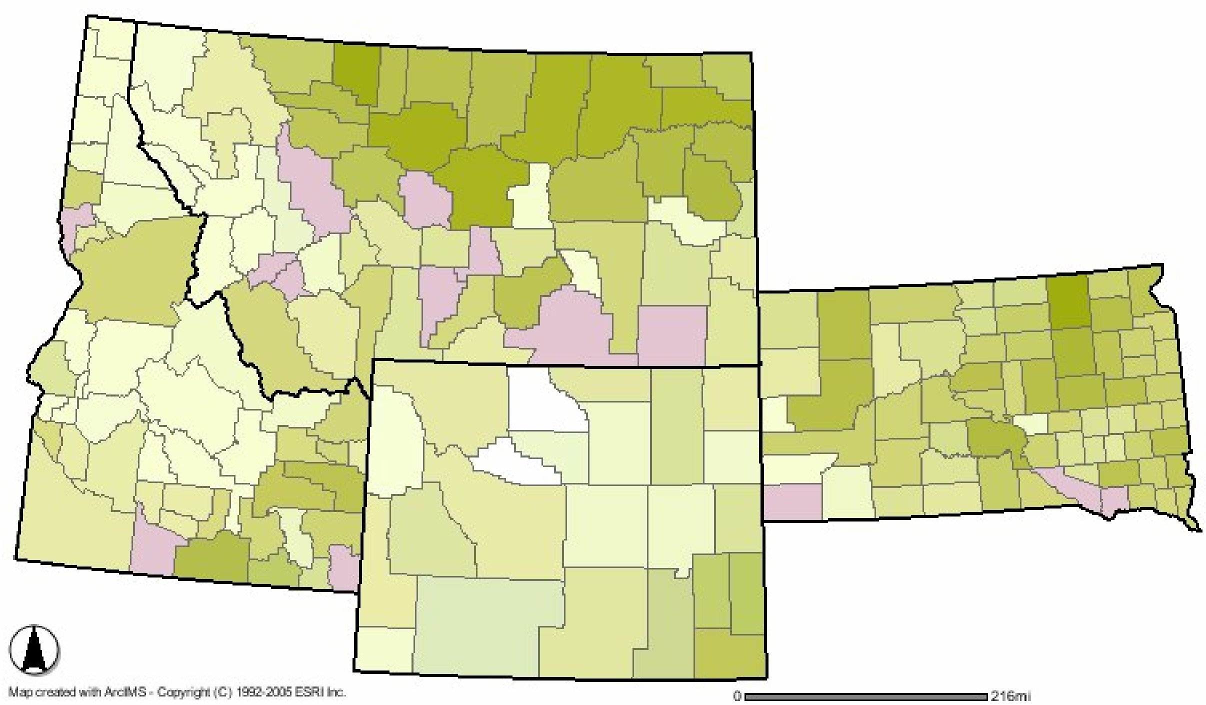


Figure 22. Diversity of terrestrial sequestration locations in the Big Sky region [Big Sky Regional Carbon Sequestration Partnership]

Conclusions regarding energy technology innovation and the Big Sky carbon sequestration resources: 1) clean coal technologies would improve the thermal efficiency of coal production and use, reduce emissions, minimize investment risk, and would give a major boost to prospects for coal demand; 2), the region offers diverse terrestrial and geologic sequestration opportunities; and 3) the Big Sky region currently has very low carbon emissions that are substantially offset by agriculture and forestry carbon storage; and 4) new energy products derived from hydrogen and carbon dioxide streams could be sold in regional markets.

3. Conclusions

Evaluating future energy growth in the Big Sky region is a complex undertaking that must account for many dynamic conditions. One emerging condition that has the potential to impact energy growth is climate change. The Big Sky region is well positioned to be the location for future energy development due to the wealth of energy resources, including both renewable and nonrenewable assets, and access to growing energy markets. The Big Sky region has the capacity to increase its energy production and provide a wealth of carbon sinks for carbon dioxide produced through energy production. The Big Sky Regional Carbon Sequestration Partnership is examining regional carbon sequestration resources that could be used to reduce or offset the carbon emissions from fossil power energy production and other industrials. This study will be used by the Big Sky Partnership to gain insight into the issues impacting regional energy demand and facilitate the development of a regional infrastructure that can support future energy development with carbon sequestration resources. The methodologies created through this partnership are intended to be applicable to other regional applications.

Acknowledgements

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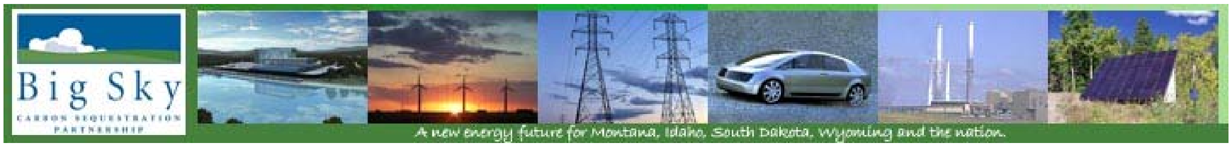

Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 9: Report on Interface between C-Lock and Producer Decision Support Framework

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Report on Interface between C-Lock and Producer Decision Support Framework(s) for Assessing Terrestrial sinks and Participation in Carbon Market Programs in the Big Sky Region

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and
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The information summarized in this report is a status report on (i) the structure, capabilities, and use of C-Lock as part of a decision support framework for assessing terrestrial carbon sequestration opportunities, which has been developed at South Dakota School of Mines, and (ii) a brief description of the current status of the economic-based decision support framework that Montana State has developed that is designed to be used with carbon models such as C-store, Comet (possibly), or C-Lock. Both C-Store and C-Lock are based on the Century biophysical model.

I. Overview of C-Lock and its capabilities

Summary of C-Lock Features:

C-Lock's web interface and database allows landowners to register land parcels for which carbon emission reduction credits (CERCs) will be estimated and certified based on client-specified management changes. C-Lock CERCs are uniform units produced in a standardized, transparent, repeatable, verifiable manner. At the same time, individual producers can optimize their potential income because each parcel is estimated using site-specific parameters.

C-Lock depends on publicly-available spatial and climate databases and the biogeochemical model CENTURY, developed by Colorado State University, that produce field-level estimates of soil carbon stocks. CENTURY estimates are sensitive to historic management data, which are collected from public data sources and surveys, as well as to current management, which is specified by the client.

Project verification occurs at three levels: internally, via data quality flags, which can affect the final confidence ranges, and requirements for client substantiation (e.g., by provision of FSA records), externally, via third party auditing of the system, and scientifically, based on peer-reviewed regional data and model validation studies, remote sensing and greenhouse gas flux measurements.

The system serves as an efficient aggregation and marketing platform because all client data are constrained to a uniform metric and format, and processed in the same way. Further, an uncertainty analysis process provides well-defined confidence bounds for estimated CERCs.

C-Lock's field-specific modeling approach addresses one of the most problematic issues with respect to terrestrial offset projects: that of ensuring project additionality, or that sequestered carbon is in excess of that which would occur under business-as-usual (BAU) management. It does this by modeling client-specified and BAU management scenarios in parallel, thereby factoring out all non-anthropogenic influences on soil carbon storage.

C-Lock minimizes measurement and monitoring costs because it doesn't rely on field sampling to estimate changes in carbon stocks. Adequate sampling of soil to produce high-quality estimates of parameters such as nutrients and organic matter is so costly as to comprise a major constraint to performance-based soil sequestration contracting. By focusing on the need to quantify incremental change rather than absolute carbon stocks, C-Lock minimizes the need for field sampling. Therefore not only measurement and monitoring but transaction costs are reduced because producers can register their parcels, estimate and certify credits, and aggregate them into a seller's pool all in the same location, without the intervention of third-party brokers or aggregators.

Mechanistic Description of the C-Lock System:

I. C-Lock consists of the following components:

1. A Web interface with public (informational) sites and a password-protected private (user) site that allows potential CERC producers to register and provide information about their fields.
2. A secure (currently Oracle) database that is used to store user information (see below) and default management data used to populate forms. Default historical management files are complete for SD and interim for ID and MT.
3. The Century (v.4) model from CSU – to generate estimates of soil C stocks and fluxes. We are working to implement Century 5.
4. A GIS (ARC-INFO) database of soil texture (from SSURGO where available, and STATSGO) and climate parameters – currently complete for ID, MT, SD and WY.
5. A system of AML, Unix Shell and Perl scripts that create Century input files, perform the Monte Carlo randomizations, link the various components, track data and generate reports.

II. C-Lock requires the following information from registered producers:

Personal information needed: (Registration Page) Name, Address, Social Security Number*, Contact Information, Total farmable acreage, Password

Field Information: (Add New Field) Field Name, County Name, Field identification information (FSA?), State code, farm number, tract ID, Field ID, Sub-Division, Stakeholders role in field (Owner, manager, renter, or combination), Area of Field in acres, Percentage of tillable acreage for most years*, Average soil texture (if known).

Field Location: Field corners in UTM or Lat Lon

General Time Block History:

Year first plowed plus or minus number of years*
Year family started farming plus or minus number of years*
Year I started farming plus or minus number of years*
Detailed general history for:
1900-1935 Management type, Irrigated, fertilized
1936-1945 Management type, Irrigated, fertilized
1946-1965 Management type, Irrigated, fertilized
1966-1982 Management type, Irrigated, fertilized
1983-1989 Management type, Irrigated, fertilized

Management type options: Crop/Fallow or Recrop- Conventional Till, Reduced Till, No-Till; Grazed Grass; Ungrazed Grass; CRP; Hay; Alfalfa; Fallow; Average (don't know).
Irrigation options: Yes, No, Don't know
Fertilizer options: Yes, No, Don't know

Detailed History for field: (1 input for every year 1990 – present)

Crop type: Barley, Beans, Conservation Reserve, Corn, Fallow, Flax, Grain (Other), Grass, Hay (Alfalfa), Hay (Other), Legume (Other), Millet, Oats, Potatoes, Sorghum, Soybeans, Sugar Beets, Sunflowers, Wheat (Winter), Wheat (Spring), Weeds

Cultivation Values: (Type and Month for each cultivation activity during the year)

Type: Sweep, Row Cultivator, Rod-Weeder, Roundup, Moldboard plow, Chisel, Disc, Field Cultivator, Planter, No-Till-Planter, Anhydrous Applicator, Herbicide

Month: Month cultivation practice was done

Fertilizer: (Amount (lbs/acre), Type, and Month for each addition of fertilizer during the year)

Amount in lbs/acre: for Nitrogen, phosphorous, potassium, and sulfur

Type: Liquid, dry, or anhydrous

Month: month fertilizer applied

Organic Matter Additions: (Month, Type, and Amount (Tons/acre) for each addition of organic matter during the year)

Month: month organic matter was added

Type: Straw and manure, wheat straw, or manure

Amount in Tons/acre: for type of organic matter

Irrigation: (Month, Type, and Amount each time irrigation occurs)

Month: month irrigation was done

Type: amount unknown, inches per month, or flood

Amount in inches: of irrigation applied

Harvest: (Type, Month, Yield per acre, and Units for each harvest)

Type: 90%, 75%, 50%, or 25% Removal of Stalks, Hay, Root Harvest, Grain Only, Thin

Month: month organic matter was added

Yield per acre: Total yield per acre in **units**

Units: bushels, tons, or lbs

Grazing: (Type of grazing and months (Animal units, and Animal units per 100 acres for each Month grazed for pasture grazing))

Type of grazing: none, Winter Grazing of Standing Dead, Pasture Grazing

Animal units type: Horses, cattle, sheep/goats, bison, or other

Animal units per 100 acres: number of animals per 100 acres

Month: Months that animals are pasture grazed

C-Lock processing:

Information entered on the User forms is compiled into a secure database. Upon submission, field location and management information are sent to the system back end, where a Unix cron initiates script-driven processing to create Century event schedule and site parameter files. It uses the field location information to retrieve applicable, pre-processed data from an ARC-INFO database of 30-m soil texture grid values and nearest-station climate files, which provide temperature and precipitation data from 1895-present. In its final form, C-Lock will provide three Submit options for registered fields:

1. **Baseline Submit**. Only enter data for historical time blocks (up through 1989), and up to the present. The pre-1990 data are entered entirely via menus of quasi-generic management options, although internally the "generic" files are customized by NCDC climate division. 1990-present data are entered on an annual basis (although we may change the "historical" period to include through 1996 if the 2002 - 5 baseline period becomes established as the norm). The system performs a single Century run and returns an estimate of standing C stocks and average rate of stock change, given the selected management options.

2. **Exploratory ("Potential") Submit**. The user enters anticipated management data for the next 8 years. This may be done by recycling various chunks of previously-entered annual data or by entering new data. The final part of the 8 defined years of anticipated management is recycled into the future up to a selected final date (e.g. 2020 or 2030). Upon Submit, a single Century run, using a stochastic future weather scenario, is performed. Modeled rates of C stock change between the present and the simulation

end date are used to project total marketable CERCs over that period. Following one of these runs the user may go back and modify his anticipated management scenario; therefore this serves as the decision support phase.

3. **Final Submit.** This Submit is only permitted once per registered field per year. Once the user has decided on the optimal future management scenario he Submits the field to the full C-Lock analysis. This entails (1) creating a BAU management scenario based on historical (pre-baseline) management, then (2) running the BAU and the client-defined scenarios 200+ times, using Monte Carlo "randomized" parameter and stochastic weather files (identical for each pair of scenarios). Each scenario generates a range of stock change (□C) values from which confidence intervals can be constructed; the difference between the lower-95% confidence bound for the (presumably) client-defined scenario and the upper 95% bound of the BAU scenario serves as the basis for the creation of a "certified", i.e. marketable, CERC pool. Estimates that fall only within the outer bounds are relegated to a "reserve" pool for risk management. A report of marketable and reserve CERCs on 10-year timesteps is posted on the user's personal account page, and a notice sent to the user, when the analysis is complete.

II. Potential for incorporating economic decision support into C-Lock:

C-Lock has been designed primarily as a marketing tool; however, the Submit (2) option has been included to permit some decision support by providing quick feedback to changes in anticipated management. It would be fairly straightforward to link this component to production cost and estimated CERC price data so as to allow economic criteria to enter into the producer's decision whether or not to commit to a CERC contract. One potential complication is that the anticipated ("future") management scenarios are not standardized, i.e. the producer can potentially defined different individual management strategies for each the 8 definable "future history" years. Therefore it may not be practical to link these to pre-packaged enterprise budget data. Production costs would have to be estimated on an input-by-input basis, although the number of production inputs would be limited to those made available through the C-Lock menus. Alternatively, it might be sufficient to simply maintain a database of current default production costs (not customized) for each crop/tillage (CT or NT) combination, perhaps with an irrigated/non-irrigated modifier. At minimum the ERS-CARE system provides some representative enterprise budgets for major crops for each state, with irrigated/non-irrigated variants.

An additional issue is opportunity cost: is it practical to maintain a database of (1) current commodity prices (surely the USDA does this), and (2) current land rental costs for each area (by county? by state? climate zone?). Is there a public database one can link to?

Another alternative would be to provide, from the User page, a live link to C-Store where they could explore management alternatives in a more generalized way and have access to the economic tools incorporated therein. It would be nice if their entered historical data, at least could transfer directly but I'm not sure how well they would match up with C-Store's options.

In sum, our alternatives are to (in descending order of likely cost and effort required):

1. Develop an opportunity and input cost database for each state for each major crop. It is probably not practical to develop it on a more localized basis.
2. Provide a link and data filter that would allow us to directly benefit from C-Store's capabilities, assuming that CSU would be willing to cooperate on that development effort.
3. Simply provide a link to C-Store where the user could go and re-enter all his data in order to use C-Store's economic DS tools, which are being developed at MSU (see next section).

Effort estimate: Establishing compatibility and data exchange capability with C-Store would probably require 1-2 person-months, depending on how compatible they currently are. Simple inserting a link to C-Store would require only the existence of a live C-Store website.
Developing similar capabilities for C-Lock as it stands (up to 4 states) could require anything from 6 to 24 person-months to achieve a beta-testable version, depending on whether we can use the cost data developed for C-Store or have to redevelop it from scratch. This would have to be done again for each state that is added to the C-Lock GIS.

II. Developing the Economic component of an Integrated Decision-support framework.

The process, started almost three years ago with combined funding from DOE and USDA, was to design a web-based tool for decision support that could incorporate many uses including an assessment of the potential benefits from participating in a carbon management policy. Since that time, the technology to deliver this kind of decision aid to producers has changed dramatically. With the recent advent of this technology, we are now focused on delivery of a desktop decision aid for producers. This approach also has the capability to run interactively on the web. This effort is very much evolving as we proceed into Phase II of this project.

Economic component: The objective and goals of the economic component of the decision support framework is the development of the linkages to the CSTORE system, and facilitating similar linkages to other models such as Comet or C-lock. A flowchart of the economic model is presented in Figure 1.

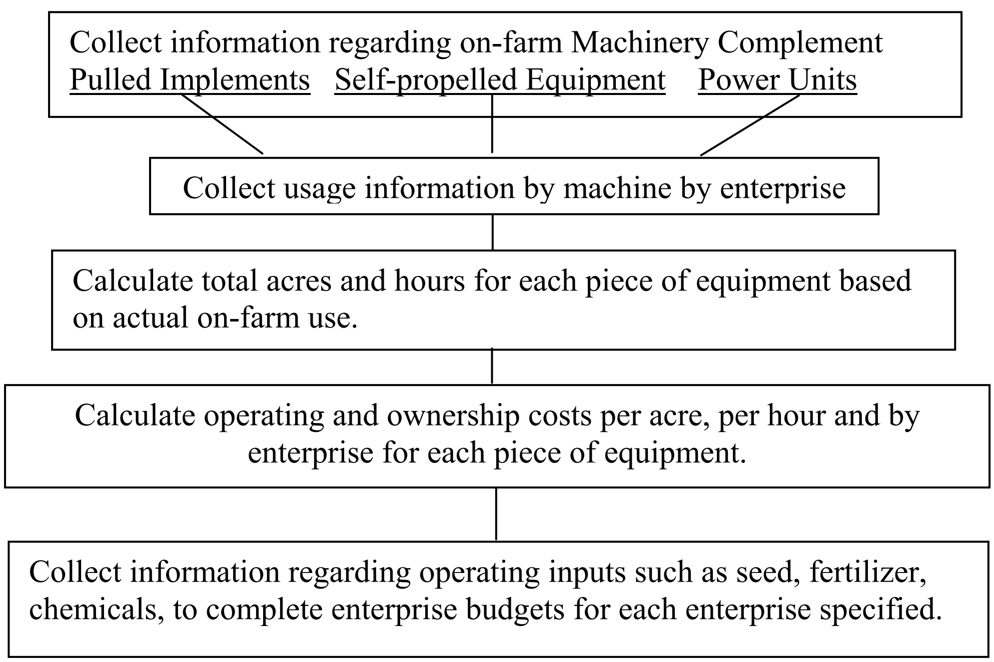


Figure 1. Montana State University Tillage Systems Analysis Model.

Much of the work related to carbon sequestration in soils relates to tillage systems and the carbon-nitrogen relationships. Producers who are asked to consider markets for carbon sequestration will want to know the economic implications for their individual operations. The model Montana State University uses to analyze the economic implications of farm size and tillage systems would be adopted to analyze the costs and benefits of adopting GHG mitigation strategies. The needed information includes the best management practices for sequestering C, the quantities of soil C sequestered as a result of changing practices, and proposed costs of monitoring and measurement of soil C levels which is available from existing budgets. The additional information that is needed pertains to estimates of the costs and potential benefits of adopting the alternative technologies. Thus the focus of efforts under this activity has been to generate enterprise budgets and to develop the software for linking farm-level production activities to site-specific measures of potential increases in soil C and to changes in producer net returns.

This model already incorporates detailed machinery use calculations to accomplish a particular farming task or cultural practice, such as a combination of a mechanical and chemical fallow system, for example. This model also allows for analysis of co-costs and co-benefits in a limited fashion.

The on-farm model will allow an economic analysis of any new investments a producer may have to make to implement a particular BMP or set of BMPs and their impact on profitability. Estimates of both short and long run impacts on profitability and the equity position of the individual operation will be provided for the selected set of BMPs analyzed. The on-farm model will be used to develop educational material for agricultural policy makers that addresses the process producers will use to make decisions regarding implementation of recommended BMP's for carbon sequestration. Specifically, educational material will address the producer's need to manage for a profitable business when making investment decisions regarding change in cultural practices over the long run.

The on-farm model is used to develop case studies for farms in several regions in the Northern Great Plains. The case studies will represent a range of farm size, biophysical and geographic conditions, and current cultural practices. These studies will serve to analyze the potential impact on a regional scale of implementing BMPs and/or policies proposed by other task groups for dry land agricultural in the Northern Great Plains. Case studies for a selected region will be used to develop a web based computer model that will simulate the tradeoffs between agricultural production practices, and potential for carbon sequestration and GHG mitigation. The target audience for this model will be producer groups and other stakeholders.

Individual producers will use the on-farm software to analyze their specific operations. It will be interactive and allow for the producer to input site and farm-specific economic and biophysical information. The web software will allow users to load the case study data and learn about the concepts and potential costs and benefits of implementing BMPs for C sequestration.

The economic model which was going to be converted to visual basic to run on the web is now being reformatted in Excel. New software available will compile the Excel spreadsheet and allow producers to run detailed analysis without having to own Excel. In addition to the ability to compile Excel, this software adds the ability to change the way input is entered and output is displayed. An example printout of what the current user interface might look like is shown below.

This example allows the user to change the acreages of the crop mix, fuel prices and indicate a percent change in fertilizer and chemical prices. All of this is done with easy to use sliders to control input values. Behind this software is a compiled spreadsheet that is approximately 500 rows long and 400K in size. Again, the user never sees the actually spreadsheet but has the full power of all the calculations included in the spreadsheet.

This is primarily the Economics component. The final version of this software will include the ability to change crop mixes and evaluate more completely the economic implications of the energy prices impacts. It will, or can, also list one or more indicators of energy use. Examples may be the BTUs of energy used by the each type of fertilizer or chemical applied or by the fuel and other petroleum products used (Gas, Diesel, Oil) on the operation. With the ability to change crop mix and or tillage systems with the final version, evaluations of energy use and impacts can be made by the end user.

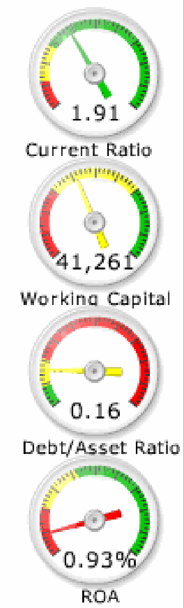
To demonstrate the capabilities of this software, follow this link for the Dashboard (http://www.bigskyco2.org/RDFinancial_HTML_DashBoard.swf). Additionally, the Economics/CStore/Energy product is shown in this file (http://www.bigskyco2.org/EconCStoreDemo.swf).

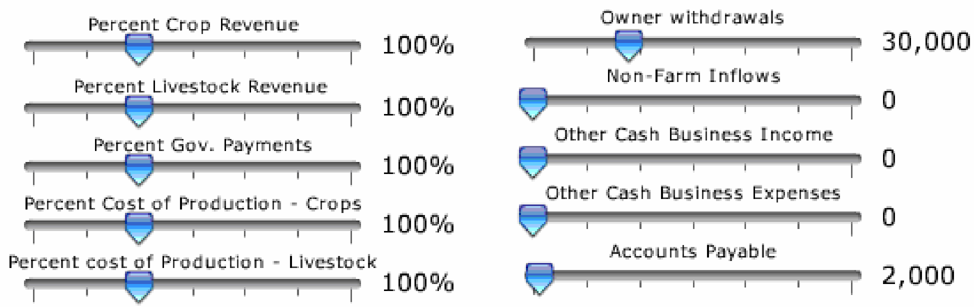
Balance Sheet	Assets Beginning	Assets Ending		Liabilities Beginning	Liabilities Ending
Cash on Hand	1,500	2,711	Accounts Payable (Exp)	2,000	2,000
Crops Held for Feed	18,000	18,000	Accrued Interest (Exp)	17,330	16,170
Crops Held for Sale (	45,000	45,000	Current Principal	15,920	17,080
Market Livestock (In	0	0	Other Current Liability (I	10,000	10,000
Other Current Assets	15,000	15,000	Short Term Notes Payabl	0	0
Cash Invt Growing C	0	0	Other Current Liab. (Not	0	0
Supplies&Prepaid Ex	5,800	5,800	Def. Tax on Current Asse	0	0
Total Current Assets	85,300	86,511	Operating Loan Carryove	0	0
Non-Current Assets			Total Current Liab.	45,250	45,250
Mach. & Equipment	225,000	202,500	Non-Current Liabilities		
Breeding Livestock	146,000	149,333	Prin. on T.D. & C.L.	257,538	240,459
Real Estate (Land, Bl	1,380,000	1,370,850	Total Business Liab.	302,788	285,709
Total Business Ass	1,836,300	1,809,195	Business Net Worth	1,533,512	1,523,486
			Change in Equity From Beginning to End of Year		(10,026)

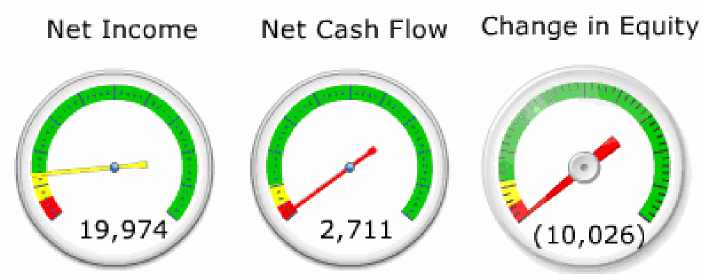
Cash Flow Statement	Inflows			OutFlows
Crop Sales	179,245	Operating Expenses	No Interest >	289,301
Mrkt & Cull Livestock Sales	106,810	Other Cash Business Expense		0
Government Payments	78,827	Cash Int. Exp. - T.D. & C.L.*		17,330
Other Cash business Income	0	Cash Int. Exp. - Operatir	8%	5,786
Operating Loan Proce 50%	144,651	Loan Prin. Payments - T.D. & C.L.		15,920
Loan Proceeds Capital Assets	0	Breeding Livestock Asset Purchases		5,333
Non-Business Inflows/Revenue		Mach & Equip & Real Estate Purchase		0
Other Nonfarm Inflows	0	Owner withdrawals		30,000
Other Nonfarm Inflows	0	Cash Taxes Paid (Income & SS)		0
Total Cash Inflows	509,532	Other Cash Outflows (Not Expenses)		0
**** T.D. = Term Debt, C.L. = Capital Lease***			Subtotal	363,670
		Operating Loan Prin. Payments		144,651
		Total Cash Outflows		508,321
		Annual Net Cash Flow (never < zero)		2,711

Income Statement - Accrual Adj.	Income
Cash Income (adj. for cull lvstk sales)	348,322
Non-Cash Income Adjustments	0
Non-Cash Income (Raised Brdg Lvstk)	18,000
Capital Gain/Loss on Breeding Lvstk (I	-1,440
Gross Revenue	364,882
	Expense
Cash Expense (Excluding Interest)	289,301
Non-Cash Feed Inventory Adjustment	0
Other Non-Cash Non-Interest Expense	0
Depreciation (Land, Bldgs, Equip.)	33,650
Total Operating Expense	322,951
Cash Int. Exp. - T.D. & C.L.	17,330
Cash Int. Exp. - Operating	5,786
Non-Cash Interest Expense	-1,160
Total Expense	344,907
Net Business Income From Operati	19,974
Net Business Income	19,974
Income & SS Taxes (Cash & Non-C	0
Net Income	19,974

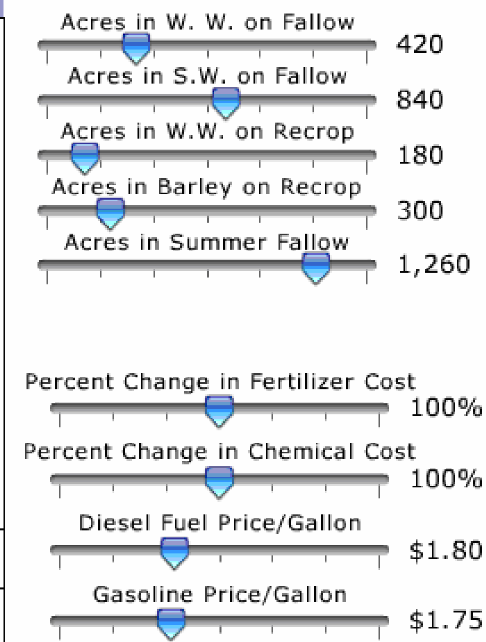
Statement of Owner Equity		
Beginning Net Worth (Cost/Mrkt)		1,533,512
Net Income	+	19,974
Non-Business Cash Inflow	+	0
Owner Withdrawals (Cash	-	30,000
Asset Valuation Change or Cc	+/-	0
Calculated Ending Net Wo	=	1,523,486
Reported Ending Net Worth (Cost/		1,523,486
Discrepancy		0

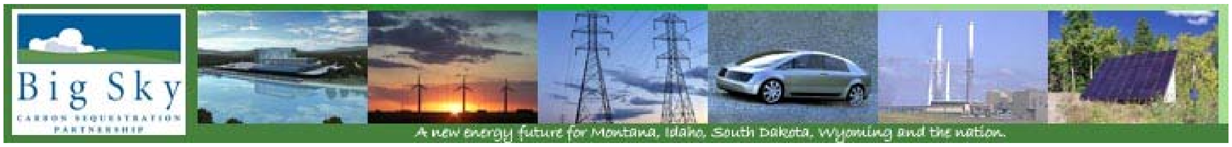






	WW on Fallow	SW on Fallow	WW on Recrop	Barley on Recrop	Summer Fallow	
Acres in this Enterprise	420	840	180	300	1,260	3,000
FSA Yields	35.00	30.00	40.00	30.00	0.00	
Government Payments	$0.50	$0.75	$0.50	$0.25	$0.00	
Expected Yield	35	30	40	30	0	
Expected Local Cash Price	$3.50	$4.00	$2.50	$2.50	$0.00	
Other Income Per Acre	$0.00	$0.00	$0.00	$0.00	$0.00	
Total Income	$140.00	$142.50	$120.00	$82.50	$0.00	$224,850
Operating Input Costs						
Seed and Treatments	$4.50	$5.00	$4.50	$3.12	$0.00	$7,836
All Chemicals	$5.17	$7.27	$5.18	$5.49	$4.91	$17,050
All Fertilizer	$12.50	$15.40	$16.70	$11.60	$0.00	$24,672
Crop Insurance	$8.05	$8.05	$9.40	$6.00	$0.00	$13,635
Hired Labor	$0.00	$0.00	$0.00	$0.00	$0.00	$0
Other Misc	$2.00	$0.00	$2.00	$0.00	$0.00	$1,200
Machinery Operating Costs	$24.14	$20.02	$19.22	$20.84	$9.58	$48,739
Interest on Operating Costs	$3.38	$1.67	$3.42	$1.41	$0.43	$4,412
Total Operating Costs	$59.75	$57.41	$60.43	$48.46	$14.93	$117,544
Total Ownership Costs	$45.63	$41.10	$43.46	$41.64	$26.93	$107,944
Total Cost	$105.38	$98.51	$103.89	$90.10	$41.86	$225,487
Returns Over Operating Costs	$80.25	$85.09	$59.57	$34.04	-$14.93	$107,306
Returns Over Total Costs	$34.62	$43.99	$16.11	-$7.60	-$41.86	-$637
Breakeven Prices at Given Yields						
Operating Costs	$1.71	$1.91	$1.51	$1.62	$14.93	
Total Costs	$3.01	$3.28	$2.60	$3.00	$41.86	





Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 13: Measurement, Monitoring and Verification Technology Assessment Report

Part A –
"An Integrated Geological Sequestration MMV System"
Part B –
"An Integrated Terrestrial Sequestration MMV System"

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Part A - An Integrated Geological Sequestration MMV System

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Introduction

Atmospheric carbon dioxide levels have been rising dramatically over the last century resulting in a measurable temperature increase. This increase is primarily a result of increased industrial and economic growth by both the industrialized and emerging third world nations. The consequence of allowing CO_2 levels to continue to rise unchecked could be catastrophic. The focus of this paper is to outline the current state of Monitoring, Mitigation, and Verification (MMV) capabilities specifically for geological sequestration. MMV is a central aspect of any sequestration effort. First and foremost, MMV is needed to establish public credibility by verifying the viability of the approach. MMV needs to demonstrate quantitatively that sequestration is worth the public investment. Sequestration will work only if economic incentives exist and MMV is needed to quantify the effectiveness of the sequestration. Perhaps most importantly, MMV is required to safeguard the public and determine the existence of local threats to the public before these threats emerge. An integrated ensemble of tools is needed to complete these tasks. In this paper, we discuss the methods currently available to monitor a basalt sequestration site. Some of these technologies are mature and ready for deployment. Other technologies are ready for deployment but need to demonstrate that the detection sensitivity is sufficient. Regardless, we conclude that these tools need to be deployed to at the basalt sequestration site to quantitatively demonstrate their capabilities.

We conclude that only an integrated ensemble of diagnostics will provide the data required. A GIS system is capable of serving as this integrating platform. Data from each measurement along with a GPS location will be uploaded into the GIS system for further analysis. The GIS system will integrate these data points to provide a larger picture of the site's performance. This information will be uploaded into various modeling and decision making tools so that additional measurements can be taken as the situation demands. However, advanced analytical methods offer improved detection limits, increased ease of operation, and the potential to analyze samples in the field.

Finally, in order manage and limit MMV costs while protecting the site's workers and general public, an automated system of MMV capabilities is required. A carefully selected ensemble of subsurface, surface and atmospheric diagnostics should be permanently deployed at the site. Decision making tools could use these data sets to initiate actions needed to preserve the sites integrity.

As an example, passive seismic monitoring can be operated continuously. When increased seismic activity occurs, indicating a potential problem with the sequestered CO_2, other monitoring methods could be deployed to more thoroughly characterize the site. The relatively inexpensive passive monitoring would trigger data acquisition of the more costly MMV methods when the potential of CO_2 leakage is high.

Performance Goals for Geological Sequestration

A reduction in atmospheric carbon dioxide levels and other greenhouse gas (GHG) concentrations can be achieved through a multi-faceted approach including alternative energy sources and increased energy use efficiency, greenhouse gas capture in terrestrial and aquatic sinks, and development of advanced technologies for geological capture of GHGs. Geological sinks include depleted oil and gas reservoirs, saline water reservoirs, coal beds, and other potential reservoirs, and can be managed to provide long-term reductions in CO_2 concentration. In this report, we will focus on monitoring, mitigation, and verification (MMV) for a basalt sequestration reservoir.

Site Monitoring and Verification

Geophysical methods

Surface seismic reflection: Surface seismic reflection is the method of choice for monitoring changes in reservoir characteristics. These methods could provide detailed images/information of the subsurface, cover large areas, and provide abundant information about the reservoir's physical and structural properties. Unfortunately, surface seismic reflection methods have a poor history of imaging beneath flood basalt terranes (Pujol et al., 1989). The basalt flow/interbed stratigraphy of flood basalt terranes causes strong reverberations in the data, obscuring coherent reflections that may be present (Jarchow et al., 1994). However, to detect changes in the subsurface may not require good-quality images and therefore, the surface seismic reflection could still has the potential to detect changes. By placing either sources or receivers in a well or bore-hole, we will have a better chance of successfully imaging the CO_2 injection zone.

Cross-well seismic methods: In basalt environments such as in the Columbia River Plateau and the Snake River Plain, geophysical monitoring is likely to focus on the cross-well seismic method, active doublet (or coda wave interferometry), and passive seismic monitoring. Cross-well seismic methods will have higher spatial resolution of the injection volume than surface-based methods. Modern cross-well analysis methods provide an image of subsurface structure in the vicinity of the wells, as well as a tomographic view of the velocities between the wells (Dong et al, 2005). Pre-injection cross-well measurements will establish baseline conditions for comparison to post-injection measurements. In addition to measurements taken immediately after an injection, an episode of cross-well measurements done after the planned 3-6 month residence time would establish the feasibility of seismic monitoring for discerning in-situ reaction and equilibration of the CO_2.

Vertical seismic profile: Another method for characterizing the reservoir is the vertical seismic profile (VSP). VSPs are less expensive than crosswell tomography. For VSPs, only one well is necessary. The geophones are placed down the well and record surface sources to image/analyze the subsurface changes. These sources have a variety of location geometries, from zero-offset, fixed offset, walk away surveys, to fully 3D geometries to best image/analyze the desired target. Because VSP geophones can be placed closer to reservoirs, and signal to noise ratios and dominant frequency of VSP signals are higher than surface seismic. 3D VSP has great potential for accurately monitoring of CO_2 sequestration. Even though VSPs will have a similar, though less severe ringing problem compared to the surface reflection data (Pujol et al., 1989), they still have the potential to detect changes because detecting changes doesn't requires good-quality time-lapse images.

Active Doublet (or coda wave interferometry): Active doublet and coda wave interferometry are essentially the same methods. They require both the sources and receivers are located at the same positions for time-lapse surveys. They can use data from surface reflection, VSP, or cross well surveys.

Active doublet or coda wave interferometry has the potential to detect changes of the subsurface using the scattered/coda waves, but they cannot tell where the changes occur (Roberts et al., 1992; Gret et al., 2004; Gret et al., 2005; Snieder and Hagerty, 2002; Snieder et al., 2004). Either a highly repeatable active or passive seismic source is recorded. The method relies on repeatable measurements to remove the noise from the signal. In coda wave interferometry, the noise is the constant background energy, while the signal of interest is the change in the waveform due to changes in the subsurface.

Passive seismics: To monitor CO_2 injection/movement using passive seismics, geophones should be placed in boreholes, close to reservoirs as much as possible. The geophones will record signals from micro-earthquakes induced by CO_2 injection/movement. The signals can be used to locate where the induced micro-earthquakes occur. Passive seismic monitoring may help discern the dimensions and extent of the injected CO_2 "bubble". Passive seismic monitoring has a long history in reservoir monitoring (e. g. Rutledge et al., 2004; Ake et al., 2005). The method records seismic energy generated in the ground, either naturally as from earthquakes, or induced seismic energy such as fluid injection. The recorded waves are inverted for their hypocenter location and for focal mechanism solutions to determine the sense of motion of the generating displacement. Installed seismographs can continuously monitor local seismic activity.

An increase in measured activity could indicate that more thorough MMV of the sequestered CO_2 is necessary. Detected anomalies in seismic activity may indicate changes in the subsurface due to CO_2 sequestration. Other monitoring methods could be deployed to better characterize the sequestration site and detect potential CO_2 leaks.

An advantage using passive seismic for MMV, compared to traditional passive seismic methods, is that the approximate location of the excitation source, the injection, is known. Also, from the well log information, we have a reasonable idea of the subsurface geology. This information provides constraints to the inversion procedures, such as those used in the seismic methods, and thus will lead to more accurate and better resolved models.

The recorded signal and the separation of the geophones control the resolving power of the seismic methods. Higher recorded frequencies and higher spatial sampling result in smaller objects being imaged. In general, downhole sources and receivers provide higher, more broadband energy than surface instruments. However, drilling costs for wells and bore-holes usually preclude high spatial resolution. Electromagnetic induction and electrical resistivity methods are also capable of MMV (Newman, 1995; LaBrecque et al., 1996; LaBrecque et al., 1999; LaBrecque and Yang, 2001; Kirkendall and Roberts, 2004). These methods are not commonly used in MMV, but their potential is great, so a number of researchers are studying these techniques (Hoversten et al., 2003).

Electromagnetic methods: Electromagnetic methods are sensitive to the pore fluids in the subsurface (Kirkendall and Roberts, 2004). EM studies show a large contrast between formation water and CO_2 (Kirkendall and Roberts, 2004), thus EM imaging has great potential to directly image the injected and sequestered CO_2.

Integration of methods: Integrating the results from the tests will allow us to evaluate key parameters needed for commercial-scale monitoring at multiple locations and provide the tools and techniques needed to do site-specific engineering for future commercial-scale sequestration facilities in basalts. Also, prior to, during, and following the pilot test, we will monitor vadose zone gases near the injection well.

Geochemical methods

Chemical tracers: Chemical tracers will be a key aspect of planned MMV activities. Although limited to a single injection well in this pilot, similar tracer tests are known to be effective in the characterization of several subsurface flow and reactive transport properties, including kinematic porosity, permeability, phase volume fractions, kinetics of sorption, dissolution, microbial transformations, ion exchange phenomena, dispersion and formation damage (Bachmat et al., 1988;

Haggerty et al., 2001; Davis et al., 2002). A suite of tracers will be designed to: 1) interact with the CO_2, water and mineral phases of the reservoir, 2) limit the problem of interference from naturally occurring CO_2 background concentrations, and 3) provide a statistically superior monitoring and characterization method due to the redundancy built in by using multiple tracers. The method is based on established principles of tracing in geological systems (Zemel, 1995**).** Pre-injection tracer tests will be performed using conservative tracers (such as bromide, PFBA, tritium) to establish the basic hydrologic properties such as porosity, hydraulic conductivity and dispersion. During the CO_2 injection phase, pulses of different tracers will be added to the CO_2 stream. Based on reservoir analyses conducted at PNWD, the leading chemical tracer candidates are SF_6, CH_3F, and CH_2F_2. At set times during the injection period, CO_2 injection will be temporarily suspended to accommodate pump back sampling to collect breakthrough BTCs of the different injected tracer pulses. After the brief interruption, CO_2 injection will be resumed and completed as planned. The succession of BTCs for each tracer during this phase, when analyzed together and in comparison with the pre-injection BTCs, will reveal information about the fate and transport of injected CO_2 as a function of time. The injected tracers will also serve as sensitive markers for vadose zone gas monitoring will allow us to recognize if leakage occurs during or following the pilot test.

Fluid, core, and vadose gas sampling: Collection of fluid and core samples from the target injection zone is a key post-injection characterization task to verify and assess in situ mineralization rates. The core samples will be obtained from the CO_2 injection horizon but in the aqueous phase underneath the supercritical CO_2 bubble. Prior to, during, and following the pilot test, we will monitor vadose zone gases near the injection well to look for sub-biotic fluxes of CO_2 that may emanate. Groundwater will also be monitored prior to, during, and following the pilot test by collection and analysis of water samples from within the target zone of the injection well.

Summary and Conclusions

At the basalt sequestration site, the best geophysical MMV methods are the crosshole geophysical methods. Unfortunately, these methods are cost prohibitive at this time. Active doublet or coda wave interferometry and passive seismic monitory are the most cost-effective methods with the best likelihood of success. A combination of the following geophysical techniques is likely:

1. Passive seismics, for continuous monitoring and location of plume front;
2. Active doublet, for detecting small differences in subsurface conditions, presumably due to plume movement.
3. VSP, for detecting geological structure and plume.

Geochemical methods will consist of chemical tracers and traditional fluid, core, and vadose gas sampling. The chemical tracer method should also provide results at a smaller, higher resolution scale.

Summary Table for Geological Sequestration MMV Systems

Technology	Application	Comment
<u>Geophysical Methods</u>		
Surface seismic reflection	Changes in reservoir characteristics	Poor history of imaging beneath flood basalt, but could still has the potential to detect changes.
Cross-well seismic methods:		
• Cross-well seismic imaging	High spatial resolution of injection volume	
• Active doublet (or Coda wave interferometry)	Detect changes in media using scattering/coda waves from time-lapse data recorded using the same sources and receivers.	Has the potential to detect small changes, but could not tell where the changes occur.
• Passive seismics	Detect microseismicity due to CO2 injection and movement.	Long history in reservoir monitoring; continuous monitoring; location of plume front
Vertical seismic profile	Down-well 3-component geophones and surface sources for 3-D coverage	Image geological structure and plume
Electromagnetic methods	Sensitive to subsurface pore fluids	
<u>Geochemical Methods</u>		
Chemical tracers	Established principles of tracing in geological systems	Fate and transport of injected CO_2 over time
Fluid and core sampling	Verify and assess *in-situ* sequestration rates.	Direct measurement
Vadose gas sampling	Sub-biotic fluxes of CO_2	Vertical CO_2 fluxes

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Part B - An Integrated Terrestrial Sequestration MMV System

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2. Performance Goals for Terrestrial Sequestration
3. Available Analytical Tools
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4. Conclusion
5. References

Introduction

Atmospheric carbon dioxide levels have been rising dramatically over the last century resulting in a measurable increase temperature. This increase is primarily a result of increased industrial and economic growth by both the industrialized and emerging third world nations. The consequence of allowing CO_2 levels to continue to rise unchecked could be catastrophic.

Terrestrial sequestration has the potential to reduce the growth rate of atmospheric CO_2 levels while other technical options are developed, such as geological and ocean sequestration. The focus of this paper is to outline the current state of Measurement, Monitoring (or Mitigating) and Verification (MMV) capabilities specifically for terrestrial sequestration. Since terrestrial sequestration is a relatively large and amorphous concept at this time, we decided to focus on just the MMV systems that support croplands for terrestrial sequestration. We will also highlight those technical capabilities that could be extended to other terrestrial sequestration sites such as rangelands and forestry.

MMV is a central aspect of any sequestration effort. First and foremost, MMV is needed to establish public credibility by verifying the veracity of the approach. MMV needs to demonstrate quantitatively that sequestration is worth the public investment. Sequestration will only work if there are economic incentives and MMV is needed to quantify the sequestration economy. Perhaps most importantly, MMV is required to safeguard the public and determine whether there are any local threats to the public before these threats emerge.

An integrated ensemble of diagnostics is needed to complete all of these tasks. This paper discusses the technical capabilities that are currently available to monitor a cropland sequestration site. Some of these technologies are mature and ready for deployment. Other technologies are ready for deployment but need to demonstrate that the detection sensitivity is enough to complete the mission. Regardless, we believe that this ensemble of diagnostics needs to be deployed to various demonstration sequestration sites to quantitatively demonstrate their capabilities. Finally, we believe that only an integrated ensemble of diagnostics will provide the data required. A world-class GIS system is required and capable of serving as this integrating platform. Data from each measurement along with a GPS location will be uploaded into the GIS system for further analysis. The GIS system will integrate these data points to provide larger picture of the sites performance. This information will also be uploaded into various modeling and decision-making tools that are capable of requesting additional measurements as the situation demands.

Current methods of carbon analysis provide one set of analytical tools required to estimate changes in soil organic carbon (SOC) stocks with some precision[1]. However, advanced analytical methods offer improved detection limits, increased ease of operation, and the potential to analyze samples in the field[2-6]. These advanced methods could improve SOC measurements significantly and improve estimates of uncertainties in carbon inventories. Improved accuracy and precision of carbon measurements is needed to support national and international policies on carbon emissions and carbon trading, but these improvements must be more cost-effective than current methods. Once fully developed and tested, advanced methods must optimize the amount of information about SOC pools per dollar spent, and deliver carbon assessment data at less than 10% of the total costs of sequestration practices[7].

Finally, this paper was prepared for the National Energy Technology Laboratory (NETL). It is rather long but is more complete than one could publish. Our next step is to truncate the paper into a more coherent story of about half this length and consequently will lack some of the technical details.

Performance Goals for Terrestrial Sequestration

A reduction in atmospheric carbon dioxide levels and other greenhouse gas (GHG) concentrations can be achieved through a multi-faceted approach including alternative energy sources and increased energy use efficiency, greenhouse gas capture in terrestrial and aquatic sinks, and development of advanced technologies for geological capture of GHGs. Terrestrial sinks include forestry, cropland and rangelands and can be managed to provide immediate reductions in CO_2 concentration. In this paper, we will focus on GHG capture in cropland agriculture includes several key management aspects:

1) Tillage reduction, primarily as adoption of no-till cropping systems.
2) Increased cropping intensity, primarily as omission of fallow years in semiarid regions and inclusion of 'shoulder season' cover crops in sub humid regions.
3) Convert annually cropped land to perennial cover, including grazing land, idle land (i.e. Conservation Reserve Program), and riparian vegetation buffers.

Research data exists for CO_2 capture rates for these land management alternatives, demonstrating technical potential for CO_2 capture. The remaining major challenge for cropland agriculture is developing efficient methods for measuring, monitoring and verifying (MMV) CO_2 capture since current scientific methods are far too expensive relative to current (and future expected) market values for CO_2 credits.

CO_2 capture in rangeland is dependant on changes in grazing management and is tied not only to changes in soil chemistry but also to change in feeding efficiency of ruminant livestock, via methane emissions. Research data for CO_2 capture in rangeland is less well developed than for cropland agriculture but will doubtless require efficient technologies for measuring, monitoring and verifying CO_2 capture.

Reduced tillage can increase soil C, effectively removing CO_2 from the atmosphere. The single reduced tillage practice that has the most widespread promise is no-till cropping. Soil C sequestration rates resulting from the adoption of no-till farming in the USA typically range from 0.1 to 0.5 t ha^{-1} yr^{-1} for an unknown period, predicted to last from 15 to 30 yr, until a new soil C equilibrium is attained. This equates to a CO_2 capture rate of 0.4 to 1.8 t ha^{-1} yr^{-1}. Current 'gold standard' soil measurement methodology could exceed the economic value associated with CO_2 credits. Further complicating the MMV issue for soil C, nitrous oxide (N_2O) is a potent GHG (300X warming potential of CO_2 on equivalent mass basis) that represents a potential leakage issue for soil C capture. Nitrous oxide emissions can also be managed by change in agricultural management, either through precision N management or reductions in chemical fertilizer or legume N additions. It is key to note that there is a general soil C:N relationship that dictates increases in soil C must be accompanied by increased soil N, at an approximate 10:1 ratio. If current 'gold standard' science methodology for measuring soil C in agricultural soils is too costly to employ in a C credit market, then efficient ways of measuring, monitoring and verifying GHG capture must be developed.

Available Analytical Tools

Land Use Change Detection and Soil C Modeling

Direct measurements provide the necessary information to develop models for soil C responses to agricultural practices. Implementing these models over regional or larger expanses for monitoring and verification, however, is generally not practical with direct measurements. We potentially can use remotely sensed imagery for such purposes if we can extract from the imagery the key parameters for modeling agricultural C dynamics.

Our examination of current models demonstrated that several key agricultural practices are primarily responsible for changes in agricultural soil C, although these practices are parameterized in a diversity of ways [8,9]. Key practices include tillage systems, levels of soil disturbance, crops grown, including crop rotation practices, and amount of residual crop left after harvest. Previous studies, most of which were not focused on soil C, strongly suggest that satellite remote sensing can monitor and verify all of these practices over regional scales.

Tillage disturbance has been shown to greatly influence soil C dynamics due to increased erosion and microbial decomposition [10]. The adoption of no-till (NT) can reduce losses of soil and can increase soil organic C [11]. Several studies have used remote sensing to predict tillage systems using various classification methods. Logistic regression (LR) of Landsat Enhanced Thematic Mapper Plus (ETM+) imagery had >95% accuracy in verifying NT fallow fields in a study in north central Montana [12]. LR had 93% map accuracy using Landsat Thematic Mapper (TM) data in a corn/soybean rotation in Ohio [13]. Landsat TM and logistic regression have also been used to map tillage practices in the Lower Minnesota River watershed using logistic equations developed by van Deventer et al. (1997) and TM band 5 (middle infrared) or the difference between TM bands 3 (red) and 5 with 70-77% accuracy [14]. Logistic models applied to Ikonos imagery principal components had 80% and 77% overall accuracy for discriminating corn/soybean residues and conventional/conservation tillage in Nebraska, respectively (Viña et al., 2003). The Crop Residue Index Multiband (CRIM) model using ETM+ imagery of the Minnesota River Basin, although not specifically addressing the NT/tillage question, had 79-80% accuracy classifying 2 categories, 0-30% and 31-100% residue cover, which were equivalent to conventional and NT management, respectively [15]. Soil disturbance also has been estimated within 5% using regression tree analysis of Landsat ETM+ images (Bricklemyer et al., in review).

Monitoring cropping systems requires identification of various crop types. Identifying crop types and estimating yields using Landsat satellite imagery has been a focus of remote sensing experiments beginning with the Large Area Crop Inventory Experiment or LACIE in the middle 1970s (MacDonald and Hall, 1978). Studies subsequently have investigated improving classification methods for increasing crop type discrimination accuracy by overcoming a primary issue of separating crops. That primary issue was identified as the variability in crop maturity that can occur within a Landsat scene [16]. Methods used to improve classification accuracy include the use of maximum likelihood classification (MLC) of single and multidate Landsat imagery, principal component analysis, discriminant analysis, and active microwave response. MCL accuracy for classifying rice, maize, sorghum, and soybean increased from 89% using single date imagery to >95% accuracy using 2 and 3 image dates in an iterative approach (Van Neil and McVicar, 2004). Accuracy of 97% was achieved for discriminating oilseed crops from orchards, scrubs, and forest using MLC of a singe date and including middle infrared bands and principal component analysis (Sharma et al., 1995). Classification of maize, durum wheat, and bread wheat using MLC and a single image date had overall accuracy of 72% for Landsat ETM+ imagery and 81% for Earth Observing-1 Advanced Land Imager imagery [17-19]. Discriminant analysis of combined visible, near infrared, and active microwave response data had 92% accuracy for classifying corn, bare soil, bare soil with weeds, pasture, millet, weeds, and wheat stubble [20,21].

Related to crop type is the amount of crop residue remaining after harvest. The Century model for agricultural C dynamics uses a crop production submodel to estimate crop biomass, yield, and residue biomass using inputs of crop type, fertilizer application, annual climatic data, and harvest practices [8]. Site specific data could be used instead and would likely enhance the predictive capabilities of the model [22]. Studies specifically quantifying crop residue biomass have not been documented.

Many studies, however, have successfully estimated the proportion of crop residue covering the soil using remote sensing techniques such as radar satellite data [23], laser induced fluorescence [24,25], and Landsat TM and ETM+ [13,15,26].

Direct Soil Measurements

Visible and Infrared Diffuse Reflectance Spectroscopy

Visible and infrared diffuse reflectance spectroscopy has become a powerful tool to study organic and inorganic soil carbon. This spectroscopic technique involves probing the soil sample in three regions that provide complimentary information, visible light (VIS, 0.4 – 0.7 µm), near-infrared (NIR, 0.7 – 2.5 µm), and mid-infrared (MIR, 2.5-25 µm). Spectral signatures of materials are defined by their reflectance, or absorbance, as a function of wavelength (Fig. 1). Under controlled conditions, the signatures are due to two processes: (i) electronic transitions of metals in crystalline matrices; and (ii) vibrational stretching and bending of structural groups of atoms that form molecules and crystals. Electronic absorptions are primarily associated with Fe-bearing minerals (e.g. hematite, goethite, biotite, and olivine) with fundamentals found in the VIS and short-wave NIR range [27,28] and giving rise to distinctive colors long employed in the field characterization of soils [29]. The fundamental features related to various components of soil organic matter generally occur in the MIR range (2.5–25 µm or 4000–400 cm^{-1}), with their overtones found in the NIR region. The strongest absorptions in the NIR are largely due to overtones and combinations of O-H, C-H and N-H stretches as well as the H_2O bend.

To measure diffuse reflectance, a broad-spectrum light source is focused on the soil material to be analyzed and the reflected light energy measured at specified wavelength intervals across the spectrum of interest. Reflectance (R) is reported in values from 0 (complete absorption) to 1 (all incident light energy at a given wavelength is reflected). Since we are primarily interested in modeling the absorption of light energy at specific wavelengths, reflectance spectra are commonly transformed in one of several possible ways:

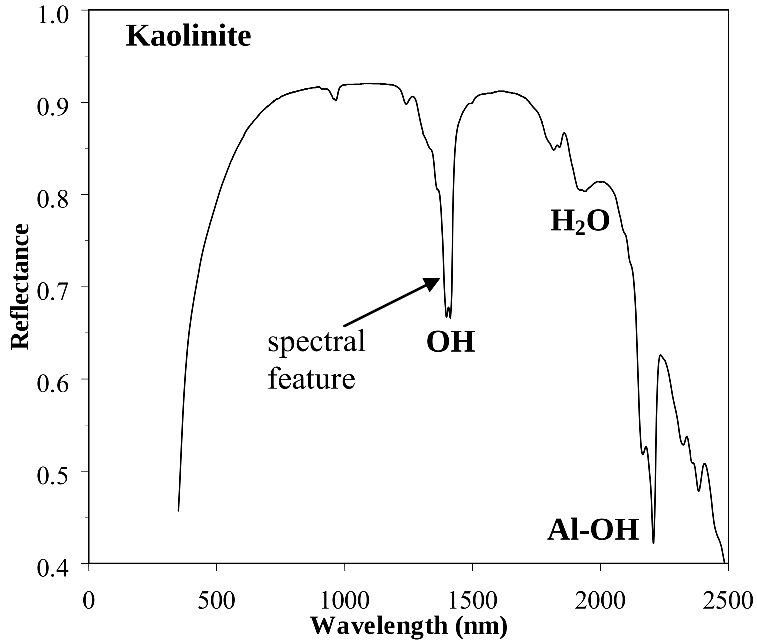

Figure 1. VNIR spectrum for kaolinite with major OH and H_2O absorption features labeled. The absorption depth of the H_2O feature is computed as $(R_c - R) / R_c$, where R = reflectance and R_c = continuum line reflectance (dotted line).

- Absorbance = log(1/R)
  This metric is commonly employed in the analysis of NIR diffuse reflectance spectra, but is theoretically justified only in transmission spectroscopy [30].
- Kubelka-Munk = $(1\text{-}R)^2 / 2R$
  The Kubelka-Munk (KM) equation is theoretically justified for reflectance spectroscopy and is commonly employed in MIR analysis. Ideally, for a wavelength-specific absorption KM $\propto$ analyte concentration [30]. However, Kubelka-Munk theory only applies for materials with small total absorption, which rarely holds for soils [31].
- 1^{st} and 2^{nd} derivatives
  Because reflectance can vary with particle size, moisture and presentation, derivatives of reflectance spectra have been found empirically useful in diffuse reflectance spectroscopy. The 1^{st} derivative captures leading and trailing edges of spectral features while the 2^{nd} derivative quantifies the "sharpness" of an absorption feature.

Visible and Near-Infrared (VNIR) vs. Mid-Infrared (MIR)

Both VNIR and MIR spectroscopy have been used to quantify soil C. These related techniques have distinct advantages and disadvantages that can be summarized as follows: (i) organic absorption features are sharper and more distinct in the MIR relative to VNIR; (ii) non-linear distortions and inversions due to specular reflectance interfere with the analysis of diffuse reflectance spectra in the MIR range, with minimal problems in the VNIR range; and (iii) instrumentation commonly employed in VNIR spectroscopy can be more readily employed in the field than that for MIR spectroscopy.

The fundamental absorptions for soil organic materials can be found in the MIR region. These absorption features tend to be both sharp and distinct. So, for example, specific functional groups and constituents organic molecules can be identified and quantified using MIR spectroscopy [32]. The combinations and overtones of these absorptions, found in the NIR, are broad, weak and overlapping. For this reason, statistical and chemometric approaches dominate in NIR spectroscopy [33].

There are two types of reflected light: (i) specular and (ii) diffuse. Specular reflectance occurs at planar surfaces with reflected light at -α relative to normal given an incident angle α. Diffuse reflectance is ideally scattered in all directions equally above the material surface. Unfortunately, specular reflectance is greatest at wavelengths that show strong diffuse reflectance absorption, leading to "specular inversions" that greatly complicate identification and quantification of analyte concentrations. Specular reflectance problems can be reduced through optical engineering. However, with randomly oriented materials as are commonly found in soils, the only way to eliminate specular reflectance is to powder and dilute sample material (a time-consuming procedure), commonly to ~1%, with spectrally "inert" materials like KBr that allow deeper penetration of light into sample material. Because VNIR absorptions are broad and weak, specular reflectance is rarely a problem in this range. In the MIR range, however, specular reflection significantly distorts diffuse reflectance measurements [34,35].

Instrumentation

While a full discussion of infrared spectroscopy instrumentation lies outside the scope of this review, a short discussion of instrumentation, however, explains why field-portable VIS and NIR instruments are commercially available while field-portable MIR remains largely experimental.

Dispersive instruments employ reflective diffraction gratings to separate wavelengths and narrow detection slits to capture light energy at specific wavelengths. Depending on the wavelength range and associated costs, (i) detectors are placed at each slit for simultaneous data collection at all wavelengths or (ii) a single detector rapidly scans across the slits to sequentially collect light energy at each wavelength band. Unfortunately, with the slit-detection system only a fraction of available light energy at each band is actually captured and increasing energy efficiency leads to a trade-off in lower wavelength resolution. Therefore, dispersive instruments are commonly used for Vis and NIR spectroscopy where both reflectance and light energy are greater than in the MIR region. High spectral resolution (2-10 nm), field-portable VNIR spectroradiometers are commercially available.

Fourier-Transform Infrared (FTIR) instruments achieve greater light energy detection efficiency than dispersive systems. This is accomplished by splitting incoming light to hit both a fixed and a movable mirror. The light beams are then recombined and focused onto a single detector. Interference patterns are generated by moving one mirror across a prescribed range of wavelength distances that generate interference patterns when the two beams are combined. From the interference patterns generated, a reflectance curve can be computed using a Fourier transform. FTIR instruments, by using virtually the entire incoming light energy have greater sensitivity than dispersive instruments which is particularly important in the MIR range. However, using of FTIR instrumentation in the Vis and NIR ranges is more difficult as the shorter wavelengths require very precise mirror movement (though modern commercial research-grade FTIR instruments are capable of operation in the Vis and NIR ranges). These instruments are not generally field-portable.

Almost all of the soil C studies published to date have relied upon empirical calibrations, using high dimensional modeling techniques like step-wise multiple linear regression (MLR), principal components regression (PCR), partial least squares regression (PLSR) [36,37], multivariate adaptive regression splines (MARS) [38] or boosted regression trees (BRT) [39,40]. Given the high dimensional nature of DRS modeling, calibrations alone have little value and great care must be taken to adequately validate models with an independent dataset [41]. Soil C calibrations can be inadvertently based upon indirect correlations with other soil constituents (e.g. clay content, Fe-oxyhydroxides), leading to models that fail completely outside the calibration dataset. Brown et al. [42] have demonstrated that the random selection of a "hold out" validation set is not adequate for soil-spectral modeling and that validation samples must be geographically independent relative to the intended spatial scale of model use. Accordingly, the many soil C diffuse reflectance studies that report only calibration results are not included in this review, and information on spatial sampling design is provided for each reported study.

Soil C Prediction

A summary of published results from field-scale studies is presented in Table 1. For within-field calibration and validation, estimated prediction errors for NIR and MIR are an acceptable 0.9 – 1.8 g OC kg^{-1} dry soil, with MIR slightly outperforming NIR. However, it should be noted that there is little utility, for example, in using 117 samples from a single field to construct a model that can only be successfully applied to that same field [43]. A sample collected at 0-2.5 cm at one location is hardly independent of samples from the same location at 2.5-20 cm [44,45]. Demonstrating the lack of robustness for such models, NIR and MIR models calibrated using one field in Maryland performed poorly when used to predict C in another Maryland field [44,45]. For a rolling field in Manitoba, even holding out 50% of the sample set at a time for cross-validation yielded a notably higher NIR RMSD value of 3.3 g OC kg^{-1} dry soil [46].

A summary of published results from regional to global studies is presented in Table 2. The reported prediction errors are, as one might suspect, notably higher than for field-scale calibrations. Lower RMSE values are reported by McCarty and Reeves [5] for a US Great Plains study, but given the clustered sampling by profile and location the validation data set (selected randomly with no geographic consideration) cannot be considered truly independent. In attempting to predict OC at one central location in Nebraska using the other 13 locations for calibration, RMSD was much greater [5]. NIR and VNIR regional topsoil calibrations for studies in Australia [47] and Africa [48] show relatively improved predictions (RMSD = 2.5 and 3.1 g OC kg^{-1} dry soil, respectively). This is perhaps due to: (i) the larger datasets employed; or (ii) the limited range of soil mineralogy commonly found in surface soils in warmer climates. A lower RMSD = 2.2 g OC kg^{-1} dry soil with site-holdout cross-validation is reported by Brown et al. [49] for six sites scattered across the glaciated wheat fields of north central Montana. However, for this region OC values have a limited range of 2-16 g kg^{-1} dry soil, and prediction errors for some sites were anomalously high (max = 3.5 g kg^{-1} dry soil). More troubling, the spectra from these anomalous sites could not be distinguished from the remaining sites.

It remains to be seen whether either VNIR or MIR DRS are viable techniques for soil C determination. While calibrations for both techniques show promise at the field scale, developing new calibrations for every field encountered can hardly be a cost-effective approach. Prediction errors for regional models are largely unacceptable for the measurement, monitory and verification of soil C sequestration.

VNIR might best be employed to map the spatial variability of soil C and sequestration-related properties like mineralogy and clay content at the field scale [49]. Using such maps, representative sites could be selected for conventional sampling and analysis. The VNIR data could then be used to interpolate between sample locations to make area predictions of SOC stocks and dynamics. The strength of VNIR lies in rapid scanning, large spot size (~ 2.5 cm diameter) and instrument portability. Given the lack of field-portable MIR instruments and the need for fine grinding to reduce specular reflectance, MIR is largely a lab-based technique. The smaller spot size with FTIR instruments (~ 1 mm in diameter) and longer acquisition times (~ 30-60 sec with liquid N-cooled MCT detector), also make MIR less rapid than VNIR analysis. Given the well documented problems with specular reflectance in MIR [34,35], it remains to be seen whether robust calibrations can be developed using neat samples. Given the time and labor required to collect, dry, sieve and grind soils to a powder for MIR analysis, the additional time required to dilute this material with a KBr powder (to eliminate specular reflectance) seems incremental. Creating a KBr pellet is not required as diluted soil organic molecules in powder form have a linear concentration relationship with Kubelka-Munk transformed MIR DRIFT spectra [50]. Given the work required to obtain MIR spectra free of specular reflectance, this technique is actually more time-consuming and expensive than traditional analytical methods. However, there is potential with MIR to quantify not just SOC, but the various organic fractions as well [32,50]. The ability to characterize these organic fractions (as well as mineralogy and other soil parameters) supports the further development and application of MIR for soil C sequestration MMV.

Table 1. Summary of published results **field**-scale diffuse reflectance spectroscopy (DRS) soil C 1st derivative models

Author	Model	Spectral range	N (total)	OC RMSD (g kg^{-1})	Sample Prep.	Validation	Sampling design
Reeves, 1999	PLS	NIR	179	1.0	“	Cross-valid.	Two fields in Maryland, USA, 2.5 cm depth intervals to 20 cm
“	PLS	NIR	179	0.9	“	1/3 random	“
“	PLS	NIR	179	4.7	“	Cross-field	“
Reeves III, 2001	PLS	MIR	180	0.9	“	Cross-valid.	“
“	PLS	MIR	180	1.3	“	1/3 random	“
“	PLS	MIR	180	2.6	“	Cross-field	“
Martin, 2002	MLR	NIR	287	3.3†	< 2 mm	50%-holdout Cross-valid.	A horizons, field in Manitoba, Canada
Udelhoven, 2003	PLS	VNIR	114	1.4	< 2 mm	Cross-valid.	13 ha plot, surface, 60 x 60 raster sampling
Viscarra Rossel, 2005	PLS	NIR MIR	118	1.8 1.5	< 2 mm powder	Cross-valid.	Surface samples (0-20 cm) from 17.5 ha field, Australia

†Standard error of prediction (SEP)

Table 2. Summary of published results from **regional- to global**-scale DRS soil C 1st derivative models

Author	Model	Spectral range	N (total)	OC RMSD ($g\ kg^{-1}$)	Sample Prep.	Validation	Sampling design
Chang, 2001	PCR	NIR	743	7.9	< 8 mm	Cross-valid.[1]	Western US, surface & subsoils, < 30 cm
McCarty, 2002	PLS	NIR MIR	273	5.5 3.2	powder	Random, N = 60	3 profiles per location sampled by horizon 14 Great Plains locations, western US
"	"	NIR MIR	"	7.9 6.0	"	One central site, Nebraska (N = 16)	"
Shepherd, 2002	MARS	VNIR	1011	3.1	< 2 mm	Random, N = 337	Surface soils, Eastern & Southern Africa
Dunn, 2002	PLS	NIR	360	2.5†	powder	Random, N = 90	surface, 0-10 cm, southern New South Wales, Australia
Islam, 2003	PLS	UV-VNIR	161	4.4	< 2 mm	Random, N = 40	SE Australia, geographically dispersed, 112 surface, 49 subsurface
Sorensen, 2005	PLS	VNIR	By set: 1) 472 2) 228 4) 139	 4.4† 4.2†	< 2 mm	Calib. → Valid Set 2 → Set 1 Sets 1&2 → 4	0-20 cm, composited by field, Denmark Large archive subsampled by: Set 1. geographically stratified, clay < 26% Set 2. clay stratified, clay ≤ 74% Sets 4. clay stratified, 0 < clay < 26% year 2003 only
Brown, 2005	PLS	VNIR	283	2.2	< 2 mm	Site-holdout cross-valid.	0-10, -20, -50, -100 cm six sites in NC Montana
Brown, 2005	BRT	VNIR	3793	9.0	< 2 mm	1/6th cross-valid.	Global distribution (majority US), all horizons

[1]Subset of 30 similar samples, based upon 1st derivative reflectance, used to construct calibration for each sample.
†Standard error of prediction (SEP)

Laser Induced Breakdown Spectroscopy (LIBS)

LIBS has emerged as one of the more authoritative analytical tools to quickly and accurately study soils. LIBS is a universal detection technology that is capable of identifying most of the elements within the sample with every experiment. LIBS involves focusing a laser on a solid sample forming a microplasma of elements in an electronically excited state. As these elements relax back to some ground state, they emit light characteristic of the elemental composition of the sample. Some of the emitted light is collected, spectrally resolved, and detected to monitor concentrations of elements via their unique spectral signatures. When calibrated, the method provides quantitative measurements of soil carbon in a sample. The method is readily adaptable to field-portable instrumentation, which would provide investigators a means to measure soil carbon in near real time and in remote locations[51] or in a laboratory setting with high-throughput analysis. Due to its portability and analytical precision and accuracy, LIBS is becoming an exceptionally versatile component of MMV networks for carbon monitoring[3,51,52] and soil science in general.

We calibrated LIBS against dry combustion analysis using soils that were similar in morphology and ranged in carbon concentration to about 4.8%[3]. Soils were silt loam in texture and of mixed mineralogy and could be considered as "typical" agricultural soils in the Midwest. Details of the calibration and instrumental configurations are found elsewhere[3,51].

We determined that carbon could be identified and quantified using LIBS. A plot of the LIBS signal versus carbon concentration for soils from the cultivated plots (Colorado soils) shows excellent correlation and provides a calibration curve. The calibration curve was effective in predicting the carbon content of additional samples from the cultivated plots. The same calibration curve was also effective in predicting carbon concentrations in semiarid alfisols (Los Alamos samples) even though the genesis of the alfisols was significantly different. The effectiveness of the calibration curve supports our hypothesis that the magnitude of the carbon signal detected by LIBS is a good indicator of the total soil carbon concentration. We estimated LIBS detection limit to be 300 mg-C kg^{-1} with precision of 4% to 5% and accuracy of 3 to 14%.

Our initial work on application of the LIBS method to total soil carbon measurement suggests that LIBS can provide rapid and efficient measurements of total soil carbon with appropriate limits of detection, accuracy, and precision. Good carbon measurements with LIBS were obtained with two distinct soil types; additional work is under way to evaluate if measurements must be adjusted for effects such as soil type and texture, a wide range in carbon concentration, carbonate, bulk density, and soil water content. High-resolution analysis, on the order of millimeters, is technically feasible with LIBS as well and could provide carbon concentration information from soils that is not obtainable with standard methods.

Analysis time for LIBS samples is significantly more rapid than conventional methods. Data collection requires 10 to 20 seconds, and spectral analysis usually takes less than an hour for most samples. The short time required to provide workable data on soil carbon makes LIBS a strong candidate as a field based instrument as well as a portable instrument that could serve as part of a carbon MMV system. The short analysis time and field portability make LIBS a potentially useful tool for obtaining large numbers of carbon measurements in the field. Large data sets collected with field-based LIBS could be used to address issues of variability in carbon concentration with soil series, between study sites, and across landscapes. Addressing the spatial variability of carbon concentrations in soils is a key step to a better understanding of carbon cycling in terrestrial ecosystems as well as a critical part of management strategies to minimize carbon dioxide loss from rangeland, agricultural systems, and forest ecosystems. This understanding of carbon cycling at a finer scale than is currently available is also key to establishing baseline measurements then analyzing soils over time to account of any changes in carbon concentrations due to land management, land use, or natural processes. LIBS has clear applications in a local or regional MMV network to monitor such changes over time and cost-effectively.

Raman Spectroscopy

Raman spectroscopy is very complimentary to the visible and infrared techniques discussed above in that some components within soil that are "inactive" in the visible and infrared regions are Raman "active." Raman spectroscopy is based on the inelastic scattering of light where frequency shifts of the scattered light are attributed to changes in vibrational and rotational energy levels of molecules within the sample. The magnitude of the frequency shift depends on the type of molecular bond, indicating, for example, a soil sample containing C – O, C – H, or C – N bonds. The bond specific information gives Raman spectroscopy the potential to distinguish between organic and inorganic carbon if appropriate signals from specific bonds are measured and identified as originating from organic or inorganic speciation. This attribute makes Raman spectroscopy a desirable addition to the list of techniques available for taking direct soil measurements.

The ability to distinguish between organic and inorganic carbon is crucial to any monitoring, measurement, and verification system for assessing carbon stocks in terrestrial landscapes. For the most part inorganic soil carbon will be bound in the form of the carbonate anion (CO_3^{2-}), which has specific Raman active vibrations. If, for example, the inorganic carbon in a soil is mostly due to the presence of the mineral dolomite ($CaMg(CO_3)_2$), then there will be a peak in the Raman spectrum at ~1097 cm^{-1} corresponding to the symmetrical stretch of carbonate ions in $CaMg(CO_3)_2$. Other Raman peaks of less intensity may be visible if the soil contains dolomite in sufficient quantities (723, 1443, 1761, 176, and 300 cm^{-1}). The Raman signal from the carbonate anion is also sensitive to the cation (e.g. Ca, Mg, Fe, Mn, Zn, CaFe) as well as the mineral morphology. For example, Calcite and aragonite are both $CaCO_3$, but they have distinguishable Raman spectra due to different crystalline structure.

Most organic soil carbon is contained in humic acids, the end products of microbial degradation of plant and animal debris. The humic acids are divided into three main subclasses, the tannins, lignins and fulvic acids. A substantial fraction of the mass of humic acid is contained in the carboxylic acid functional group while a smaller fraction is due to the phenolic functional group. Both functional groups contain bonds that are Raman active and therefore have the potential to quantify organic carbon. Also, terrestrial humic acids tend to be aromatic in nature and contain multiple ring structures with numerous C – C, C – O, C – H, C – O – C, C – O – H, and C – N bonds, which are also Raman active.

Many Raman spectrometers employ a frequency doubled Nd:YAG laser for excitation at 532nm. Some of the inelastically scattered light is directed into a spectrograph and detected with an intensified charge coupled device (ICCD) detector. It is also essential to use an ICCD for detection of the pulsed Raman signal when the sample contains molecules that fluoresce. The electronically controlled intensifier allows precise timing of the collected light. In addition to increasing the intensity of the signal, the intensifier can be used to gate the detector and lower the contribution of the longer lived fluorescence. Signals are summed from multiple laser shots to produce a spectrum.

Detecting and measuring the Raman signal becomes even more challenging if the sample undergoes fluorescence. The humic acids in soil samples that contain organic carbon tend to absorb the laser energy and then emit light at a lower frequency during the relaxation process; thus they fluoresce. Fluorescence can quickly overwhelm the Raman signal making it impossible to resolve. Consequently, one needs to carefully design their instrumentation to discriminate between the fluorescence and Raman signals. It is possible to discriminate between the two signals using pulsed lasers and electronic gating because the lifetimes of Raman Scattering and fluorescence are different.

The Raman signal is short lived (0.0001 to 0.001 nanoseconds) while fluorescence can last 1 to 100 nanoseconds.

Work by Sharma et al. has demonstrated the feasibility of performing pulsed Raman spectroscopy at stand-off distances using a 532nm frequency doubled Nd:YAG laser to analyze minerals similar to those on planetary surfaces. A telescope was used to collect scattered light at distances ranging up to 66m. Spectra of marble, dolomite, calcite, gypsum, water, ice, Epsom salts, olivine, augite, quartz, plagioclase and microcline were recorded. Recently Wiens et al. showed different Raman spectra for similar hydrous and anhydrous minerals such as gypsum and anhydrite using a similar pulsed Raman experimental set-up. A Raman spectrum of chalk was also compared to that of calcite to demonstrate differences in fluorescence. Martin et al. recently published pulsed Raman spectra of soil samples with low and high concentrations of soil organic matter (SOM). Peaks were identified and attributed to HCC – HCO bending, CH – CH2 stretching and O – H stretching. The peaks associated with SOM were definitely larger for the soil sample containing the higher %C.

Carbon Soil Flux & Atmospheric Measurements

Carbon Flux Traps

Carbon decomposition through microbial and root respiration are the dominant natural sources of CO_2 from the soils in terrestrial environments. Soil moisture, soil temperature, initial carbon, and nitrogen/phosphorous ratios are the dominant variables that will cause CO_2 flux rate to change. Typically regions with high organic loads, in temperate to tropical regions have the highest CO_2 flux rates over the globe. Atmospheric CO_2 measurements show highest CO_2 concentrations within the atmospheric column in the northern hemisphere during the summer time. This is because the CO_2 is primary released from terrestrial environments. Ocean water provides a buffering capacity that will retain CO_2 due to carbonate chemistry and slowly changing surface temperatures. A recent study of surface CO_2 flux has shown that as global temperatures rise, decomposition and microbial activity in soils have increased, resulting in enhanced CO_2 loss from soils to the atmosphere[53]. As a result, a positive feedback has begun where increased atmospheric CO_2 concentrations due to anthropogenic emissions have started to change global temperatures, which are now releasing more CO_2 out into the atmosphere, which may cause an even greater global temperature rise. There is a need to determine mitigation strategies for either enhancing terrestrial capture of atmospheric CO_2 or to stop terrestrial loss of CO_2.

To accurately determine the movement of carbon from the terrestrial environment, there are several techniques that have been used over the past 20 to 50 years. There are both regional and local CO_2 flux measurements available to determine CO_2 movement from the terrestrial environment. Regional atmospheric measurements began in 1958 by Charles David Keeling where he used flask isolation of air taken from remote islands that sampled the atmospheric boundary layer[54]. These measurements then expanded to local analyses of CO_2 concentration measured on towers through eddy covariance[55]. In the 1990's a group in Canada began using FTIR to measure CO_2 in the atmospheric column[56] and just recently, 2005, there is now work to use a laser based ranging system to measure CO_2 in the atmospheric column with LIDAR. Local CO_2 fluxes were first estimated from soils in the 1950's by measuring the oxygen demand in the soil column through respirometers[57]. The science then expanded to using soil chambers placed on top of the soil column to look for CO_2 accumulation in closed traps[58]. Soil CO_2 concentration profiles where then used to calculate CO_2 diffusion through the soil column and calculations of flux were made from gradients[59]. Finally, open topped field chambers were first designed to measure pollution impacts on plants, but have expanded to measure CO_2 flux from soils[60,61].

Currently, the majority of local CO_2 flux measurements are collected with open- and closed-topped chambers. These chambers range in surface area coverage from 0.008 m^2 to 1 m^2 where compromises are made in portability versus microsite integration. Specifically, small chambers are used to easily measure many point locations over difficult terrain, but large chambers are used to accurately measure microsite variation in CO_2 flux within a single site. Typically, the chamber is attached to an Infrared Gas Analyzer (IRGA) with a data logger, a drying trap, and a pump to circulate the chamber air into a dry analyzer that will accurately measure CO_2 concentration. The system is usually set up as a closed loop, but recently CO_2 flux measurements have been taken from open-topped chambers where air is pumped from an open collar into a drying trap and IRGA/data logger system. The soil CO_2 flux is determined by calculating the change in CO_2 concentration over time within the system. If the system is in a closed arrangement, then CO_2 can build up inside the chamber and cause a negative feedback on the gradient of CO_2 out of the soil resulting in a decrease in flux rate. The open-topped system is meant to bypass this concentration saturation problem that the closed-topped systems can acquire over time.

A disadvantage of the chamber systems in measuring flux is that these devices provide point measurements of CO_2 flux in a location. Typically, soil CO_2 flux can vary dramatically over an ecosystem. Typically, soil CO_2 flux increases under plant communities and adjacent to tree stems[62]. This is often due to increased nutrient, water, temperature, and microbial communities under and adjacent to plants (in the rhizosphere). As a result, point measurement from soil chambers are not enough to get an accurate estimate of flux from a region. Therefore, atmospheric column measurements, through tower or aircraft arrays provide better estimates of regional CO_2 flux.

Carbon and Oxygen Stable Isotope Ratios

In terrestrial settings, stable isotope ratios of CO_2 are used to determine the origin of the carbon and oxygen in the CO_2, the pathway the CO_2 has taken, the impact of the local meteorology on the terrestrial system, the type of ecosystem the CO_2 has originated from, and the amount of CO_2 flux taking place within the reservoirs of an ecosystem. Stable isotopes of CO_2 have been measured since the 1950's[63] and carbon was the premiere element of interest to the atmospheric community because it directly correlated (inversely) to the concentration of CO_2[54]. It was believed that the carbon isotope signature was dominated by land through photosynthesis and respiration and that land provided one value for carbon isotopes in CO_2. This value was –26.2 ‰. The geochemical community believed that they could use this value, coupled with the concentration changes in CO_2 in the atmosphere to determine the amount of atmospheric CO_2 originating from the land versus the oceans[64], as the ocean value for carbon was thought to be –2 ‰[65]. In the 1990's, it was determined that the carbon isotope value of CO_2 originating from land was not –26.2 ‰, but could vary as high as –19.5 ‰[66] due to plants with photosystems that incorporate a 4 carbon compound (C4 plants). In the 200's, it was determined that ecosystems of varying age could change the regional carbon isotope signature [67] and that local meteorology could also change the regional carbon isotope signature[68]. In fact an ecosystem could respond within 4 days of a meteorological event (rainfall) and change the regional carbon isotope signature[69]. Therefore, it has now been determined that the carbon isotopes of CO_2 can change dramatically in terrestrial ecosystems.

Plants, microbes, and soil types in terrestrial settings control stable carbon isotopes of CO_2. Specifically, the plant type (either C4 or C3) can change the carbon isotopes respired by 10 ‰; the microbe communities can change the CO_2 respired from soils by 2.5 ‰ (microbes vary in activity and respond differently to temperature, moisture and nutrient variation); the soil type can impact the CO_2

respired from soils by 5 ‰ (through diffusion and carbonate concentrations). The carbon isotopes of CO_2 are also impacted by local meteorology through variations in respired photosynthate from the leaves, stems, and roots of plants due to stomata closure in drought stressed conditions[68].

Water dominates the oxygen isotope signature of CO_2. Specifically, the oxygen in CO_2 (atmosphere, plant, and soil) will exchange with the local condensed water and the oxygen isotopes in the water will be completely transferred to the CO_2 (though there is a fractionation effect depending upon the temperature in which the exchange took place[70,71]. Therefore, the precipitation in an ecosystem will dominate the oxygen isotope signature in the CO_2 respired from the soils[72]. There are slight variations in the oxygen isotopes found in soil water due to evaporation influences in the upper soil column which might impact the CO_2 respired (this will vary with soil type, respiration flux, and evaporation rate) [73]. The stem water found within plants originated from the roots and does not become fractionated during the transport from root to stem[74]. As a result, the oxygen isotopes within stem tissues can be used to determine rooting depth if the oxygen isotopes of the soil column is determined[75]. The CO_2 respired or released from leaf tissues will have a more enriched oxygen isotope signal than the soils and local precipitation water due to evapotranspiration taking place at the leaf surface [76]. Often times, there can be as high as a 10‰ shift from local soil water to leaf water. As a result, oxygen isotopes of atmospheric CO_2 within an ecosystem have been used to partition the amount of CO_2 originating from the soils versus the plants[77].

Typically, isotopes of CO_2 are measured on mass spectrometers on air samples taken with glass flasks in the [78]. This constrains the amount of samples that can be collected within the field (usually maxing out at 40 samples). Recently, a new laser system has been designed by Campbell Scientific to measure carbon isotopes real time in the field. Here one point location can be measured over time[69]. There is a need to look at spatial analyses of isotopes in the field. This has not been done yet, but future work needs to go in this direction.

LIght Detection And Ranging (LIDAR)

Light Detection And Ranging (LIDAR) is potentially one of the more powerful techniques for terrestrial sequestration MMV. It was first reported by R.M. Schotland in 1966 as a means of evaluating the atmospheric water content. It has since been developed for a variety of activities including spatially resolved chemical detection, laser altimetry, and feature characterization. In fact, LIDAR is such a broad topic that it could consume several different reviews alone and has been reviewed by Measures. Here, we will focus on the spatially resolved chemical detection of atmospheric CO_2.

The details of a specific LIDAR system vary substantially depending on the intended application. A very general and overly simplified description of a LIDAR system is described here while additional details can be found in later sections of the paper and elsewhere. LIDAR involves directing a pulsed laser at a specific wavelength at the region or target of interest and the selection of the laser and frequency will depend on the nature of the target of interest. For CO_2 detection, one selects a laser with an optical frequency that will be absorbed by CO_2. This illuminating laser beam is usually modified and filtered to the optical characteristics. Most systems also employ a monostatic configuration where the laser is directed through the center of the telescope used to collect the return signal.

This return signal is a result of either scattering off of atmospheric aerosols or from a hard target at a fixed located some distance from the source. The return signal is processed through a spectrum analyzer such as a monochromator to further reduce background and onto a detector such as a CCD array. The detector electronics are carefully selected such that the time it takes for the laser to reach the target and obtain a return signal are used to determine the range to the target.

Differential Absorption LIDAR (DIAL) is a specific type of LIDAR that is more common today for quantitative chemical detection. DIAL fundamentally involves acquiring at least two signals, one at a frequency that is absorbed by the target gas (CO_2 for example) and one frequency that is slightly detuned from an absorption feature. The concentration of CO_2 is proportional to this change in signal and the range to target.

Most of the work is developing a robust LIDAR system capable of monitoring CO_2 has been in the laser development area. One needs to select a laser that is capable of probe frequencies that are free from absorption by other atmospheric species. Secondly, the absorption coefficient must be carefully balanced such that it is strong enough to be detected over the probe range desired but not so strong that the probe is completely absorbed before reaching the detector. Menzies and Tratt completed a detailed study of the optimal frequencies to quantitatively measure atmospheric CO_2 as a function of altitude. They employed the HITRAN96 database to identify the specific spectral lines from 1.4 to 2.2μm with large spectral line strengths and used the GENLN2 radiance code to calculate the transmittance. They concluded that only three lines within the 1.4 to 2.2μm region were optimally suited for CO_2 detection, 1.57, 1.60 and 2.06μm. They further determined that probing at 2.06μm was more ideally suited to probe in the lower troposphere and the boundary layer where those interested in terrestrial source and sinks will be of most interest.

Laser systems that emit in the 1.5μm region have been largely developed to support the telecommunications community. Consequently, there are a number of potential sources, amplifiers, electronics and detectors that are ideally suited to the 1.5μm region. There are however, very few laser sources that operate efficiently in the 2 - 3μm region. Several research groups have been developing diode pumped Tm,Ho:YLF (75mJ/pulse) and Tm,Ho:LuLF (220mJ/pulse) lasers that operate at 2.05μm specifically for CO_2 and H2O DIAL systems. Perhaps one of the more important benefits of these 2μm lasers is that they are considered eye-safe.

A team at NASA's Langley Research Center led by Grady Koch is clearly at the forefront in the development of DIAL for CO_2. The recently reported a series of measurements with their Tm,Ho:YLF based DIAL system over a 1200m distance and validated the results against a LI-COR system. Their measurements demonstrated a precision of 1 – 2% which was sensitive enough to monitor part of the CO_2 diurnal cycle.

Conclusion

Both LANL and Montana State University reviewed many different types of diagnostics that may be ready for a Phase 2 demonstration program and terrestrial sequestration deployment and demonstrations. While the Partnership finds the deployment of a large portion of our portfolios to be scientifically valuable we are recommending that the focus be on three technologies. This includes Laser Induced Breakdown Spectroscopy (LIBS), Visible and Near Infrared (VINR), and Stable Isotope analysis. Technology transfer will continue as a priority.

Summary Table for Terrestrial Sequestration MMV Systems

Technology	Application	Comment
Land Use Change Detection and Soil C Modeling - Remotely Sensed Imagery	Monitoring and verification for regional or larger expanses	
Logistic regression (LR) of Landsat Enhanced Thematic Mapper Plus (ETM+) imagery	Map tillage practices; identify crop types and estimate yields; estimate proportion of crop residue	>95% accuracy verifying fields in Midwest
Logistic regression (LR) using Landsat Thematic Mapper (TM)	Same	93% accuracy verifying fields and 70-77% accuracy verifying watershed in Midwest
Logistic models applied to Ikonos imagery principal components	Same	~80% accuracy verifying fields in Midwest
Crop Residue Index Multiband (CRIM) model using ETM+ imagery	Same	79-80% accuracy verifying watershed in Midwest
Radar satellite data	Estimate proportion of crop residue	
Laser induced fluorescence.	Same	
Direct Soil Measurements		
Visible and Near Infrared Spectroscopy (VNIR)	Quantify organic and inorganic soil carbon	Minimal problems with non-linear distortions and inversions; instrumentation readily employed in the field
Mid-Infrared (MIR) Spectroscopy	Quantify organic and inorganic soil carbon	Organic absorption features are sharper and more distinct than VNIR; field-portable MIR largely experimental
Laser Induced Breakdown Spectroscopy (LIBS)	Quantitative measurements of soil carbon	Readily adaptable to field-portable instrument; excellent analytical precision and accuracy
Raman spectroscopy	Quantify organic and inorganic soil carbon	Distinguish between organic and inorganic carbon

Summary Table for Terrestrial Sequestration MMV Systems (continued)

Technology	Application	Comment
Carbon Soil Flux & Atmospheric Measurements		
Carbon flux traps	Determine movement of carbon from terrestrial environment	Open- and closed-topped chambers equipped to measure co_2 concentration; only provides point measurements of co_2 flux.
Carbon and oxygen stable isotope ratios	Determine: origin of carbon and oxygen in CO_2; CO_2 pathway; impact of the local meteorology; type of ecosystem generating CO_2; amount of CO_2 flux.	Air samples that can be collected within the field and measured with measured on mass spectrometers in lab; real time analysis in the field with lasers still experimental.
Light Detection And Ranging (LIDAR)	Spatially resolved chemical detection of atmospheric CO_2.	Pulsed laser at a specific wavelength at the region or target of interest

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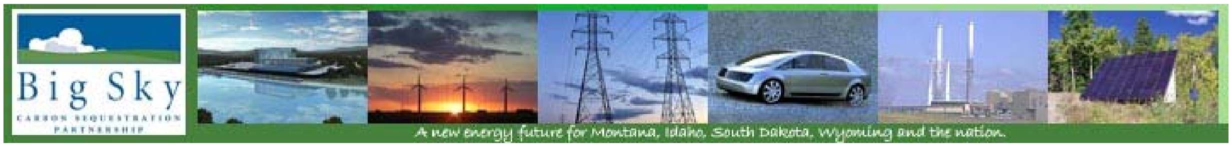

Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 16: Report on Common Methodology for Assessing Tradeoffs Among Carbon Sinks

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Assessing the Economic Potential for Carbon Sequestration and Quantifying Regional Carbon Supply Curves

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The common methodology for assessing both the economic potential for carbon sequestration and the tradeoffs among carbon sinks in the Big Sky region utilizes an economic framework that incorporates the cost of changing land use management in the case of terrestrial sequestration and the costs of injecting carbon dioxide into alternative geological formations in the region. The analysis will provide an economic understand of the capacity of the potential sinks and quantify the economic impacts of terrestrial and geologic C sequestration at both the project and regional levels. In this deliverable, we (i) addresses the economic potential for terrestrial sequestration and summarizes a conceptual framework for quantifying the supply curves for carbon in the case of terrestrial sequestration; (ii) summarize results for terrestrial carbon sequestration in the Golden triangle grain producing areas of MT that was done in conjunction with support from USDA; and (iii) consider the expansion of this framework to other geological and terrestrial sinks. In particular, under phase II the Partnership will expand this framework to include its geologic field tests which will culminate in a regional carbon (C) supply curve(s) showing at each price of C, the total amount of C that could be sequestered in the region. This framework will be a valuable tool to enable the Partnership, its industry members and the region to assess the economic potential of all its sequestration options, on a common basis.

Assessing the Economic potential for terrestrial sequestration: Combining biophysical and economic models and analysis

The Partnership's economic analysis in Phase I focused on terrestrial sequestration at an aggregate level. Research on the technical potential for forestry and agricultural sequestration has been ongoing for over a decade and existing methods are scientifically sound. Analysis of economic potential has been developed and published in peer-reviewed scientific journals by team members and is considered state-of-the-art (Antle et al. 2001, 2002, 2003, 2004, and 2005; Plantinga 1997; Plantinga, Mauldin, and Miller 1999; Plantinga and Mauldin 2001; Plantinga and Ahn 2002; van't Veld and Plantinga, forthcoming).

Estimates of technical potential for soil sequestration within the region (ID, MT, WY, and SD) in cropland are in the range of 2 million MgC/yr over 20 years (Antle et al. 2005). Estimates of economic potential are represented as supply curves of C sequestered as a function of economic incentives to farmers. Estimates show that about 50% of the technical potential could be achieved at a price less than $50/MgC, with the technical potential at a price less than $200/MgC. Transaction costs could reduce the economic potential at low prices for C, but the costs decrease in relative terms as the value of C increases.

Estimates of the technical/economic potential for sequestration in grazing lands do not exist. Because the region has a large share of the U.S. total, the Partnership will develop these estimates. Estimates of the technical potential for regional sequestration on forested lands are available from Phase I as a separate deliverable. In Phase II, the Partnership will produce estimates of the economic potential for forestry using technical data from pilots and existing forestry models to assess large-scale deployment.

Conceptual framework

This section extends the economic literature on C sequestration by showing how the integrated assessment approach to analysis of agricultural production systems developed in earlier research by Antle and Capalbo (2001) can be used to estimate the marginal cost of sequestering C in soil. This approach to the analysis of soil C links biophysical data and models with economic data and models on a site-specific basis. In this way, the analysis can account for the spatial heterogeneity of biophysical conditions (soil C sequestration rates) and economic decisions (land use) and how these conditions interact to determine the marginal cost of sequestering C in soil.

Assuming that agricultural producers are initially utilizing those land use and management practices that yield the highest economic return, it follows that producers will adopt different practices that increase soil C if and only if there is a perceived economic incentive to do so. While there are many possible ways to design policies to sequester soil C, we have adopted the basic structure of a soil C contract program, where soil C can be purchased by either the government or a private entity.[2] Within a given region, let a contract pay the farmer g^{is} dollars per hectare per year for T years to change from management practice *i* to management practice *s* that sequesters additional soil C. Letting the total increase in soil C over the time period t = 0 to T from switching from *i* to *s* be $\Delta c^{is} = c_T^{\,s} - c_0^{\,i}$, the average increase is $\Delta c^{is}/T = c^{is}$ (metric tons per hectare per year). Although the time path for the increase in the stock of soil C in response to the adoption of improved practices is non-linear, the path is often approximated linearly with the annual average rate of soil C increase (e.g., see the soil C rates discussed in Watson et al.). Furthermore, because it is not practical to measure soil C rates accurately on an annual basis, we assume that these average annual rates are what would be actually measured and used in soil C contracts.

The per hectare capitalized value of the contract to the farmer to switch from *i* to *s* is

$$\sum_{t=1}^{T} g^{is}\,(1+r)^{-t} = g^{is}\,D(r,T), \tag{1}$$

where D(r,T) denotes the present value of $1 at interest rate r for T periods. The value of a C contract to the government or other purchaser of carbon depends on the soil C rate parameter c^{is} and the time period over which the practices are adopted. If the buyer of the carbon can sell the C for *p* dollars per metric ton, it follows that the value of the contract to the buyer is

$$\sum_{t=1}^{T} p\,c^{is}(1+r)^{-t} = p\,c^{is}\,D(r,T). \tag{2}$$

The equivalence of (1) and (2) implies that $g^{is} = pc^{is}$. If a program pays farmers g^{is} dollars per hectare per year for soil C sequestration, then the implicit price per metric ton being paid by the government or any other buyer of soil C is equal to g^{is}/c^{is}. Under the assumption of static price expectations for carbon, the payment per hectare per year to the farmer is equal to the value of the C sequestered per hectare per year. More generally, if prices are constant but the rate of increase in soil C varies with time, then it follows that $pk = g^{is}$, where $k = \sum_t c_t^{is}\,(1+r)^{-t}/D(r,T)$.

Producers will switch production practices if and only if the profits per hectare of their profit-maximizing practices are less than the alternative practices plus the payment per hectare. Let the total amount of agricultural land in a region be A hectares, and let the share of land in a given region that is entered into C contracts for switches from i to s be $z^{is}(g)$, where we have assumed that $g^{is} = g$ for all i, s that result in a positive amount of soil C accumulation and $g^{is} = 0$ otherwise. This region would sequester $C(g) = T \sum_i \sum_s c^{is} z^{is} (g) A$ metric tons of C, or $C(g)/T$ metric tons of C per year. The region's marginal cost function for sequestering soil C, $M(C)$, can then be defined as the correspondence between p and $C(g)$.

When a producer switches to alternative practices as part of the program the reduction in profitability, net of the payment, is the opportunity cost of entering into the contract. Given site-specific data on net returns, the opportunity costs differ across regions and thus an economic production model of land-use choices is needed to determine the share of land that would be entered into a specific type of contract as payment levels increase. An upward-sloping marginal cost curve for soil C in a region reflects the fact that different land units have different opportunity costs.

Given $M(C)$, the corresponding total cost can be calculated by integrating under the marginal cost curve adding any fixed transactions costs. Revenue generated by producers selling C contracts is equal to $R = pC(g)$ and the net benefit to producers is the usual producer surplus measure. In the case of a government payment program that pays farmers \$$g$ per hectare the total cost to the government is revenue R.

Thus the integrated assessment approach to assess the cost of agricultural soil C sequestration involves linking the output of two disciplinary models—an econometric-process simulation model and a crop ecosystem model—to quantify the responses of farmers to economic incentives to sequester soil C. The econometric-process model, which is discussed below, simulates expected returns to alternative production systems on a site-specific basis, in response to incentives provided through a policy that pays farmers to change land use or management practices. These expected returns are used to simulate the farmer's choice of production system for a given land unit. This simulation model utilizes the stochastic properties of the economic production models and sample data, so its output can be interpreted as providing a statistical representation of the population of land units in a given region. The crop ecosystem model provides estimates of the levels of soil C and productivity (yields) associated with each production system. Following the marginal cost presentation, simulated changes in production systems are combined with simulated changes in soil C to compute the implied marginal costs, government costs, and producer surplus associated with policies in given regions. Thus, the integrated assessment model provides answers to policy questions about the effects of different payment schemes on the quantity of carbon sequestered and the marginal cost of sequestering soil C, and how the costs vary spatially. This approach also provides a basis for estimating the value of using government-based carbon payments as a part of the policy options to offset greenhouse gas emissions.

Econometric-process model

In previous work, an econometric-process model was developed to model a producer's intensive- and extensive-margin production decisions. The motivation for the development of the econometric-process approach was the need to link economic analysis of production systems to site-specific bio-physical simulation models to assess the economic and environmental impacts of changes in policies, technologies, or biophysical conditions (Antle et al., 1999; Antle and Capalbo). Site-specific data are used to estimate the economic production models which are then incorporated into a simulation model that represents the decision making process of the farmer as a sequence of discrete and continuous choices.

The economic model is specified as follows: the production process of activity i at site j in period t is defined by a non-joint production function $q_{ijt} = f_i(\mathbf{v}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{jt})$ where **v** is a vector of variable inputs, **z** is a vector of allocatable quasi-fixed factors of production and other fixed effects, and **e** is a vector of bio-physical characteristics of the site (soils, topography, climate, etc.) (random terms are suppressed here for notational conv8enience). For expected output price p_{ijt}, the profit function is $\pi_{ijt} = \pi_i(p_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{jt})$. If a crop is not grown, the land is in a conserving use with a return of π_{hjt}. Define $\delta_{ijt} = 1$ if the i^{th} crop is grown at site j at time t and zero otherwise. The land-use decision on site j at time t is

$$(3) \qquad \max_{(\delta_{1jt}, \ldots, \delta_{njt})} \sum_{i=1}^{n} \delta_{ijt}\, \pi_i(p_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{jt}) + (1 - \sum_{i=1}^{n} \delta_{ijt})\, \pi_{hjt}.$$

The solution takes the form of a discrete step function

$$(4) \qquad \delta^*_{ijt} = \delta_i(\mathbf{p}_{jt}, \mathbf{w}_{jt}, \mathbf{z}_{jt}, \mathbf{e}_{jt}, \pi_{hjt}),$$

where $\mathbf{p}_{jt}$ is a vector of the p_{ijt} and likewise for the other vectors. Using Hotelling's lemma, the quantity of the i^{th} output on the j^{th} land unit is given by

$$(5) \qquad q^*_{ijt} = \delta^*_{ijt}\, \partial\pi_i(p_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{jt})/\partial p_{ijt} = q_{ijt}(\mathbf{p}_{jt}, \mathbf{w}_{jt}, \mathbf{z}_{jt}, \mathbf{e}_{jt}, \pi_{hjt}).$$

Variable input demands are likewise given by

$$(6) \qquad \mathbf{v}^*_{ijt} = -\, \delta^*_{ijt}\, \partial\pi_i(p_{ijt}, w_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{jt})/\partial w_{ijt} = v_{ijt}(\mathbf{p}_{jt}, \mathbf{w}_{jt}, \mathbf{z}_{jt}, \mathbf{e}_{jt}, \pi_{hjt}).$$

The econometric process approach combines the econometric production model represented by the supply and demand functions given in (5) and (6) with the process-based representation of the discrete land-use decision represented by (3) and (4). The model simulates the producer's crop choice, and the related output and costs of production at the field scale over time and space. This simulation structure utilizes the stochastic properties of the econometric models and the sample data, so its output is interpreted as providing a statistical representation of the population of land units in the region.

By operating at the field scale with site-specific data, the simulation can represent spatial and temporal differences in land use and management, such as crop rotations, that give rise to different economic outcomes across space and time in the region. Moreover, because of the detailed representation of the production system, the econometric-process model can be linked directly to the corresponding simulations of the crop ecosystem model to estimate the impacts of production system choice on soil C. Each field in the sample is described by area, location, and a set of location-specific prices paid and received by producers, and quantities of inputs. Using sample distributions estimated from the data, draws are made with respect to expected output prices, input prices, and any other site-specific management factors (e.g., previous land use). The econometric production models are simulated to estimate expected output, costs of production, and expected returns. The land-use decision for each site is made by comparing expected returns for each production activity. These spatially and temporally explicit land-use decisions are combined with simulated outputs of the crop ecosystem model to assess changes in soil C. It is the spatial heterogeneity that needs to be captured if we are to develop supply curves for terrestrial carbon that reflect the regional and county-level variations. These would be essential to use this framework to assist policy-makers designing carbon management policies or industry interested in participating in a carbon trading market.

An Illustrative example from Montana dryland crop practices: constructing supply curves for C

The econometric production model described above was estimated using cross-sectional data from a sample of 425 farms and over 1200 fields for the 1995 crop-year that are statistically representative of the USDA's Major Land Resource Areas (MLRA) in the grain-producing regions of Montana. The MLRAs were stratified into sub zones (sub-MLRAs) based on high or low precipitation according to historical climate data. Log-linear production models for winter wheat, spring wheat, and barley were estimated using nonlinear three stage least squares. The parameter estimates are reported and discussed in Antle and Capalbo (2002).

Biophysical Process Model

The crop ecosystem model known as Century is utilized to represent the processes controlling crop growth, water, nutrient, and organic matter dynamics that determine the productivity of agricultural ecosystems (Parton et al. 1994; Paustian, Elliott, and Hahn, 1999). Century is a generalized-biogeochemical ecosystem model which simulates C (i.e., biomass), nitrogen and other nutrient dynamics. It includes submodels for soil biogeochemistry, growth and yield submodels for crop, grass, forest and savanna vegetation and simple water and heat balance. For use in agricultural and grassland ecosystems, the model incorporates a large suite of management options including crop type and rotation, fertilization, tillage, irrigation, drainage, manuring, grazing, and burning. The model employs a monthly time step and the main input requirements (in addition to management variables) include monthly precipitation and temperature, soil physical properties (e.g., texture, soil depth) and atmospheric nitrogen. For the current application, soils and climate data for each of the sub-MLRAs are used as Century model inputs in addition to management variables such as crop type and rotation, fertilization and tillage practices. The variability in the levels of soil C predicted by the Century model across the six major crop producing sub-MLRAs and production systems in Montana is shown in Figure 1. Simulations of the crop-fallow, continuous cropping, and permanent grass production systems with the Century model show that the equilibrium levels of soil C under a crop-fallow rotation range from 3–7 MT per hectare less than continuous grass over a twenty year horizon, and that soil C levels under permanent grass range from 1–5 MT per hectare less than under continuous cropping depending upon sub-MLRA. In sub-MLRA 52-low, soil C levels under permanent grass compare favorably with soil C levels under a continuous cropping system. The variability across sub-MLRAs reflects the heterogeneity in biophysical and climatic conditions, which translates into different equilibrium levels of soil C for the production systems.

Simulation of Soil C Levels and Costs

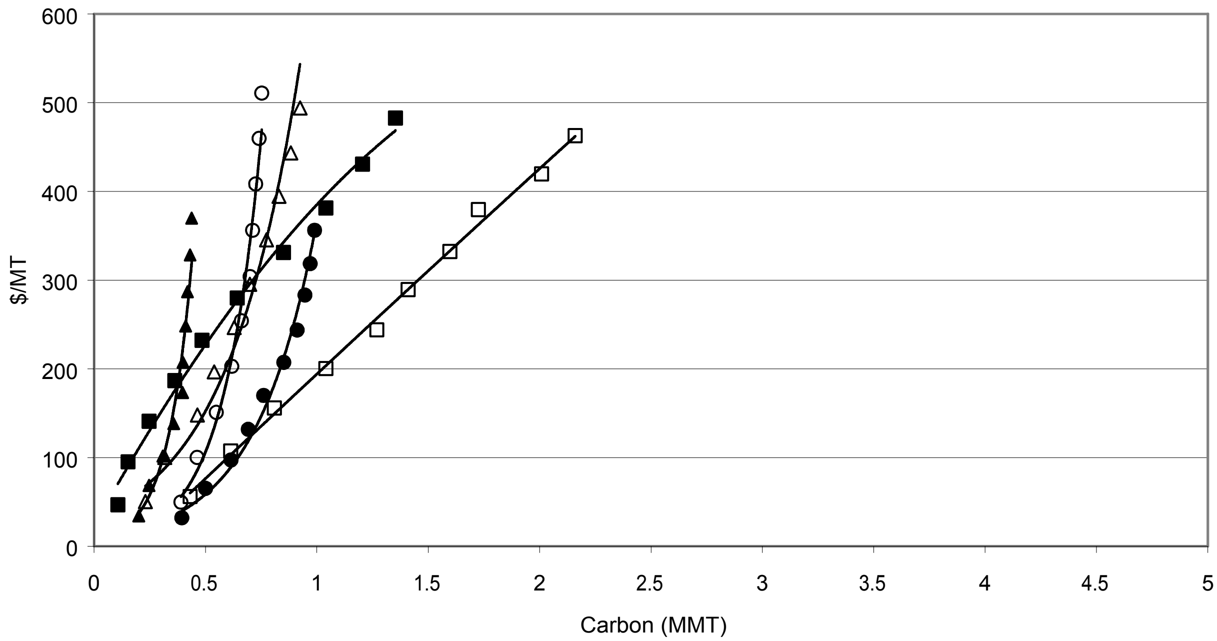
The economic simulation model selects the land use that maximizes expected returns for each sample field for each policy scenario that is investigated. When using this model to address soil C sequestration analysis, the net returns are augmented by the per hectare payment, g, to switch to management and land uses that would sequester additional carbon. The economic simulation is executed over a time horizon (approximately 20 years) sufficient to reach an equilibrium for each policy setting g.

The land-use patterns are then summarized for each sub-MLRA for each policy setting in the form of proportions $z^{is}(g)$ of land reallocated from activity i to activity s. The Century model is used to simulate the soil C levels and annual average rates for each land use in each sub-MLRA over a given time horizon. Given the land-use changes within each sub-MLRA based on maximizing expected returns, we calculate the levels of soil C sequestered and the resulting C sequestration costs using the procedures discussed earlier.

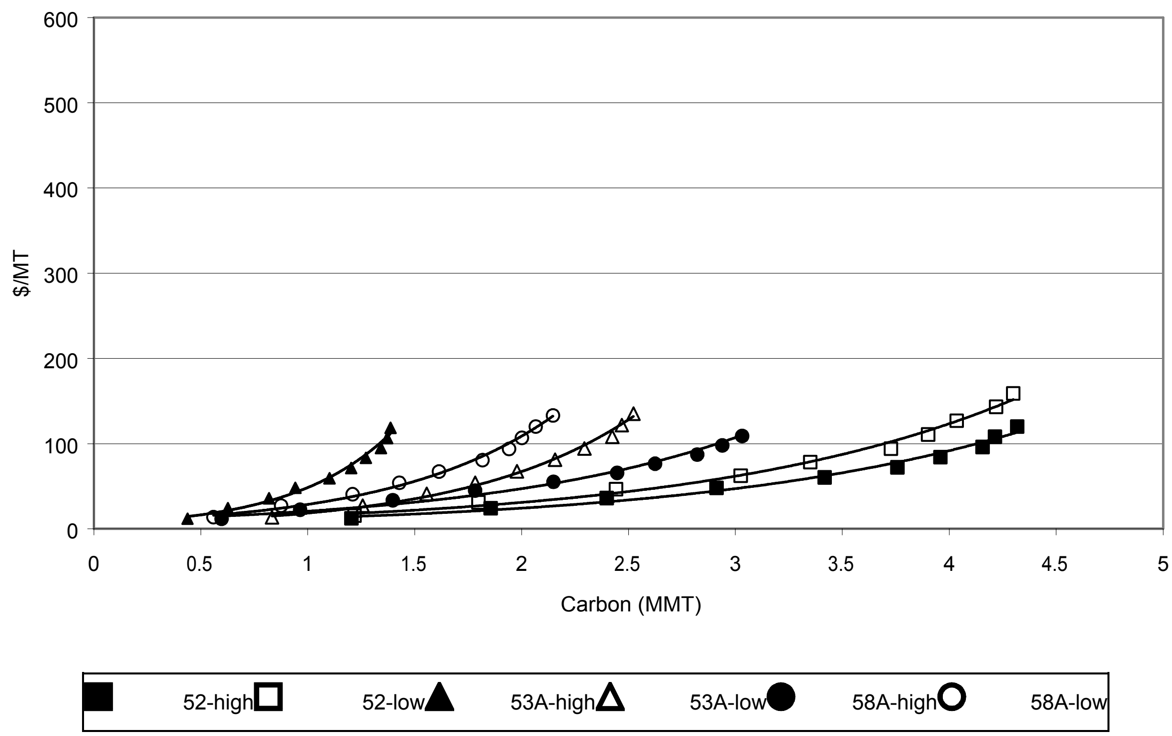
We have also applied the integrated assessment approach to quantify the costs of sequestering C from changes in land use and management practices and compare the relative efficiency of sequestering soil C for two alternative policies relevant to the Northern Plains region: one that provides producers with payments for converting crop land to permanent grass (PG) (similar to the Conservation Reserve Program in the United States), and one that provides payments to farmers to switch from a crop-fallow rotation or permanent grass to a continuous cropping system (CC). Our analysis shows that the economic efficiency of C sequestration depends on site-specific opportunity costs of changing practices, the rates of soil C sequestration associated with changing practices, and the policy design. (See illustrative supply curves for C in Figure 2). Using this framework we can offer an assessment of the competitiveness of agricultural soil C sequestration in the Northern Great Plains with industrial emissions reductions and forestry sinks in other parts of the United States, and geological sinks. This is the thrust of our future efforts on assessing the carbon sinks in the Big Sky region using a common metric.

Table 1 presents a comparison of the quantity of soil C sequestered over the twenty year time horizon and undiscounted government costs and estimates of producer surplus, aggregated across all sub-MLRAs.[4] In order to sequester approximately 7 MMT of C (more precisely 6.76 MMT in the PG scenario and 7.61 MMT in the CC scenario), the PG policy would involve government outlays that are more than ten-fold larger than the CC policy, and total costs that are nearly twice as high. From taxpayers' point of view the CC policy is far superior to the PG policy, providing much more soil C sequestered for a given government cost. From producers' point of view, the PG policy provides much larger income transfers per metric ton of soil C sequestered. These differences in the efficiency of the two policies can be measured at either the aggregate level or on a sub-MLRA basis. Over all sub-MLRAs, the efficiency gains associated with sequestering approximately 7 MMT of C using the CC policy rather than the PG policy amounts to over $430/MT of C at the margin.

The effects of spatial heterogeneity on government costs and benefits to producers are illustrated in Table 2 which compares similar data for sub-MLRAs 52-high and 58A-low. Within the payment levels considered in the simulation model, the CC policy always sequesters more C than the PG policy and the marginal costs per MT of C are lower. As payment levels are raised beyond the $125/hectare under the PG policy, the increases in soil C are minimal, as less productive land is switched into grass at a decreasing rate. Such an intensive switch to permanent grass may actually cause a decline in the overall soil C levels if the acreage is taken from the land that was continuously cropped. For the CC policy, payments in excess of $50/hectare do not add appreciably more soil C because the share of land in continuous cropping at payment levels of $50/hectare is at least 90% of the cropland acreage. For a given marginal cost of producing soil C, the PG policy provides a higher producer benefit in sub-MLRA 58A-low, where the opportunity cost of switching to permanent grass is relatively low, as compared to sub-MLRA 52-high. However, the CC policy provides producer benefits roughly in proportion to cropped area due to the similar opportunity cost of switching from crop-fallow to continuous cropping in the two areas.



(a) Permanent Grass Payment Policy



(b) Continuous Cropping Payment Policy

Figure 1. Marginal cost for soil C by sub-MLRA and policy scenario

Table 1. Levels of Carbon Sequestered, Costs to Government, and Producer Surplus, by Policy Scenario for All Sub-MLRAs

A. Permanent Grass Payment Policy

Payment Level ($/hectare/year)	Quantity of Soil C Sequestered (MMT)	Cost to Government (Million $)	Producer Surplus (Million $)
$25	2.37	216.9	81.3
$50	3.71	670.2	325.1
$75	4.82	1305.3	673.0
$100	5.82	2121.5	1135.4
$125	6.76	3084.0	1674.4

B. Continuous Cropping Payment Policy

Payment Level ($/hectare/year)	Quantity of Soil C Sequestered (MMT)	Cost to Government (Million $)	Producer Surplus (Million $)
$10	7.61	201.7	66.4
$20	12.22	647.1	303.4
$30	15.54	1226.3	639.6
$40	17.28	1818.6	1063.5
$50	18.25	2404.9	1531.2

Table 2. Simulation of Land-use Changes, Carbon Sequestration Levels, and Costs for Sub-MLRAs 52-high and 58a-low

A. Permanent Grass Payment Policy[a]

Area	Payment Level ($/hectare/year)	Change in Share of Land in Permanent Grass	Quantity of Soil C Sequestrated (MMT)	Marginal Cost of Carbon Sequestrated ($/MT)	Average Cost of Carbon Sequestrated ($/MT)	Government Costs (million $)	Producer Surplus (million $)
MLRA 52-high	$25	0.04	0.15	95	67	14.6	4.2
	$50	0.10	0.37	186	123	67.6	22.9
	$75	0.17	0.64	279	185	179.7	60.7
	$100	0.28	1.04	381	247	396.7	138.8
	$125	0.37	1.35	482	294	653.4	255.4
MLRA 58A-low	$25	0.23	0.46	100	55	46.2	20.4
	$50	0.31	0.62	203	76	125.3	78.0
	$75	0.35	0.70	304	95	213.0	146.2
	$100	0.37	0.73	408	105	296.3	219.4
	$125	0.38	0.75	510	117	384.7	294.8

B. Continuous Cropping Payment Policy[b]

Area	Payment Level ($/hectare/year)	Change in Share of Land in Continuous Cropping	Quantity of Soil C Sequestrated (MMT)	Marginal Cost of Carbon Sequestrated ($/MT)	Average Cost of Carbon Sequestrated ($/MT)	Government Costs (million $)	Producer Surplus (million $)
MLRA 52-high	$10	0.33	1.86	24	16	44.7	14.3
	$20	0.51	2.91	48	24	139.6	67.0
	$30	0.66	3.76	72	34	271.0	143.1
	$40	0.73	4.15	96	40	399.3	235.5
	$50	0.75	4.32	120	42	518.1	337.6
MLRA 58A-low	$10	0.32	0.88	27	18	23.7	7.2
	$20	0.51	1.43	54	28	77.2	37.0
	$30	0.65	1.82	81	39	146.4	74.7
	$40	0.70	2.00	107	44	213.8	124.9
	$50	0.75	2.15	133	50	285.9	177.8

[a] Baseline share of land in permanent grass: MLRA 52-high=0.07, MLRA 58A-low= 0.36

[b] Baseline share of land in continuous cropping: MLRA 52-high=0.15, MLRA 58A-low=0.13

Total hectares: MLRA 52-high=0.68 million, MLRA 58A-low=0.36 million

Competitiveness of Agricultural Soil C Sequestration

Our analysis shows that soil C sequestered by grain producers in the northern Great Plains region under the CC policy could be competitive with C sequestered from afforestation or through industrial emissions reductions. A recent study of afforestation in Maine, South Carolina, and Wisconsin indicates that the average cost estimates are in the range of $45–$60 per MT of C (Plantinga, Mauldin, and Miller; Plantinga and Mauldin). Stavins estimates that the average cost per MT of C sequestered through afforestation to be in the range of $38 for the Delta states to approximately $70 for the United States. These are comparable to the range of the average costs reported in Table 2 for the CC policy although the quantities of soil C that can be sequestered at these costs differ. However, as we noted earlier in the discussion of soil C permanence and contract duration, the costs of sequestering soil C would be higher if contracts were extended over a longer time period to ensure that C sequestered would remain in the soil, or if payments were not targeted to land uses that changed. How much higher the costs would be depends on the duration of the contracts and the share of land currently in production systems that generate the greatest levels of soil carbon.

Studies of the cost of reducing C emissions through C taxes in the United States found that compliance with the Kyoto protocol would require C to be priced in the range of $100 per metric ton (Wiese and Tierney, 1996). A U.S. government study that assumed C emissions credits could be traded internationally found that C could be priced as low as $14 to $23 per metric ton (Council of Economic Advisers). Experience with the SO_2 trading system in the United States showed that large-scale energy models are likely to overestimate the costs of attaining emissions reductions (Joskow, Schmalensee, and Bailey, 1998). Partly based on this experience, and based on evidence about the cost of reducing industrial CO_2 emissions, Sandor and Skees suggest that a market in tradeable C emissions credits could price C in the range of $20 to $30 per MT of C. Kopp and Anderson argue that these low values for C are not likely given the various practical considerations that may limit the effectiveness of a global emissions trading system. They argue that with trading only among the developed countries as would be allowed by the Kyoto protocol, C emissions costs would be at least $72 per ton. Under the assumption that the United States would meet a larger share of its emissions reductions commitments through reductions in energy consumption, the higher estimated costs of compliance obtained in earlier studies become relevant.

Thus, we developed a conceptual framework for analysis of the economic potential for C sequestration in agricultural soils which shows that the economic efficiency of soil C sequestration depends on site-specific opportunity costs of changing practices and on the rates of soil C sequestration associated with changing practices. We then showed how an integrated assessment approach to simulation modeling can be used to implement this analytical framework and to derive estimates of the costs of agricultural soil C sequestration. Linking a site-specific econometric-process model of production system choice with a crop ecosystem model designed to simulate soil C dynamics, we obtain estimates of the marginal costs of sequestering C that account for the spatial heterogeneity in agricultural land use and in rates of soil C sequestration.

Our analysis of dryland grain production systems in the Northern Plains shows how site-specific land-use decisions change in response to policy incentives, and how this induces changes in soil C within a given region. The analysis shows that a policy providing payments for converting crop land to permanent grass is a relatively inefficient means to increase soil C, with marginal costs per MT of C ranging from $50/MT to over $500/MT. In contrast, payments to adopt continuous cropping were found to produce increases in soil C at a marginal cost ranging from $12 to $140 per MT of C even in the less productive regions of the northern Great Plains. For this policy, the average costs do not exceed $50 per MT of C.

Areas for expansion of the terrestrial analysis are noted later.

Toward Regional Economic Assessment of Sequestration Technologies and Potential for Large Scale Deployment

The thrust of the regional economic assessment is to better integrate geological and terrestrial analyses of economic potential, culminating in a regional C supply curve. In phase I we have designed the key parameters that would need to be quantified in order to find a common metric for evaluating the different sequestration options in terms of relative efficiency and magnitude as well as other desirable characteristics such as environmental stability and long term storage. Combining results provides a regional C supply curve that shows, at each price of C, the total amount of C that could be sequestered in the region (Figure 2). The analysis of each sequestration technology is linked to the large-scale deployment assessment to show which technologies would be viable at alternative C prices, their location, and how much C can be sequestered. The development of the C supply curve(s) will be of significant value in assessing carbon potential across options.

Using the regional supply curve as a policy tool, one of the objectives of the regional partnerships is to provide research and demonstration projects that will ultimately contribute to a downward shift in the supply curve for carbon, i.e., lower the cost of sequestering a unit of carbon.

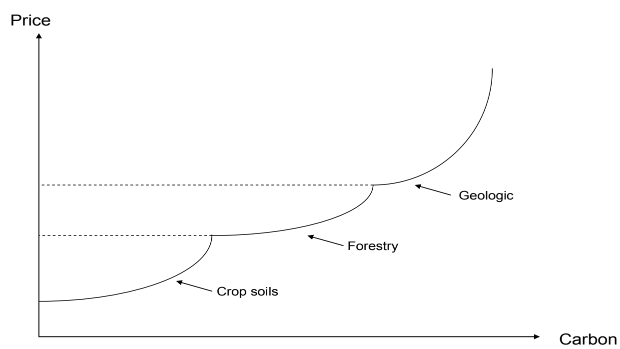


Figure 2. Regional Carbon supply curve.

Economic Potential for Geological Sequestration

The economic team will obtain key technical parameters and economic data for each geologic field validation test system from project scientists, industry members and studies. (e.g., costs of capture, transport, and processing CO_2, costs of drilling and pumping, management labor costs, MMV activity costs, quantity and value of oil or methane recovered, quantity of C sequestered). These data are used to estimate investment and operating costs as the net of any revenues from resource recovery for potential sequestration sites determined according to the data in the Carbon Atlas started in Phase I, state geological surveys, etc. An economic simulation model is the basis to determine, for a specified price of C, whether the sequestration option is economically feasible at any given site. The C supply curve for each option is then derived, by summing across sites, the quantity of C that would be sequestered at each C price, and an overall sequestration supply curve is derived by summing the supply curves across options. Sensitivity analysis is performed to investigate uncertainties over model parameters (technical coefficients, prices of oil and methane, MMV costs, etc.). The Partnership's geologic industry member, Energy Northwest, will provide in-house expertise to assist with obtaining the needed parameters and for assessing the economics of the carbon sequestration options as they pertain to its proposed IGCC power plant. The deliverables from this activity are needed for developing the company's CO_2 mitigation plan.

Deriving an overall sequestration supply curve is complicated by several factors:

Interdependencies across space and time—The costs of a sequestration project at one site is likely to depend significantly on whether sequestration is also simultaneously undertaken at nearby sites, or sequentially at the same site using a different technology.

Uncertainty and timing—The derivation of sequestration supply curves for EOR and ECBM projects (thereby the overall supply curve) is complicated by the inherent uncertainty of oil and gas prices and the fact that investments to undertake EOR or ECBM reversible at great expense. One implication is that sequestration costs are also inherently uncertain, since these costs must be calculated based on the net of the revenues from oil or gas recovery.

Permanence. Unless CO_2 is mineralized (chemically bound to substances to form solid compounds) there is a potential for leakage. Therefore, sequestration rates will be adjusted for possible leakage as long as the per-ton value of sequestration does not rise faster than the discount rate.

Safety liability, and risk assessment. Accidental release of a significant amount of CO_2 from pipelines or geologic sites near human populations could result in harm. Preventative measures add costs as does damage liability for any accidents that might occur. The Partnership will use a probability risk assessment methodology with three major elements: hazard identification, event and failure quantification, and risk characterization. Identifying and quantifying potential failure modes at a CO_2 storage site, during the injection as well as after the project lifetime, is key. Risk is assessed and quantified by effects of the likelihood and the severity of a failure/event. Overall risk and repair costs will be estimated and incorporated into the economic/risk assessment for each sequestration technology.

Data. Data on drilling costs are derived from the American Petroleum Institute's annual survey, the *Joint Association Survey on Drilling Costs.* Oil and gas field capital and operating costs are obtained from *Costs and Indices for Domestic Oil and Gas Field Equipment and Production Operations,* provided by Energy Information. Pipeline construction costs are obtained from True, Warren R., *Oil & Gas Journal* (various articles). Geological data are derived from the Carbon Atlas, state geological surveys, state oil and gas regulatory commission databases, and USGS oil and gas resource assessments. Technical data on both C capture and the sequestration potential of various geological options are obtained from research reports of ongoing pilot or commercial-scale projects.

Economic Potential for Terrestrial Sequestration

Agricultural and forest sequestration analyses will employ econometric models in which actual land-use changes are analyzed to estimate relationships between land-use choices and relative prices. Therefore, factors affecting land-use decisions in practice are captured yet they are difficult to include in engineering and optimization models (Plantinga, Mauldin, and Miller 1999; Stavins 1999; Antle and Capalbo 2001). Econometric models provide the basis for simulations of sequestration incentives, leading to estimates of supply curves. The agricultural analysis builds on earlier work by Antle et al. (2001, 2005) using county-level data and C rates estimated with the Century model (see the summary discussion in earlier sections of this paper). The forestry analysis builds on earlier work by Lubowski, Plantinga, and Stavins (2005) (hereafter, LPS) that developed an econometric land-use model to derive a national-level sequestration supply curve. The Partnership will employ data from these regional and national studies to develop regional agricultural and forest sequestration models.

A potentially additional benefit of terrestrial sequestration is the environmental co-benefits associated with adoption of practices that sequester C such; however, co-benefits are difficult to quantify and data are limited. To the extent feasible, the Partnership will estimate environmental co-benefits and incorporate those into the analysis of sequestration.

The data used for the agricultural sequestration analysis include county-level Agricultural Census data for 1987–2002. Output and input price data are used from USDA and other federal agencies. The forestry analysis uses data from the National Resources Inventory (NRI), which provides detailed information. A critical issue for terrestrial implementation is the cost of aggregating a large number of acres owned and managed by numerous individuals. Using the results of the forestry pilots and working with Sempra Generation to design a significant portfolio (approximately one M tons of CO_2 equivalent) for terrestrial carbon credits, the Partnership will address these issues. Following research by Mooney et al. (2004), the Partnership will construct costs of MMV protocols based on conventional soil sampling methods and advanced measurement technologies being tested by the MMV team. These costs will be incorporated into the simulation of C supply curves as in Antle et al. (2005). The MMV protocols/costs will be further quantified/addressed in the terrestrial demonstration pilot projects.

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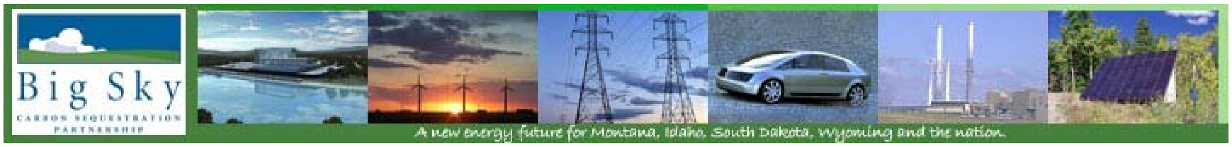

Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 17:
Advanced Concepts: Overall Assessment and Evaluation Report

December 2005

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Overview

The Big Sky Partnership focused in Phase I on studying numerous land based sequestration opportunities, geological reservoirs, and the means to implement sequestration opportunities with cost-effective and environmentally-responsible technologies. The Partnership objectives include: (i) identify and catalogue sources of carbon dioxide (CO_2) and promising geologic and terrestrial storage sites; (ii) develop a risk assessment and decision support framework to optimize the region's carbon storage portfolio; (iii) enhance market-based, voluntary approaches to carbon storage; (iv) identify and apply advanced GHG measurement technologies to improve verification protocols, support voluntary trading and stimulate economic development; (v) engage community leaders to define carbon sequestration implementation strategies and (vi) create forums to inform and secure input from the public.

The advanced concepts phase of our efforts (as reflected in objectives (iii) and (iv)) was designed as a means to integrate these key elements into a coherent thread that would provide a foundation and network for our Phase II demonstration pilots and deployment activities. The specific tasks revolve around designing market-based sequestration options; exploring mineralization trapping feasibility for geological sequestration in the Snake River Plain Basin; assessing measurement, monitoring, and verification requirements for all sinks; and developing a framework or common metric for evaluating the tradeoffs among alternative carbon sinks. Linked to these tasks we developed seven key deliverables as noted below, plus a white paper on future energy opportunities given growth projections and resource constraints in the West.

Deliverables
Phase 3 – Advanced Concepts
1. Planning Standards, Protocols and Contracting Options Within Region in Phase 2 2. Contracting and Project Implementation Handbook 3. Measurement, Monitoring & Verification Technology Assessment Report 4. Report-Feasibility of Mineralization Trapping in Snake River Plain Basin 5. Report-Results of Best Production Practice for soil C sequestration 6. Report on Common Methodology for Assessing Tradeoffs 7. Overall Assessment, Evaluation & Workshop Proceedings

In this deliverable we provide an overall assessment of the advanced concepts efforts and relate them to the foundation of our Phase II efforts. The paper is organized as follows: a summary of the Big Sky's regional energy future, followed by a critique of the Phase I advanced concepts contribution to the design and outcomes of the Phase II pilots and demonstration efforts, and to our integration efforts.

I. Big Sky's Energy Future including sequestration options

The West faces critical energy issues over the next 20 years. There is significant uncertainty about energy supplies, prices and reliability, the regulatory framework for new power generation and transmission - including carbon dioxide (CO_2) emissions - and how these uncertainties could impact economic growth and prosperity. Therefore, as energy demand increases, the region must understand the risks and opportunities (technical and economic) of different energy supply options including the potential of advanced energy technologies such as FutureGen, the U.S. Department of Energy's (DOE) proposed Integrated Gasification Combined Cycle (IGCC) power plant that co-produces electricity and hydrogen with carbon (C) capture and sequestration.

Future energy growth in the West will also require access to transmission. Recent developments to meet that requirement include passage of $6.6 million by the Wyoming (WY) Legislature and Governor to work toward the goal of opening new transmission corridors to meet growing Western power needs. Western coal-producing states are arguably poised to launch the nation's next generation power plants including IGCC and FutureGen with C sequestration. In particular, the Big Sky Carbon Sequestration Partnership will build on its success in DOE's Phase I Regional Partnership Program and assist the region prepare for this energy future and understand potential economic impacts on both a project and regional basis.

The Big Sky region currently produces some of the lowest-cost electricity in the country, largely through hydroelectric and coal-fired power plants fueled by vast sources of regionally mined coal. However, hydroelectric capacity additions are unlikely and it is clear to many energy analysts - and particularly to the Partnership's industry members - that coal and coal-fired power including advanced technology such as IGCC with C sequestration will play a key role.

<u>Factors Affecting Energy Growth</u>

Factors affecting energy growth in the region include climate change, water availability, population growth, availability and costs of fossil-fuels and for energy production, renewables, and the available sinks for carbon sequestration should CO2 management that become a reality. According to the Intergovernmental Panel on Climate Change and the United Kingdom's Hadley Centre's climate model (HadCM2), the Western states are predicted to experience warming trends of 4–5°F over the next century, with the greatest temperature increases during winter. Conclusions reached regarding the affects from climate change on energy growth indicate that less dependence should be placed on hydroelectricity, due to restricted summer flows and multiple conflicting demands and future energy sources need to conserve water usage and be located in areas less likely to experience major variations in water availability.

Availability of cooling water is critical to the siting of future power plants. Thermoelectric power has been the largest water user in the U.S., accounting for 48 percent of total withdrawals (195 Bgal/day in 2000). Most of this water is derived from surface water and is used for once through cooling at power plants. In the Pacific Northwest, hydroelectric-power generation is used to supply a substantial part of the regional demand for electricity; therefore relatively small water withdrawals from fresh or saline-water sources are required. Changing water supplies in the Big Sky will directly impact down stream water users throughout the West. The importance of the water resources produced in the Big Sky region will grow in step with energy demands and population expansion in the region;

climate change can impact groundwater and surface water supplies, which can directly influence the availability of water needed for power production from hydro or thermal energy systems.

The Western states are the fastest growing region in the United States. Population growth in six Western states has averaged more than twice the U.S. average of 16% percent, from 1990–2003, and the West is projected to grow at ~1.4-1.8% per year, versus the national average of ~0.9%. Expanding populations in the West, if coupled to growing economies, will drive demands for electricity, and population migration to the intermountain West can cause greater interregional demands in addition to energy exports to the West Coast and Southwestern states.

On the supply side significant reserves of coal are available in Wyoming and Montana. The Energy Information Agency (EIA) reports that Montana and Wyoming hold nearly 40% of the total U.S. coal reserves. Renewable energy from wind may also be tapped in the Big Sky region. Non-conventional reserves—coal-bed methane, tight gas and shale gas—mostly found in the Rocky Mountains could provide a major source of new supply.

There are increasing restrictions associated with the carbon emissions from fossil power plants in Washington State and Oregon. Examples include:

• In the State of Washington, House Bill 3141 (signed in March 2004) requires that fossil fueled power plants with a generating capacity of 25 MW or more to mitigate 20% of the carbon dioxide emissions the plant produces over 30 years. This requirement also applies to new power plants seeking site certification and existing plants that increase production of carbon dioxide by 15%. [14]

• In 1997, the Oregon legislature gave the Energy Facility Siting Council authority to set carbon dioxide emissions standards for new energy facilities. The standard requires new power plants to emit 17% less carbon dioxide than the most energy-efficient plant available. The standard can be met by offsetting emissions through energy efficiency or carbon sequestration projects. Energy facility operators may implement offset projects directly, or by payment to the Climate Trust, which encourages and funds projects to reduce or offset CO2. New energy facilities can meet the standard in four ways: 1) building high-efficiency plants; 2) cogeneration projects; 3) invest directly in CO2 offset projects; 4) pay a fee (raised in October 2001 from $.57 per ton to $.85 per ton) for excess CO2 emissions. Plants constructed or planned since passage of the standard will double the generating capacity within Oregon.

There is reasonable likelihood that carbon emissions will be regulated within the operational timeframe of any power plant built in the future. The other Western states could adopt carbon emission restrictions similar to Washington and Oregon, or federal laws could be passed that restrict carbon emissions or require mandated cap and trade programs. Current regulations in the Big Sky region are not restrictive on carbon emissions. Fossil energy produced in the Big Sky may become more competitive as further emission restrictions are placed on other energy producers in the region. Longer term, the regulation of carbon capture, transportation, and geologic sequestration is another area of uncertainty. Future regulations may decide if geologically stored carbon dioxide is classified as a product or waste.

Finally, implementation of clean coal technologies, which would improve the thermal efficiency of coal production and use and reduce emissions, could minimize investment risk and give a major boost to prospects for coal demand. New techniques have been developed for coal mining and the preparation of coal for use in power stations, as well as for coal combustion, emissions-control and the disposal of solid waste. Technologies on the horizon such as carbon capture and storage could achieve near-zero emissions of all pollutants from coal-fired power plants.

Sequestration opportunities: the big picture

Future energy concepts, including FutureGen, would include the production of hydrogen and sequestration of carbon dioxide. Siting of these future power plants would need to consider market opportunities for hydrogen and new fossil energy products (e.g., syngas), and sequestration locations for storage of carbon emissions. In the big picture, the Big Sky region has several unique characteristics relative to the production and storage of carbon. First, the region is very near zero-net carbon emissions resulting from a small but growing industrial base, low populations, and large areas of forest and agricultural lands which hold the capacity to store carbon.

The Big Sky region has diverse geologic formations, as shown in Figure 1, which could take carbon captured from power plants and permanently store it in geologic reservoirs in a solid carbonate form. Carbon offsets could be also achieved through terrestrial sequestration in the rich agricultural and forested areas of the Big Sky region. Processes are being developed to increase soil organic carbon and store carbon in biomass. The Big Sky region has diverse agricultural, timber, and grasslands that could be used to store carbon, as shown in Figure 2.

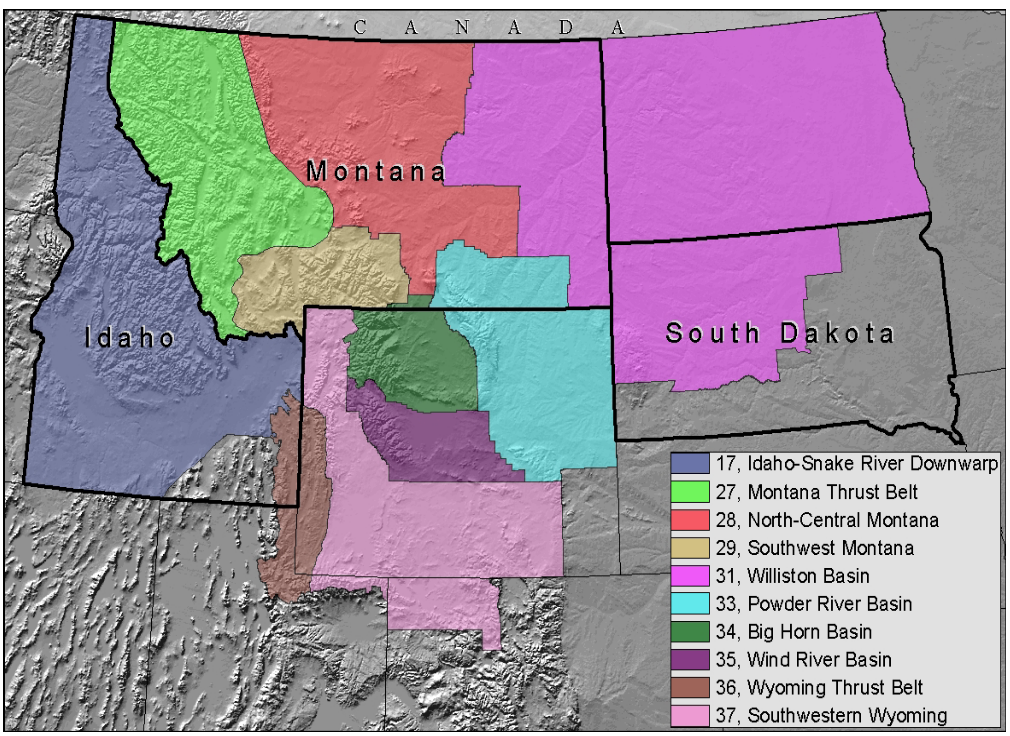

Figure 1. Diversity of geologic sequestration locations in the Big Sky region. [Big Sky Regional Carbon Sequestration Partnership]

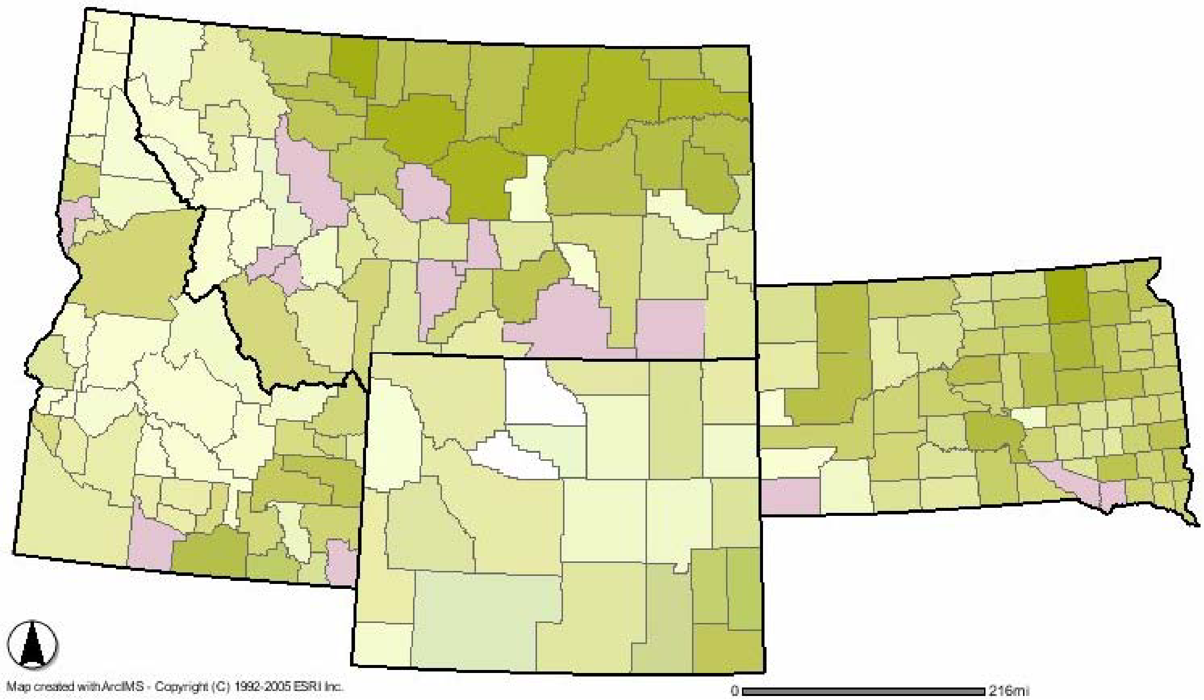

Figure 2. Diversity of terrestrial sequestration locations in the Big Sky region [Big Sky Regional Carbon Sequestration Partnership]

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In conclusion, evaluating future energy growth in the Big Sky region is a complex undertaking that must account for many dynamic conditions. The Big Sky region is well positioned to be the location for future energy development due to the wealth of energy resources, including both renewable and nonrenewable assets, and access to growing energy markets. The Big Sky region has the capacity to increase its energy production and provide a wealth of carbon sinks for carbon dioxide produced through energy production. The Big Sky Regional Carbon Sequestration Partnership is examining regional carbon sequestration resources that could be used to reduce or offset the carbon emissions from fossil power energy production and other industrials.

II. Advanced Concepts Foundations of the Phase II efforts

Phase I includes the evaluation of both direct and indirect methods land-based carbon sequestration in our geographic region. The Partnership has been working to identify, assess and catalogue C sources and promising geologic and terrestrial sequestration sites, and to develop an economic and risk assessment decision support framework to optimize the region's C sequestration portfolio. These data are integrated into a user-friendly geographical information systems (GIS) framework and are an important analysis tool for industry and regional energy planners. Furthermore, with the largest and most comprehensive terrestrial program in the nation, the Partnership has taken a lead in enhancing market-based C storage methods and improving verification protocols.

The objectives of the Partnership's Phase II efforts are to assist the region utilize its natural resources to meet growing energy demand with a optimal portfolio of advanced technology options coupled with geological and terrestrial sequestration opportunities, understand potential economic impacts on a project and regional basis, raise the profile of regional energy issues, enhance public involvement and trust, and effectively communicate the opportunities and risks associated with carbon sequestration.

Two of the Partnership's key industry members, Sempra Generation and Energy Northwest, are developing new coal-fired power plants in the region including an IGCC power complex. A third industry partner, Portland General Electric, is also looking at development opportunities to meet future energy demands in a cost effective and environmentally sound manner. Of crucial importance to these development programs are robust C mitigation plans that include a technical and economic assessment of regional C sequestration opportunities and participation in the Partnership's field validation tests. Therefore, the Partnership has worked closely with its industry members and national and international collaborators to design Phase II geologic and terrestrial field tests to be effective, relevant to commercial development needs and broadly transferable.

Advanced Concept: Mineralization

Based on the preliminary analysis under the Advanced Concept focus of our Phase I efforts, the Partnership's geologic sequestration team has assembled interdisciplinary experts from 10 leading U.S. and CSLF member country research organizations to understand the reactive properties of CO_2 in the region's geologic formations and define mineralization rates and sequestration capacities. The Partnership's primary geologic effort will be to demonstrate C storage in mafic/basalt rock formations, a geology not yet well characterized but with significant long-term storage potential in the region and other parts of the world including China and India. For instance, the region's Columbia River Basalt Group covers approximately 164,000 km^2 in OR, WA, and ID; conservative estimates of the CO_2 storage capacity are over 100 $GtCO_2$, enough capacity for 20 years storage of all U.S. coal-fueled power plant emissions (McGrail et al. 2003). Additionally, the Columbia River basalt group and the Snake River Plain in ID represent another 60,000 km^2 of sequestration capacity. Preliminary calculations done during the Phase I period show that basalt formations can rapidly convert injected CO_2 to carbonate minerals and complete conversion of fluid phase CO_2 to solid phase carbonate minerals in a few hundred years. If these laboratory-based estimates can be verified in the field, basalt formations may offer a unique geologic medium for long-term, zero leakage C sequestration.

Additionally, the Partnership will assess long-term CO_2 mineralization rates in the Madison Formation, a large carbonate aquifer in WY and MT. Like mafic rocks, carbonates are highly reactive with CO_2 and represent a significant opportunity for C sequestration. In collaboration with industry, the Partnership will utilize an on-going, long-term enhanced oil recovery (EOR) site at Lost Soldier and Wertz oil fields in WY to conduct a pilot on the consequences of the long-term exposure of carbonate rocks to CO_2-rich fluids. Specifically, the Partnership will model and match pre-injection conditions to assess changes in water chemistry and indirectly changes in the rocks to assess C sequestration potential.

Given resource constraints, the geologic team will take a phased approach to other sequestration opportunities in the region and develop technology networks that will continue to assess and characterize deep carbonate (limestone and dolomite) hosted aquifers and deep unminable coal beds, which have significant public perception issues associated with regional enhanced coalbed methane extraction. The Big Sky Partnership will implement its innovative outreach program to engage the public and maintain deep coalbeds as a viable C storage option.

The Partnership currently has designed in Phase I, the most comprehensive terrestrial sequestration program in the nation. This includes both addressing the terrestrial sink potential in the region as well as designing the protocols and needed verification for a trading market to develop. In Phase II, the Partnership will build upon this investment and will work closely with Sempra Generation, its Tribal members and other landowners to design and implement cropland, rangeland, and forestland field test sites and carbon portfolios, advance the Partnership's Phase I market-based C storage methods and verification protocols and demonstrate the marketability of one of the nation's emerging, cutting-edge pilot C markets. The results of this activity will be one of the largest market-based C trades in the country that is nationally recognized and in compliance with the reporting requirements of the 1605(b) National Greenhouse Gas Registry. Furthermore, the Partnership will address monitoring, measurement and verification protocols for all terrestrial sinks and integrate results from the terrestrial pilots into its economic and risk assessment framework.

Advanced concepts: Carbon Market Trading.

In the Big Sky Partnership, our initial thinking reached beyond the many technical advancements in terrestrial sequestration and into the next steps of carbon credit trading. For example, what does the Region need to prepare its industries for carbon credit trading? Does the cap and trade program established in the US under the Acid Rain Program offer a viable model for best practice in this field? Can we build on past experiences with the commercial trading of sulfur dioxide (SO_2)? If we successfully build upon the state of knowledge in indirect, terrestrial systems can we then, if successful, begin to lay a foundation for understanding the complexities of trading carbon credits in geologic storage options? We believe that the answer is yes.

In establishing carbon credits for trading there are several issues that must be addressed including the following:

1. Additionally and Baselines
2. Leakage
3. Duration
4. Monitoring and Verification
5. Transparency and Credibility

Each topic will be briefly discussed, as they are germane to various types of carbon credits trading scenarios. Additionally and baselines is the amount of net carbon sequestered when comparing the amount of net carbon measured and calculated when one compares the carbon after specific activates as compared to the baseline measurements of carbon which are measured and calculated before the activity commences. There are several ways proposed to make these calculations but there are no universal guidelines as such.

Leakage is the term applied to off-site impacts caused by a project. There have been many studies on these areas in terrestrial sequestration but there are few established programs for including leakage estimates. Several methods and guidelines can be used to estimate its impact.

Another critical area to understand is duration or permanence. Carbon stored in trees, vegetation, soil, or even in underground reservoirs presents a risk of dissipating through management actions or natural events. One task in evaluating carbon credits is to understand the risks and ways to mitigate them. The higher the risks the lesser the values of the credits. One approach that is evolving is to properly calculate the value of carbon sequestered over differing times, as well as, protecting against premature losses through MMV systems and risk mitigation strategies. Many liability rules have been suggested in order to account for non-permanence of carbon credits generated through land based sequestration activities. Designing proper monitoring, measurement and verification systems is a pathway to minimize these concerns.

Monitoring and verification is essential to determine that sequestered carbon or emission reductions attains a market value for example a "creditable" ton if it is to become a commodity. Carbon credits unlike other commodities that are bought and sold in markets do not physically move from the control of the seller to control of the buyer. Instead, what moves is a certificate or statement proclaiming the existence, stability and legitimacy of the claim subject to monitoring ad verification. This concept might include approaches like monitoring plans and auditing by a third party. This leads to the final area of discussion of transparency and credibility. Transparency and credibility are influenced by project reports that feature fully transparent measurements and calculations. Acceptability of these reports will be influenced and more readily accepted than those accept where calculations of reported amounts of carbon cannot be readily determined from available material and information. A project plan, measured pools, reported GHG's and locations can influence credibility.

These five areas of concern are only examples of the complexities facing carbon credit trading. These are some of the advanced concepts that industry will be facing if carbon credits begin trading on an exchange. For more detailed information on this complex subject please review the deliverable report in its entirety.

Advanced concepts: Economic as an Integrating Factor.

The Partnership has devoted a substantial effort in Phase I to the integrating elements of the advanced concept focus. These are the foundation of the Phase II integration efforts: assembling a strong economic team that integrates findings from all pilots, the education/outreach efforts and the regional Energy reports and industry-environment-government coalitions, the holistic MMV program, and the GIS-based tools. The economic team that will build on its work in Phase I and assist the region to understand the economic impacts of terrestrial and geologic C sequestration at both the project and regional levels. In Phase I, the Partnership's economic analysis focused on the economic potential of terrestrial sequestration which has been published in peer-reviewed journals and is considered sate-of-the-art. The Partnership will expand this framework to include its geologic field tests which will culminate in a regional C supply curve showing at each price of C, the total amount of C that could be sequestered in the region. This framework will be a valuable tool to enable the Partnership, its industry members and the region to assess the economic potential of all its sequestration options on a common basis. In fact, the Partnership's industry members recognize this activity as a key component of their carbon mitigation plans. For its regional analysis, the Partnership will prepare the Big Sky Annual Energy Report, an assessment of the region's current energy use, future energy scenarios and potential economic impacts. The foundation for this Energy Report was the white paper done as part of the Advanced Concepts focus of Phase I. The report will serve as a basis for the Partnership's Regional Technology Implementation Plan and will be a critical resource for industry, regional and national policy discussions and planning.

Advanced Concepts: MMV activities

Monitoring and measuring of CO2 storage is critical in ensuring that CO2 storage systems and projects are both safe and predictable. Building on industrial experience in current industrial storage programs and a strong base R&D program, Los Alamos National Laboratory led the Phase I effort in examining the needs for monitoring, measurement and verification (MMV) of CO2 land based storage options in the Big Sky Region. The LANL role was to work with partners to identify the current state of capability for monitoring and measuring both terrestrial and geologic storage. Monitoring and measurement diagnostics needed for a Phase II demonstration program were evaluated in Phase I within strict budget boundaries. Only those systems that have been proven and were necessary to complete the experiments were considered.

One of the most significant technical ideas to result from the Phase I effort is the basic concept of a low cost, low technology approach to 7/24 monitoring at experimental sites. As far as we know, we are the only partnership considering the development and integration of an automated, remotely managed MMV operation. Current budgetary constraints in Phase II do not allow for the demonstration of this concept, but plans can be developed for future experiments. This might allow for the continuous analysis and modeling of information so that potential problems can be identified before they become critical assisting in the mitigation efforts, if needed.

Montana State University and LANL worked together to review many types of diagnostics which could be ready for Phase II deployment. Although deploying the portfolio of possible technologies is scientifically valuable, we decided to focus on three technologies: Laser Induced Breakdown Spectroscopy (LIBS), Visible and Near Infrared (VNIR) and Stable Isotope analysis. All three of these diagnostic systems will be integrated into the terrestrial program led by MSU.

In addition, LANL will assist Boise State University in developing a MMV program for the mafic rock experiment. LANL recommendations suggest that the project site be thoroughly baselined and the site explored seismically (3D, 4D, and passively). In addition, LANL has pioneered and patented the development of a completely novel passive seismic diagnostic that is also suited to the approach of automation discussed above. If properly designed and managed then MMV systems can quickly identify problems, but mitigation and response protocols require further design and development. Designing and developing new MMV systems is necessary but not sufficient.

Big Sky did not stop at the hardware and software development of MMV systems, but took the next steps to ensure technical information developed by its partners was shared within the region. This includes industry, NGO's, and higher education. We accomplished this through the LANL Technology Transfer Office, workshops, technical meetings, poster sessions, and public outreach activities. For example one of the technologies discussed above, LIBS, was developed at LANL for carbon measurement in soils by the DOE, NASA, and the USDA. LIBS was chosen for an R&D 100 award and selected by NASA to send to Mars as part of a Rover Mission to analyze soils and rocks on that planet.

After attending a workshop held in Montana and listening to the needs for land owners, Carbon Credit Exchange managers, and federal leaders, we knew that a totally new concept in soil carbon measurement would be required if carbon credits were to be fairly valued and commercially traded. In addition, we calculated that costs would have to be reduced by more than an order of magnitude from current best practices while increasing the accuracy of those measurements. Industry wanted to take measurements in situ with a person portable system, instead of sending samples to various laboratories for diagnosis. Industry wanted results that could be determined in a matter of minutes instead of weeks. Industry also felt that this technology must be available to all of those who needed it. LANL design targets were to reduce the cost per sample from about $20 to about 10 cents. We wanted to reduce the turn-around time from about 2-3 weeks to about 10 seconds. We believe that LIBS will be a good commercial opportunity for small business ventures in the region when carbon credit trading actively starts and new markets expand.

As advanced concepts in MMV systems are developed and tested by Big Sky partners, then these emerging developments will be shared within the Big Sky Region and across DOE Region Carbon Partnerships emphasizing the need to listen to industry and work to meet its needs

Conclusions

The Partnership was well aware of an opportunity emerging in Phase II, which would require a campaign of field tests including technology verification, public outreach and regulatory permitting. For example, we needed to understand our resource base, our existing energy and transportation infrastructures, our regulatory environment along with the entrepreneurial nature of the people. This included developing communications across the region and working with stakeholders, regulatory groups and the public. In Big Sky, we went one step further as we included two Tribal Nations as partners and began exchanging information and building technical relationships across the border with colleagues in Canada, and with other nations who had similar geological and terrestrial sequestration opportunities.

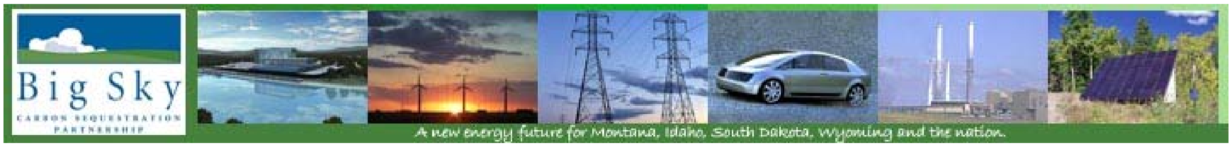
In addition, we have kept close watch of the industrial carbon market place evolving in the US and in Europe, and in our trading program have learned from the lessons provide in other carbon markets and with other trading for environmental goods and pollution control. As noted above, the Big Sky region is not a major source of CO_2 emissions in the US, but we are a key player for designing energy programs and portfolios for meeting future energy demands using fossil-based as well as renewable sources.

Peter Drucker once said that you cannot manage what you cannot measure. If carbon credits are to be commercially traded, then cost-effective measurement and monitoring systems need to be developed and transferred to industry for carbon baselines and verification. Carbon credit sellers, buyers, and third party verifiers need sound tools which are cost effective, accurate and readily available to those who need them. In Phase I a priority was building a foundation for small business interactions, landowner participation, and setting the stage for manufacturers, as well as, independent, third party verification companies. This concept applies to both terrestrial and geologic storage systems. For example, US Industry has more than three decades of experience in transporting and injecting CO_2 in depleted oil reservoirs for enhancing oil and gas recovery from traditional and non-traditional sources of stored fossil energy. However, the nation has only laboratory scale and experimental evidence of long-term CO_2 storage in mafic rock systems. Mineralization of CO_2 might account for CO_2 storage that is more permanent with less long term risk of surface leaks and plume migration, then more traditional options. Based on the Phase I results, Big Sky selected mafic rock systems for its marquis CO_2 sequestration experiment and demonstration as it represented a large multi-state resource base and presented opportunities for international collaboration, and transferability of the results learned to other key developing countries. The successful storage of CO_2 in mafic rock will be a critical factor in allowing the economies of developing countries to continue on a path of enhancing their standard of living and GNP while at the same time allowing for a responsible means for dealing with CO_2 emissions.

Our partnership reexamined the value and multiple benefits of terrestrial sequestration in the context of creating a short term insurance policy for the nation. This insurance policy provides the nation additional time for the full evaluation and understanding of geologic storage and the time to commercialize underground CO_2 storage with the minimum of risks. Big Sky was able to jump start this approach by leveraging investments previously made by DOE, USDA, NASA and the State of Montana and sharing technical results with our colleagues in Canada. We were able to visualize the next market driven steps to commercial acceptance.

Organizations began to build the contractual tools and understanding necessary to contract with farmers, ranchers, foresters and other landowners. Discussions were started with domestic Climate Exchanges to understand the fundamental requirements and practicalities for actual carbon credit trades. Again, the Big Sky Partnership looked to the market place for technical priorities and industrial expertise.

Because we believed so strongly that the integration of economics into understanding sequestration opportunities in the region was critical, we formed a team of internationally recognized economists to examine the economic potential of the geological and terrestrial sinks. This team is building on current knowledge bases and integrating technical, environmental and financial risks into quantification of carbon supply curves and tradeoffs among alternative sequestration options. This knowledge is designed to be shared with the other Regional Partnerships, state governments, and industry as it is fully developed in Phase II.



Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 20: Summary of Innovation Sessions/Workshops, Seminars, Roundtables

December 2005

U.S. Department of Energy (DOE)
National Energy Technology Laboratory (NETL)
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Innovations Networks and Key Messages Report: Education and Outreach

The focus of the Partnership's Phase I education and outreach activities was to lay the foundation for regional support of Phase II field validation testes. An Education and Outreach Action Plan was developed to identify key Stakeholder groups, develop targeted messages, and guide Phase I activities. Stakeholder groups included: industry, state government representatives and energy and environment agencies, environmental NGOs, Tribal Councils, economic development groups, and the public. Focus was given to communicating the opportunities and risks associated with carbon sequestration and working with decision makers to determine possible issues associated with field validation test implementation and ultimately commercial deployment.

Phase I proposed the creation of three regional "innovations networks," comprised of a small group of decision makers who would define possible carbon sequestration implementation strategies. However, carbon sequestration is not well known and very few individuals in the region – even those with energy and environmental backgrounds – were familiar with the topic. If there was any familiarity, people were inclined to associate carbon sequestration with terrestrial and the potential benefits to farmers, ranchers and foresters. Therefore, Phase I required more emphasis on identifying key stakeholders and building individual relationships to communicate the range of sequestration technology options and issues than anticipated. Instead of conducting regional innovations workshops, increased emphasis was placed on working with Stakeholders in other venues ranging from individual meetings, legislative briefings, workshops, and symposia, to poster sessions, presentations, web networks and the news (Table 1). Attention was given to working with key individuals from various Stakeholder groups that could help establish networks in Phase II.

Table 1: Education and Outreach Activities and Exposure

Activity	Number
Stakeholder Meetings	21
Legislative Briefings	6
Workshops/Symposia	8
Poster Sessions	5
Presentations	Over 25
Web Networks	800 + individuals
News Articles	15

In addition, we also were involved in a number of education and outreach symposia, workshops and conferences (Table 2.) Feedback from education and outreach activities indicate that given potential energy resource development in the region and the need for economic growth, there is considerable interest in carbon sequestration. Regional environmental management and stewardship is also of considerable interest; therefore, the Partnership's primary conclusion from its outreach activities is that the region as a whole is cautiously optimistic about sequestration's potential, supportive of Phase II field validation tests and would like to learn more.

Other lessons or key messages include:

Global climate change is the 1000 lb. gorilla. The region has abundant natural beauty and there are many local and regional environmental groups concerned and engaged on a range of environmental issues from various endangered species to water quality and smart forest growth. Many also recognize the impact global climate change has on the local environment but in essence, the region is very locally oriented. Messages that focus on the multiple benefits of terrestrial sequestration and potential reductions in local particulates haze through carbon capture and geologic storage resonate with individuals from environmental groups. These individuals are cautiously optimistic and willing to help engage their groups to help the Partnership deliver these messages in Phase II.

Economic development matters a lot. It is a key issue in all of the Partnership's states, in which many have the opportunity for energy resource development. Messages that highlight the economic development potential energy development coupled with carbon sequestration resonate. In Phase I, the Partnership engaged various individuals from economic development groups throughout the region who are willing to become an integral part of Phase II education and outreach efforts.

Engaging state leadership is key. At the end of Phase I, governors of multiple states in the region launched major energy initiatives. Based on Phase I outreach efforts, the Partnership is poised to further engage state leadership to elevate the profile of carbon sequestration's potential throughout Phase II.

Conclusion

The Partnership's primary conclusion from its outreach activities is that the region as a whole is cautiously optimistic about sequestration's potential, supportive of Phase II field validation tests and would like to learn more. This conclusion is driven by the fact that a high value is placed on potential energy resource development for regional economic growth as well as environmental management and stewardship. Based on the foundation established in Phase I, the Partnership is poised to establish networks in Phase II that can help advance sequestration demonstration and commercial deployment within its region.

Table 2. Summary of Education/Outreach Conferences and Workshops

Date - 2004	Location	Meeting/Conference	Notes/Conclusions
Jan 20	Billings, MT	Precision Ag. Meeting	Approx 50 participants. Increased awareness of terrestrial sequestration opportunities. Introduced geo storage. General questions on technical feasibility and safety.
Jan 21	Tucson, AZ	7th Electric Utilities Conf.	500+ participants. Presentation and networking with industry.
June 8	Great Falls, MT	Big Sky Workshop	Approx 15 participants, largely farmers and ranchers with interest in terrestrial sequestration. Geo unknown. General questions on technical feasibility and safety. Support for “clean” natural resources development.
June	Bozeman, MT	NETL EIS Public Meeting	Approx 6 participants. General support for CCS with concern and opposition over ocean storage. Interest in natural resources/econ development.
June	Bozeman, MT	Greater Yellowstone Coalition Roundtable	10 reps from small NGOs. Climate change is a big issue but most focused on specific enviro challenges, i.e. endangered species. CCS not known. Push back on ocean storage but open to geo if reg frameworks are put in place.
June	Bozeman, MT	The Nature Conservancy Roundtable	6 attendees. Similar as above.
June	Bozeman, MT	Native Waters	4 attendees. Similar as above.
June 19-22	Santa Fe, NM	Western Governors’ Association	Presentation, poster and general networking. Western Gov, staff and industry participation and networking
Aug	Helena, MT	Gov. Sequestration Advisory Committee	Focus on terrestrial. Introduction to geo. General support and interest in natural resources/econ development
Aug 26	Idaho Falls, ID	ASME Symposium	Approx 30 participants. Topic known to a few but largely unknown. Questions on national and international CCS activity, safety and permanence.
Sept 20-22	Spokane	INRA/INEEL Symposium	Approx 50 participants.
Oct 13-14	Billings, MT	Western Fuels Symposium	Approx 100 participants.
Oct 13	Billings, MT	MT World Trade Center	Fraser McLeay. Interest in CCS and economic development.
Dec 4	Great Falls, MT	MT Grain Growers Convention	100+ participants. Increased awareness of terrestrial sequestration opportunities. Introduced geo storage.

Date - 2005			
Jan 10	Spokane, WA	Intertribal Forestry Council	approx 20 participants, largely tribal foresters and a couple of private sector technology developers with interest in terrestrial and little knowledge of geo. Questions on national/international activities and safety.
Jan 11	Idaho	Tribal Workshop	Approx 10 participants. Same as above.
Jan 16	San Diego, CA	Chapman CCS Conference	Presentation and poster
Jan 20-21	Great Falls, MT	Harvesting Clean Energy	300+ participants. Big Sky poster – little knowledge in the topic. General questions of interest.
March 30	Boise, ID	Gov Sequestration Advisory Committee	Focus on terrestrial opportunities. Inclusion of geo options.
April 11	San Diego, CA	Sempra Generation Roundtable	Approx 8 reps from Sempra. Little knowledge of geo. Interest in terrestrial offsets
April 21	Queenstown, MD	Discussion	Rep. Denny Rehberg
Aug 9-10	Colstrip, MT	2nd Energy Open	Approx 40 participants. State Gov, industry, etc. Rep. Denny Rehberg and staff. Interest in natural resources development and CCS, ideas for current and potential education and outreach
Sept 12	Helena, MT	MT Gov Economic Dev Office	5 attendees. Interest in CCS and natural resources/econ development
Oct 17-19	Bozeman, MT	MT Gov Energy Summit	200 + participants. Meeting with Sen Burns staff. Presentations, poster and discussions w/ MT Gov reps, industry, etc.

Appendix C

Big Sky Carbon Sequestration Partnership – Phase I

Deliverables

1. Report on Infrastructure Data Compilation and Analysis (no report required – included in final technical report)
2. Report on Technology Needs
3. Report and Action Plan on the Evaluation of Geologic Sinks and Pilot Project Deployment Reports will identify approach taken; type of data generated as well as where and how it was deposited; type of analysis performed and conclusions
4. Literature review and data collection report (no report required – included in Quarterly Report 2)
5. Action Plan Report and infrastructure needs for enhancing terrestrial sequestration sinks
6. Manuscript on Carbon Budget and Analyses/GIS database
7. Data Collection Summaries (no report required – included in Quarterly Report 4)
8. Report on Evaluation of Terrestrial Sinks
9. Report on the interface between C-lock and producer decision support framework
10. Volume table development (no report required – included in Quarterly Reports)
11. Planning standards, protocols and contracting options ready to implement within the region (no report required – included in Quarterly Reports)
12. Contracting and Project Implementation Handbook
13. Measurement, Monitoring and Verification Technology Assessment Report
14. Report on the feasibility of mineralization trapping in the Snake River Plain Basin
15. Report on results of best production practice for soil C sequestration
16. Report on Common Methodology for assessing tradeoffs among carbon sinks
17. Overall Assessment and Evaluation Report and workshop proceedings on advanced concepts for geological and terrestrial sequestration
18. Action Plan for Carbon Sequestration Implementation
19. Web site - see http://www.bigskyco2.org
20. Summary of innovation sessions/workshop, seminars, roundtables

Technical and Quarterly Reports

21. Final Technical Report
22. Quarterly Report 1
23. Quarterly Report 2
24. Quarterly Report 3
25. Quarterly Report 4
26. Quarterly Report 5
27. Quarterly Report 6
28. Quarterly Report 7

STATEMENT OF WORK
NORTHERN ROCKIES AND GREAT PLAINS
REGIONAL CARBON SEQUESTRATION PARTNERSHIP
MONTANA STATE UNIVERSITY – BOZEMAN
P.I., Dr. Susan Capalbo

A. SCOPE OF WORK

The Partnership's objectives are: (i) identify and catalogue sources of CO_2 and promising geologic and terrestrial storage sites; (ii) develop a risk assessment and decision support framework to optimize the region's carbon storage portfolio; (iii) enhance market-based, voluntary approaches to carbon storage; (iv) identify and apply advanced GHG measurement technologies to improve verification protocols, support voluntary trading and stimulate economic development; (v) engage community leaders to define carbon sequestration implementation strategies and (vi) create forums to inform and secure input from the public. The project has four phases: geologic sequestration, terrestrial sequestration, advanced concepts, and outreach. The Northern Rockies and Great Plains Regional Carbon Sequestration Partnership consists of the states of Montana, Idaho, and South Dakota.

B. TASKS TO BE PERFORMED

Task 1 – Regional GHG Source and Geologic Sequestration Characterization

Task 1.1 – Source Characterization

The project will survey both industrial and agricultural GHG (CO_2, CH_4 and N_2O) sources within three major categories: (1) fossil fuel power plants; (2) industrial plants including metals manufacturing, chemical processing and ethanol production and (3) agricultural sources (principally feedlots). Emissions will be estimated using standard guidelines and emissions factors recommended by EPA's Emission Inventory Improvement Program (EIIP Document Series Vol. VIII, Estimating Greenhouse Gas Emissions) [2], supplemented with information from the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, and the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories [3]. Source data will be collected from cooperating state agencies (Idaho DEQ, Montana DNRC, SD DENR) and from national databases (EPA E-Grid, NEI facility data, DOE-EIA state energy data). Industrial facility and utility information will be derived where possible from air-quality permit data assembled by the respective state air quality agencies. Livestock inventories will be collected from the NASS county-level farm census data (through 2001) for each state. Other approaches for estimating GHG emissions may be used depending on the availability and quality of our sources of information.

Task 1.2 – Geological Sequestration Characterization

Evaluate the geologic sequestration potential of sedimentary and volcanic basins the region, which includes Idaho, Montana, South Dakota, and geologically contiguous areas in

North Dakota and Wyoming. At a minimum, the following geologic formations will be assessed: deep saline aquifers, depleted oil/gas reservoirs, deep unmineable coal beds, and mafic/ultramafic rocks. Available characterization data will be issued to evaluate the potential for each formation to serve as a CO_2 sequestration reservoir against the following criteria: potential for hydrodynamic trapping; potential for solubility trapping; potential for mineralization trapping; technical feasibility and time frame for implication and offsetting economic benefits. Compilation of geologic data: e.g. prevalent geology, porosity, formation thickness, extent of formations. Coal properties such as coal rank, average pore-size distribution, surface area will be collected for coalbed methane reservoirs. Determination of storage capacity for oil/gas reservoirs, storage capacity would be evaluated in terms of volumetric capacities as well as capacity. For aquifers, the storage capacity would be mainly determined from solubility in water/brine. For coalbed methanes, storage capacity would be evaluated in terms of volumetric capacity as well as capacity resulting from displacement of methane by CO_2. Determination of long-term storage capability: Geologic and geophysical information would be carefully analyzed to determine whether adequate geologic barriers exist to trap CO_2 long term. The evaluation will result in each formations classification of either: 1) favorable and worthy of further consideration; 2) unfavorable; or 3) insufficient information to classify, unless a different ranking scheme is determined more appropriate during the project.

Task 2 – Infrastructure Characterization
Existing and infrastructure requirements will be evaluated within the region. Transportation information such as pipeline and rail infrastructure will be derived from siting boards and transportation departments, or other relevant information. In addition, assess the maturity of sequestration technologies and the availability of the necessary infrastructure for implementation. All the relevant infrastructure information for each sink would be evaluated and included in the database and GIS under Task 3. This will include number of active wells, surface facilities required for storage and processing of CO_2 as well as produced oil/gas/water, CO_2 pipeline and other transportation availability, proximity to major sources. Costs associated with developing the infrastructure necessary for large-scale sequestration would be determined. Technological and economical issues related to separation/capture and transportation of CO_2 would be identified and evaluated.

Task 3 – Incorporate Geologic, Infrastructure, and GHG Source Data into GIS
The results of the geologic sequestration, infrastructure, and GHG source characterization assessments will be embodied in a geospatial database that is integrated with the terrestrial sequestration assessment.

Task 4 – Data Collection and Literature Review for Terrestrial Sequestration
Conduct a literature review and collect data on terrestrial sequestration potentials in the region. The type of land uses the data will be collected for, at a minimum, will include croplands, grazing lands, and agroforestry, on private and public lands. Collection and preparation of forest inventory, growth and yield plots, biomass and productivity data and collection of soil data if necessary for the Partnership region. Collection of climate and disturbance data (such as fire,

land use, harvesting). Other information may be collected depending on requirements to estimate terrestrial sequestration potential.

Task 5 – Evaluate all Terrestrial Sinks for GHG Emissions in Regional Ecosystems, Identify Infrastructure Requirements, and Prepare as Information Reports
Compilation of data analysis and management will be conducted. Integration of all possible data from Task 4 and derived during Task 5 into GIS map format. Preparation of TRIPLEX input data.

Task 6 – Overlay the Technical Terrestrial Sequestration Potential With Assessment of Opportunity Costs and Net Economic Benefits
Estimate carbon stocks and fluxes in the Partnership region. Perform comparative projective analysis under different assumed forest management practices, agricultural policies, as well as changing climate scenarios.

Task 7 – Prepare Manuscript(s) on Carbon Budget and Analyses
Prepare estimates of carbon sequestration for Partnership region using TRIPLEX model. Examine the use of the TRIPLEX in a decision-support role within Kyoto Protocol and indicators of sustainable forest management. The evaluation will result in each terrestrial sink being assigned a classification of either: 1) favorable and worthy of further consideration; 2) unfavorable; or 3) insufficient information to classify, unless a different ranking scheme is determined more appropriate during the project. Expand upon C-Lock model to the entire Northern Rockies and Great Plains region by linking the economic component on land use decision-making with expanded C-Lock modules. Estimates for potential soil C sinks at field/farm scale as well as more regional county and state levels a generalized geospatial database for the region which includes not only information on soil C levels in the soils but also data on land use changes, soil characteristics, cropping practices and economic and management information will be determined.

Task 8 – Terrestrial Sequestration Outreach
Participate in discussions, consulting, meetings, public outreach and user workshop training for terrestrial sequestration as appropriate (Oct. 2004-March 2005).

Task 9 – Advanced Concepts
Survey state of the art, commercially available GHG measurement systems and conduct gap analysis of technical criteria versus available systems, identify costs and reliability if possible. Assess available instruments and evaluate their cost effectiveness and applicability to each viable source and sink.

Task 10 – Identify Common Methodology for Evaluating Tradeoffs Among Geological and Terrestrial Sequestration Sinks
Develop a risk assessment and decision support tool to evaluate sequestration options that incorporates a number of elements including: system costs (capture, transport); external costs

(environmental and societal); sequestration effectiveness (duration, quantity, uncertainty) and legal and regulatory barriers.

Task 11 – Develop Carbon Sequestration Project Protocols
Finalize contracting models, assess measurement, monitoring and verification (MMV) technologies and improve protocols required to trade carbon credits.

Task 12 – Evaluate Regulatory Issues
Evaluate federal, state, and local permitting issues within the region that may affect carbon sequestration projects. Assess the impacts to project implementation of the regulations that will affect projects and develop approaches to ensure limited impact to project implementation.

Task 13 – Protocol and Planning Standards for Reporting
Develop protocols and planning standards consistent with the revised 1605 B National Greenhouse Gas Registry to insure that at final proposed protocols and planning standards meet national requirements.

Task 14 – Assess Existing Conservation Programs for Terrestrial Sequestration Projects
Assess the potential to leverage existing federal and state conservation cost share programs for terrestrial based carbon sequestration projects. Determine whether projects funded under these conservation programs would qualify as reportable projects. Develop a matrix of types of projects and potential programs that could support these projects.

Task 15 – Determine the infrastructure contracting issues for buyers and sellers, and carbon credit aggregators necessary to implement carbon sequestration projects.

Task 16 – Identify and validate best production practices for soil C sequestration using field test plots
Assess and Validate Using Field Test Plots (MSU-Miller, Engel, Brown): The field studies will validate the capacity of soils in the region to sequester soil carbon. Six paired farm fields in north central Montana have been selected to compare management approaches. Soil organic C will be measured to a depth of 30 cm following accepted field (2 x 5 m geo-referenced grid) and lab (dry combustion analysis) protocols. Assessment of Diffuse Reflectance Infrared Spectroscopy (DRIS), and / or other advanced measurement techniques, for field-scale soil C monitoring will be performed by comparing dry combustion soil C analysis against this spectroscopic procedure. Periodic measurements of soil emitted N_2O will be collected using established vented chamber techniques. A second key objective is to determine the efficiency with which remote sensing can be used to assess carbon storage. Satellite imagery from approximately 200 fields on 70 MT farms will be analyzed for accuracy in documenting tillage systems and crop types (i.e. ground truth). Results will demonstrate the potential of soils in the region to store C, and validate and refine Century model predictions of C sequestration. Potential benefits to the global carbon balance will be assessed against a more complete analysis of other GHGs, particularly N_2O.

Task 17 – Assess Mineralization Trapping Potential
Conduct a literature search and assessment of methodologies for mineralization trapping of CO_2 for carbon sequestration. This will evaluate, at a minimum, the potential mineralization approaches, conducting a cost/benefit analysis, and evaluate infrastructure in the region (e.g. existing mines, transportation, etc.). Incorporate data into the database and GIS system for project selection.

Task 18 – Assessment of feasibility in the Snake River Plain Basin
Conduct a feasibility assessment of using mineralization technologies to sequester carbon in the Snake River basin based on the regions' conditions with respect to CO_2 sources, mineral deposits, existing and required infrastructure, and other factors that will influence carbon sequestration via mineralization.

Task 19 – Assess available Measurement Instruments that can be Used to Measure, Monitor and Verify Carbon Storage in Carbon Sequestration Projects
Assess available instruments and evaluate their cost effectiveness and applicability to each viable source and sink. MMV technologies and systems must be cost effective and made broadly available.

Task 20 – Evaluate the Cost Effectiveness and Risk Components for Each Viable Source and Sink
Develop a risk assessment and decision support tool that can be used in both geological and terrestrial sequestration projects. The tool will incorporate a number of elements including: system costs (capture, transport); external costs (environmental and societal); sequestration effectiveness (duration, quantity, uncertainty) and legal and regulatory barriers. By having a common methodology/tool for all sequestration options, this will ensure that the results effectively compare the costs and benefits of alternative terrestrial and geological projects in the region.

Task 21 – Hold Workshop for Technology Transfer to Local Entities
Regional businesses, entrepreneurs, labor unions and Tribal Nations will be engaged in examine opportunities to design and build these MMV systems locally. This economic development approach will engage key constituents to support carbon sequestration projects, help foster vital economic activity and cost-effective project implementation.

Task 22 – Establish Innovation Clusters
Establish three innovation clusters (one in each state) to engage community leaders who will be keys to implementing carbon sequestration projects. Groups may include: elected and regulatory officials; state sequestration advisory committee members; tribal leaders; journalists; environmental NGOs; labor organizations; entrepreneurs; industry; land owners and academia.

Task 23 – Outreach & Education Plan
Develop a public outreach and education plan detailing how the partnership would educate the public and encourage involvement during a sequestration project.

Task 24 – Community Roundtable Discussion of Carbon Sequestration
Plan and hold a series of community roundtables or small seminars to discuss sequestration approaches. Seminars will be conducted at high schools, universities, state legislatures and other public venues.

Task 25 – Website
Establish a partnership web site which describes our technical approach and findings and highlights results from the innovations network and roundtables. The web site will include a bulletin board to provide an open forum to exchange views and seek additional information.

C. DELIVERABLES

The periodic, topical, and final reports shall be submitted in accordance with the attached "Reporting Requirements Checklist" and the instructions accompanying the checklist. In addition, the Contractor shall submit the following information for review and approval:

1. Quarterly update to project using a PowerPoint-format presentation to include, at a minimum, the data contained in an NETL-provided template.
2. List of key participants from each partner including details on: name, organization, address, phone, role in project, congressional district. The recipient will update this list upon request by DOE and/or upon addition, deletion, and/or reorganization of partnership organizations/personnel.
3. Topical report – Atlas of geographic sequestration options that will contain at a minimum an illustration and description of the regions CO2 emissions sources, transportation infrastructure, geologic and terrestrial sinks, types of data used to compile the atlas, and legend for the atlas.

Geological Sequestration, GHG Source and Infrastructure Characterization (Tasks 1-3)

4. Report on Infrastructure Data Compilation and Analysis (July 04)
5. Report on Technology Needs (Nov. 04)
6. Report and Action Plan on the Evaluation of Geologic Sinks and Pilot Project Deployment Reports will identify approach taken; type of data generated as well as where and how it was deposited; type of analysis performed and conclusions.

Terrestrial Sequestration (Tasks 4-8)

7. Literature review and data collection report (Mar. 04)
8. Action Plan Report and infrastructure needs for enhancing terrestrial sequestration sinks
9. Manuscript on Carbon Budget and Analyses/GIS database
10. Data collection Summaries (Sept. 04)
11. Report on Evaluation of Terrestrial Sinks (June 05)
12. Report on the interface between C-lock and producer decision support framework (Mar. 05)
13. Volume table development (Mar. 05)

Advanced Concepts (Tasks 9-21)

14. Planning standards, protocols and contracting options ready to implement within the region (Mar. 04)

15. Contracting and Project Implementation Handbook (Nov. 04)
16. Measurement, Monitoring and Verification Technology Assessment Report (Dec. 04)
17. Report on the feasibility of mineralization trapping in the Snake River Plain Basin. (June 05)
18. Report on results of best production practice for soil C sequestration. (Mar. 05)
19. Report on Common Methodology for assessing tradeoffs among carbon sinks. (June 05)
20. Overall Assessment and Evaluation Report and workshop proceedings on advanced concepts for geological and terrestrial sequestration. (June 05)

Outreach 4 (Tasks 22-25)

21. Action Plan for Carbon Sequestration Implementation (Oct. 03)
22. Web site (Nov. 03-June 05)
23. Proceedings from innovation sessions/workshop, seminars, roundtables (ongoing – Mar. 05)
24. Summary of public comments (June 05)

All deliverables under this award are to be submitted in publicly releasable form, and thus shall not contain any limited rights data or data that is otherwise represented as being non-releasable. The Recipient shall be responsible for enforcing this requirement with regard to all team members. The Government shall have the option to return any deliverable submitted in other than publicly releasable form to the Recipient and to consider such deliverable to be delinquent until submitted in the proper form.

D. BRIEFINGS/ TECHNICAL PRESENTATIONS

1. The Contractor shall prepare detailed briefings for presentation to the COR at Pittsburgh, PA or Morgantown, WV. Briefings shall be given by the Contractor to explain the plans, progress, and results of the technical effort.

    1) Attend Kickoff Meeting at NETL for 1.5-2 days to provide briefing to NETL upper management and staff on Partnership goals and tasks. Participate in breakout sessions for GIS designs; public education; regulatory issues; geologic sequestration issues; and terrestrial sequestration issues.
    2) Attend Semi-Annual Contractor Review meeting at NETL Pittsburgh/Morgantown to present progress of partnership during the performance period the project is active.
    3) Attend 2004 NETL Carbon Sequestration Conference (anticipated to e in Alexandria, VA) to present the progress of partnership.
    4) Attend 2005 NETL Carbon Sequestration Conference (anticipated to e in Alexandria, VA) to present the progress of partnership.
    5) Attend final contractor review meeting to discuss results of partnership at the end of the project.

Appendix E

Partnership Principals and Contributors to Final Report

Key Participants to the Big Sky Carbon Sequestration Partnership, Phase I

NETL Project Manager	John Litynski
Principal Investigator Montana State University	Susan Capalbo
Key Participants Montana State University	John Antle, David Brown, Rick Engel, Perry Miller, Ross Bricklemyer, Todd Kipfer, Aaron Jones
Boise State University	Warren Barrash, William Clement
EnTech Strategies, LLC	Pamela Tomski
National Carbon Offset Coalition	Ted Dodge, Emily Tafoya
South Dakota School of Mines & Technology	William Capehart, Maribeth Price, Karen Updegraff, Patrick Zimmerman
Texas A & M University	Jay Angerer, Jerry Stuth, Robert Blaisdell
University of Idaho	Robert Smith, Nathan Erickson
Idaho National Laboratory	David Shropshire, Randy Lee, Travis McLing, Eric Robertson
Los Alamos National Laboratory	Richard Benson, Paul Rich, Sam Clegg, Julianna Fessenden-Rahn
Montana Governor's Carbon Sequestration Working Group	Mark Lindberg
The Confederated Salish and Kootenai Tribes	D. Fred Matt
Nez Perce Tribe	Aaron Miles, John DeGroot
Inland Northwest Research Alliance	Steve Billingsley
Idaho Carbon Sequestration Advisory Committee/ Idaho Soil Conservation Commission	Bill Whittom, Tony Bennett
Idaho State University	Scott Hughes
Montana Bureau of Mines and Geology	Marvin Miller, David Lopez
Western Governors' Association	Alison Wilson
Wyoming Carbon Sequestration Advisory Committee	George Vance

Montana Department of Environmental Quality	Art Compton
Wyoming Department of Environmental Quality	Gary Beach
The Sampson Group	Neil Sampson
University of Nebraska-Lincoln	James Brandle
University of Wyoming Geographic Information Science Center	Jeffrey Hamerlinck
University of Wyoming Enhanced Oil Recovery Institute	James Steidtmann
University of Wyoming Ruckelshaus (Wm. D.) Institute for Environmental and Natural Resources	Harold Bergman
Montana State Library, Montana Natural Resource Information System	Jim Hill
Montana Dept. of Administration-Montana GIS Services Bureau Info Technology Services	Stewart Kirkpatrick
Unifield Engineering	Jim Stevenson
Jackson Hole Center for Global Affairs	David Wendt
Battelle Pacific Northwest Divison	Pete McGrail
Puget Sound Energy	Mike Jones
Portland General Electric	Dominic Green
Sempra Generation	Bruce McCulloch
Energy Northwest	Tom Krueger
Columbia University-Lamont Doherty Earth Observatory	Juerg Matter, David Goldberg
Intertribal Timber Council	Donald Motanic
National Tribal Environmental Council	Robert Gruenig

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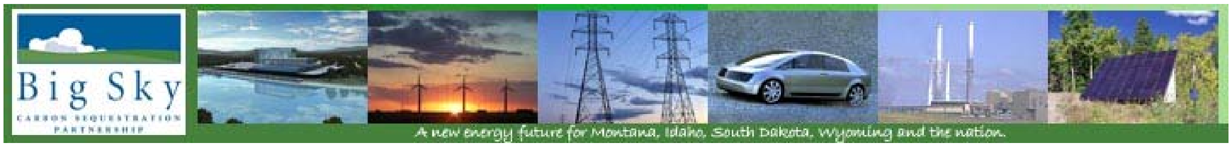

Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 2 and Deliverable 3:
Report on Technology Needs
and
Report and Action Plan on the Evaluation of Geologic Sinks and Pilot Project Deployment.

July 2005

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CO_2 Sequestration Potential of Sedimentary Basins in the Big Sky Region

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Presented in this section is an annotated description of the (carbon dioxide) CO_2 sequestration capacity of the large sedimentary basins contained within the Big Sky region. A master's thesis by Nathan Erickson at the University of Idaho, Idaho Falls campus contains a more complete description of the data and methodology. Mr. Erickson is expected to complete his thesis in December 2005.

Introduction

The region encompassed by the Big Sky Partnership hosts a number of large sedimentary basins including the Powder River, Williston, and the Green River and associated basins (Figure 1). Together these basins cover more than 400,000 km^2 of Wyoming, South Dakota, and Montana. These basins range from 1,500 to 3,000 meters thick and are comprised of bedded sandstones, shales, thick coal beds, dolomites and limestone. The same geologic conditions (i.e. basins depth, structure, and permeability), that have made these basins productive coal and hydrocarbon producers also make them attractive targets for large scale CO_2 sequestration. In addition to representing large storage potential, the basins also posses desirable mineral characteristics. These minerals, when exposed to CO_2 and water, can rapidly convert to stable secondary minerals phases, effectively sequestering CO_2 indefinitely. Also contributing to CO_2 sequestration suitability are thick deposits of unminable sub bituminous coal, located deep within many of the basins. These thick coalbeds can adsorb CO_2 onto the internal surfaces of its microporous structure releasing methane that can then be captured and used. Preliminary empirical data shows that the sub bituminous coal found in the Wyoming and Montana sections of the Powder River basin (Figure 1) is superior to other higher ranked coals for CO_2 storage.

The importance of evaluating the sequestration potential of these basins is self evident when considering the growing power demands of the west and the vast resources and energy producing potential of this region. It is clear that the resources of these basins will be used for energy production well into the future. Therefore, a full characterization of sequestration capacity will be beneficial for locating future power plants built to meet the energy demands of a growing population in the western U.S.

Because of the wealth of natural resources associated with the basins in the Big Sky region they represent significant targets for future energy exploitation and CO_2 sequestration. During the performance period of Phase I, the Big Sky Partnership geology team has developed techniques to evaluate the sequestration potential of these basins. As a result of the Phase I assessment, a capacity and location catalog of sedimentary target reservoirs has been developed.

Discussion

Because of the vast amounts of oil, natural gas and coal associated with the Powder River, Williston, and the Green River basins, a large volume of data has been collected on them, much of it from the public domain. The states of Wyoming and Montana have organized the collected data from their respective states into publicly accessible databases. The assessment of the volume of CO_2 that can be sequestered in these reservoirs was evaluated at a sub-basin scale. For convenience, these basins were broken into manageable parcels of like geology. These parcels are known throughout the oil and natural gas industries as plays[1] which are defined as geologic units comprised of a potential hydrocarbon source, reservoir rock, and cap. In order to maintain uniformity with the other six regional partnerships, the Big Sky Partnership geology team based its play location and boundaries on the 1995 National Assessment of United States Oil and Gas Resources conducted by the United States Geological Survey (USGS 1995). The National Assessment identified 10 provinces (Figure 2) and 107 plays (Figure 3a, 3b) in the Big Sky region. Of the 107 plays, 80 are conventional (Figure 3a) or plays with oil and natural gas deposits that can be extracted using traditional methods. The remaining 27 are unconventional plays (Figure 3b)which are generally characterized as continuous geologic formations that because of rock type, geologic timing, or seal failure do not contain hydrocarbons. The Big Sky Partnership's geologic team has utilized the copious volume of data available from the 107 plays to calculate the sequestration potential of the large sedimentary basins occurring in its region.

Each play has one or more geologic formations that were identified; the needed properties for each formation were collected based on availability. Wyoming's data is typically available at the well level, while Montana's depth to formations is recorded at the well level, and all other properties are only available for each oil or natural gas field. South Dakota does not have a unified database for the collections of oil and natural gas field properties; as a result, an assessment of sequestration potential has not been made. Generally, a great deal of data is available for plays that have produced or are thought to be capable of producing hydrocarbons, as there is an economic driver for collecting the data. The States of Montana and Wyoming have gone to great lengths to collect the available data into state managed databases which are available to the general public.

Evaluation Parameters

The evaluation of sequestration potential for sedimentary basins requires the collection of specific parameters for each play (Table 1). The parameters of interest for each play include the properties that describe the rock chemistry, brine chemistry, hydraulic conditions, depth to play, etc. In most cases this data is easily obtainable as the parameters are typically collected to determine hydrocarbon production. Oil, natural gas, and coal data for Montana and Wyoming are recorded differently in each state; Wyoming has an advanced system of collecting and recording all data for each well to a single source. The Wyoming Oil and Gas Conservation Commission maintains a web site that contains all oil and natural gas wells, their corresponding well logs and/or other properties measured for each well. Montana's data system is not as advanced and requires the use of several different sources; 1) Montana Board of Oil & Gas Conservation which has the well locations and depth to each formation that is maintained on a their website, and 2) Montana Geological Society, which identifies the reservoir properties of each oil and natural gas field, in book form, for all of Montana. Each of these sources provides important information that will be used to calculate the amount of CO_2 a reservoir will contain. Table 2 shows a list of important properties and the source from which they are collected. The data is used in calculations to determine the amount of CO_2 that can be contained in each reservoir. All information is collected into a Microsoft Access database and converted into a GIS format for the assessment.

CO_2 capacity is calculated for all of the 107 identified plays. Properties listed in Table 1 are used to make the calculations with the assumption that 50 percent of the reservoir pore space is available to

[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

store CO_2. Using the reservoir specific data, a series of calculations (appendix A) determine the sequestration volume. These calculations are extremely sensitive to: temperature, pressure, salinity, reservoir thickness, reservoir area, porosity, and water saturation. Subtle changes in these values could result in a significant change of calculated reservoir capacity.

Wyoming Data

Wyoming's data is available from the Wyoming Oil & Gas Conservation Commission website (http://wogcc.state.wy.us/), with information on 117,304 wells and 351,823 formations available for download. Some wells are recorded in multiple oil and natural gas fields; therefore, a query is used to exclude duplicate records. Formation names are sorted and normalized for consistency in naming, this avoids duplication of records in the database. The water analysis data for each formation in Wyoming also is downloadable and includes sample date, ion concentrations, total dissolved solids, pressure temperature, and pH. The same database also contains formation parameters including depth interval, temperature, water resistivity, and shut in pressure. In addition, records for porosity, grain density, oil content, and water saturation are available for all formations with a core analysis record. Average values for each formation are calculated and entered into a Microsoft Excel spread sheet and later used to determine the porosity and water saturation for each play.

Montana Data

The data for Montana's wells and the depth to each formation are obtainable from the Montana Board of Oil and Gas Conservation website (http://bogc.dnrc.state.mt.us/). The formation properties are available from the Montana Geological Society, which in 1985, produced two books containing information on all of Montana's oil and natural gas fields (Tonnsen and others, 1985). The Montana Oil and Gas Fields Symposium books report properties for each formation within each field, including porosity, water saturation, lithology, salinity, and other properties. This data is entered into Microsoft Excel manually and quality control checks eliminate errors. Data from a total of 253 oil and natural gas fields and 489 formations were downloaded.

Sequestration Potential

The assessment of each plays capacity to sequester CO_2 shows the enormous volume of CO_2 that could be sequestered in each play, an from the Lakota formation is shown in Figure 4). The volumes for each play are the sum of all formations in that play and do not take into account formation ranking. According to the Energy Information Administration, (www.cia.doe.gov), the total CO_2 emissions for the United States year are 5.8 billion metric tons, while many of the saline aquifer capacities in the Big Sky region are in the 10,000 to 100,000 million metric tons range. Total sequestration volumes for the Wyoming, Montana, and South Dakota sedimentary basins have been organized by reservoir type: saline aquifer, oil and natural gas reservoir, and coal seams. These capacities range from .1 to 10^6 million metric tones of CO_2. In general, non oil producing saline aquifers represent the most volumetrically significant target for sequestration with some of these formations reaching nearly 1,000,000 million metric tones of capacity. An example of how this information can be use is shown in Figure 4. In this example, the Lakota formation contained within the Power River Basin is present in terms of its sequestration potential as a function of depth. Also presented is the formations proximity to cities, wells, pipelines, power plants, and state boundaries. Although this approach represents an inherently conservative estimate for CO_2 sequestration capacity, it does provide the appropriate information needed to determine if a given location is suitable for further investigation. Overall, every sedimentary formation investigated in the region has the potential to sequester large amounts of CO_2. Many other formations are lacking sufficient data to conclude upon their ability to sequester CO_2. As information is made available, these formations will be evaluated and may also prove to be favorable carbon sequestration targets.

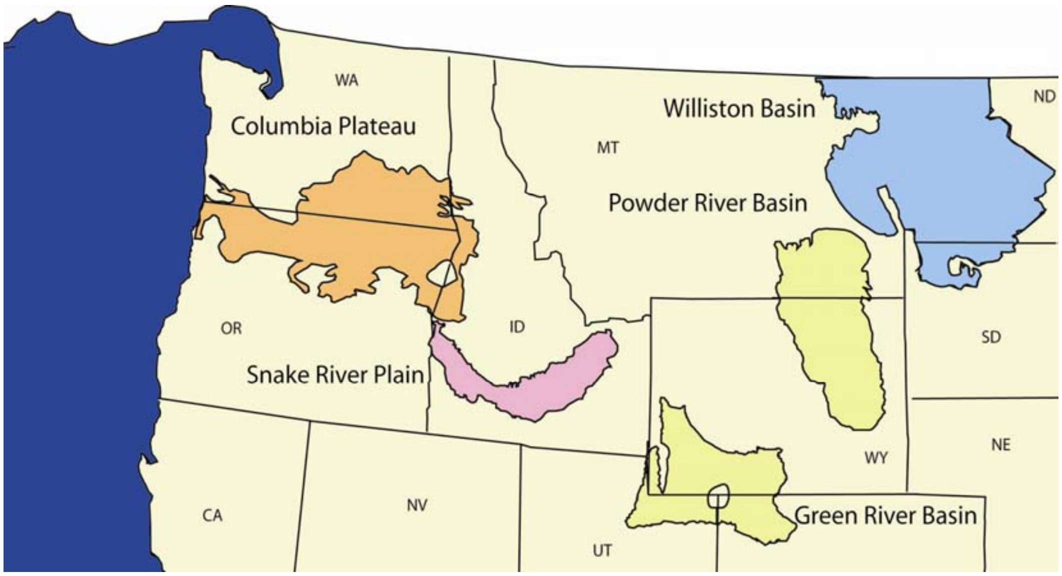


Figure 1. Major sedimentary and volcanic basins within the Big Sky Partnership.

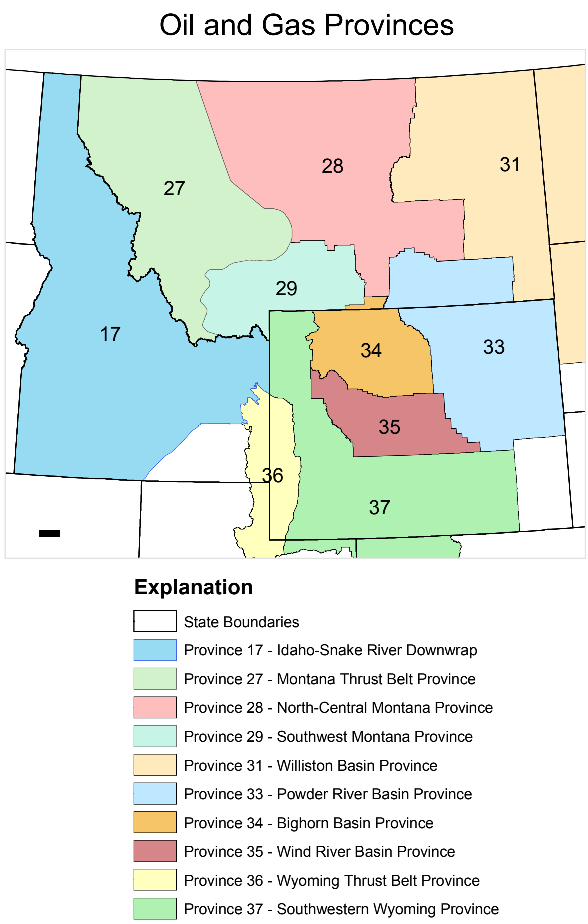
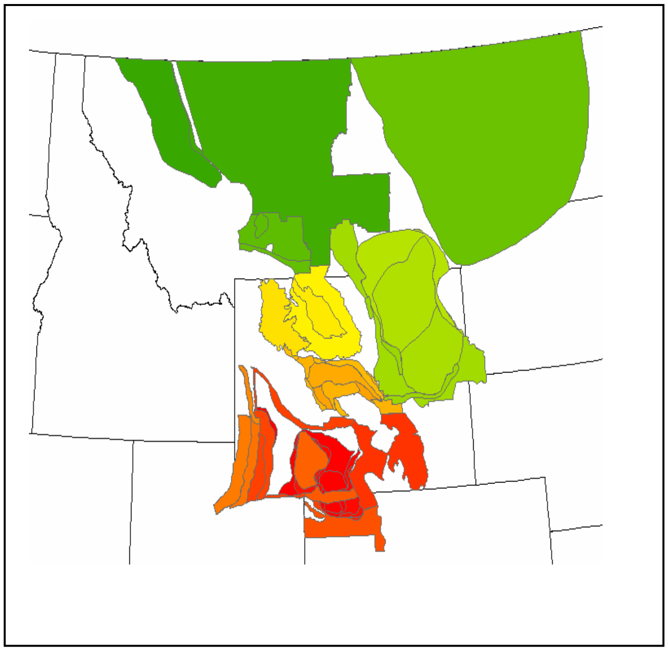


Figure 2: Oil and gas provinces located within the Big Sky Carbon Sequestration Partnership.



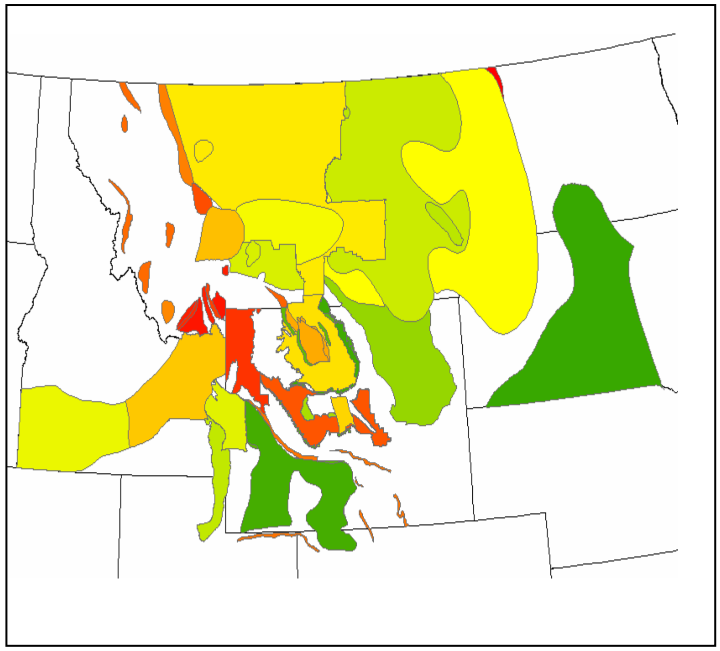


Figure 3a Known sedimentary plays

Fig 3b unconventional Plays

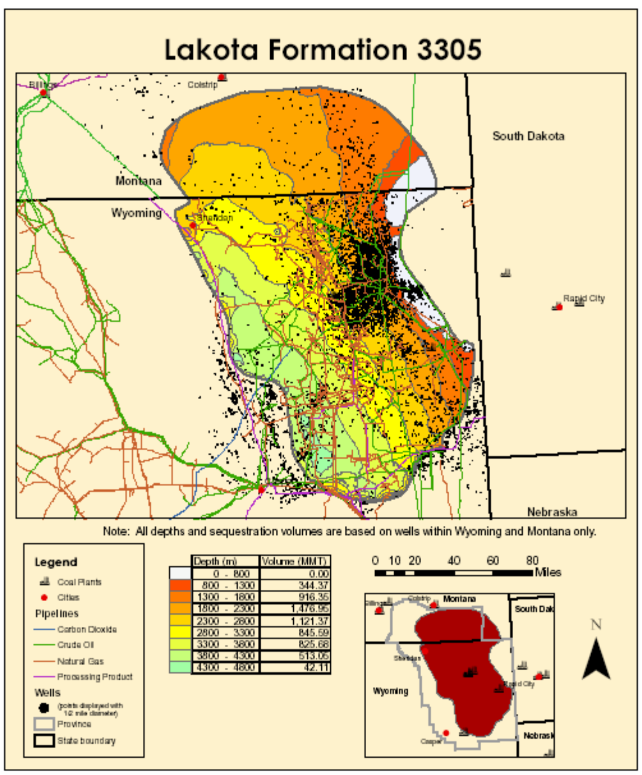


Figure 4. Sequestration and infrastructure information
for Lakota formation in Play 3305

	Evaluation Properties
1	Porosity
2	Depth
3	Pressure
4	Temperature
5	Lateral extent
6	Thickness
7	Water saturation
8	Gas content of coal
9	Salinity
10	Rock type
11	Cap rock
12	pH
13	Fluid properties
14	Permeability
15	Faults
16	System integrity
17	Whole rock chemistry

Table 1: Required properties needed to calculate CO_2 sequestration potential.

	Wyoming Data Sources				Montana Data Sources	
	Lithology & Location	Pressure &Temp	Water Chemistry	Cores	BOGC Web Page	Symposium Book
Api (Identification #)	X	X	X	X	X	
Formation	X	X	X	X	X	X
Latitude	X				X	
Longitude	X				X	
Field	X				X	X
Elevation	X				X	
Well Class (oil, gas...)	X				X	
Depth	X				X	
Temp		X				X
Pressure		X				X
RW		X				X
Chemistry			X			
Salinity			X			X
pH			X			
Porosity				X		X
Perm.				X		X
Saturation				X		X
Unit Thickness						X
Cap Rock						X
Rock Type						X

Table 2. List of all characteristics and sources for which data was available in Montana and Wyoming.

Appendix A

Oil and Natural Gas Reservoir Calculations

Once all properties are in a usable format, applications to facilitate calculations are explored. ArcMap 9.0 has an application called Model Builder which allows users to combine multiple processes or calculations in the same application. The calculations for oil and natural gas reserves and saline aquifers are combined in the same model. The complete model has a total of 26 steps. The following information provides the equation for each step, any assumptions, and explanations.

1 - Calculate pressure in psia. To calculate a pressure for the entire area of interest an equation that uses the depth to calculate pressure was used (McDonald, 2003).

(Equation 1) $P(psia) = .433 * Depth$

2 – Calculate pressure bar. Pressure was converted from psia to bar. A value of 1×10^{-15} was added for future calculations that required there be no zero values.

(Equation 2) $P(bar) = (P(psia) * .0689475729) + 1 \times 10^{-15}$

3 – Calculate pressure mpa. Pressure was converted from bar to mpa.

(Equation 3) $P(mpa) = P(bar) * .101325$

4 – Calculate temperature in Fahrenheit. To calculate a temperature for the entire area of interest on equation that relates temperature to depth was used (McDonald, 2003).

(Equation 4) $T(f) = 61 + (.007 * Depth)$

5 – Calculate temperature in Kelvin. Temperature was converted from Fahrenheit to Kelvin. A value of 1×10^{-15} was added for future calculations that required there be no zero values.

(Equation 5) $T(K) = (((T(f) – 32) * 5/9) + 273.15) + 1 \times 10^{-15}$

6 – Calculate the reference Henry's constant or H_{CO2}. Based on experimental data a relationship using temperature (K) to calculate H_{CO2} was developed (Bachu and Adams, 2003).

(Equation 6) $H_{CO2} = -5032.99 + 30.741113T – 0.052667T^2 + 2.630218 \times 10^{-5}T^3$

7 – Calculate the molar volume of CO2 at infinite dilution or v_{CO2}. Based on experimental data, a relationship using temperature (K) to calculate v_{CO2} was developed (59).

(Equation 7) $v_{CO2} = 1799.36 – 17.8218T + 0.0659297T^2 – 1.05786 \times 10^{-4}T^3 + 6.200275 \times 10^{-8}T^4$

8 – Calculate constant a_{CO2}. Based on the Redlich-Kwong parameters, a relationship was developed to calculate the a_{CO2} constant (Spycher and others, 2003).

(Equation 8) $a_{CO2} = 7.54 \times 10^7 – (4.13 \times 10^4 * T(K))$

9 – Calculate CO_2 volume. The input values of pressure, temperature, and the a_{CO2} constant were converted from a raster to ascII files for use in this calculation. The volume of the compressed gas phase is computed by recasting the Redlich-Kwong equation as a general cubic equation in terms of volume. For this step it was necessary to develop a script in visual basic that would loop through the equation until the desired tolerance was met (Appendix A). A starting volume was calculated using the ideal gas law:

(Equation 9) $V = 83.145 * T / P$

The starting volume was substituted in to the cubic equation:

(Equation 10) $V^3 – V^2(RT/P) – V(RTb/P – a_{CO2}/PT^{0.5} + b^2) – (ab/PT^{0.5}) = 0$

where:

$b = 27.80\ cm^3/mol$

The derivative of equation 10 was calculated.

(Equation 11) $3V^2 – 2V(RT/P) – ((RTb/P) – (A/(PT^{0.5}))) + b^2 = 0$

The tolerance for the equation was set at .0001, if the first guess for the equation did not equal .0001 or less then a second guess was calculated using Newton's method (Hornbeck, 1975). Iterations of guess volumes were continued until the tolerance was meet, these calculations occurred for each 500m x 500m cell.

10 – Convert asscII file to Raster. This step required a change of file format for use in GIS.

11 – Calculate fugacity coefficient. The fugacity coefficient was calculated from standard mixing rules using the Ridlich-Kwong equation (Spycher and others, 2003).

(Equation 12) $\ln(\Phi_k) = \ln(V/(V - b_{mix})) + (b_k/(V - b_{mix})) - (2a_{CO2}/(RT^{1.5}b_{mix})) \ln((V + b_{mix})/V) + (a_{mix}b_k/(RT^{1.5}b_{mix}^2)) [\ln((V+b)/V) - (b_{mix}/(V + b_{mix}))] - \ln(PV/RT)$

where:

$b_{mix} = 27.80\ cm^3/mol$

$b_k = 27.80\ cm^3/mol$

$a_{mix} = a_{CO2}$

12 – Calculate fugacity. Fugacity was calculated from the fugacity coefficient, and converted from bars to mpa (Spycher and others, 2003).

(Equation 13) $f_{CO2} = e^{(\Phi k)} * P * .101325$

13 to 15 – Calculate mole fraction. The calculation of mole fraction took place in several steps because the model had problems making the calculation as a whole. Step 13 uses the pressure (mpa), H_{CO2}, v_{CO2}, and fugacity to calculate the part of the mole fraction within the parentheses (Bachu and Adams, 2003). Step 14 introduces the negative to the equation. And step 15 takes the inverse of the natural log of the equation to calculate the mole fraction of CO_2.

(Equation 14) $\ln x_{CO2} = -(\ln HCO_2 + v_{CO2}P/RT - \ln f_{CO2})$

16 – Calculate mass fraction.

(Equation 15) $X_{CO2} = (x_{CO2} * 44) / ((1-x_{CO2}) * 18)$

17 – Calculate the total dissolved solids (TDS). This step uses the depth raster as a template for applying the TDS, a depth raster is brought in and all values are made zero, then the value for TDS is added. The purpose of this step was to help in automating the entry of TDS. The TDS value is also converted from ppm to wt.% by dividing by 10,000.

(Equation 16) S = Depth * 0 + (TDS/10,000)

18 – Calculate mass fraction of solubility.

(Equation 17) $Xs_{CO2} = X_{CO2}(1.0 - 4.893414\ x10^{-2}S + 1.302838\ x10^{-3}S^2 + 1.871199\ x10^{-5}S^3)$

19 – Convert units of solubility. This step converts the units from g/cm3 to scf/bbl water (McDonald, 2003).

(Equation 18) $Xs_{CO2} = Xs_{CO2} * .00220462262 * 28316.8466 * 5.61458 * 8.615$

20 – Calculate aquifer sequestration volume. This calculates the volume of CO_2 that can be sequestered in the saline aquifer based on water saturation, porosity, reservoir area, thickness, and CO_2 solubility (McDonald, 2003).

(Equation 19) $Q = ((7758 * sw * \phi * a * h * CO_2s)/1000)/18.95$

where:

Q = sequestration volume (metric tons)

7758 = convert everything to ft^3

sw = water saturation

ϕ = porosity

a = reservoir area (acres).

h = thickness (feet).

$CO_2s = CO_2$ solubility (scf/bbl water)

18.95 = conversion factor from mcf to metric tons

21 – Convert saline aquifer sequestration volume to an integer. This was necessary for the next step.

22 – Convert integer raster to points. This allowed the total sequestration volume for the play to be summed. Each point represented the same amount of area 500m.

23 – Calculate density. This calculated the density based on mass and volume, and then converted the units to lb/acre-ft.

(Equation 20) $d = (44/V) * (.0022046/.0000353) * 43560$

24 – Calculate oil and gas reservoir sequestration volume. This calculates the volume of CO_2 that can be sequestered in the oil and gas reservoirs based on water saturation, porosity, reservoir area, thickness, and CO_2 density (McDonald, 2003).

(Equation 21) $Q = \rho_{co2} * h * a * \phi * (1-Sw)/2200$

where:

Q = sequestration volume (metric tons)

ρ_{co2} = CO2 density (lbs/acre-ft)

h = net thickness (feet)

a = area (acres)

ϕ = porosity (percent)

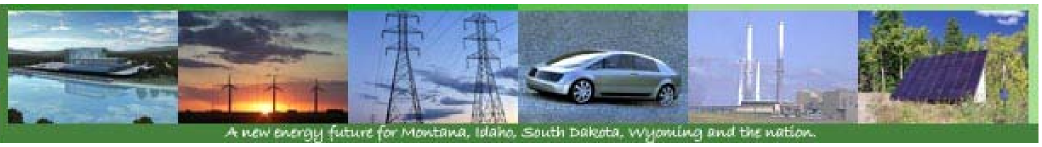
Sw = Water saturation (percent)

2200 (lbs) = 1 metric ton

25 – Convert oil and gas reservoir sequestration volume to an integer. This was necessary for the next step.

26 – Convert integer raster to points. This allowed the total sequestration volume for the play to be summed. Each point represented the same amount of area 500m.

The raster and point files created by the model were saved for each of the calculations. The sum of sequestration volume for oil and natural gas reservoirs and saline aquifers was recorded in a Microsoft Excel spreadsheet for the area of each play that had data.



Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 5:
Action Plan for Enhancing Terrestrial Sequestration

Attachment B: Rangeland Terrestrial Sinks Forestry
(see separate file for PDF document)
Attachment C: Forestry and Agroforestry Opportunities for Carbon Sequestration in the Big Sky

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Forest and Agroforestry Opportunities for Carbon Sequestration in the Big Sky

A contribution to

The Big Sky Carbon Sequestration Partnership

by

R. Neil Sampson
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The Sampson Group, Inc.
February 10, 2005

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Executive Summary

The Big Sky Carbon Sequestration Project is attempting to characterize the carbon sequestration potential in the agricultural and forest areas of the 4-state region, comprising Idaho, Montana, South Dakota and Wyoming. This study addresses the portion of that potential related to agroforestry practices and biomass production on agricultural lands, as well as afforestation of marginal agricultural soils and changing the management of existing private forests. None of these opportunities are overwhelmingly large, as one would expect in a region characterized by a high proportion of federal land, vast areas of arid and semi-arid ecosystems, and widely scattered production areas. But they could be important contributors to state, regional, and national efforts to mitigate greenhouse gas emissions in the near term, as these management practices are available immediately, with mature technologies that are widely known to landowners and technical agents in the region. In the event that carbon sequestration were to gain some market value, these opportunities could become a badly-needed supplement to income in a region dependent on agriculture and forestry for much of its rural economy.

Table 1 illustrates the estimates produced by the study. These estimates have a high degree of uncertainty, in that while most of the practices are well established, the policies and incentives to implement them are not. An example is found in the agroforestry practice of field windbreaks. The values of field windbreaks for soil erosion reduction, soil moisture retention, fuel use reduction, and farm yield protection have been known for decades, and there have been federal cost-sharing incentives since the 1930's. But there are still thousands of acres where windbreak protection would be beneficial, but remains undone. Farmers have resisted the existing incentives, and it is not yet clear how an added incentive tied to carbon sequestration would make a significant difference.

Table 1 contains estimates that reflect the total physical area in the region that is suitable for each practice. While these lands are available in the physical sense, they do not reflect actual implementation. The "potential area" is an author's estimate of what is most likely to be realized over the next 5-10 years unless much additional work is done to produce the policy, economic, and institutional support needed to assure increased success.

Table 1. Summary of carbon sequestration potential in agroforestry, biomass, and forestry, Big Sky Region.

Practice	Available Area (1,000 Ac)	Potential Area (1,000 Ac)	Potential Mitigation ($TgCO_2e$/yr)*
Afforestation	34,000	3,400	4 – 6
Forest Management	10,900	6,200	1.5 – 2
Field Windbreaks	594	300	1.0 – 1.5
Riparian Forest Planting	1,500	750	2.0 – 2.5
Biomass for co-firing	10,500	330	0.25 – 3

* Tg = terragrams = million metric tonnes

Table 1 suggests a total agroforestry, biomass, and forest opportunity in the range of 9 – 15 $TgCO_2e$ per year on the non-federal lands of the region. In comparison, USDA currently estimates that the forests of the region (including federal forests) are sequestering around 41 $TgCO_2e$ per year (Table 8). Thus, while 9-15 will not represent a huge national or global impact, it would mean that activities on private lands could increase regional sequestration by 25 to 35 percent. That, accompanied by the many other environmental values associated with improved carbon sequestration practices, would seem substantial.

Background of the Study

The Sampson Group, Inc. is a contributor to the Big Sky Carbon Sequestration Partnership, working together with other institutions and organizations under sponsorship of the U.S. Department of Energy to coordinate a study of the carbon sequestration opportunities in the region encompassing the states of Idaho, Montana, and South Dakota (www.bigskyco2.org). Wyoming has recently joined the partnership, as well, thus data for Wyoming have been included in this study.

This study is designed to contribute to the task of evaluating the terrestrial sequestration potential in regional ecosystems through forestry, agroforestry, and bioenergy opportunities.

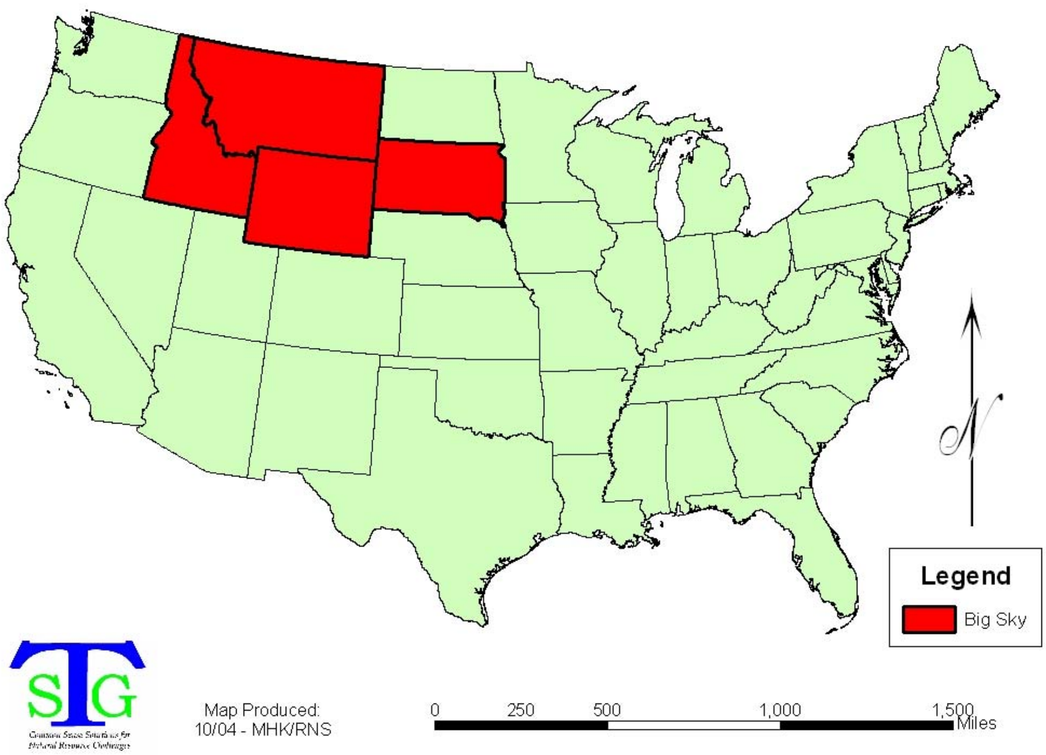

Figure 1. The Big Sky Region covers the states of Idaho, Montana, South Dakota, and Wyoming.

The Big Sky Land Base

The Big Sky region, for the purposes of this paper, consists of the states of Idaho, Montana, South Dakota, and Wyoming (Figure 1). Large areas of arid and semi-arid grazing and croplands are common on the eastern and southern sides of the region, while forested mountainous areas characterize the west. Average annual precipitation rates are highly variable (Figure 2), and even more locally variable in mountainous forest areas where topography and micro-climatic change significantly affect growing conditions.

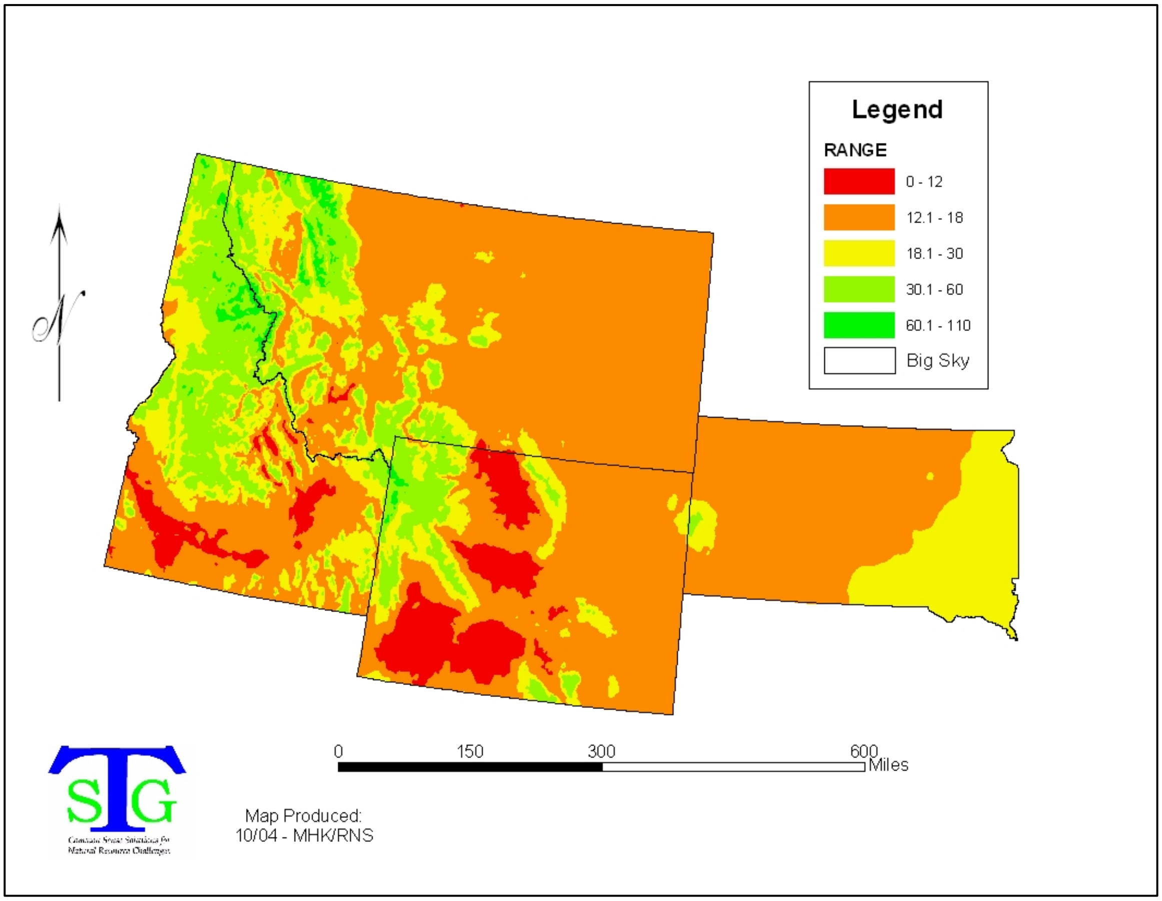

Figure 2. Average annual precipitation, in inches, Big Sky Region. Source: PRISM

The region is 40% federal land (Table 2; Figure 3). These lands are included in the federal Greenhouse Gas Inventory (USDA 2004) that is outlined below (Tables 7 & 8), but are excluded from the estimates of potential opportunity for the creation of additional GHG reductions through state or market programs for carbon sequestration. The exception to this was in the analysis of potential for biomass fuels, where the federal forest land was included as a potential source of woody biomass.

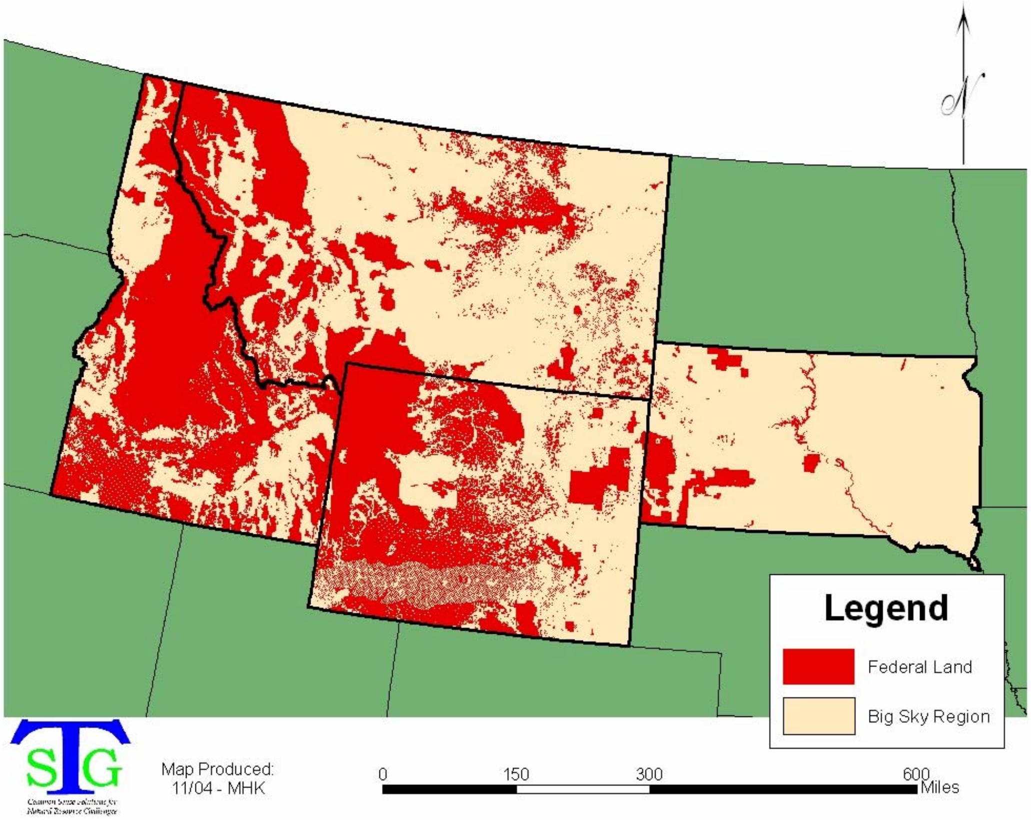

Figure 3. Federal land in the Big Sky Region.

This analysis focuses on the 161 million acres of rural, non-federal land in the region, estimating the potential for increasing carbon sequestration through forestry, agroforestry, and bioenergy strategies.

Table 2. Surface area of nonfederal and federal land and water areas, by state, 1992

			Nonfederal Land			Total
State	Federal Land	Water	Developed	Rural	Total	Surface area
	------------------------------ 1,000 acres ------------------------------					
Idaho	33,480.9	552.2	690.0	18,764.4	19,454.4	53,487.5
Montana	27,089.7	1,052.5	758.6	65,209.2	65,967.8	94,110.0
South Dakota	3,107.9	874.4	957.9	44,417.8	45,375.7	49,358.0
Wyoming	28,748.0	430.9	662.8	32,761.1	33,423.9	62,602.8
Total Big Sky	92,426.5	2,910.0	3,069.3	161,152.5	164,221.8	259,558.3

Source: USDA-NRCS 2000; 1997 NRI, Table 1, National Summary.

The current (1992) use of non-federal rural land is indicated in Table 3. We used the 1992 NRI data (as corrected in 1997) (USDA-NRCS 2000) for this analysis since the only available land use/land cover geographic data was developed in 1992 (USGS 1998). The NRI data provides an independent source against which to test the GIS-derived estimates of potential land use change for improving carbon sequestration. The GIS-derived estimates were derived by identifying areas of non-forested land as shown by the 1992 National Land Cover Data (NLCD) (USGS 1998) that occurred on general soil types that supported native forest cover, as shown by the STATSGO general soil map (USDA-NRCS 2004). For a fuller explanation of how the potential land use change estimates were derived, see Appendix A. Both the NRI and NLCD for 2002 are in development, and the analysis could be fairly easily updated when both become available for use.

Table 3. Land use of non-federal land, 1992, by state.

State	Cropland	CRP	Pasture	Range	Forest	Other rural land	Total rural land
				(1,000 acres)			
Idaho	5,600.0	823.7	1,299.0	6,517.2	4,019.9	533.2	18,793.0
Montana	15,035.0	2,781.3	3,406.6	36,982.0	5,413.6	1,404.5	65,023.0
South Dakota	16,436.7	1,756.8	2,199.7	22,078.9	524.1	1,477.3	44,473.5
Wyoming	2,271.9	251.7	935.3	27,312.1	1,030.2	1,006.1	32,807.3
Big Sky Total	39,343.6	5,613.5	7,840.6	92,890.2	10,987.8	4,421.1	161,096.8

Source: USDA-NRCS 2000; 1997 NRI, Table 2, National Summary.

Much of the cropland (19%) in the region is irrigated (Table 4). The opportunities identified in this paper for converting marginal crop and pasture land to forest are limited to non-irrigated cultivated cropland where soils and climate conditions could support forest growth. Irrigation is too expensive to be used for growing forest (with the possible exception of fast-growing hybrids), and this land would be too arid for trees if the irrigation was discontinued, so irrigated cropland was not considered an opportunity for conversion. Non-cultivated cropland is largely meadow hayland, hayland, vineyards, or orchards, so was also not considered a high opportunity for conversion. While the non-irrigated cropland area is large, only a portion lies in climate zones where trees are adapted. The GIS analysis used to identify those climate zones is described in Appendix A.

Table 4. Cropland use, by state, 1992

State	Cultivated Cropland			Non-cultivated Cropland			Total
	Irrigated	Non-irrigated	Total	Irrigated	Non-irrigated	Total	
				(1,000 Acres)			
Idaho	2,862.2	1,793.0	4,655.2	633.0	311.8	944.8	5,600.0
Montana	884.4	11,597.9	12,482.3	1,193.0	1,359.7	2,552.7	15,035.0
South Dakota	420.9	13,983.7	14,404.6	61.4	1,970.7	2,032.1	16,436.7
Wyoming	456.5	518.5	975.0	962.9	334.0	1,296.9	2,271.9
Big Sky Total	4,624.0	27,893.1	32,517.1	2,850.3	3,976.2	6,826.5	39,343.6

Source: USDA-NRCS 2000; 1997 NRI, Table 3, National Summary.

Land use change has not been a major factor in the region since 1982, as illustrated in Table 5. Virtually all of the Conservation Reserve land that has been established has come from cropland, and this land retirement was the main factor in a cropland reduction of about 3.5 million acres (8.2%) over the past 15 years. Both the total area (~ 11 million acres) and the individual sample plots on nonfederal forest land have been essentially unchanged since 1982 (the margin of error in the 1982 and 1997 total estimates is around 500,000 acres, so the changes shown are not statistically significant).

Implementation of the most recent signup in the CRP program has resulted primarily in the conversion of cropland to grassland, as shown in Table 6. Even in the counties where conversion to trees looks biologically possible, the amount of CRP land planted to trees has been very low. These factors suggest that conversion of marginal cropland to trees is a difficult "sell" in this region, even in those counties where trees are a logical option. This is not a recent phenomenon, nor is it limited to this region. Esseks et al. (1992) found that farmers outside the Southeast, where forest production is a common practice on private lands, were generally unwilling to commit to the permanence of forest cover and opted, instead, for the land use flexibility of planting a grass cover.

One possibility, largely unused to date, is the potential for the Conservation Reserve Enhanced Program (CREP) for establishing riparian forests as a means of enhancing water quality.

Table 5. Land Cover/Land Use Change, 1982-1997, Big Sky Region.

Land Cover/Use in 1982	Land Cover/Use in 1997: Cropland	Pasture-land	Range-land	Forest Land	CRP Land	Other Rural Land	Devel-oped Land	Water & Federal Land	Total in 1982
	(1,000 Acres)								
Cropland	**35,609**	1,599	218	9	5,066	219	221	182	43,122
Pastureland	1,682	**5,618**	162	19	153	54	93	46	7,825
Rangeland	2,037	625	**91,373**	159	207	134	202	320	95,055
Forest Land	13	19	176	**10,458**	0	18	86	201	10,972
CRP Land	0	0	0	0	**0**	0	0	0	0
Other Rural Land	77	83	86	41	12	**3,925**	21	16	4,261
Developed Land	13	5	23	6	0	2	**2,768**	0	2,816
Water & Federal Land	169	65	393	209	0	27	0	**94,643**	95,507
Total in 1997	39,600	8,011	92,430	10,901	5,438	4,380	3,391	95,408	259,558

Source: NRCS 2000 (1997 NRI). Note: Acreage in bold is unchanged from 1982 to 1997.

Table 6. Conservation Reserve Program Acres, Big Sky States, by Cover Type, Signup #26, 2003

State	Total CRP	Grass		Trees	
	Acres		*Percent*	*Acres*	*Percent*
Big Sky Region	129,985	127,847	98.4%	2,138	1.6%
Idaho	53,750	51,829	96.4%	1,921	3.6%
Montana	50,255	50,242	100.0%	13	0.0%
South Dakota	25,980	25,776	99.2%	204	0.8%
Wyoming	0				

• Greenhouse Gas Emission Inventory

The U.S. Department of Agriculture has conducted a comprehensive assessment of greenhouse gas emissions and sinks in U.S. agriculture and forests (USDA 2004). Estimates are provided at State, regional, and national scales, categorized by management practices where possible. The estimates are consistent with those published by EPA in the official Inventory of U.S. Greenhouse Gas Emissions and Sinks that was submitted to the United Nations Framework Convention on Climate Change in April 2003. For the Big Sky Region, cropland soils were estimated to be an annual sink of 5.4 $TgCO_2e$ (Table 7), while forests (not counting soils or forest products) were estimated to be a sink of 40.8 $TgCO_2e$ per year (Table 8). (Tg stands for teragrams, or million metric tons.)

Table 7. State estimates of soil carbon changes in cropland and grazing land in 1997 by major activity categories.

State	Plowout of grassland to Annual cropland[1]	Cropland manage-Ment	Other Crop-land[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land man-agement	CRP	Manure applica-tion	Cultiva-tion of organic soils	Net soil carbon Emissions[4]
						Tg CO_2e					
Idaho	1.1	-0.07	0	-1.03	-0.04	-0.26	-0.04	-0.59	-0.34	0.07	-1.19
Montana	1.91	-0.59	0	-1.28	-0.07	-0.48	0	-1.8	-0.08	0.11	-2.28
South Dakota	4.07	-0.18	0	-2.9	-0.04	-0.44	0.07	-1.39	-0.31	0.07	-1.04
Wyoming	0.51	-0.07	0	-0.62	-0.04	-0.29	0	-0.37	-0.04	0	-0.92
Big Sky Totals	7.59	-0.91	0	-5.83	-0.19	-1.47	0.03	-4.15	-0.77	0.25	-5.43

Negative numbers indicate net sequestration.

[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).

[2] Perennial/horticultural cropland and rice cultivation.

[3] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.

[4] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

Source: Appendix Table B-11, USDA 2004.

Tg = terragrams = million metric tonnes

Table 8. State summaries of forest area, total area, forest non-soil stocks (2002), forest non-soil stock change (2001), and forest products stock change (2001).

State	Forest Area	Total Area	Forest non-soil stocks	Forest non-soil stock change	Products stock change
	1,000 ha		*Tg CO_2 e*	*Tg CO_2 e/yr*	
Idaho	8,760.0	21,646.0	4,145.0	-12.1	-3.4
Montana	9,426.0	23,291.6	3,938.0	-21.5	-2.3
South Dakota	655.0	1,618.5	192.0	0.6	-0.2
Wyoming	4,449.0	10,993.5	1,897.0	-7.8	-0.2
Big Sky Totals	23,290.0	57,549.6	10,172.0	-40.8	-6.1

Source: Appendix Table C-1, USDA 2004

- **Forestry Opportunities for Carbon Sequestration in the Big Sky**

- ***Afforestation***

We define the biological opportunity for afforestation as all non-federal, non-forest land (primarily cropland and grassland) identified in the 1992 NLCD data in areas where the STATSGO soil survey (USDA-NRCS 2004) identifies woodland as being the native vegetation (Figure 4). See Appendix A (Tables A-1 and A-2 for the classifications used.) That estimate may overstate the real biological opportunity, since some of those sites have been degraded by soil erosion to the point where an ecological type change has occurred that may prevent successful re-establishment of trees. That overestimation has been taken into account by discounting the estimates of feasible afforestation from the estimate of total suitable land. The amount of discount was based on the current land use and the forest type suitability (Appendix Table A-6).

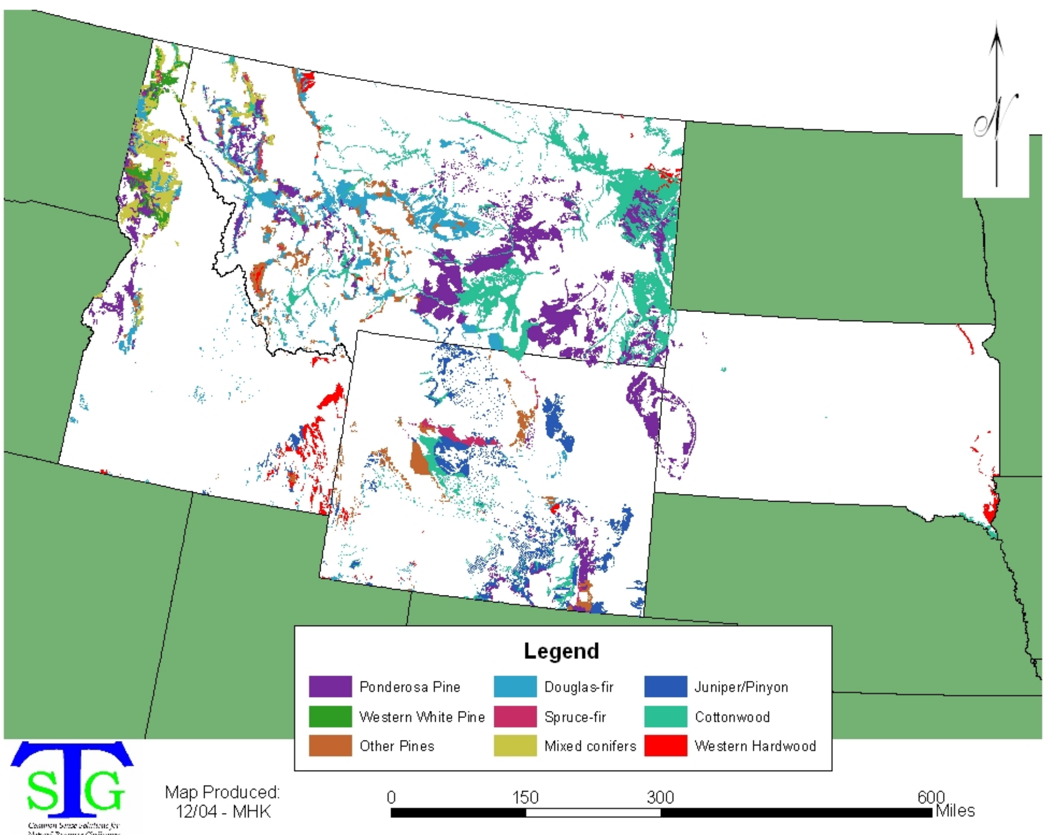

Figure 4. Potential forest types on non-federal lands, as indicated by general soil type (STATSGO).

To develop estimates of the impact of afforestation, tables were developed by state indicating the current non-forest area that coincided with a native forest type. These were then combined in a regional table (Appendix Table A-3). See Appendix A for a description of the analytic methods used. Average annual forest growth estimates were developed from Birdsey (1996) (Appendix Table A-4). Estimates of potential timber volume growth were developed by multiplying the acreage of land available to be afforested times the average annual growth rate of the appropriate forest type.

The estimates of potential timber volume growth were converted to carbon dioxide equivalents by the factors published by Birdsey (1992, 1996). When the specific factors are applied to the species in the region, they range from 88 to 127 lbs CO_2e per ft^3 of timber grown.

The resulting biological opportunity is around 44.6 TgCO_2e per year (Appendix Table A-5) on the region's non-federal lands. This estimates the upper limit of potential afforestation impact. This would represent a significant impact, more than doubling the amount of sequestration currently occurring in the forests of the region (Table 8). If the estimate of available, suitable acres (34.3 million) is reasonable, however, the estimated sequestration rate is about 1.3 tCO_2e per acre per year. That is conservative, as there are existing default factors, such as those used by the Chicago Climate Exchange, that run in the range of 1.4 to 1.5 tCO_2e per year.

Since it is anticipated that only a small portion of the potential will be realized (and that it will be realized at a different rate for different existing land uses and timber types, see Table A-6), a final table (Table A-7) was constructed based on an author's estimate of the potential for conversion, based on experience in the region. These factors can be debated by experts in the region and changed to reflect other opinions. The impact of this calculation was to reduce the biological potential estimate by nearly 90%. In other words, we think it reasonable for the region to seek a goal of sequestering about 10% of the total biological opportunity available for afforestation (Table A-7).

On this basis, we estimate that the potential for additional carbon sequestration from an effective afforestation program in the 4-state Big Sky Region is in the range of 5 TgCO_2e per year. The range of uncertainty in the estimate is significant, running from near zero to an upper estimate of some 15-20 TgCO_2e per year. That would suggest an increase in the range of 10 to 50% compared to what is currently sequestered in all the region's forests (Table 8). Given that Table 8 includes millions of acres of federal forestlands, such a potential increase from the limited amount of non-federal forests is fairly significant. An economic supply curve could be constructed that would estimate the prices that might be required to realize the quantities within this range, but that is beyond the scope of this paper.

- ***Forest Management***

The analysis for forest management opportunity is based on data from the 1997 National Resources Inventory (NRI) that, for the first time, included an attribute for woodland species on the non-federal lands (USDA-NRCS 2000). Here, the land that was forest in 1997 was tabulated by forest type. There are no data on forest age or condition, how intensively these forests are currently being managed, or what opportunities might exist to improve that management through practices like enrichment planting (to fill understocked stands), thinning to improve health and growth in overstocked stands, or fertilization. The carbon dynamics in these forests can also be changed by lengthening the growing rotation on managed forests to provide larger trees, and larger wood products that last longer in use (Row 1996).

Table 9 contains 1997 estimates of non-federal forest by species groups as one basis for understanding the potential for carbon sequestration through improved forest management.

Table 9. Forest species groups on non-federal land, by state, 1997.

Group	Species	Idaho	Montana	S Dakota	Wyoming	Total
				1,000 acres		
1	Ponderosa Pine	462.0	1,116.7	346.5	660.7	2,585.9
2	Lodgepole Pine	47.0	662.7		49.3	759.0
3	Douglas Fir	1,272.5	2,335.0		23.8	3,631.3
4	Fir; Spruce	122.0	439.6		98.2	659.8
4	Hemlock; Sitka Spruce	658.0	-			658.0
4	Spruce; Fir		8.2			8.2
5	Larch	946.1	296.1			1,242.2
5	Western White Pine	60.7	16.2			76.9
6	Pinyon; Juniper	5.4	-			5.4

7	Elm; Ash; Cottonwood		40.6	89.4	3.2	133.2
8	Aspen; Birch		54.4	10.1	15.9	80.4
8	Oak; Pine			40.1	10.7	50.8
8	Western hardwoods	248.4	192.6	26.6	107.4	575.0
9	Noncommercial	3.6	90.5	5.0	32.9	132.0
9	Non-stocked	122.1	178.2	0.6	2.0	302.9
	Total non-federal forest	3,947.8	5,430.8	518.3	1,004.1	10,901.0

Source: 1997 NRI (USDA-NRCS 2000)

The next question that arises is the extent to which the existing forests can be managed differently to increase carbon sequestration. Not knowing the level of current management intensity, we applied general factors across the area, recognizing that on any one forest, the departures from average will likely be significant.

There are some forest types that are more likely to be managed for improved growth and productivity than others. One example would be ponderosa pine versus pinyon pine. Ponderosa is widely managed for timber and other forest values, while pinyon is generally a scattered forest across broad areas that are primarily used for grazing land by private landowners. Thus, pinyon/juniper is one forest type that is unlikely to be managed to increase carbon sequestration. Most of the western hardwoods in the Big Sky Region probably fall into this category, as well. Based on these factors, the forest types were divided into three classes on the probability that state or regional carbon sequestration programs would be likely to impact forest management (Table 10).

As a general rule, the average annual carbon sequestration impact from changing forest management is quite low (Table 10). Lengthening harvest rotations, thinning and weeding for improved species adaptation and forest health, inter-planting to achieve optimum stand density, and fertilization all can change forest growth dynamics, but the region's forest types are fairly slow-growing, and changing management does not impact the annual change in standing biomass rapidly. The result is fairly low estimates of potential annual impact from forest management. The large area involved, almost 10 million acres in the "high" and "medium" categories, result in fairly significant estimates of potential impact. The bottom line of 1.5 to 2 $TgCO_2e$/yr, would represent a change of some 3-5 percent in the region's currently estimated annual forest sequestration (Table 8).

- **Table 10. Non-federal forest land, Big Sky Region, with estimates of the management opportunities for increasing carbon sequestration**.

		Management Opportunity*		
Species Group	1000 Acres	High	Medium	Low
Ponderosa Pine	2,585.9	2,585.9		
Other Pines	759.0		759.0	
Douglas-fir	3,631.3	3,631.3		
Fir-spruce	1,326.0		1,326.0	
Mixed conifers	1,319.1		1,319.1	
Pinyon/juniper	5.4			5.4
Cottonwood	133.2			133.2
Western Hardwood	706.2			706.2
Non-stocked	434.9			434.9
Total	10,901.0	6,217.2	3,404.1	1,279.7
* Rated by authors on the basis of the likelihood that landowners will manage them for long-term timber or carbon sequestration goals.				
tCO_2e/acre/year		0.25	0.1	0
Sequestration Opportunity		1,554.3	340.4	-
Total Annual Sequestration Opportunity (1000 tCO_2e)				1,894.7

• Agroforestry Opportunities

• *Field Windbreaks*

The analysis for field windbreak needs and opportunities is based on data from the 1997 NRI (USDA-NRCS 2000). We used the NRI to identify all non-irrigated cropland with an erosion index (EI) of 5 or higher that did not have windbreaks or cross-wind stripcropping established in 1997 (Table 11). These lands may have other erosion control practices such as conservation tillage, vegetative soil traps, or other herbaceous wind barriers, but there is a good indication that windbreaks would be a helpful addition to the wind erosion control strategy on many of them, and the carbon sequestration impacts would be an added benefit to the landowners and the environment. (Soils with EI values over 5 are erodible, and USDA classifies those with EI values over 8 as highly erodible (USDA-NRCS 2000)).

For those erodible dry croplands, we estimated that field windbreaks occupying 5% of the cultivated surface area would be a realistic goal for the establishment of needed windbreaks (Brandle et al., 1992a). At an average one-row windbreak width of 16½ feet, such a windbreak would occupy 2 acres per mile. At 8 to 10-foot spacing between trees, there would be 530 to 660 trees per mile. The carbon sequestration rate was estimated at 3 tCO_2e per acre per year (Table 11, see Table 12 for representative species). No credit was given for the emissions reductions inherent in the soil conservation effect of windbreaks, or the reduction in cultivated area and associated fuel and fertilizer use, etc. What is clear, however, is that field windbreaks offer significant ancillary environmental benefits in addition to their impact on carbon sequestration (Brandle et al., 1992b). Work is currently underway at the University of Nebraska to develop more definitive tables of sequestration in windbreaks, and could become available for use in the near future (Table 12, Zhou and Brandle, unpub.).

• Table 11. Croplands with a wind erosion index (EI) greater than 5, and annual carbon sequestration from establishing windbreaks on 5 percent of those that lacked stripcropping or windbreaks in the 1997 NRI.

Category	Idaho	Montana	South Dakota	Wyoming	Big Sky
			1,000 acres		
Cultivated Cropland, Wind EI > 5	2,823.1	12,350.9	3,584.9	870.1	19,629.0
Dry Cultivated (DC) Cropland, EI > 5	172.8	11,534.1	3,535.0	467.0	15,708.9
DC Cropland, EI > 5, with no Stripcropping	164.6	8,711.1	3,452.9	217.9	12,546.5
DC Cropland, EI > 5, with no Stripcropping or Windbreaks	164.6	8,682.9	2,818.3	217.9	11,883.7
Windbreaks on 5%	8.2	434.1	140.9	10.9	594.2
tCO_2e/acre/year	3.0	3.0	3.0	3.0	3.0
$TgCO_2e$/year	0.025	1.3	0.42	0.033	1.78

Table 12. Estimated sequestration rates for 3 common windbreak species.

Species	KgC/tree/yr	Lb/tree/yr	Trees/acre	tC/ac/yr	tCO_2e/ac/yr
Green Ash	5	11.02	264	1.32	4.85
Austrian Pine	4	8.82	264	1.06	3.88
Eastern Redcedar	1.5	3.31	330	0.50	1.82

After Zhou and Brandle, unpub.

- ***Riparian Forest Establishment***

Many of the private lands with soils adapted to forest establishment are in riparian areas, particularly in the drier areas of the region. A close inspection of the forest-growing soils (Figure 4) shows many linear patterns, particularly with the western hardwood types. These patterns outline stream valleys for the most part, and the forest opportunities there are significant. The ancillary environmental benefits to water quality and wildlife habitat are also important in these riparian areas. Table A-3 indicates 1.5 million acres of western hardwood sites in the region, which is one indicator of the riparian forest opportunity. Yields will respond in these areas due to favorable soil and moisture conditions, leading to an estimated carbon sequestration gain of 2 – 2.5 $TgCO_2e$ per year if one-half of these lands were planted to species such as cottonwood, willow, and other adapted local species with yields of around 3 tCO_2e per acre per year.

• Biomass Energy Opportunities

The use of biomass as a substitute for fossil fuel (primarily coal) is an excellent opportunity to replace fossil carbon emissions with renewable fuels that grow and sequester carbon in the same general time as the emissions occur. Thus, the use of biomass is often referred to as an offset for fossil emissions (Klass 1998; Sampson et al. 1992).

Biomass for fuel can be harvested from existing forests, particularly those that are overstocked and need thinning. Thinning that removes small trees and ladder fuels can be a major contributor to helping these forests become less susceptible to uncharacteristic wildfires, improving forest health, and opening up overcrowded forests for additional biological diversity (Sampson et al. 2001).

While it is possible to build power plants that rely solely on biomass fuels, another opportunity lies in co-firing biomass in existing coal-burning power plants. Research indicates that firing with up to 10 percent biomass is technically feasible and provides reductions in pollution emissions, including carbon dioxide emissions (Payette and Tillman 2004). Biomass, while having several environmental advantages, can also be used effectively in co-firing despite supply variations due to things like annual weather or harvest conditions. The coal plant is not dependent on the biomass, so if a yield shortfall occurs, the plant is not forced to cut back on production.

One of the key economic limitations in biomass energy production is the transportation costs involved in moving heavy, low-value fuels large distances. For that reason, many authors suggest that a radius of about 50 miles is reasonable in calculating the region that can feasibly supply biomass fuel to an existing power plant (Klass 1998).

Figure 5 shows the existing coal-fired power plants in the Big Sky Region, according to the 2002 version of the eGRID database produced by the Environmental Protection Agency (USEPA 2003). A GIS analysis estimated the 1992 land cover/land use within a 50-mile radius of each plant. This analysis included federal lands, because federal lands in the region are in serious need of thinning to restore forest health and fire adaptability (Sampson et al. 2001).

Growing short-rotation crops like hybrid poplar or willow on agricultural land produces biomass yields in the range of 4-10 dry tons per acre per year (Tuscan 2000). Switchgrass should produce about 4 dry tons per acre per year on dry croplands in eastern South Dakota (Graham et al. 1996). Limited rainfall will preclude its growth west of there, according to the ORNL data (Graham et al. 1996). Thinning overcrowded forests produces one-time biomass yields of around 15 tons per acre

(Sampson et al. 2001). Although heat values vary considerably with the moisture content of biomass fuel, we assumed that 1 bone dry ton (BDT) of biomass would produce 1 MWH of electricity. Thus, around 8,700 BDT of biomass is needed to produce 1MWH for a year.

There is a significant difference in these biomass sources, however. Farm-produced biomass (switchgrass or short-rotation woody crops such as hybrid poplar) should yield around 4 tons per acre per year on a sustained basis. Thinning overcrowded forests is largely a one-time biomass removal, since converting the forests to a more sustainable condition will result in fewer small and uneconomic stems in the future (Sampson et al. 2001). There will be future production that may need removal by mechanical means, but the average per-year production rate will be slow. Thus, a power plant dependent on forest thinning needs an available acreage that is some 25-30 times larger than what is needed for its annual consumption.

Table 12. Estimates of land required, land available, and proportion needed to provide biomass sufficient for co-firing to replace 10% of the current MWh produced by coal-burning power plants in the Big Sky Region.

Plant No.	State	Name	2000 annual coal net generation (MWh)	Biomass to replace 10% of MWh[1] (BDT)	Land Required		Land Available		Proportion Needed	
					Crop-land[2]	Forest[3]	Cropland[4]	Forest[5]	Crop-land	Forest
1	ID	AMALGAMATED SUGAR CO LLC NAMPA FACTORY	42,436.9	4,244	1,061	283	403,505	317,587	0%	0%
2	ID	THE AMALGAMATED SUGAR CO LLC	28,238.3	2,824	706	188	897,829	22,657	0%	1%
3	MT	COLSTRIP + COLSTRIP ENERGY LP	14,715,206.9	1,471,521	367,880	98,101	318,606	538,893	115%	18%
4	MT	CORETTE	1,161,874.8	116,187	29,047	7,746	1,134,961	393,154	3%	2%
5	MT	LEWIS & CLARK	323,757.0	32,376	8,094	2,158	1,810,108	25,179	0%	9%
6	SD	BEN FRENCH	166,314.0	16,631	4,158	1,109	320,936	1,104,604	1%	0%
7	SD	BIG STONE	3,504,262.0	350,426	87,607	23,362	1,171,048	513	7%	4554%
8	WY	DAVE JOHNSTON	5,661,946.0	566,195	141,549	37,746	10,206	117,212	1387%	32%
9	WY	GENERAL CHEMICAL + JIM BRIDGER	16,380,196.4	1,638,020	409,505	109,201	7,671	13,848	5338%	789%
10	WY	OSAGE	245,439.0	24,544	6,136	1,636	48,978	349,676	13%	0%
11	WY	LARAMIE RIVER 1 + LARAMIE RIVER 2 & 3	12,440,471.0	1,244,047	311,012	82,936	495,047	222,950	63%	37%
12	WY	NAUGHTON	5,311,532.0	531,153	132,788	35,410	26,470	241,123	502%	15%
13	WY	NEIL SIMPSON + NEIL SIMPSON II + WYODAK	3,534,324.0	353,432	88,358	23,562	64,957	71,524	136%	33%

[1] Estimated on the basis of 1 BDT yielding 1 MWH of power.

[2] Estimated sustainable yields of 4 BDT biomass per acre per year with grass or woody crops

[3] Estimated one-time yield of 15 BDT per acre of otherwise non-merchantable wood during thinning.

[4] Total row crops, small grains, and fallow from NCLD within 50 miles of plant.

[5] Total evergreen forest within 50 miles of plant. (Omits deciduous and mixed forests as unlikely sources.)

This analysis suggests that there are significant differences between locations as to the possibility of co-firing biomass from agricultural or forest sources. Some (i.e. 1 and 2) are located in the midst of irrigated agricultural areas where production costs might be too high to support biomass production. Forest resources are plentiful within 50 miles, and may be a better opportunity. Some plants (i.e. 3,8,9,11,12, and 13) would clearly be too large to be considered for agricultural inputs since they are so large in comparison with the available cropland nearby. Others (3,7,8,9,11,12, and 13) would overwhelm surrounding forest resources because of their size. Some of the smaller plants (i.e. 1,2,4,5,6, and 10) may be potentials for consideration as a co-firing opportunity.

Those six plants were responsible for annual emissions of 2.5 $TgCO_2e$ in 2000, according to the eGRID data, so if co-firing were feasible on all of them, a reduction of some 0.25 $TgCO_2e$ per year may be realized. While it is unlikely that all of this could be realized by co-firing, the estimate could also under-estimate the future opportunities if the current trend toward building new fossil-fired power plants were to include biomass co-firing as part of initial design, or if new technologies or economic conditions make construction of dedicated biomass plants feasible.

Figure 5. Existing coal-fired power plants, with 50-mile radius indicated.

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Appendix A. The Geographic Information System (GIS) Analysis for Afforestation Opportunity

Data Sources

Three primary data sources were used in this analysis. This included a vector layer containing the location of Federal lands, the U.S. Geological Survey National Land Cover Data (NLCD) raster coverages and State Soil Geographic (STATSGO) vector data. These layers were downloaded via the Internet from federal sources. Each layer was in the same projection system and measurement units (Albers Conical Equal Area, meters).

To obtain the location of Federal lands within the scope of the project, the *Federal Lands and Indian Reservations* vector file was downloaded from www.nationalatlas.gov. This is a federal website supported by the United States Department of the Interior that provides a platform to download federally produced GIS data sets. This layer contains polygons of the federally owned or administered lands throughout the United States. For the purposes of this study it was determined that federal lands were not eligible for afforestation, but Indian reservations could be. Therefore, the Indian Reservations were removed from this layer before it was used as a filter to remove Federal land.

The USGS National Land Cover Data (NLCD) was downloaded by state from *http://www.usgs.gov*. This data was derived from Landsat satellite TM imagery (circa 1992) and is provided in a Geo-TIFF format with a 30-meter resolution. Each cell contains a numeric value that represents a certain land cover based upon the NLCD Classification System.

State Soil Geographic (STATSGO) data were downloaded by state from http://www.nrcs.usda.gov. This vector layer and its related tabular data provide locations of current and potential forests by forest type based on soil types and descriptions. Use of this layer helps identify areas containing soils suitable for growing trees.

Scale/Accuracy

Data accuracy is always a concern when performing spatial analyses using multiple data layers from multiple sources. Data accuracy and scale of each layer was considered before the analysis was performed.

According to the metadata of the Federal Lands data, it was produced for analysis "at scales appropriate for 1:2,000,000-scale data." This is a small scale, so accuracy would be a concern if this data were used in analyses conducted at much larger scale. However, this analysis was conducted at the state level and, given the large size of the western states within the scope of our project, the use of this federal lands layer was considered appropriate.

The NLCD layers were produced with a 30 by 30 meter cell-size (or resolution). Therefore, each cell represents 900 square meters or 0.222 acres. These data were produced with the highest level of detail of any data used in this analysis and were appropriate for our state-level analysis.

According to its metadata, STATSGO data was "designed primarily for regional, multistate, river basin, state, and multi-county planning, managing and monitoring," so was considered appropriate for this analysis.

Procedures

The GIS analysis was conducted in several steps. The first step determined existing areas on non-federal lands that would be available for afforestation on the basis of current use (mainly cropland or pasture). The second step determined soil and climate situations suitable for afforestation based on the STATSGO data. The third step combined the outputs of the first two steps to compute a *Final Suitability* layer. Finally, the tabular data were converted from acres of potential forest into estimates of sequestration by primary forest groups, based on projected average annual yields of timber converted into its equivalent carbon dioxide sequestration impact.

<u>Step 1- NLCD land cover on non-federal lands</u>

The Federal Lands layer was first clipped to the Big Sky states within the scope of the project: Idaho, Montana, Wyoming and South Dakota. The polygons associated with the Indian Reservations and null values were then removed from the resulting federal land layers, since the Indian Reservations are considered potential cooperating lands for the purposes of this study. Each state-clipped federal land layer was converted to a raster grid with the same resolution (30m) and extent of the NLCD layer associated with each particular state. The resulting grids were then reclassified, so that the cells containing federal land held a value of zero and all other cells contained a value of one.

A raster calculation within each state multiplied the reclassified federal lands grids and the NLCD grids. The resulting grids contained a value of zero where federal lands exist and the previous value of the NLCD classification in all other areas.

Not all NLCD classes are available for afforestation (Table A-1). Areas already classified as forests, and areas such as urban, wetlands, etc., were excluded from the analysis. In order to isolate the suitable areas, the non-federal NLCD grids were reclassified to remove the cells that contained unsuitable values. The result provided maps and area estimates of the non-federal land within each state that is potentially available for afforestation based on NLCD classifications (Figure 4). (Note: this map contains areas unsuited for forests due to soil and climate conditions.)

Table A-1. NLCD classes identified as suitable/non-suitable for afforestation on the basis of 1992 land use or cover.

Suitable			Non-Suitable	
Code	Description	Comments	Code	Description
33	Transition Areas	Poss. Clearcuts	11	Water
51	Shrubland	good on suitable soils	12	Perennial Ice/Snow
61	Orchards/Vineyards/Other		21	Low Intensity Residentail
71	Grasslands/Herbaceous	good on suitable soils	22	High Intensity Residentail
81	Pasture/Hay		23	Commercial/Industrial/Transporation
82	Row Crops		31	Bare Rock/Sand/Clay
83	Small Grains		32	Quarries/Strip Mines/ Gravel Pits
84	Fallow		41	Deciduous Forest
			42	Evergreen Forest
			43	Mixed Forest
			85	Urban/Recreational Grasses
			91	Woody Wetlands
			92	Emergent Herbaceous Wetlands

<u>Step 2- STATSGO suitability</u>

For step two, the STATSGO data layers and their associated tabular data were analyzed for each state. To determine areas that are suitable for growing trees the ‘woodland’ table was joined to the base STATSGO layers. By doing so, the attributes identify polygons with soil and climate characteristics appropriate for growing trees. Only these areas in each state were included in further analysis.

The ‘woodland’ table also provides a native forest type based upon the soil and climate features. To simplify our analysis, we grouped the STATSGO forest types into nine groups (Table A-2). The federal lands were then removed, by clipping the forest group polygons to the non-federal lands layer created from the original Federal lands data. The resulting layer contained the areas of non-federal land that are suitable for afforestation based upon the STATSGO data (Figure 4).

Table A-2. Grouping of primary species in STATSGO soils data into major forest type groups.

Code	Group	Species included in Group
1	Ponderosa Pine	Ponderosa pine
2	Western White Pine	Western White Pine
3	Other Pines	Lodgepole pine, limber pine
4	Douglas-fir	Douglas-fir
5	Spruce-fir	Engelmann spruce, subalpine fir, white spruce, mountain hemlock
6	Mixed conifers	Grand fir, western larch, western redcedar
7	Pinyon/juniper	Utah juniper, oneseed juniper, pinyon, singleleaf pinyon
8	Cottonwood	Black cottonwood, narrowleaf cottonwood, plains cottonwood, eastern cottonwood
9	Western Hardwood	Bur oak, white oak, quaking aspen, silver maple

Step 3- Final Suitability

The final map layer identified areas available for afforestation by the NLCD (current cover is not forest) and potentially suited to forests according to STATSGO. These layers were combined by converting the STATSGO suitability layers to grids with the same resolution (30m) and extent of the NLCD suitability layers associated with each particular state. Each cell of the new STATSGO grids contained the forest type code (created in step 2) for the potential forest spatially associated with each particular cell.

This forest-type grid was then reclassified so that all cells containing a forest-type were given a value of 1 and all other cells contained a value of zero. A raster calculation was then performed between this reclassified grid and the NLCD suitability grid. This created a new layer that contained the NLCD codes in the areas determined suitable for growing trees by the STATSGO data.

In order to determine area estimates of potential afforestation by forest types, the original forest type grid values need to be incorporated with the NLCD values. This gives the area of potential afforestation by 1992 land cover and potential forest type. Another raster calculation is done between the suitable soil forest types and the original NLCD grid that contained the non-forest values.

Unfortunately, these grid values could not be simply added together, because the results would contain integers with potentially non-unique or overlapping values. In order to maintain the integrity of both the NLCD values and the forest group values, NLCD values were multiplied by 100 and then the forest type values were added to that number. The result was a grid with each cell identified by a four-digit number. The first two digits referred to the NLCD code associated with that cell, the third number was a zero (meaning nothing, but a place holder or separator) and the fourth number contained the forest type code associated with that cell. (Thus, a grid cell with an attribute of 7101 indicated an area of current grassland with the soil and climate potential to grow ponderosa pine.)

Step 4. Developing afforestation and carbon sequestration estimates

The final suitability grid was entered into a spreadsheet model and analyzed for potential afforestation acreage estimates within each state. Since each grid represents 900 m^2, multiplying the number of grids by 900 and dividing the result by 4047 converted the area to acres. A cross-tabulation produced a table showing current cover and potential forest type. These estimates were developed for each state and rounded to 1,000 acres to avoid the appearance of high precision. Table A-3 gives the results for the 4-state Big Sky Region – an estimate of some 34.3 million non-federal acres that are not now in forest, but that are biologically capable of supporting forest growth.

Table A-3. Area potential for afforestation, Big Sky Region

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood	Total
						1,000 acres				
Transition Areas	11.0	19.5	4.4	28.9	7.0	131.7	0.0	1.1	0.0	**203.6**
Shrubland	1,372.8	64.2	610.6	819.4	152.6	206.0	2,477.4	1,607.5	524.3	**7,834.8**
Orchards/Vineyards/Other	-	0.3	-	2.5	-	0.0	-	-	-	**2.8**
Grasslands/Herbaceous	6,807.4	72.6	1,641.9	2,233.8	312.8	165.3	1,627.7	5,130.3	466.7	**18,458.4**
Pasture/Hay	378.2	36.7	74.8	130.0	1.8	68.8	212.7	685.0	217.6	**1,805.6**
Row Crops	17.8	0.2	3.9	5.8	0.2	0.1	89.2	184.8	210.8	**512.8**
Small Grains/Fallow	1,379.9	108.5	104.4	480.5	0.8	198.6	98.9	3,007.9	118.6	**5,498.2**
TOTAL	**9,967.0**	**302.0**	**2,440.0**	**3,701.0**	**475.3**	**770.5**	**4,505.9**	**10,616.6**	**1,538.1**	**34,316.3**

Table A-4. Estimated average yields for major forest types, Big Sky Region.

Code	Group	Average Yield	Notes	lbs. total CO_2e per ft^3 timber*
		ft^3/acre/year		
1	Ponderosa Pine	25	Birdsey Table 32	100.4
2	Western White Pine	25	Birdsey Table 32	100.4
3	Lodgepole pine	27	Birdsey Table 34	111
4	Douglas-fir	29	Birdsey Table 31	88.4
5	Fir-spruce	39	Birdsey Table 33	92.5
6	Mixed conifers	29	Birdsey Table 31	92.5
7	Pinyon/juniper	10	Author's estimate	111
8	Cottonwood	30	Birdsey Table 25	126.9
9	Western Hardwood	50	Birdsey Table 26	126.9

*Factors for lbs. C per cubic foot and multiplier to total tree C taken from Birdsey (1996). Multiplied by 3.67 to produce CO_2e.

The final steps in the calculation were to estimate forest yields in terms of carbon sequestration. Yield estimates (in average ft^3 of timber per acre per year for a 50-year growing period) were taken from Birdsey (1996) where available, and estimated by the authors for species not covered in Birdsey (Table A-4). If improved local data are found, they can be readily substituted into the spreadsheet model for updating.

The estimated yields were then multiplied times the areas estimated in Table A-3 (in thousands of acres), and the product multiplied by the pounds of total CO2e (Table A-4), then divided by 2204 to convert to thousands of tonnes, and divided again by 1000 to convert to million metric tonnes of CO_2e ($TgCO_2$e). The results were the biological estimates. (Table A-5).

Table A-5. Estimated annual biological carbon sequestration from afforestation opportunities, Big Sky Region.

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood	Total
					$TgCO_2e$ per year					
Transition Areas	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
Shrubland	1.6	0.1	0.8	1.0	0.2	0.3	1.2	1.9	1.1	8.1
Orchards/Vineyards/Other	-	0.0	-	0.0	-	0.0	-	-	-	0.0
Grasslands/Herbaceous	7.7	0.1	2.2	2.6	0.5	0.2	0.8	8.9	1.3	24.4
Pasture/Hay	0.4	0.0	0.1	0.2	0.0	0.1	0.1	1.2	0.6	2.7
Row Crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	1.0
Small Grains/Fallow	1.6	0.1	0.1	0.6	0.0	0.2	0.0	5.2	0.3	8.2
TOTAL	11.3	0.3	3.3	4.3	0.8	0.9	2.3	17.4	4.0	44.6

Note: All estimates smaller than 0.05 Tg rounded off to zero.

Table A-6 estimates the impacts of an afforestation program based on current cover and potential forest. These reductions were made as an author's estimate, and could be changed on the basis of regional expert review and comment or further studies such as a supply curve related to possible future carbon credit prices. Such a study was beyond the scope of this paper.

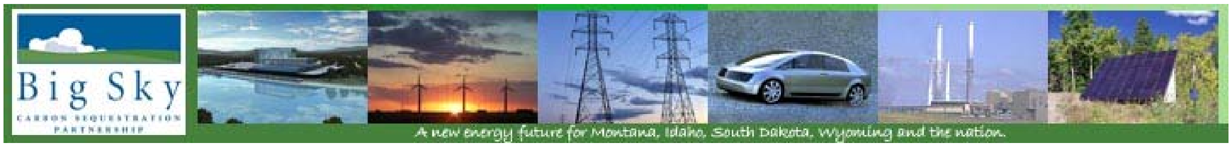
Table A-6. Estimated potential for conversion, as a percent of suitable land.

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood
					percent				
Transition Areas	10%	10%	10%	10%	0%	10%	0%	10%	10%
Shrubland	10%	10%	10%	10%	0%	10%	0%	10%	10%
Orchards/Vineyards/Other	2%	2%	2%	2%	0%	2%	0%	2%	2%
Grasslands/Herbaceous	10%	10%	10%	10%	10%	10%	0%	10%	10%
Pasture/Hay	10%	10%	10%	10%	10%	10%	0%	10%	10%
Row Crops	10%	10%	10%	10%	0%	10%	0%	10%	10%
Small Grains/Fallow	20%	20%	20%	20%	0%	20%	0%	20%	20%

The final estimate (Table A-7) was derived by multiplying the area suitable for conversion (Table A-3) times the percentage factors in Table A-6. The result was an estimate of potential annual carbon sequestration in the range of 5 $TgCO_2e$ per year in the Big Sky Region.

Table A-7. Estimated average annual carbon sequestration from afforestation opportunities, Big Sky Region

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood	Total
					$TgCO_2e$ per year					
Transition Areas	0.0	0.0	0.0	0.0	-	0.0	-	0.0	0.0	0.0
Shrubland	0.2	0.0	0.1	0.1	-	0.0	-	0.2	0.1	0.7
Orchards/Vineyards/Other	-	0.0	-	0.0	-	0.0	-	-	-	0.0
Grasslands/Herbaceous	0.8	0.0	0.2	0.3	0.1	0.0	-	0.9	0.1	2.4
Pasture/Hay	0.0	0.0	0.0	0.0	0.0	0.0	-	0.1	0.1	0.3
Row Crops	0.0	0.0	0.0	0.0	-	0.0	-	0.0	0.1	0.1
Small Grains/Fallow	0.3	0.0	0.0	0.1	-	0.0	-	1.0	0.1	1.6
TOTAL	1.3	0.0	0.3	0.5	0.1	0.1	-	2.3	0.4	5.0



Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 5:
Action Plan for Enhancing Terrestrial Sequestration

Attachment B: Rangeland Terrestrial Sinks Forestry

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Big Sky Partnership
The Northern Rockies and Great Plains Regional Carbon Sequestration Partnership_MLRAs
Appendix 1

Summary of MLRA Attributes for Montana, Idaho, and South Dakota

% of region	MLRA	NAME	Area km^2	Area mi^2	States
	10	Upper Snake River Lava Plains and Hills (10A proposed)	44,870	17,330	Idaho and Oregon
	11	Snake River Plains (11A and 11B proposed)	35,250	13,610	Idaho and Oregon
	12	Lost River Valleys and Mountains	16,380	6,320	Idaho
	13	Eastern Idaho Plateaus	21,010	8,110	Idaho
	43	Northern Rocky Mountains	282,650	109,130	Idaho, Montana, Oregon, Washington, and Wyoming
	44	Northern Rocky Mountain Valleys	32,320	12,480	Idaho, Montana, and Washington
1/2 north	46	Northern Rocky Mountain Foothills	52,070	20,110	Montana and Wyoming
	52	Brown Glaciated Plain	52,110	20,120	Montana
2/3 west	53 A	Northern Dark Brown Glaciated Plains	30,740	11,870	Montana and North Dakota
1/3 south	53 B	Central Dark Brown Glaciated Plains	44,980	17,370	North Dakota and South Dakota
	53 C	Southern Dark Brown Glaciated Plains	13,870	5,350	South Dakota
1/3 south	54	Rolling Soft Shale Plain	58,100	22,430	Montana, North Dakota, and South Dakota
	55 C	Southern Black Glaciated Plains	20,240	7,810	South Dakota
	58 A	Northern Rolling High Plains; Northern Part	105,620	40,780	Montana and Wyoming
1/2 south	58 D	Northern Rolling High Plains; Eastern Part	10,000	3,860	North Dakota and South Dakota
	60 A	Pierre Shale Plains and Badlands	23,600	9,110	Nebraska, South Dakota, and Wyoming
	60 B	Pierre Shale Plains; Northern Part	5,600	2160	Montana
	61	Black Hills Foot Slopes	8,400	3,240	South Dakota and Wyoming
	62	Black Hills (home of Rocky Racoon)	9,200	3,550	South Dakota and Wyoming
	63 A	Northern Rolling Pierre Shale Plains	29,610	11,430	South Dakota
1/2 north	64	Mixed Sandy and Silty Tableland	28,400	10,970	Nebraska, South Dakota, and Wyoming
1/3 north	66	Dakota-Nebraska Eroded Tableland	12,400	4,800	Nebraska and South Dakota
1/2 west	102 A	Rolling Till Prairie	38,600	14,900	Minnesota and South Dakota
	102 B	Till Plains	43,790	16,910	Iowa, Minnesota, South Dakota, and Nebraska

Land use
3/5 federal, 90% range, 5% (along streams) irrigated for potatoes, small grains, pasture
1/2 federal - mostly range,   annual grasses have invaded much of the rangeland, 1/4 irrigated potatoes
mostly all federal, high mountain slopes are forested, grass - shrubs on slopes and valleys are grazed
1/4 federal, 1/2 range, 1/4 dryfarm - wheat, ~10% irrigated -alfalfa, ~10% forested mt. slopes
Nearly all this area is federally owned, less than 2% cropped, Mostly forest -lumbering and mining
farms and ranches.1/2-1/3 native range (grass-shrub) , 1/3 irrigated - Potatoes, sugar beets, and peas
1/5 federal, 1/2 range of short and mid grass, 1/5 dryfarm (northeast side) wheat
Most of the land in the east is in range/ one-half of the total area is cropped (west) spring wheat
1/2+ dryland farm mostly spring wheat / sloping soils are in native grass range
1/2+ is dryfarmed -.winter wheat chief cash crop. Corn, grain, sorghum, oats, and alfalfa also grown sloping soils are in range.
2/3 dryland Spring wheat is the chief crop / flax, oats, barley, and alfalfa also grown / more sloping soil in native grass range
1/3 dry frarmed wheat/ 3/5 native grass and shrub grazed /
70% dryland farm.- Corn, small grains, and alfalfa main crops / 1/4 native range and tame pasture alone steeper slopes
Most in native grasses and shrubs grazed by cattle and sheep / rest dryland farming in wheat / sugar beets, alfalfa along river
4/5 ranches in native grasses and shrubs grazed by cattle and sheep 10-15% dryland wheat and alfalfa
Most of it is in native grasses and is used for grazing livestock / Badlands National Monument is a large tourist attraction.
Most of it is rangeland used for grazing livestock
Native grass is used mainly for livestock grazing. / the less sloping parts are farmed mainly to alfalfa and small grains
Black Hills National Forest used for mining, recreation, and hunting./Some timber / summer grazing
area is used mainly for livestock production and cash-grain farming / Dry-farming soils not suited to cultivation is destroying the native grassland
3/5 rangeland cattle / 1/3 crop cash grain and winter wheat / corn and sugar beets are irragated crops
Most of this area is in native grasses that are grazed by cattle
70 % is cropland Corn, soybeans, alfalfa, flax, spring wheat, and oats are the principal crops /
70% cropland Corn, soybeans, grain sorghum, alfalfa, and oats are the principal crops./ Urban development is expanding

Elevation	Precipitation	Temperature	Freeze free days
400 to 2,000 m	250 to 500 mm.	4 to 13 C	60 to 165 days
600 to 1,700 m	175 to 325 mm	5 to 11 C	90 to 170
1,400 m valleys to 3,100 m mt.crests.	175 to 275 mm valleys 625 mm mountains	3 to 7 C valleys	80 to 110 days valleys
1,400 to 2, 000 m plains and plateaus	300 to 625 mm	4 to 7 C	50 to 120
400 to 2,400 m	625 to 1,525 mm	2 to 7 C	45 to 120 days
600 to as much as 2,100 m	300 to 400 mm in most of the area	4 to 8 C	100 to 120 days
1,100 to 1,800 m in north	300 to 500 mm	6 to 7 C	90 to 125 days
600 to 1,400 m	250 to 375 mm	3 to 7 C	100 to 130
600 to 900 m	300 to 350 mm	3 to 5 C	110 to 125 days
400 to 700 m	425 to 475 mm	7 to 9 C	130 to 150 days
500 to 600 m	350 to 425 mm	1 to 7 C	110 to 130 days
500 to 1100 east to west	325 to 450	4 to 7 C	110 to 135
400 to 600	50 to 525 mm	7 to 9 C	l30 to 155 days
900 to 1,800 m east to west	300 to 500 mm	4 to 7 C.	120 to 140 days
700 to 1,000 m east to west	325 to 375 mm	4 to 7 C	120 to 130 days.
800 to 1,100 m	300 to 400 mm	7 to 9 C	130 to 150 days
900 to 1,000 m on uplands	300 to 350 mm	4 to 7 C.	110 to 125 days
900 to 1,200 m	375 to 450 mm	6 to 9 C	110 to 140 days
1,100 to 2,000 m	450 to 650 mm	3 to 7 C	80 to 130 days
400 to 500 m bottom 500 to 900 m upland	375 to 475 mm	7 to 9 C	130 to 160 days
900 to 1,200 m	375 to 450 mm	7 to 9 C	~140 days.
600 to 900 m	450 to 550 mm	8 to 10 C	130 to 160 days
300 to 400 m lowlands 400 to 500 m uplands	500 to 600 mm	6 to 9 C	120 to 140 days
300 to 400 m bottpm 400 to 500 m uplands	500 to 650 mm	9 to 11 C	135 to 165 days

Water

supplies small mostly untapped - low to moderate precipitation is adequate for dryfarming
Ground water is plentiful around major rivers - scarce on sites far from the major rivers
moderate precipitation for grass/shrubs on slopes, valleys depend on the streamflow
limited amount precip. for dryfarming and grazing
Moderate precipitation and many perennial streams and lakes provide ample water
Perennial streams principle source.
Presipitation too low for crops in some parts/ adequate for grain and forage in others
Most of the area depends on precipitation for water for range and crop
mostly moisture is inadequate for good crop production /
Most years, moisture is inadequate for maximum crop production.
most years moisture is inadequate for maximum crop production
most years moisture is inadequate for maximum crop production
most years precipitation is inadequate for maximum crop production
low and erratic precipitation is the principal source of water for agriculture.
low and erratic precipitation is the principal source of water for agriculture
limited precipitation, production of cultivated crops is marginal.
limited precipitation, the growing of cultivated crops is marginal
Most of the soils suitable for cultivation are dry during much of the growing season.
Precipitation, perennial streams, springs, and shallow wells provide adequate water for domestic use
In most years precipitation is inadequate for maximum plant growth
Most of the area depends on the rather low and erratic precipitation for water
limited precipitation makes farming a risk
In many years precipitation is inadequate for maximum production
Precipitation is the principal source of moisture for crops some year it is inadequate

Irrigation

Streams provide enough irrigation water along the major valleys
ground water around major rivers is used extensively for irrigation
about 1% mostly for hay and pasture
Ground water is scarce except near the large streams
Streams and reservoirs supply water to adjoining MLRA's for irrigation
Ground water is abundant some used for irrigation
1-2% irrigated (valleys) major rivers provide most water for irrigation
The Milk River provides irrigation water to its flood plains
only a small acreage is irrigated by the Missouri river
irrigated cropland is mostly along a narrow band of the Missouri river
only a small acreage is irrigated around the Missouri river
irrigation is available in quantity only from the Missouri River
Water from reservoirs on the Missouri River is used for irrigation
Strips along the Yellowstone River and main tributaries are irrigated.
no irrigation some wells provide water for stock
Few places have shallow-water wells for domestic use.
Water for livestock comes mainly from runoff that flows into dams
Domestic wate mostly from f streams, shallow wells, and springs.
moisture is adequate for normal plant growth. No irrigation
reservoirs on the Missouri River are on the eastern border
Ground water is scarce and of poor quality in most of the area
The Niobrara River is the only perennial stream.
Shallow wells iand small ponds principle water supply for for livestock
irrigation is increasingly along major rivers

Dominat soil	Vegetation type
Xerolls and Argids moderately fine textured to fine textured	shrub-grass association
Orthids, Argids, and Orthen	shrub-grass vegetation
Orthids, Orthents, Aquolls, and Xerolls (valleys)	desert shrub, shrub-grass, and forest vegetation
Xerolls and Borolls	grass-shrub vegetation
Ochrepts and Andepts	conifer forests
Orthids, Borolls, and Argids medium to fine textured	conifer forests and grassland vegetation
Borolls, Orthents, and Fluvents medium to fine textured	grass valleys/foothills, forest higher elevations
Borolls, Orthents, Argids, and Fluvents medium to fine textured	grass land vegetation
Borolls. deep, well drained, and medium textured	natural prairie vegetation
Ustolls. They are deep, well drained, and medium textured	natural prairie vegetation
Borolls. They are deep, well drained, and medium textured	natural prairie vegetation
Borolls. moderately deep - deep, loamy and clayey	natural prairie vegetation
Ustolls. deep, well to moderately well drained, sandy to clayey.	natural prairie vegetation
Orthents, Orthids, Argids, Borolls, and Fluvents. medium to fine textured, shallow to deep	grassland vegetation
Orthents, Orthids, Argids, and Borolls. They are medium to fine textured and well drained	mixed prairie vegetation
Orthids. They are moderately deep and deep and fine textured	natural mixed prairie vegetation
Orthids and Orthents. They are moderately deep and deep and fine textured	natural mixed prairie vegetation
Orthents. They are deep to shallow and fine textured to medium textured	open grassland, forest, and savanna vegetation
Boralfs. They have a frigid or cryic temperature regime	open to dense forest vegetation
Ustolls and Orthents fine textured and very fine textured	transition between mixed and true prairie vegetation.
Ustolls. They are medium textured and formed in loess or in alluvium	mixture of short, mid, and tall grasses
Ustolls. moderately and deep, medium and moderately coarse textured	mixed prairie vegetation
Borolls. They are deep and loamy and silty	true prairie vegetation
Ustolls. They are deep and silty and loa	true prairie vegetation

Potential Vegetation
Big sagebrush and bluebench wheatgrass are dominant on moderate to deep soils
Big sagebrush, winterfat, shadscale, Indian ricegrass, needleandthread, Thurber needlegrass, and Sandberg bluegrass grow on the lower Snake River Plains
Indian ricegrass, needleandthread, shadscale, gardner saltbush, and scarlet globemallow are major species in the valleys
Bluebunch wheatgrass and big sagebrush are dominant.
western white pine, ponderosa pine, lodgepole pine, western redcedar, western larch, hemlock, Douglas-fir, subalpine fir, and spruce are common
Bluebunch wheatgrass, rough fescue, Idaho fescue, and bearded wheatgrass are the major species of the grassland
Bluebunch wheatgrass, rough fescue, Idaho fescue, and western wheatgrass are the major grass species /Ponderosa pine, Rocky Mountain juniper higher up
Bluebunch wheatgrass, needleandthread, western wheatgrass, green needlegrass, and basin wildrye are dominant species.
western wheatgrass, needleandthread, green needlegrass, and blue grama. Little bluestem / important species on sloping and thin soils
Western wheatgrass, blue grama, needleandthread, and green needlegrass are dominant species
western wheatgrass, needleandthread, green needlegrass, and blue grama   Little bluestem important on sloping thin soils
Western wheatgrass, blue grama, needleandthread, and green needlegrass are dominant species / Prairie sandreed and little bluestem on shallow soils
western wheatgrass, green needlegrass, needleandthread, and porcupinegrass. Big bluestem is an important species on soil with restricted drainage
Western wheatgrass, bluebunch wheatgrass, green needlegrass, and needleandthread are dominant species /in east littlebluestem replaces bluebunch wheatgrass
western wheatgrass, green needlegrass, blue grama, and buffalograss /Little bluestem and sideoats grama grow on shallow soils
western wheatgrass, green needlegrass, blue grama, and buffalograss /Little bluestem and sideoats grama grow on shallow soils
western wheatgrass, green needlegrass, and blue grama. Little bluestem and sideoats grama grow on shallow soils.
little and big bluestem, green needlegrass, western wheatgrass, and needleandthread / Bur oak grows throughout the area
Black Hills spruce grows at higher elevations // Kentucky bluegrass, poverty oatgrass, Richardson needlegrass, and Canada wildrye are common under story grasses
Green needlegrass, western wheatgrass, needleandthread, porcupinegrass, little bluestem, and big bluestem are the major species
Blue grama, western wheatgrass, threadleaf sedge, sideoats grama, little bluestem, prairie sandreed, switchgrass, sand bluestem, and needleandthread are the major species
Little bluestem, prairie sandreed, green needlegrass, and needleandthread are dominant species / Sideoats grama and plains muhly are important on shallow soils.
big and little bluestem, porcupinegrass and green needlegrass / Needleandthread and prairie dropseed are important species on the steeper soils
big and little bluestem, indiangrass, porcupinegrass, and green needlegrass. Needleandthread and prairie dropseed are important species on the steeper soils

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

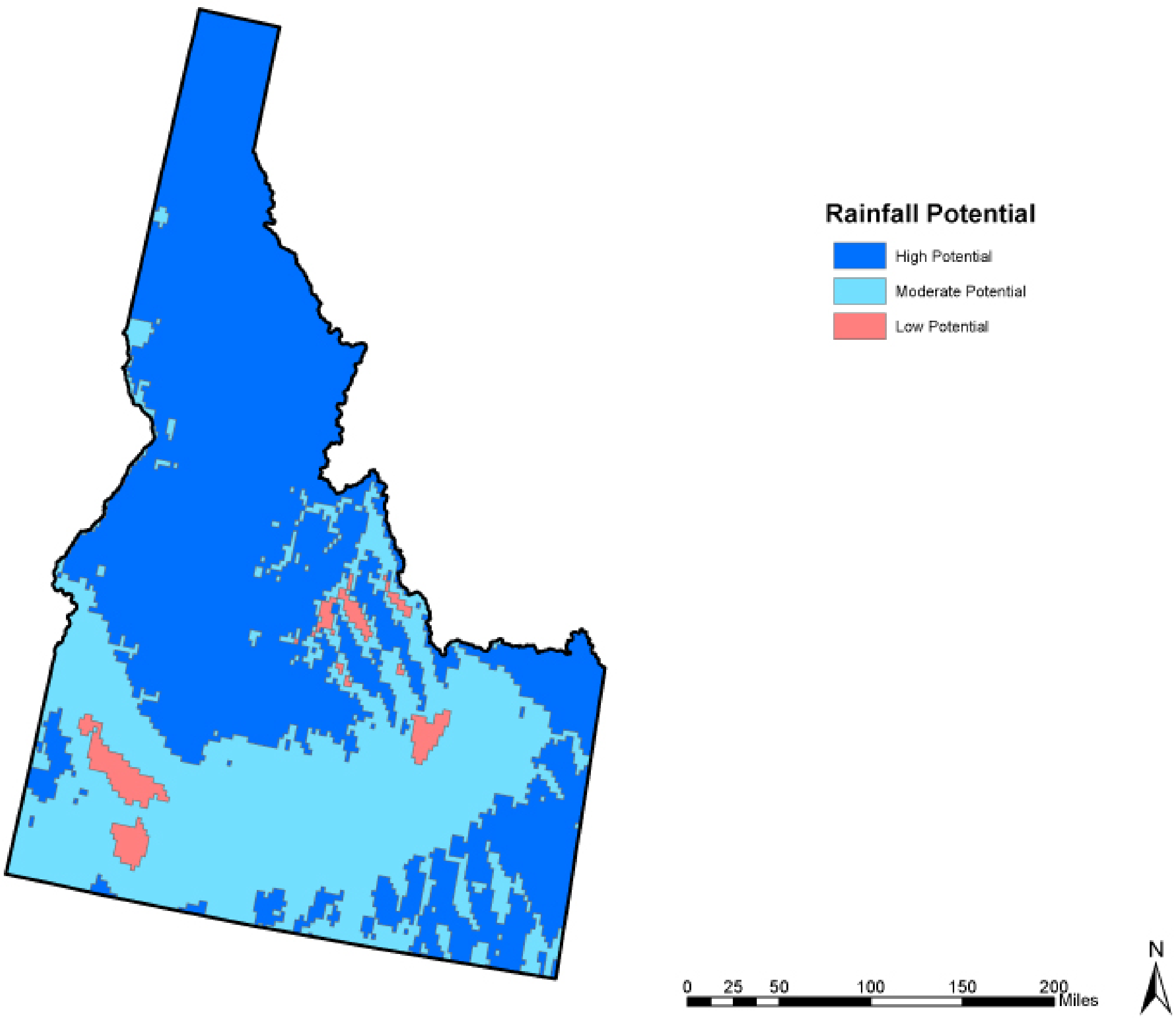


Figure 1. Spatial classification of climatic potential for Idaho. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year. Areas classified as Low Potential have between 130 and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

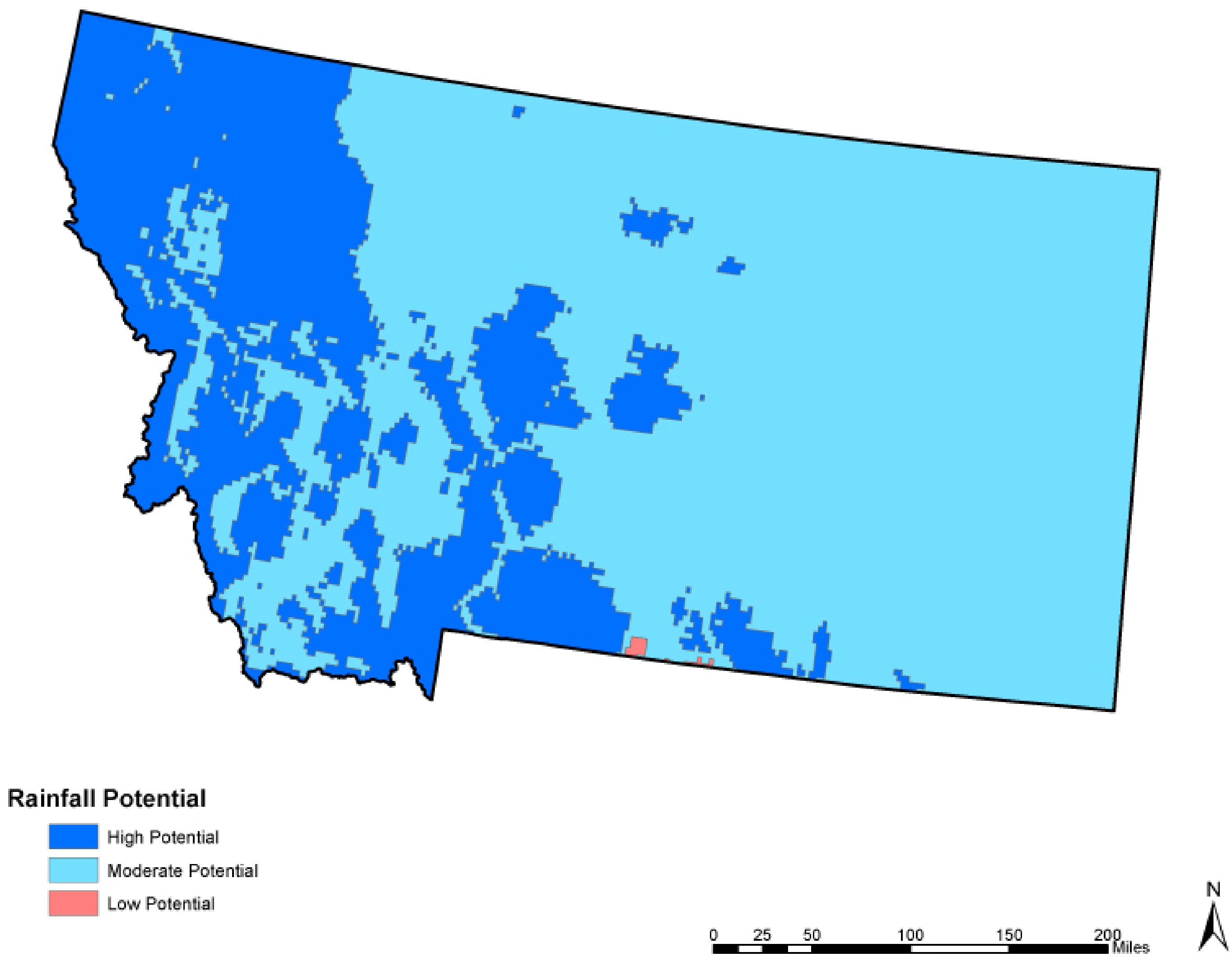


Figure 2. Spatial classification of climatic potential for Montana. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year. Areas classified as Low Potential have between 130 and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

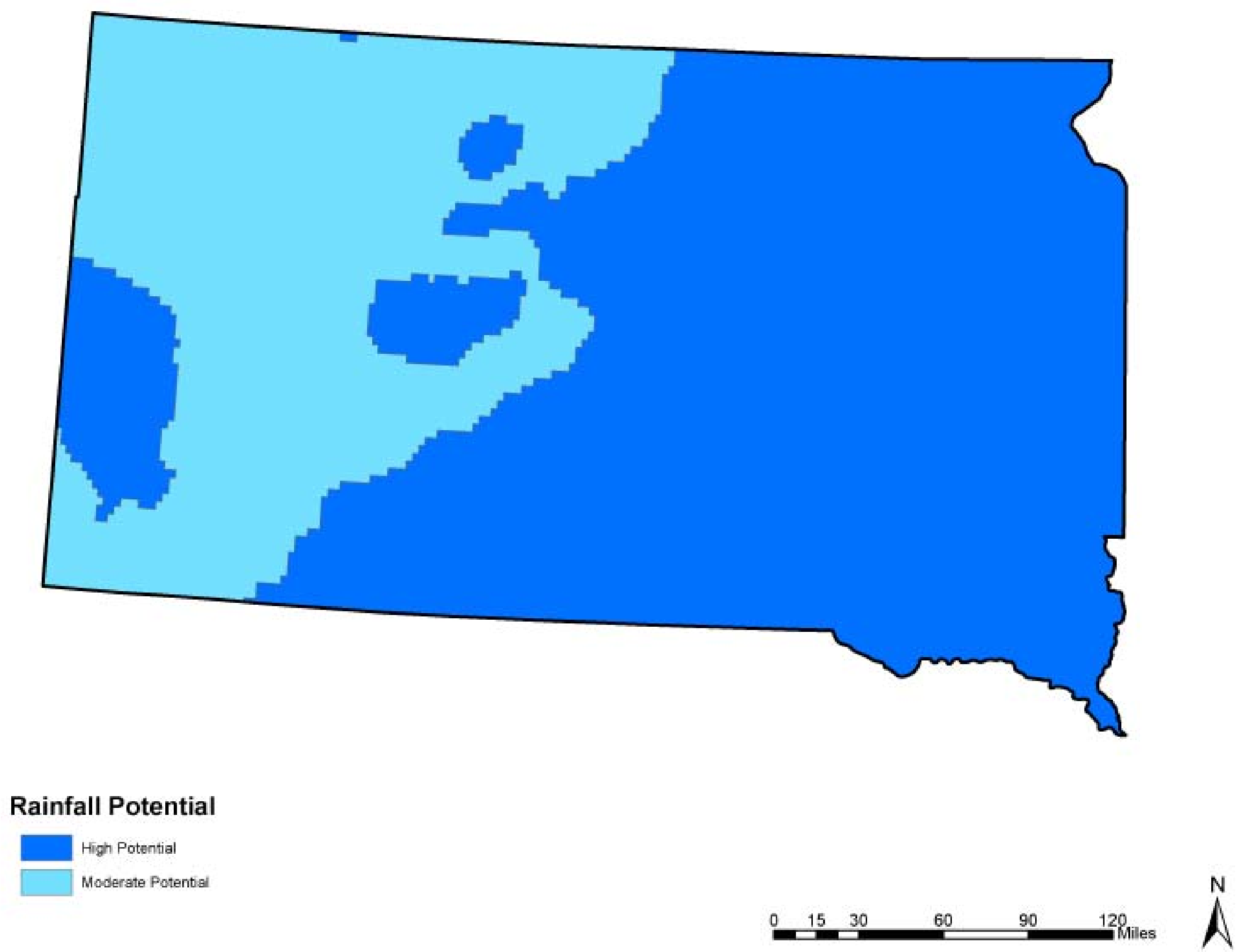


Figure 3. Spatial classification of climatic potential for South Dakota. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year.

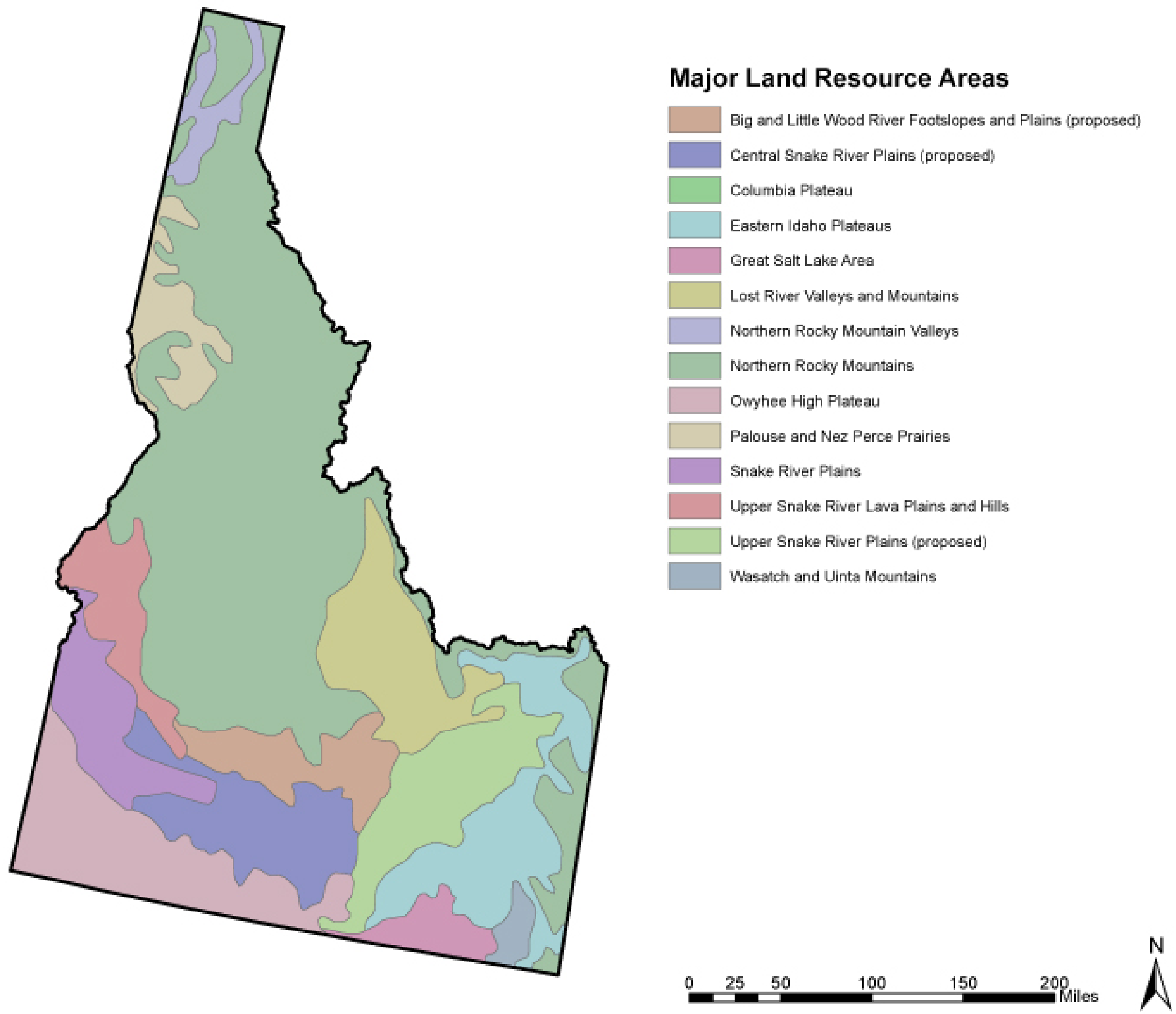


Figure 4. Major land resource areas (MLRAs) within the state of Idaho.

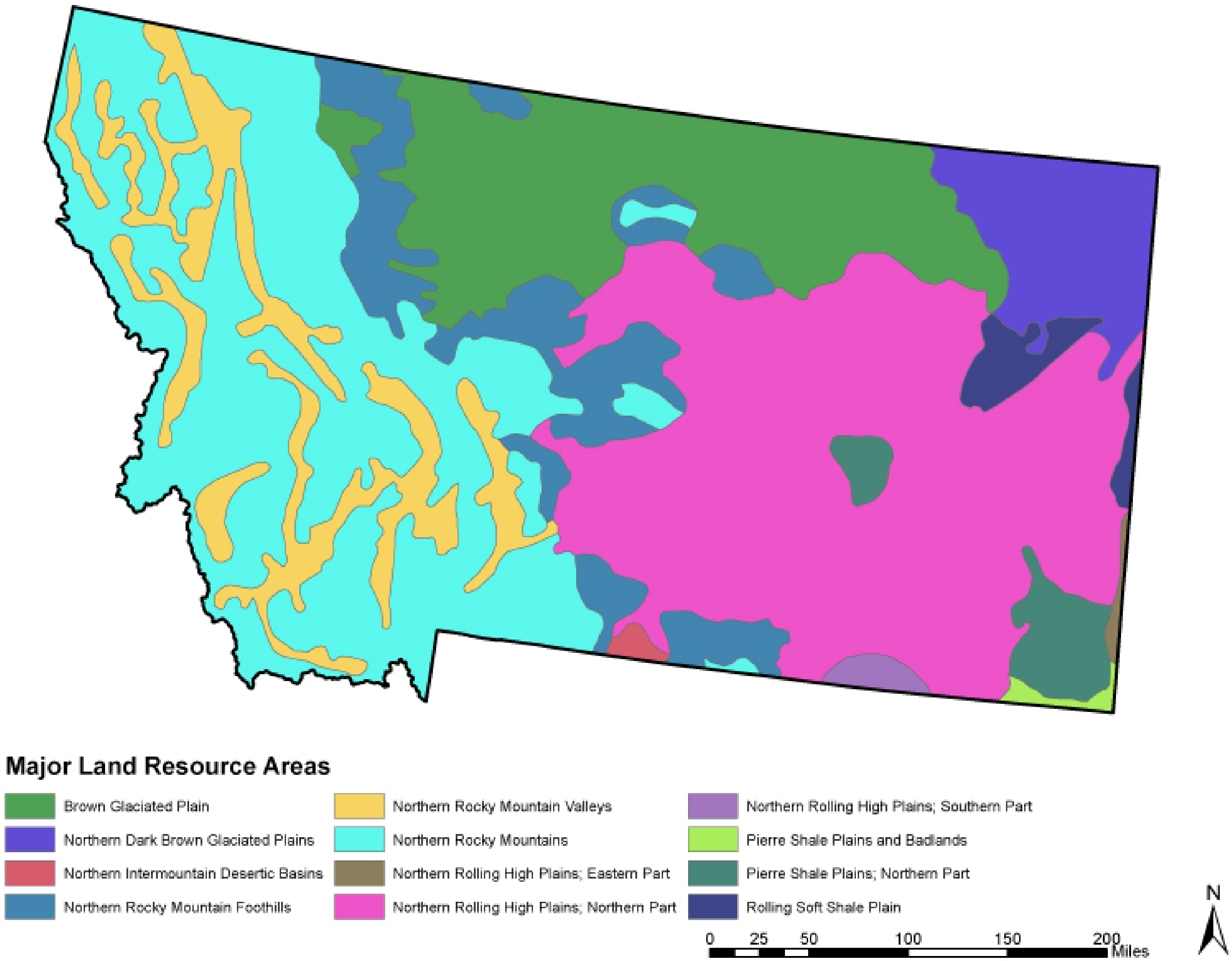


Figure 5. Major land resource areas (MLRAs) within the state of Montana.

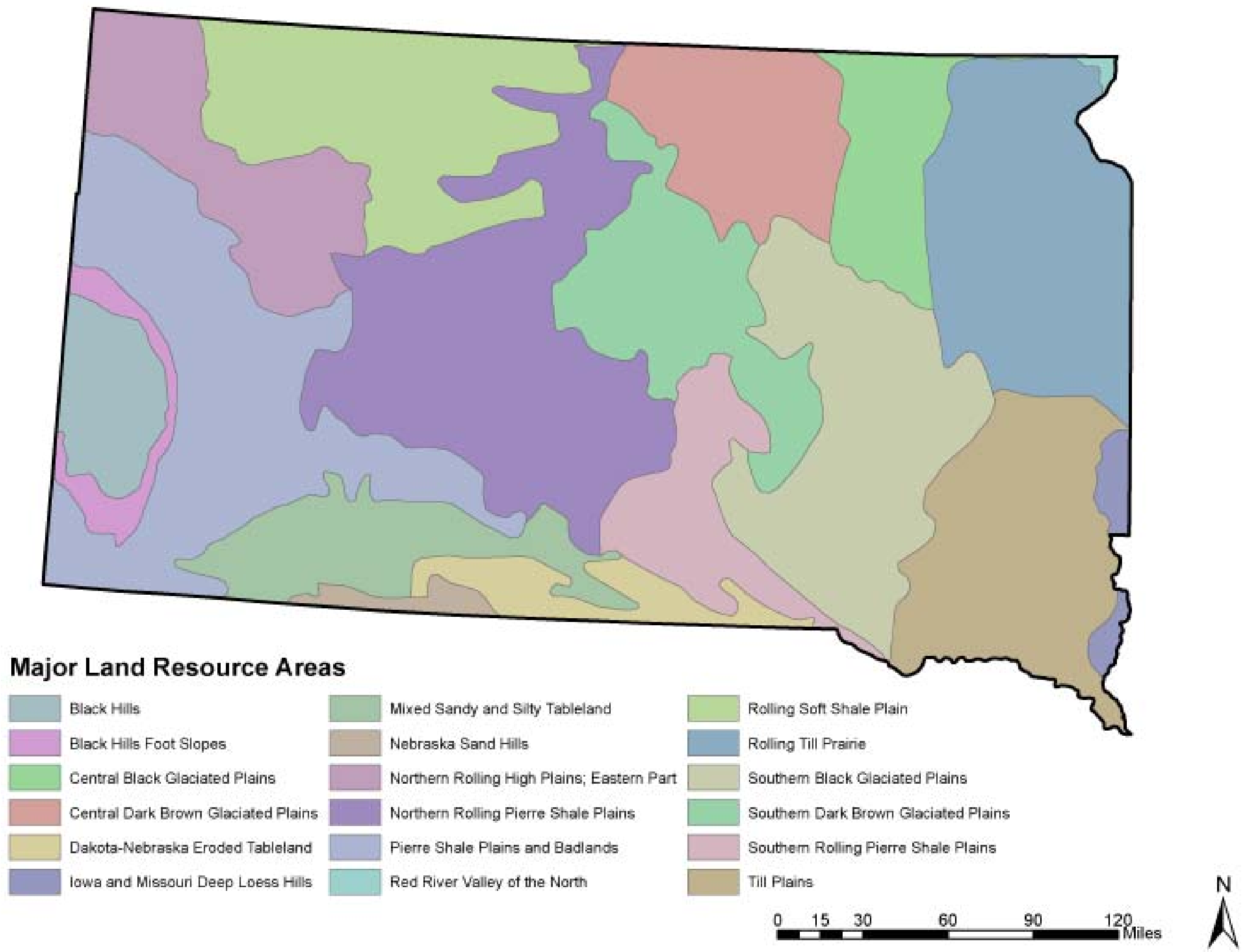


Figure 6. Major land resource areas (MLRAs) within the state of South Dakota

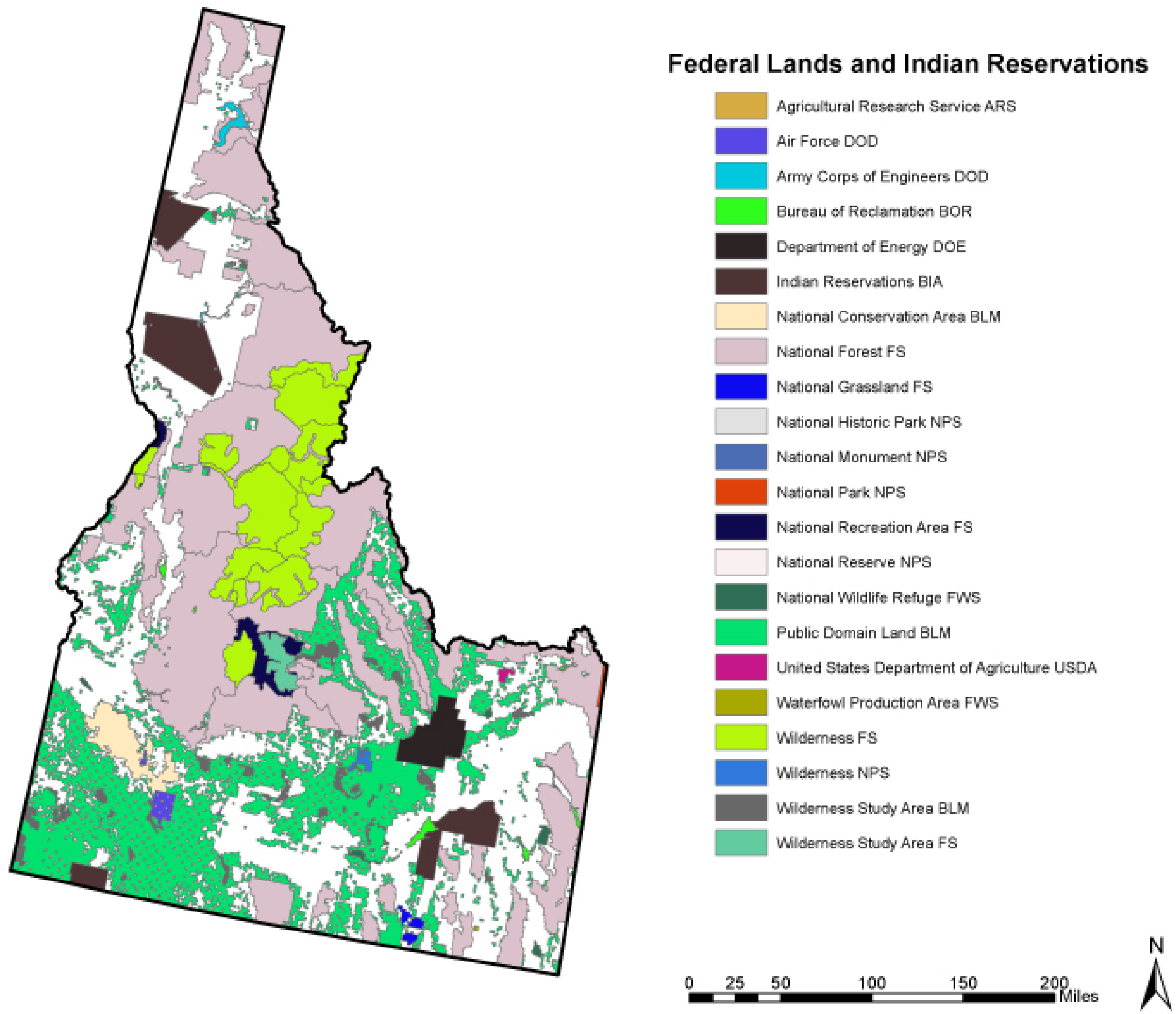


Figure 7. Federal lands and Indian reservations within the state of Idaho.

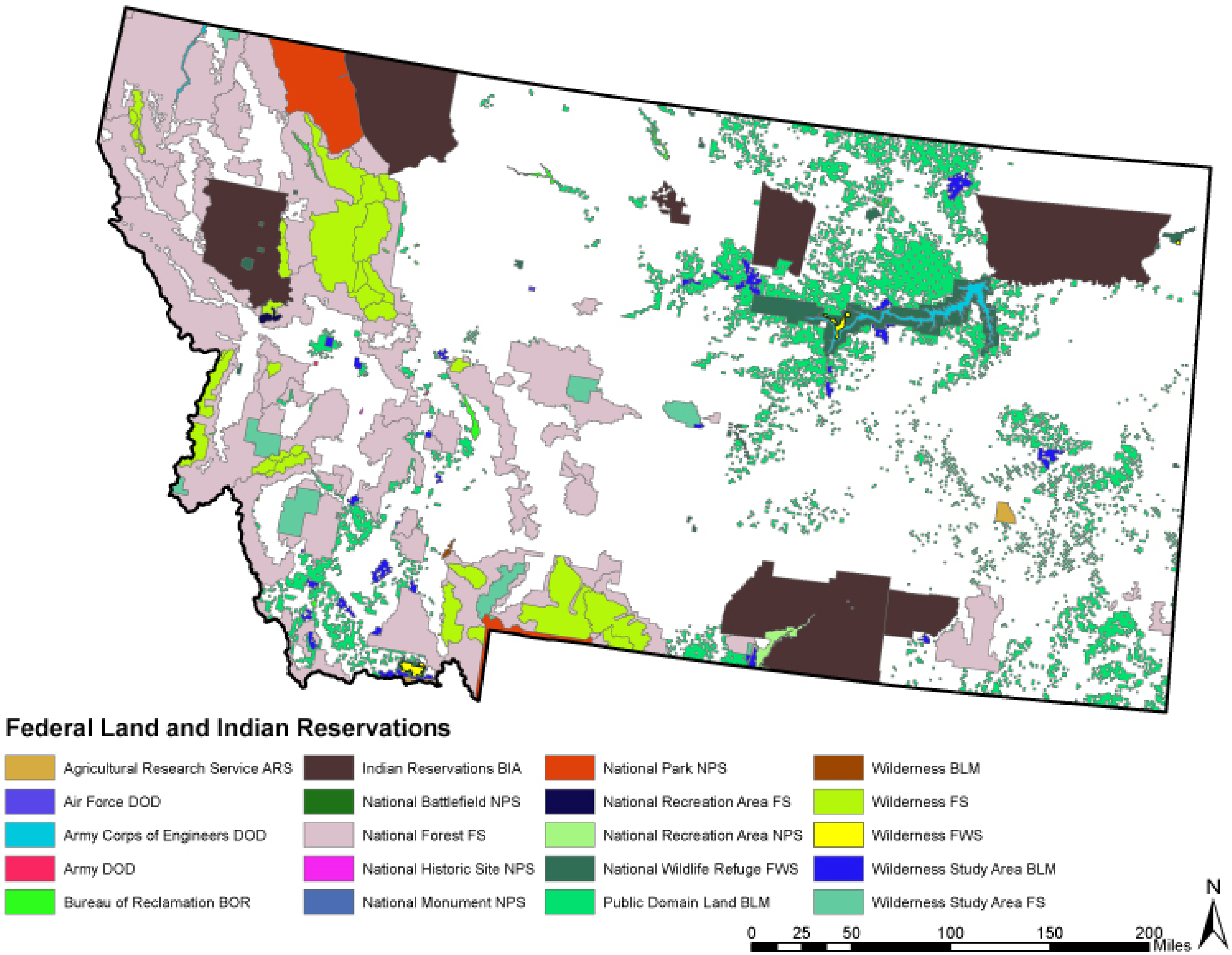


Figure 8. Federal lands and Indian reservations within the state of Montana.

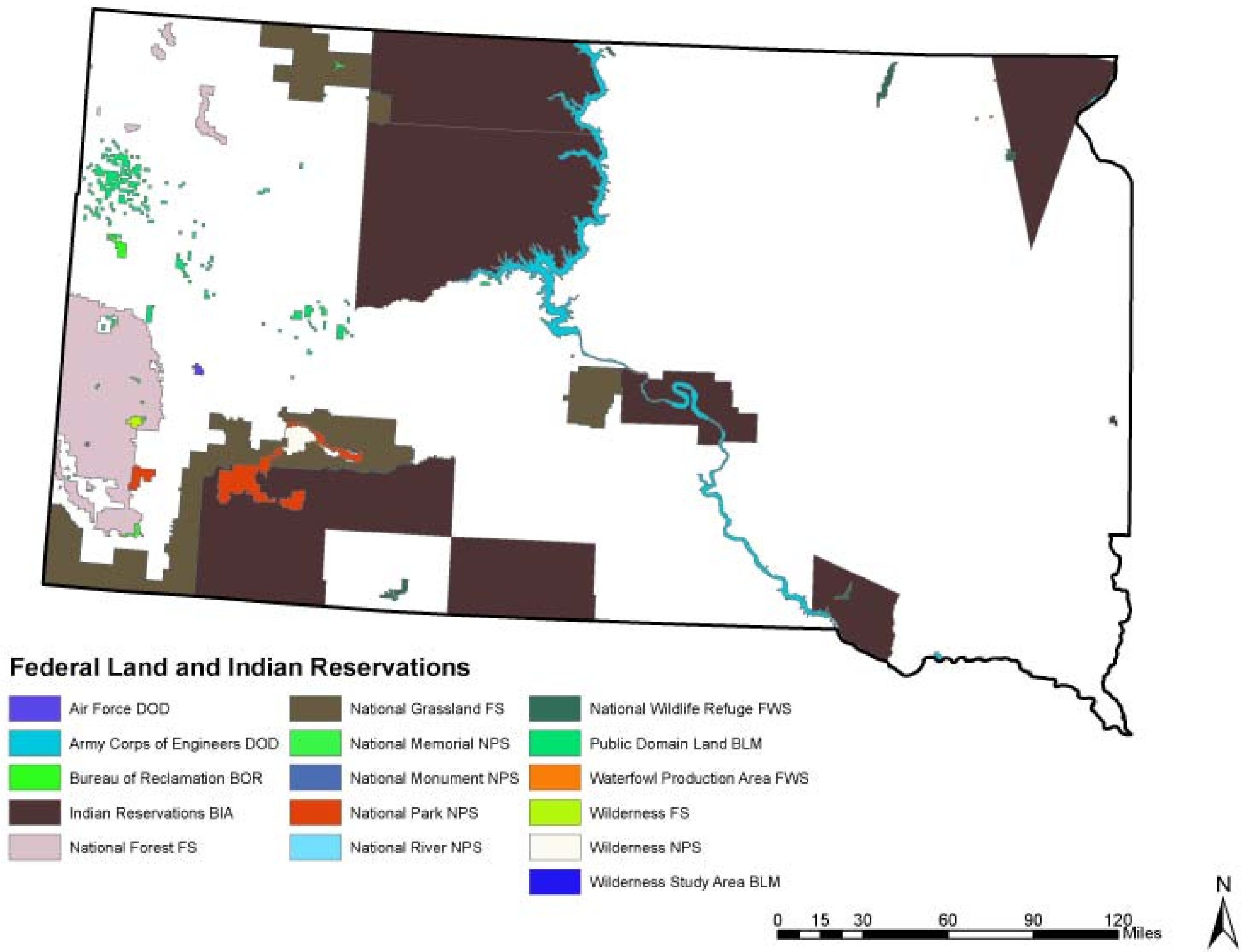


Figure 9. Federal lands and Indian reservations within the state of South Dakota

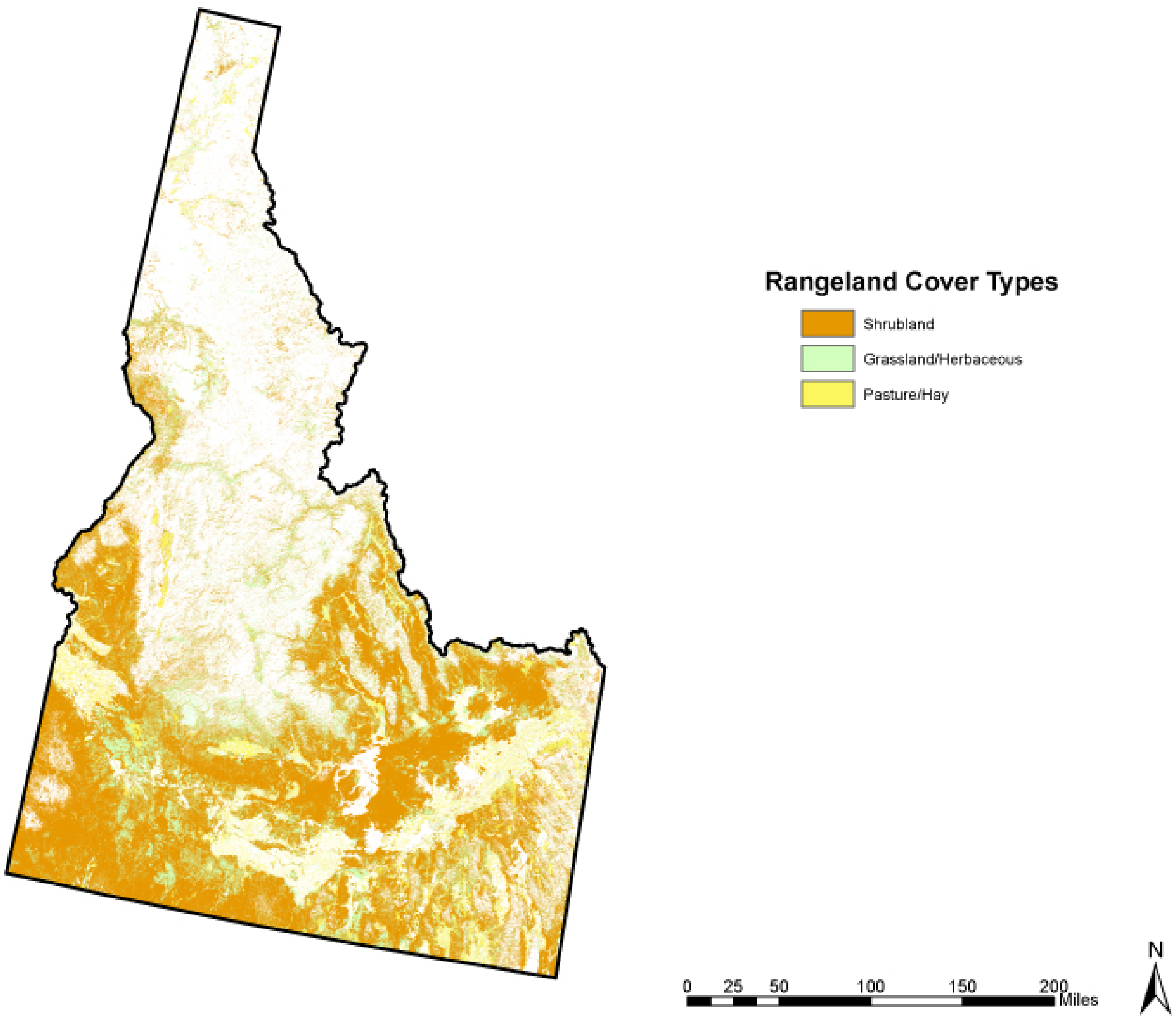


Figure10. Rangeland cover types for the state of Idaho as classified by the National Land Cover Database.

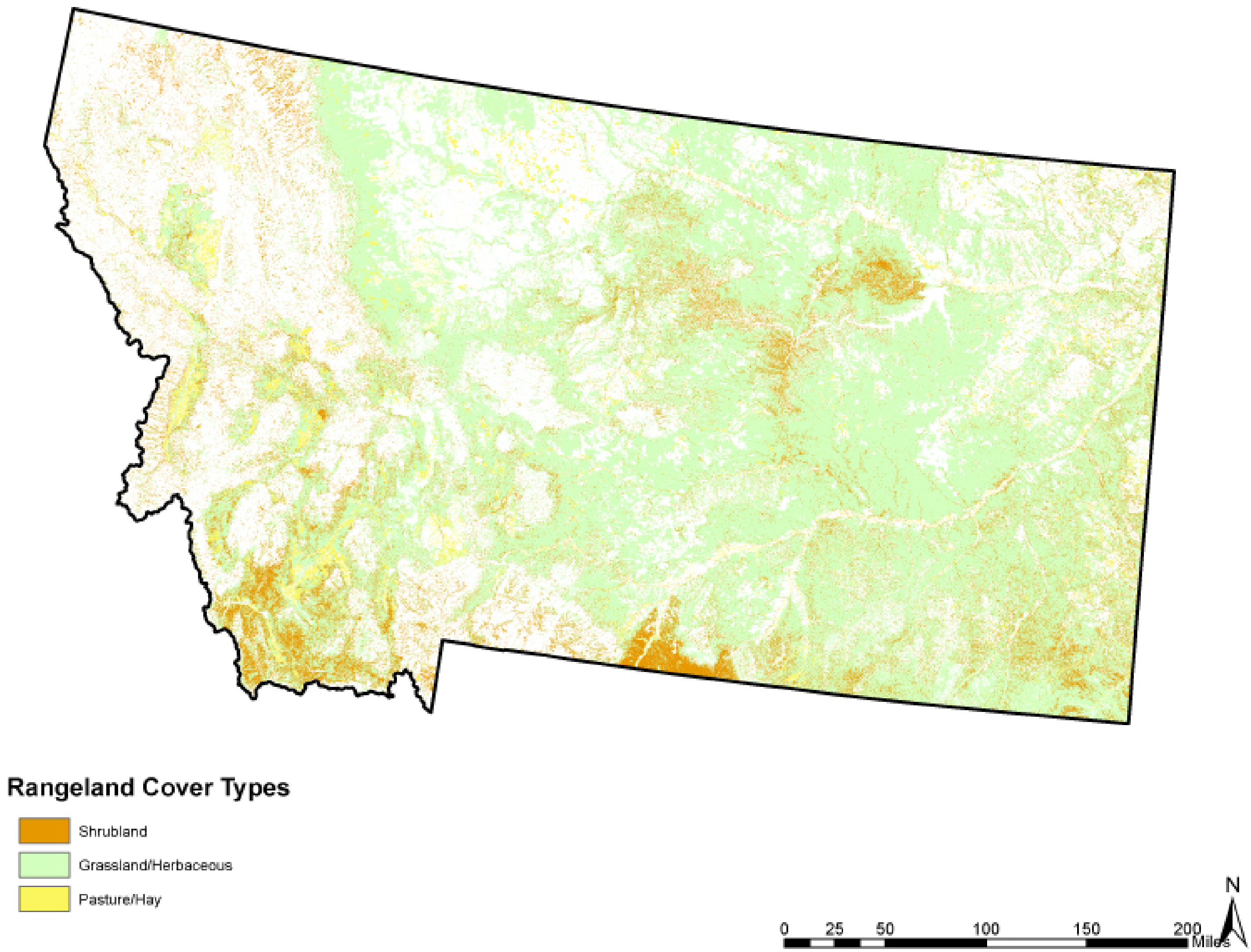


Figure 11. Rangeland cover types for the state of Montana as classified by the National Land Cover Database.

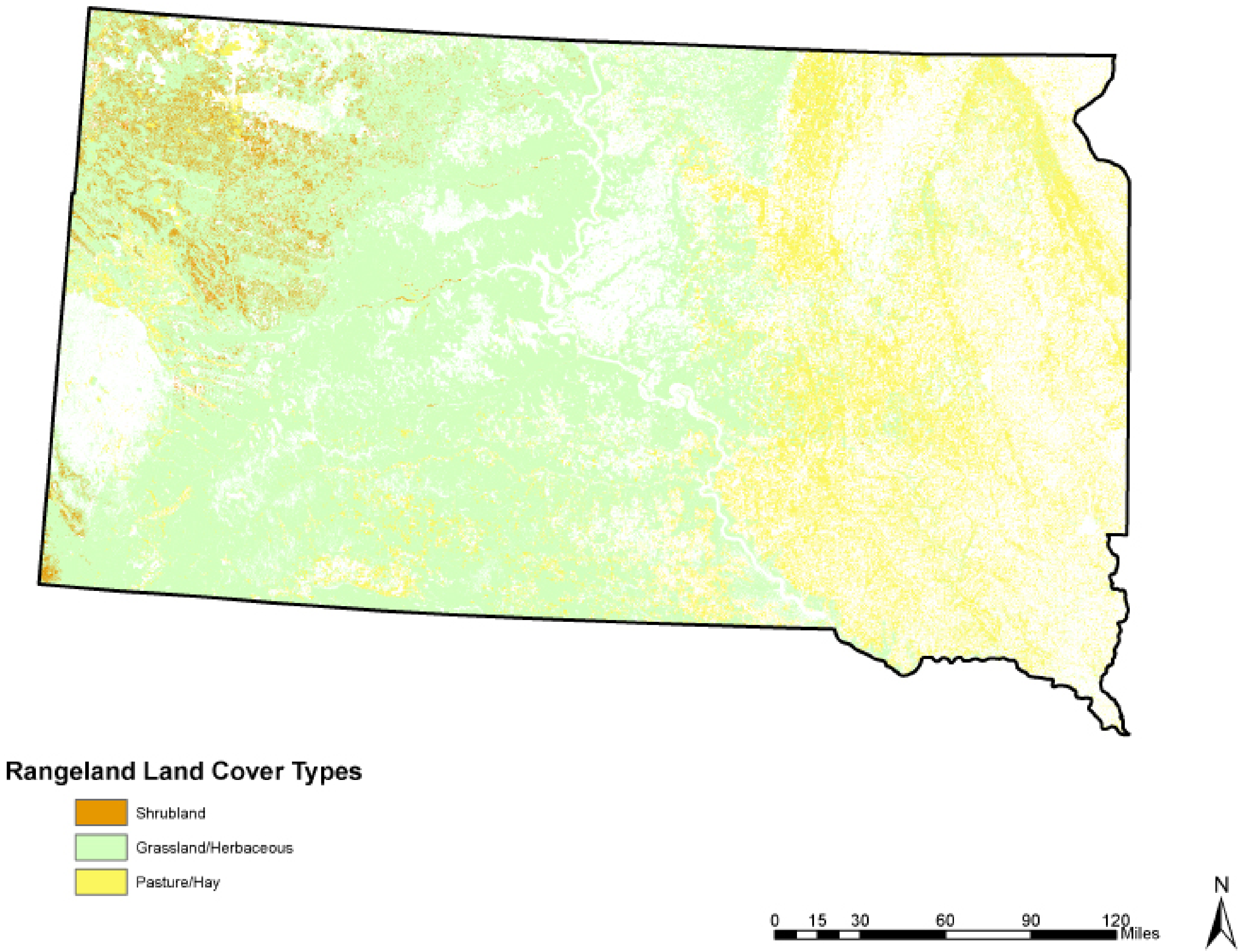


Figure 12. Rangeland cover types for the state of South Dakota as classified by the National Land Cover Database.

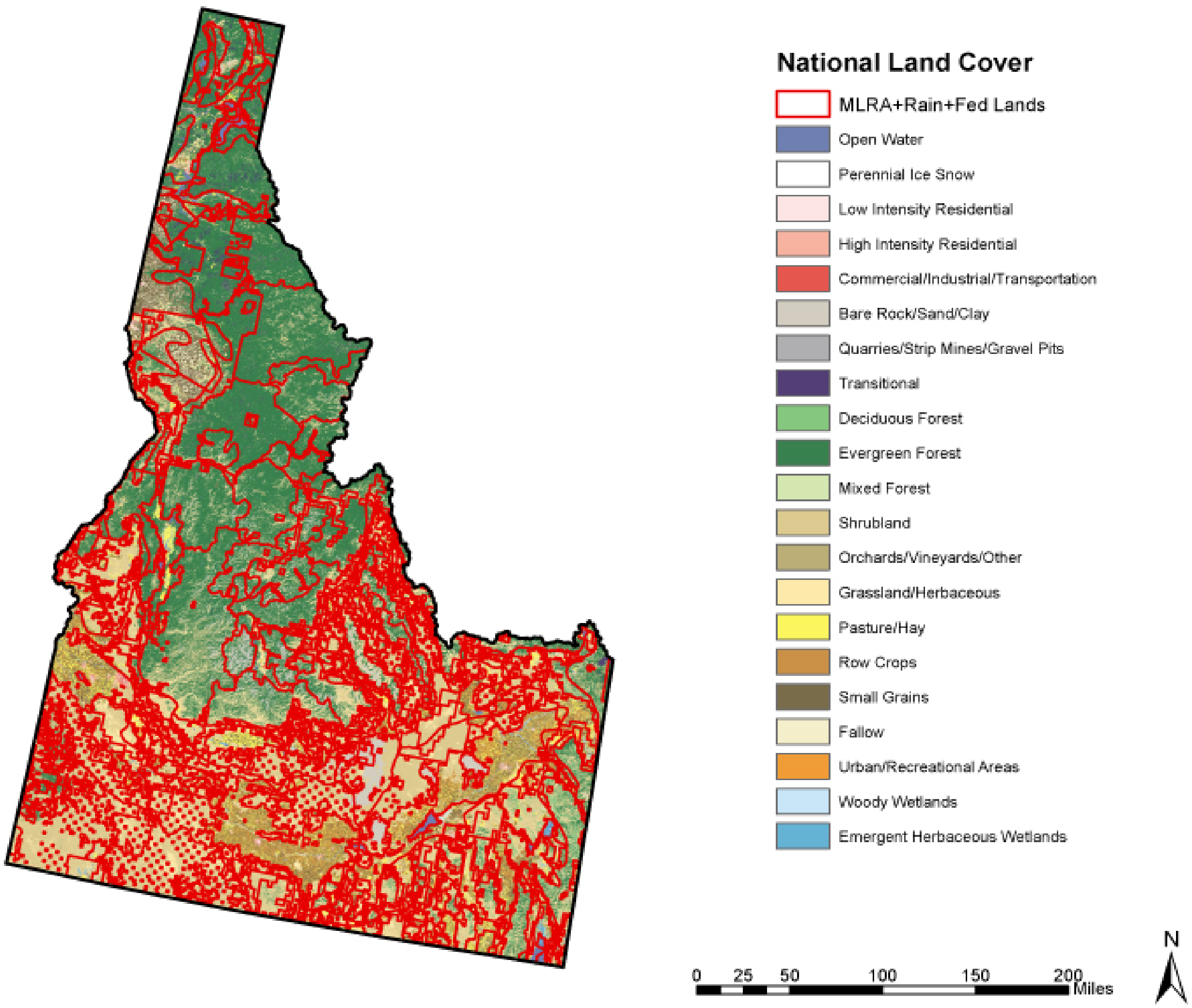


Figure 13. Sampling units (red lines) used in the spatial cross tabulation for the state of Idaho. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation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

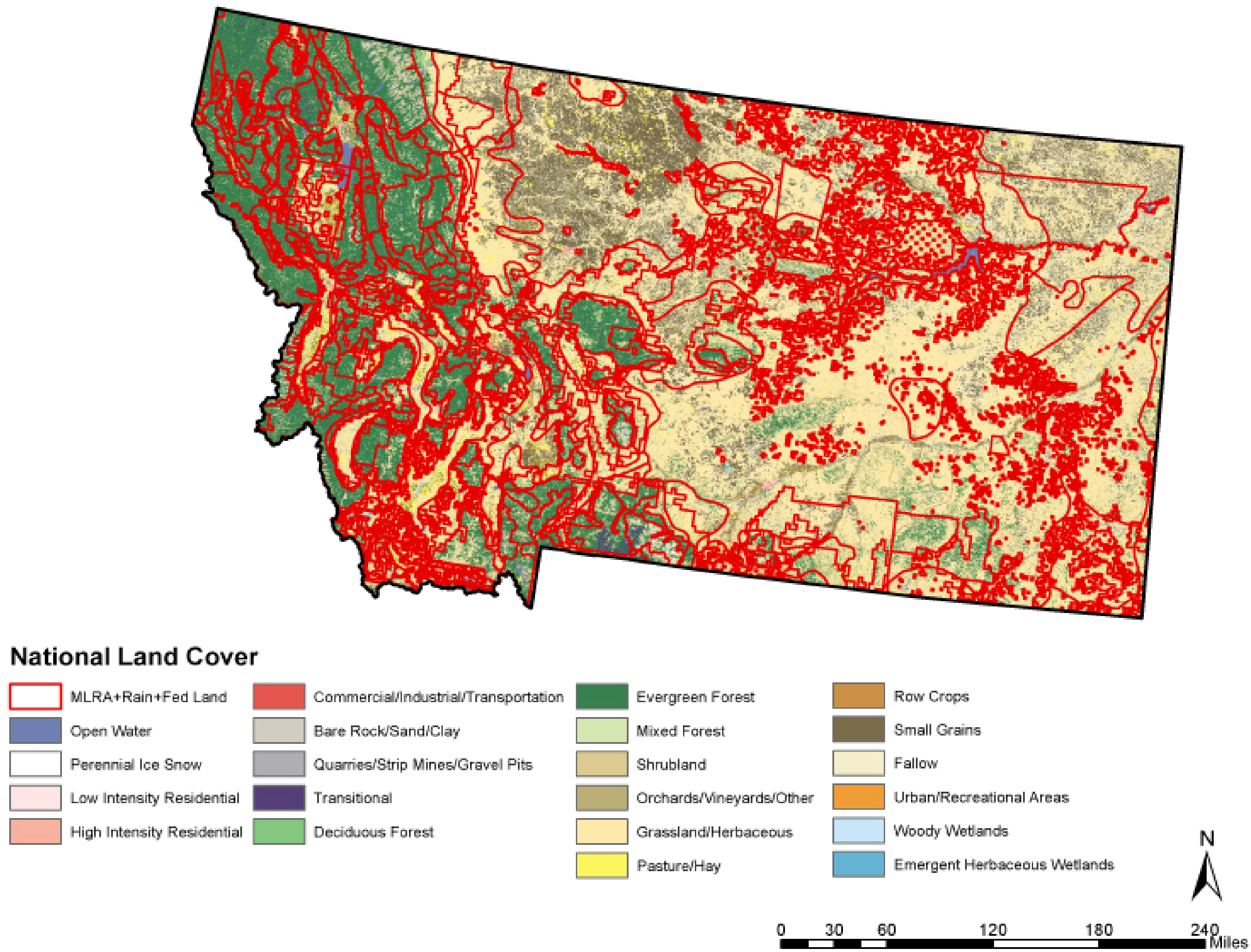


Figure 14. Sampling units (red lines) used in the spatial cross tabulation for the state of Montana. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation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

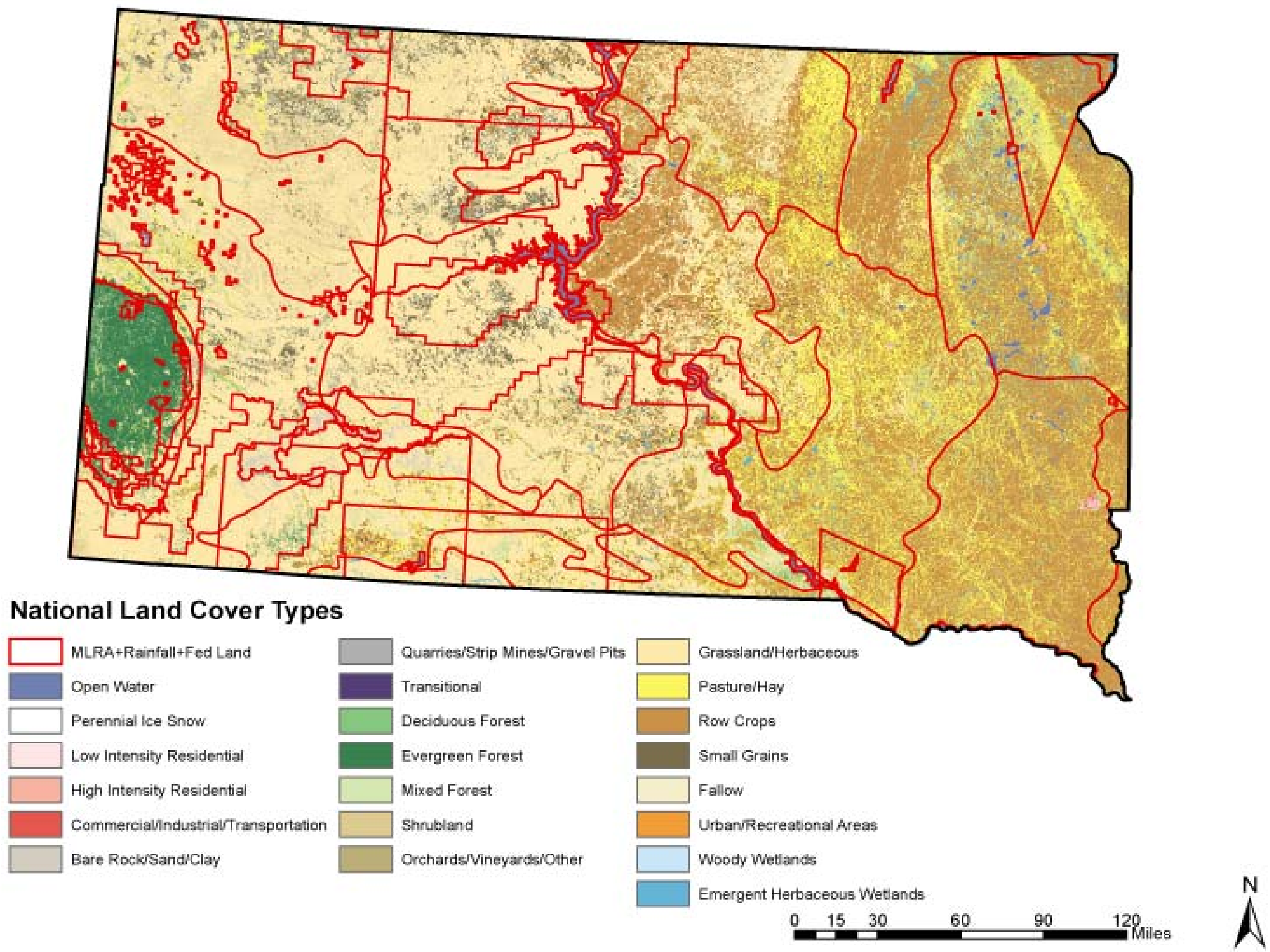


Figure 15. Sampling units (red lines) used in the spatial cross tabulation for the state of South Dakota. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation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

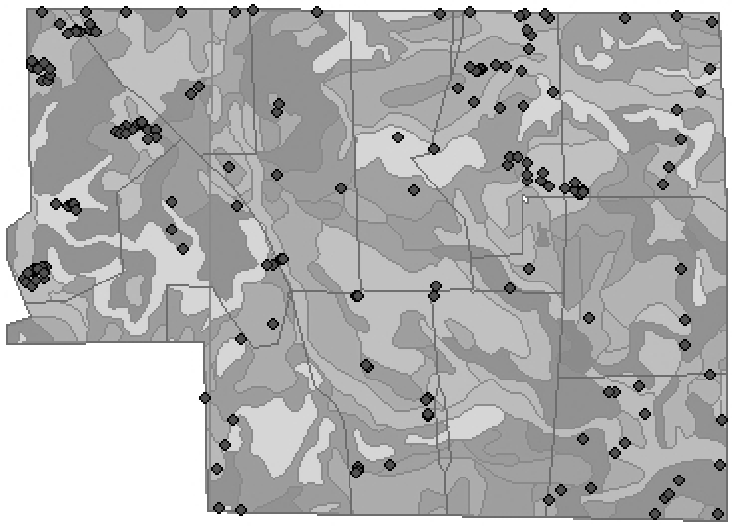


Figure 16. Distribution of sample points for Throckmorton Ranch placed over soil map and pasture boundaries.

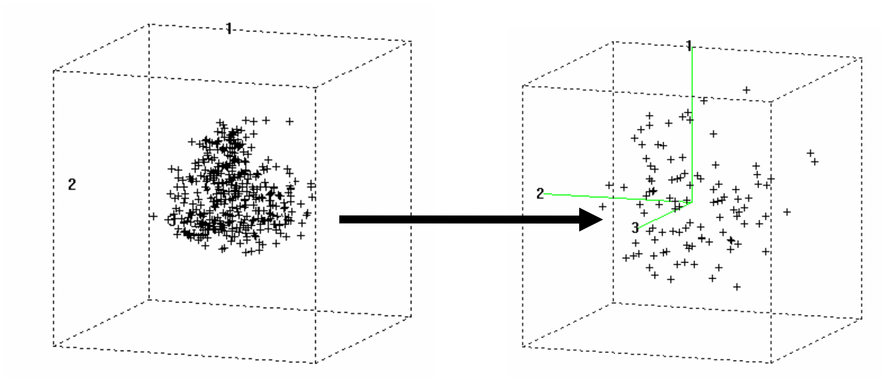


Figure 17. Selection of spectrally unique samples used to reduce laboratory costs and to choose samples that represent the range of population variance for equation development. From a total of 460 samples (left box) this procedure identified 107 spectrally unique samples (right box).

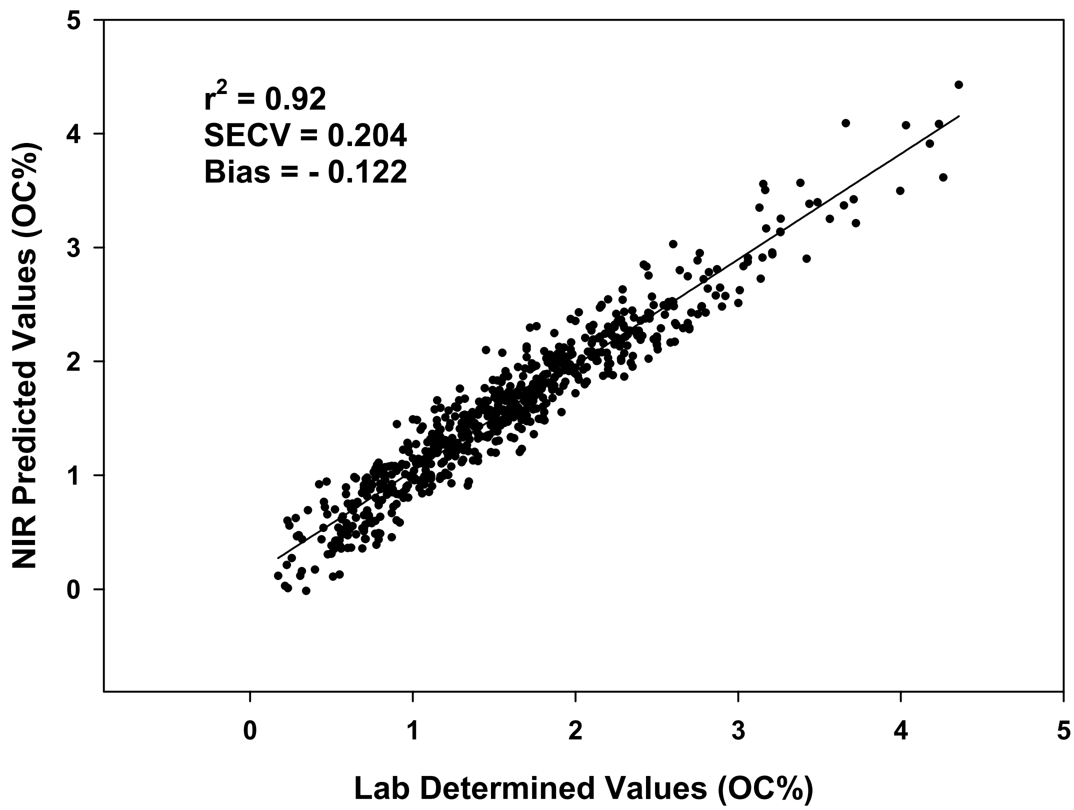


Figure 18. NIR cross validation prediction results for organic carbon using soils from diverse locations. (n = 661)

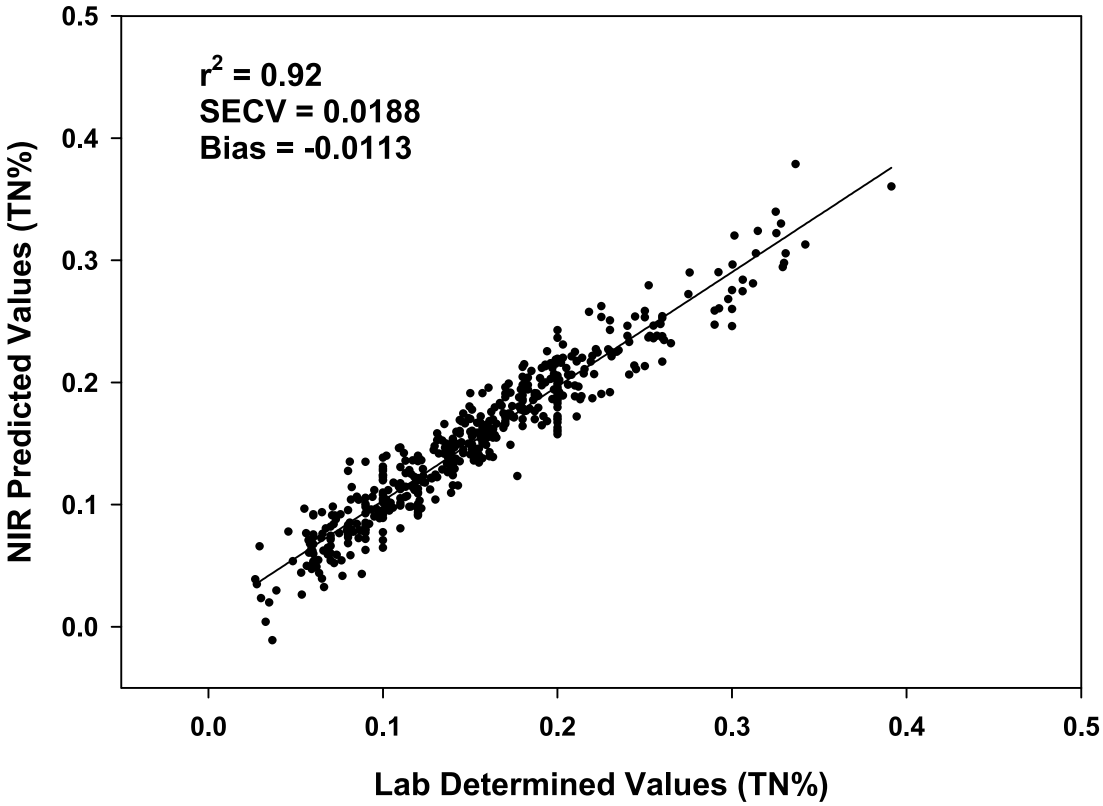


Figure 19. NIR cross validation prediction results for total nitrogen using soils from diverse locations (n = 502)

Table 1. Rangeland (ha) by land cover class and sums of the classes for Major Land Resource Area (MLRA) and land tenure class grouped according to Climatic Potential for carbon sequestration in Idaho. Percent of total reflects the percent of total rangeland occupied by the MLRA and Land Tenure class within the climatic potential grouping.

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Rangeland Totals	Percent of Total
High Climatic Potential (>460 mm)						
Big and Little Wood River Footslopes and Plains (proposed)	Federal	56,622	29,421	757	86,799	2.0
	Private or Non-Federal	27,243	15,017	92	42,352	1.0
Central Snake River Plains (proposed)	Federal	4,557	949	1	5,507	0.1
	Private or Non-Federal	829	336	41	1,207	0.0
Eastern Idaho Plateaus	Federal	193,563	63,495	3,173	260,231	6.0
	Indian Reservations	57,725	15,120	2,216	75,061	1.7
	Private or Non-Federal	314,950	105,948	75,772	496,670	11.4
Great Salt Lake Area	Federal	86,118	24,887	2,657	113,663	2.6
	Private or Non-Federal	44,230	20,983	23,323	88,536	2.0
Lost River Valleys and Mountains	Federal	164,767	82,669	261	247,697	5.7
	Private or Non-Federal	5,438	2,154	204	7,796	0.2
Northern Rocky Mountain Valleys	Federal	1,056	1,293	1,664	4,013	0.1
	Indian Reservations	0	0	0	0	0.0
	Private or Non-Federal	12,363	14,279	22,716	49,358	1.1
Northern Rocky Mountains	Federal	859,135	708,934	8,928	1,576,996	36.1
	Indian Reservations	18,552	16,882	3,180	38,614	0.9
	Private or Non-Federal	163,864	89,391	57,616	310,872	7.1
Owyhee High Plateau	Federal	136,813	21,248	85	158,146	3.6
	Indian Reservations	8,475	1,437	1	9,914	0.2
	Private or Non-Federal	68,598	7,731	665	76,994	1.8
Palouse and Nez Perce Prairies	Federal	2,418	1,595	6	4,019	0.1
	Indian Reservations	27,561	29,561	1,422	58,544	1.3
	Private or Non-Federal	27,529	21,288	1,764	50,581	1.2
Snake River Plains	Federal	3,687	68	0	3,756	0.1
	Private or Non-Federal	3,157	92	0	3,249	0.1
Upper Snake River Lava Plains and Hills	Federal	157,056	38,725	662	196,443	4.5
	Private or Non-Federal	226,480	47,414	13,631	287,525	6.6
	Federal	6,396	963	106	7,465	0.2
Upper Snake River Plains (proposed)	Indian Reservations	766	203	267	1,236	0.0
	Private or Non-Federal	7,107	2,884	4,075	14,066	0.3
Wasatch and Uinta Mountains	Federal	34,583	13,187	61	47,831	1.1
	Private or Non-Federal	25,893	8,698	5,444	40,035	0.9
	Sub Total	**2,747,530**	**1,386,853**	**230,791**	**4,365,174**	

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Rangeland Totals	Percent of Total
Moderate Climatic Potential (230 to 460 mm)						
Big and Little Wood River Footslopes and Plains (proposed)	Federal	360,770	39,236	1,796	401,803	6.3
	Private or Non-Federal	102,483	43,547	41,038	187,068	3.0
Central Snake River Plains (proposed)	Federal	454,674	173,426	5,770	633,870	10.0
	Private or Non-Federal	123,744	90,003	120,472	334,219	5.3
Columbia Plateau	Private or Non-Federal	254	161	0	415	0.0
Eastern Idaho Plateaus	Federal	51,017	9,328	2,619	62,963	1.0
	Indian Reservations	37,630	12,363	4,195	54,189	0.9
	Private or Non-Federal	140,491	57,646	79,381	277,519	4.4
Great Salt Lake Area	Federal	51,368	23,305	1,955	76,627	1.2
	Private or Non-Federal	22,751	14,359	28,563	65,674	1.0
Lost River Valleys and Mountains	Federal	447,226	100,518	6,059	553,802	8.7
	Private or Non-Federal	83,993	42,639	37,332	163,964	2.6
Northern Rocky Mountains	Federal	157,023	82,342	3,006	242,371	3.8
	Indian Reservations	173	23	0	195	0.0
	Private or Non-Federal	56,930	22,603	8,798	88,331	1.4
Owyhee High Plateau	Federal	1,032,573	160,837	3,007	1,196,417	18.9
	Indian Reservations	35,668	7,698	1,398	44,764	0.7
	Private or Non-Federal	194,881	33,059	13,933	241,873	3.8
Palouse and Nez Perce Prairies	Federal	1,780	624	0	2,404	0.0
	Indian Reservations	5,851	5,000	0	10,852	0.2
	Private or Non-Federal	22,538	10,783	0	33,321	0.5
Snake River Plains	Federal	250,264	95,717	3,502	349,483	5.5
	Private or Non-Federal	93,020	33,739	93,506	220,265	3.5
Upper Snake River Lava Plains and Hills	Federal	38,711	10,245	326	49,283	0.8
	Private or Non-Federal	115,130	26,065	11,503	152,698	2.4
Upper Snake River Plains (proposed)	Federal	394,244	82,842	2,973	480,059	7.6
	Indian Reservations	17,718	9,136	6,485	33,339	0.5
	Private or Non-Federal	162,794	85,580	122,121	370,495	5.8
Wasatch and Uinta Mountains	Federal	1,237	295	86	1,619	0.0
	Private or Non-Federal	5,737	2,328	3,317	11,382	0.2
	Sub Total	**4,462,675**	**1,275,446**	**603,141**	**6,341,262**	
Low Climatic Potential (130 to 230 mm)						
Central Snake River Plains (proposed)	Federal	8,437	2,317	6	10,759	2.3
	Private or Non-Federal	1,269	401	33	1,703	0.4
Lost River Valleys and	Federal	94,558	24,520	2,340	121,418	26.2

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Rangeland Totals	Percent of Total
Mountains	Private or Non-Federal	15,689	10,758	17,262	43,708	9.4
Northern Rocky Mountains	Federal	6,229	2,053	217	8,498	1.8
	Private or Non-Federal	1,129	506	395	2,030	0.4
Owyhee High Plateau	Federal	68,142	21,819	84	90,044	19.4
	Private or Non-Federal	3,705	1,029	1	4,735	1.0
Snake River Plains	Federal	81,218	46,044	3,122	130,384	28.1
	Private or Non-Federal	13,744	10,617	6,208	30,569	6.6
Upper Snake River Plains (proposed)	Federal	18,605	748	1	19,355	4.2
	Sub Total	**312,724**	**120,809**	**29,670**	**463,203**	
	Grand Total	**7,522,930**	**2,783,108**	**863,602**	**11,169,640**	

Table 2. Total hectares of rangeland cover types identified in Major Land Resource Areas (MLRA) in Idaho.

MLRA NAME	Rangeland (ha)
Northern Rocky Mountains	2267908
Owyhee High Plateau	1822887
Eastern Idaho Plateaus	1226633
Lost River Valleys and Mountains	1138385
Central Snake River Plains (proposed)	987265
Upper Snake River Plains (proposed)	926014
Snake River Plains	737706
Big and Little Wood River Footslopes and Plains (proposed)	718021
Upper Snake River Lava Plains and Hills	685948
Great Salt Lake Area	344500
Palouse and Nez Perce Prairies	159720
Wasatch and Uinta Mountains	100866
Northern Rocky Mountain Valleys	53371
Columbia Plateau	415

Table 3. Rangeland (ha) by land cover class and sums of the classes for Major Land Resource Area (MLRA) and land tenure class grouped according to Climatic Potential for carbon sequestration in Montana. Percent of total reflects the percent of total rangeland occupied by the MLRA and Land Tenure class within the climatic potential grouping.

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
High Climatic Potential (>460 mm)						
Brown Glaciated Plain	Indian Reservations	1,044	47,497	383	48,924	1.3
	Private or Non-Federal	154	6,993	59	7,206	0.2
Northern Intermountain Desertic Basins	Federal	1,798	2,606	0	4,404	0.1
	Private or Non-Federal	1,639	1,934	0	3,573	0.1
Northern Rocky Mountain Foothills	Federal	11,102	42,284	39	53,425	1.5
	Indian Reservations	30,045	138,512	5,937	174,495	4.8
	Private or Non-Federal	51,449	464,005	15,309	530,763	14.6
Northern Rocky Mountain Valleys	Federal	47,410	53,485	3,318	104,213	2.9
	Indian Reservations	3,492	15,622	2,129	21,243	0.6
	Private or Non-Federal	65,074	185,917	47,999	298,990	8.2
Northern Rocky Mountains	Federal	574,907	776,050	4,591	1,355,548	37.4
	Indian Reservations	30,912	107,895	6,724	145,531	4.0
	Private or Non-Federal	166,339	567,570	15,946	749,855	20.7
Northern Rolling High Plains; Northern Part	Federal	147	323	0	469	0.0
	Indian Reservations	11,539	72,612	1,957	86,108	2.4
	Private or Non-Federal	3,139	17,532	1,053	21,724	0.6
Northern Rolling High Plains; Southern Part	Federal	171	2,228	12	2,411	0.1
	Private or Non-Federal	1,359	15,404	299	17,062	0.5
	Sub Total	**1,001,720**	**2,518,468**	**105,755**	**3,625,943**	
Moderate Climatic Potential (230 to 460 mm)						
Brown Glaciated Plain	Federal	43,303	649,228	3,950	696,481	4.0
	Indian Reservations	16,450	374,909	7,319	398,679	2.3
	Private or Non-Federal	90,151	1,533,435	125,049	1,748,636	9.9
Northern Dark Brown Glaciated Plains	Federal	3,284	11,916	175	15,375	0.1
	Indian Reservations	32,783	173,152	3,429	209,364	1.2
	Private or Non-Federal	103,209	389,768	37,846	530,823	3.0
Northern Intermountain Desertic Basins	Federal	20,040	3,574	0	23,614	0.1
	Private or Non-Federal	24,763	6,049	1,423	32,235	0.2
Northern Rocky Mountain Foothills	Federal	31,919	57,980	172	90,071	0.5
	Indian Reservations	26,924	210,946	5,485	243,355	1.4
	Private or Non-Federal	72,222	983,168	58,110	1,113,500	6.3
Northern Rocky Mountain Valleys	Federal	51,065	84,188	4,337	139,590	0.8
	Indian Reservations	8,313	53,955	30,467	92,735	0.5
	Private or Non-Federal	177,486	728,161	222,278	1,127,925	6.4
Northern Rocky Mountains	Federal	146,928	189,265	2,490	338,683	1.9
	Indian Reservations	15,034	39,315	10,493	64,841	0.4

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
	Private or Non-Federal	199,634	654,437	54,658	908,728	5.2
Northern Rolling High Plains; Eastern Part	Federal	4,620	10,355	52	15,027	0.1
	Private or Non-Federal	11,434	35,177	2,490	49,102	0.3
Northern Rolling High Plains; Northern Part	Federal	310,851	1,340,477	3,688	1,655,017	9.4
	Indian Reservations	54,433	436,462	15,263	506,158	2.9
	Private or Non-Federal	648,515	5,506,180	145,777	6,300,471	35.8
Northern Rolling High Plains; Southern Part	Federal	2,479	10,565	45	13,090	0.1
	Indian Reservations	501	2,426	0	2,927	0.0
	Private or Non-Federal	25,141	104,513	1,723	131,377	0.7
Pierre Shale Plains and Badland	Federal	9,238	25,657	107	35,002	0.2
	Private or Non-Federal	6,909	65,461	2,117	74,487	0.4
Pierre Shale Plains; Northern Part	Federal	50,877	149,794	724	201,395	1.1
	Private or Non-Federal	86,067	449,058	10,616	545,740	3.1
Rolling Soft Shale Plain	Federal	227	2,763	138	3,128	0.0
	Private or Non-Federal	34,437	224,796	24,914	284,147	1.6
	Sub Total	**2,309,237**	**14,507,129**	**775,335**	**17,591,700**	
Low Climatic Potential (130 to 230 mm)						
Northern Intermountain Desertic Basins	Federal	9,260	535	20	9,815	33.5
	Private or Non-Federal	8,516	1,594	1,047	11,156	38.0
Northern Rocky Mountain Foothills	Federal	5,554	185	40	5,778	19.7
	Private or Non-Federal	471	7	0	478	1.6
Northern Rocky Mountains	Federal	1,780	254	0	2,034	6.9
	Indian Reservations	72	6	0	77	0.3
	Sub Total	**25,652**	**2,581**	**1,106**	**29,339**	
	Grand Total	**3,336,609**	**17,028,178**	**882,196**	**21,246,983**	

Table 4. Total hectares of rangeland cover types identified in Major Land Resource Areas (MLRA) in Montana.

MLRA NAME	Rangeland
Northern Rolling High Plains; Northern Part	8,569,948
Northern Rocky Mountains	3,565,297
Brown Glaciated Plain	2,899,925
Northern Rocky Mountain Foothills	2,211,864
Northern Rocky Mountain Valleys	1,784,696
Northern Dark Brown Glaciated Plains	755,562
Pierre Shale Plains; Northern Part	747,135
Rolling Soft Shale Plain	287,276
Northern Rolling High Plains; Southern Part	166,867
Pierre Shale Plains and Badlands	109,489
Northern Intermountain Desertic Basins	84,797
Northern Rolling High Plains; Eastern Part	64,128

Table 5. Rangeland (ha) by land cover class and sums of the classes for Major Land Resource Area (MLRA) and land tenure class grouped according to Climatic Potential for carbon sequestration in South Dakota. Percent of total reflects the percent of total rangeland occupied by the MLRA and Land Tenure class within the Climatic Potential grouping.

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
High Climatic Potential (>460 mm)						
Black Hills	Federal	126	63,784	11,469	75,379	1.1
	Private or Non-Federal	60	19,915	1,942	21,917	0.3
Black Hills Foot Slopes	Federal	19	10,776	689	11,483	0.2
	Private or Non-Federal	713	64,476	25,848	91,037	1.4
Central Black Glaciated Plains	Federal	0	278	1,638	1,916	0.0
	Indian Reservations	0	177	1,575	1,751	0.0
	Private or Non-Federal	45	40,388	171,125	211,558	3.2
Central Dark Brown Glaciated Plains	Private or Non-Federal	1,424	319,620	237,937	558,981	8.3
Dakota-Nebraska Eroded Tableland	Indian Reservations	0	152,108	19,518	171,626	2.6
	Private or Non-Federal	0	132,641	46,360	179,002	2.7
Iowa and Missouri Deep Loess Hills	Private or Non-Federal	1	1,618	31,220	32,839	0.5
Mixed Sandy and Silty Tableland	Federal	0	1,489	1,546	3,036	0.0
	Indian Reservations	0	264,652	44,531	309,184	4.6
	Private or Non-Federal	0	181,193	47,756	228,949	3.4
Nebraska Sand Hills	Federal	0	368	0	368	0.0
	Indian Reservations	0	43,193	1,426	44,618	0.7
	Private or Non-Federal	0	69,855	897	70,751	1.1
Northern Rolling Pierre Shale Plains	Federal	97	85,743	1,456	87,295	1.3
	Indian Reservations	1,556	235,250	1,848	238,655	3.6
	Private or Non-Federal	1,176	758,973	41,274	801,423	11.9
Pierre Shale Plains and Badlands	Federal	8	2,085	437	2,530	0.0
	Indian Reservations	0	77,028	8,188	85,216	1.3
	Private or Non-Federal	1,151	139,081	17,957	158,189	2.4
Red River Valley of the North	Federal	0	11	17	28	0.0
	Indian Reservations	0	3	1,620	1,624	0.0
	Private or Non-Federal	0	0	190	190	0.0
Rolling Soft Shale Plain	Indian Reservations	286	98,987	2,147	101,420	1.5
	Private or Non-Federal	0	796	416	1,213	0.0
Rolling Till Prairie	Federal	0	382	1,218	1,600	0.0
	Indian Reservations	1	21,170	113,190	134,360	2.0
	Private or Non-Federal	89	60,265	510,783	571,137	8.5
Southern Black Glaciated Plains	Federal	0	1,212	496	1,709	0.0
	Indian Reservations	0	15,080	54,100	69,180	1.0
	Private or Non-Federal	466	151,138	733,494	885,098	13.2
Southern Dark Brown Glaciated Plains	Federal	0	785	14	799	0.0
	Indian Reservations	30	15,325	161	15,516	0.2
	Private or Non-Federal	399	429,966	150,230	580,595	8.6

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
Southern Rolling Pierre Shale Plains	Federal	27	4,694	1,024	5,745	0.1
	Indian Reservations	75	86,247	11,763	98,085	1.5
	Private or Non-Federal	27	286,624	87,998	374,649	5.6
Till Plains	Federal	0	1,018	1,482	2,501	0.0
	Indian Reservations	0	371	822	1,193	0.0
	Private or Non-Federal	11	33,390	448,383	481,784	7.2
	Sub Total	**7,788**	**3,872,157**	**2,836,184**	**6,716,129**	
Moderate Climatic Potential (230 to 460 mm)						
Black Hills	Federal	303	2,524	53	2,881	0.1
	Private or Non-Federal	631	4,036	46	4,713	0.1
Black Hills Foot Slopes	Federal	878	34,954	686	36,518	0.7
	Private or Non-Federal	3,594	39,465	1,743	44,802	0.8
Central Dark Brown Glaciated Plains	Federal	0	17	0	17	0.0
	Private or Non-Federal	137	64,316	7,275	71,728	1.3
Mixed Sandy and Silty Tableland	Federal	0	10,346	64	10,410	0.2
	Indian Reservations	0	183,648	5,698	189,345	3.5
	Private or Non-Federal	0	9	5	15	0.0
Northern Rolling High Plains; Eastern Part	Federal	6,582	14,982	461	22,026	0.4
	Indian Reservations	399	13,283	0	13,681	0.3
	Private or Non-Federal	207,120	802,760	16,546	1,026,425	18.8
Northern Rolling Pierre Shale Plains	Federal	296	57,655	1,690	59,641	1.1
	Indian Reservations	3,225	383,905	833	387,962	7.1
	Private or Non-Federal	739	557,318	4,603	562,659	10.3
Pierre Shale Plains and Badlands	Federal	24,426	531,493	12,968	568,887	10.4
	Indian Reservations	0	154,950	3,880	158,830	2.9
	Private or Non-Federal	105,203	935,981	68,558	1,109,742	20.4
Rolling Soft Shale Plain	Federal	21,382	121,743	3,273	146,399	2.7
	Indian Reservations	27,392	653,331	6,522	687,244	12.6
	Private or Non-Federal	69,753	210,147	31,554	311,454	5.7
Southern Dark Brown Glaciated Plains	Federal	2	3,114	107	3,223	0.1
	Private or Non-Federal	10	27,258	2,694	29,962	0.5
	Sub Total	**472,070**	**4,807,234**	**169,260**	**5,448,564**	
	Grand Total	**479,858**	**8,679,391**	**3,005,444**	**12,164,693**	

Table 6. Total hectares of rangeland cover types identified in Major Land Resource Areas (MLRA) in South Dakota.

MLRA NAME	Rangeland
Northern Rolling Pierre Shale Plains	2,137,636
Pierre Shale Plains and Badlands	2,083,394
Rolling Soft Shale Plain	1,247,729
Northern Rolling High Plains; Eastern Part	1,062,133
Southern Black Glaciated Plains	955,986
Mixed Sandy and Silty Tableland	740,938
Rolling Till Prairie	707,097
Central Dark Brown Glaciated Plains	630,725
Southern Dark Brown Glaciated Plains	630,095
Till Plains	485,477
Southern Rolling Pierre Shale Plains	478,480
Dakota-Nebraska Eroded Tableland	350,628
Central Black Glaciated Plains	215,226
Black Hills Foot Slopes	183,841
Nebraska Sand Hills	115,738
Black Hills	104,890
Iowa and Missouri Deep Loess Hills	32,839
Red River Valley of the North	1,842

Table 7. Rangeland (ha) for each state in the Big Sky Project by climatic potential (annual precipitation) and land tenure class. Federal lands are not included since they will most likely not be included in carbon sequestration programs.

Land Tenure Class	Idaho	Montana	South Dakota	Big Sky Region Totals
High Climatic Potential (>460 mm)				
Indian Reservations	183,369	476,300	1,272,428	1,932,096
Private or Other Non-Federal	1,469,240	1,629,173	5,249,313	8,347,725
Moderate Climatic Potential (230 to 460 mm)				
Indian Reservations	143,339	1,518,059	1,437,063	3,098,461
Private or Other Non-Federal	2,147,225	12,847,170	3,161,500	18,155,895
Low Climatic Potential (130 to 230 mm)				
Indian Reservations	0	77	0	77
Private or Other Non-Federal	82,745	11,635	0	94,380
Totals	**3,943,172**	**16,470,702**	**11,120,304**	**31,534,178**

Table 8. Prediction statistics for the independent validation set predicted from the equation derived from the 107 analyzed samples and cross validation results obtained from combining the validation set with the calibration set. Values are percentages.

	Independent Validation				Cross Validation Combined Set				
Property	n	RSQ	SEP	BIAS	n	Mean	SD	SECV	RSQ
Inorganic Carbon	25	0.966	0.211	-0.060	120	1.85	2.11	0.279	0.98
Total Carbon	25	0.918	0.329	-0.016	120	3.46	1.90	0.313	0.97
Organic Carbon	25	0.859	0.278	0.090	120	1.63	0.73	0.266	0.87
Total Nitrogen	25	0.945	0.018	0.006	118	0.17	0.012	0.016	0.94

Table 9. Cross Validation Results for Final NIR Throckmorton Equation.

Property	n	Mean	SD	SECV	RSQ
IC	186	1.71	1.83	0.297	0.97
TC	188	3.32	1.75	0.323	0.97
OC	185	1.56	0.64	0.251	0.85
TN	118	0.17	0.012	0.016	0.94

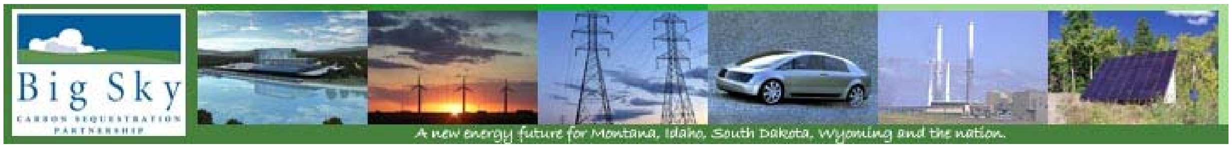
Table 10. Cross Validation Results for Second General Organic Carbon and Total Nitrogen Equation

Property	n	Mean	SD	SECV	RSQ
Organic Carbon	1110	2.10	1.10	0.36	0.89
Total Nitrogen	951	0.20	0.093	0.034	0.86

Table 11. Cross validation predictions of selected carbon fractions.

Property	n	Mean*	SD	SECV	RSQ	Bias
Glomalin	111	0.51	0.36	0.122	0.89	-0.07
POM	142	0.95	1.02	0.556	0.71	-0.33
Amino sugar	131	201.54	71.26	33.26	0.78	19.96
B -glucosaminidase	138	26.32	18.61	10.73	0.67	-6.44
B- glucosidase	130	75.94	46.76	29.10	0.61	-17.46

*units for glomalin and POM are mg g^{-1} and µg g^{-1} for amino sugar, B -glucosaminidase and B- glucosidase.



Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 6: Manuscript on Carbon Budget and Analysis/GIS Database

June 2005

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Interim Report on GIS Activities for the Big Sky Carbon Sequestration Regional Partnership
Phase 1 through March 2005

24-March-2005

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Executive Summary

Los Alamos National Laboratory (LANL) continues in the role of coordination of Big Sky geographic information system (GIS) efforts, Idaho National Laboratory (INL) continues as lead for geologic data, South Dakota School of Mines and Technology (SDSMT) continues in the role of lead for terrestrial data, Montana State University (MSU) assumed the role of lead for serving data and data coordination, and the State of Montana assumed the role of building links to state GIS databases. Big Sky GIS progress included five major areas of effort:

- **Big Sky Carbon Atlas:** further compilation of geologic and terrestrial data for the states of Montana, South Dakota, Idaho, and Wyoming;
- **Big Sky Data Warehouse:** planning and initial implemention of online access;
- **Interpartnership coordination and links with NATCARB, DOE, and national cyberinfrastructure efforts:** continued planning and communication;
- **Outreach:** continued contribution; and
- **Big Sky Phase 2 proposal:** development of the GIS component.

Big Sky GIS Overview

During phase 1, the Big Sky geographic information system (GIS) effort focused primarily on characterization of regional carbon sources, sinks, and infrastructure. The Big Sky geographic region was defined to include land area encompassing the states of Montana (MT), South Dakota (SD), Idaho (ID), and Wyoming (WY). During phase 2 this will be expanded to include contiguous areas in eastern Washington, Oregon, and Canadian provinces. Data are being made available via the Big Sky Carbon Atlas (Table 1). The Big Sky Carbon Atlas can be viewed via the Big Sky Partnership website (http://www.bigskyco2.org), and via the NatCarb distributed national databases (http://www.natcarb.org). Note that the state of Wyoming was added during year two, and supplemental funding is currently being used to complete the characterization.

Table 1. Data layers of the Big Sky Carbon Atlas (ID, MT, SD, and WY) during Phase I.

Data Type	Description	Served by Big Sky
GHG Sources	Emission point locations	Yes
GHG Inventory	State-level source & sink emission summaries	Yes
GHG Livestock	County-level livestock emission summaries	Yes
Terrestrial Sinks	Actual/potential soil sink estimates (CENTURY)	Yes
Soil	SSURGO/STATSGO & Soil Texture Grids	Yes
Climate	Monthly precipitation/temperature 1900–present	Yes
Climate Divisions	NCDC climate division boundaries	Yes
Ag Management	Cropland areas (various tillage/rangeland)	Yes
Political	State/County Boundaries	Yes
Infrastructure	Transportation/Pipelines/Powerlines	No[a]
Geologic Sinks	Oil/Gas Provinces & Plays	Yes
Wells	Oil & Gas wells	Yes

[a]. Infrastructure data layers such as gas pipelines are not served due to homeland security issues.

GIS Support for Geological Sequestration Efforts

The Idaho National Laboratory (INL), under Randy Lee, serves as the lead for geologic carbon sequestration evaluations and development of geologic database for the Big Sky Carbon Atlas. The University of Wyoming (UWy), under Jeff Hamerlinck, is providing assistance with completing geologic data layers, in particular for WY.

The region of interest for geological sequestration efforts includes Idaho, Montana, South Dakota, and geologically contiguous areas in North Dakota and Wyoming. The geologic sequestration potential is being assessed in sedimentary and volcanic basins including deep saline aquifers, depleted oil/gas reservoirs, deep unminable coal beds, and mafic/rock hosted fresh aquifers. During the first year of a two-year program, the INL Geologic Sequestration team has developed a GIS database structure, identified the sources, and collected data that now populate the database. During this second year, specific geologic data are being evaluated to determine the sequestration potential for geologic sites within the Big Sky region.

The INL is assessing the sequestration potential of the large traditional hydrocarbon basins located in Montana, Wyoming and South Dakota (Figure 1); and additionally has developed a procedure to evaluate the non-traditional volcanic basins plays found in southern Idaho.

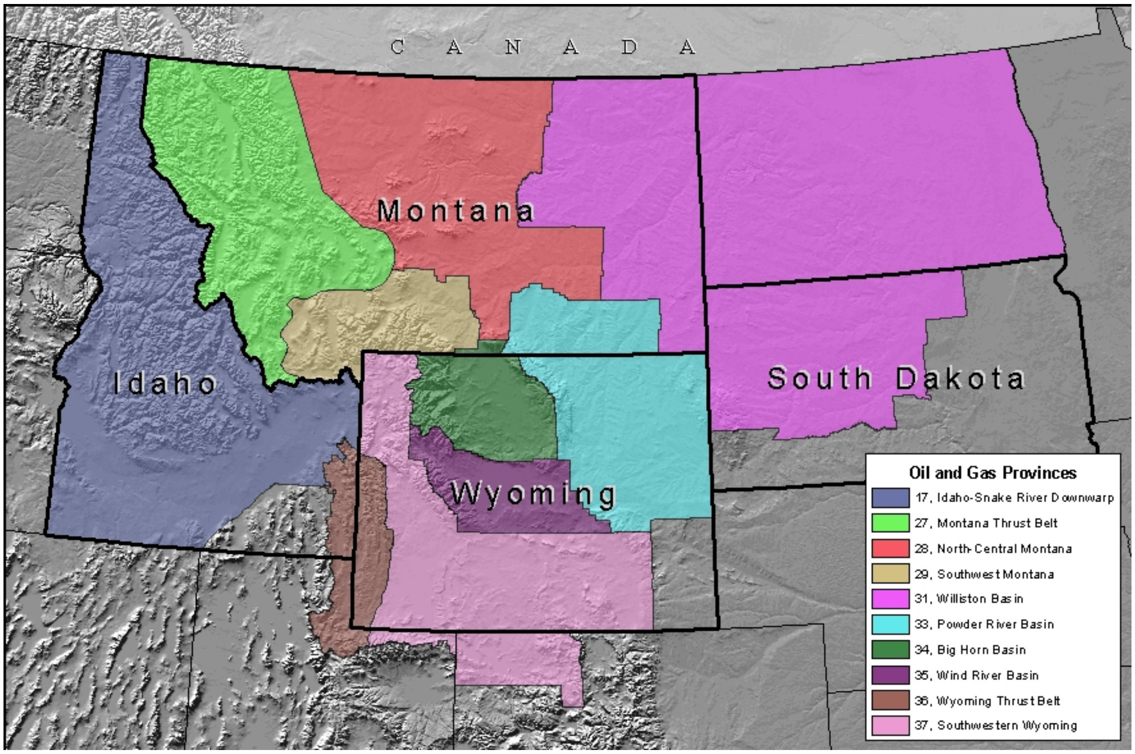


Figure 1. Big Sky region oil and gas provinces.

An overall approach to assess geologic carbon sequestration potential was developed. This assessment was based on geospatial and tabular data being collected and fed into a GIS based database. This database is structured to feed critical information into the geochemical and reservoir modeling activities (see Figure 2). During this performance period, modeling of the oil and gas regions of WY and MT to characterize the suitability of each candidate site with respect to its carbon dioxide sequestration potential has been completed. The modeling approach includes isolating individual oil and gas wells first by *play* area, then by formation within each *play*. Then calculations were performed in the model, using data from the well tables, resulting in either surfaces or tables for pressure, temperature, density, and thickness. From this new information, sequestration volumes were established for each formation within each *play*. To date, sequestration volumes have been calculated for 283 formations in 57 *plays* using data from 117,304 active wells in WY and approximately 50,000 wells in MT. A view of the model can be seen in Figure 3 and an example of the resulting information in tabular form can be seen in Figure 4.

Along with the modeling efforts during this period, additional GIS layers have been collected, cataloged and delivered to Montana State University for inclusion into the Big Sky Atlas. A complete list of geologic data is provide in Appendix A: GIS Master List.

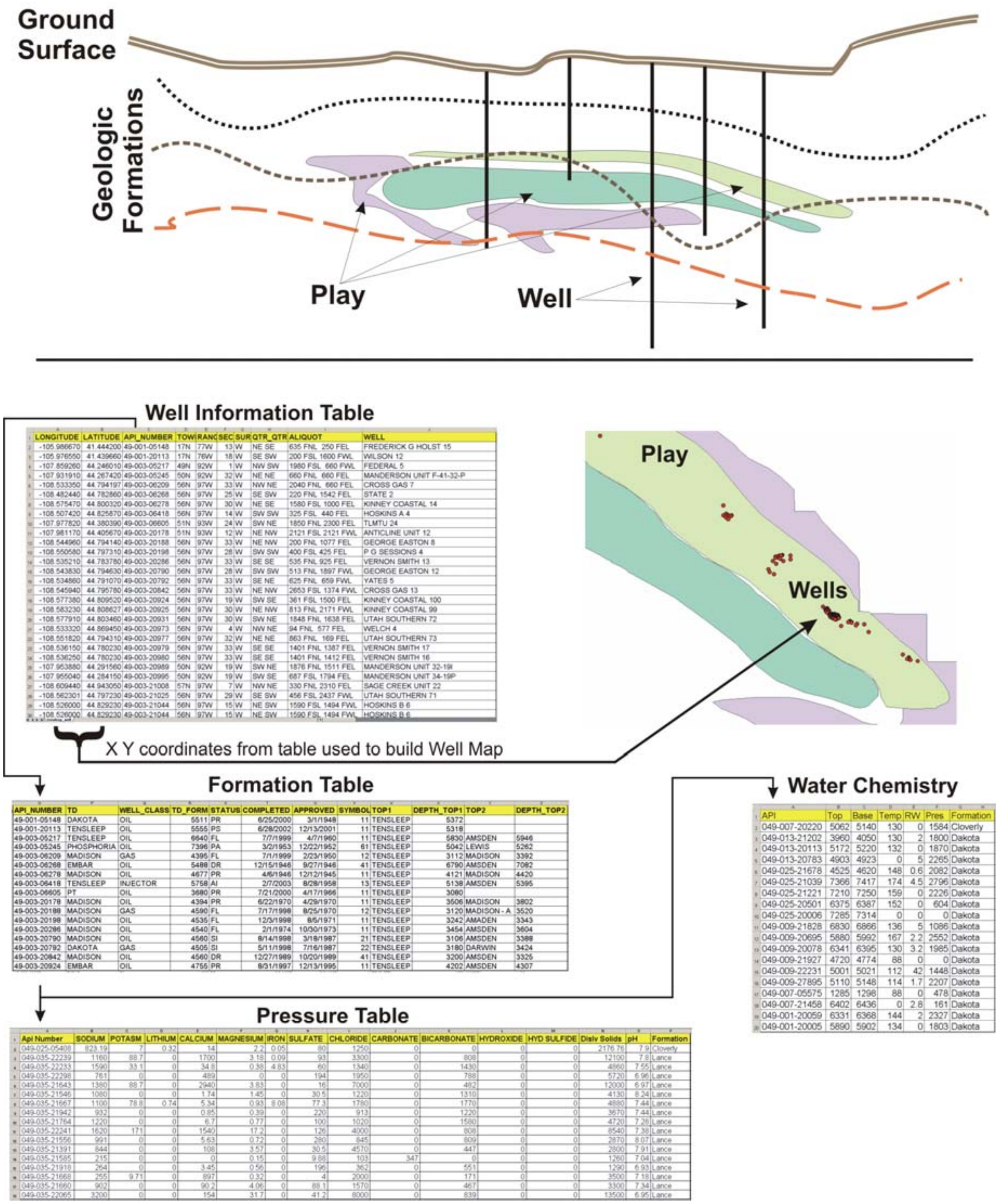


Figure 2. Big Sky GIS database structure for plays, wells, and geologic formations.

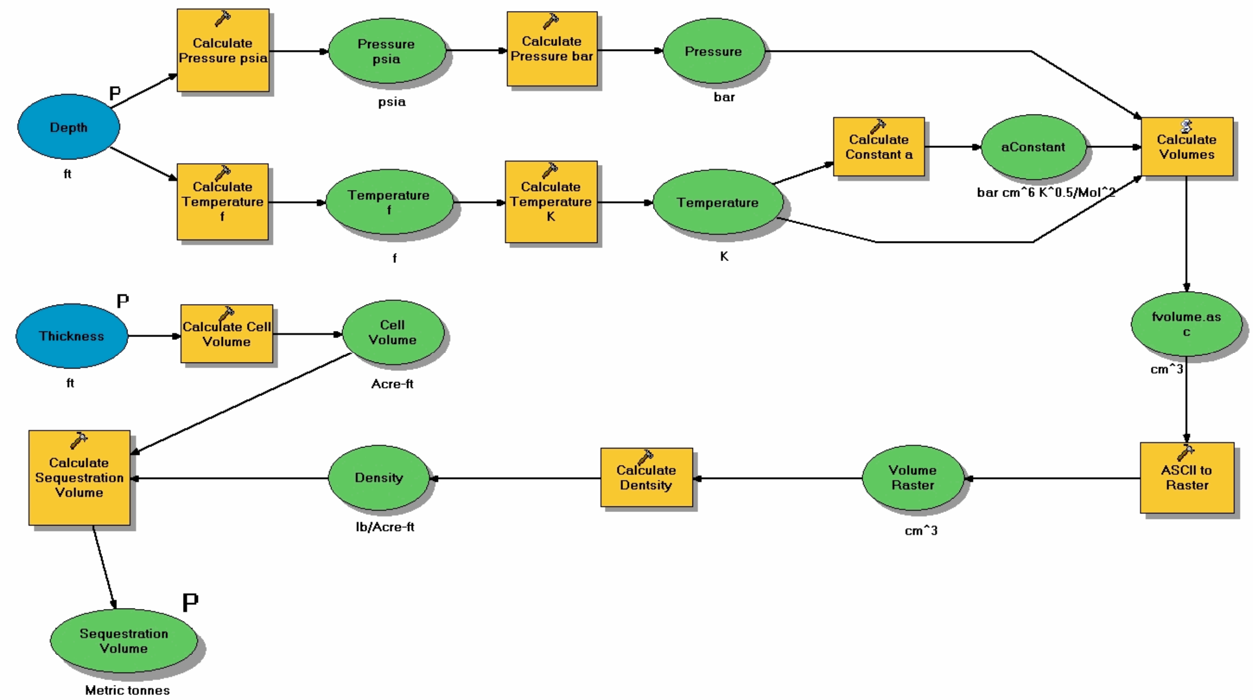
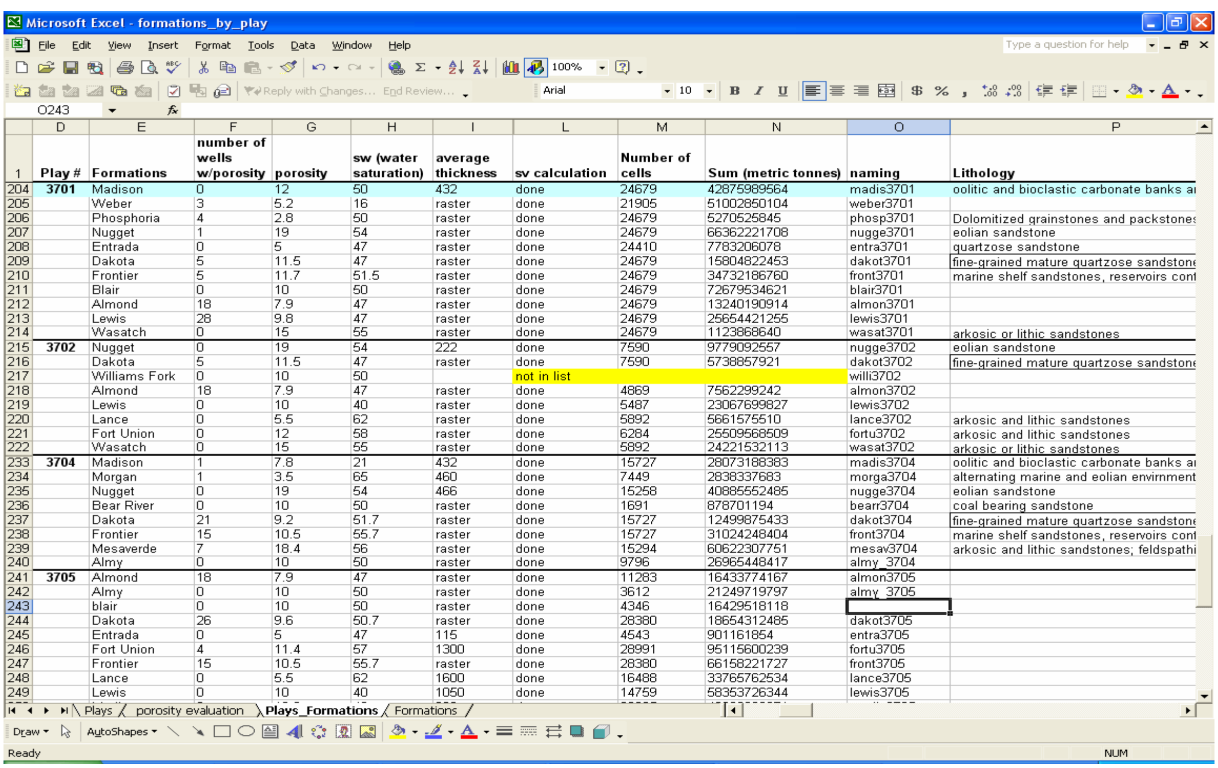


Figure 3. Big Sky carbon sequestration volume model.



	Play #	Formations	number of wells w/porosity	porosity	sw (water saturation)	average thickness	sv calculation	Number of cells	Sum (metric tonnes)	naming	Lithology
204	3701	Madison	0	12	50	432	done	24679	42875989564	madis3701	oolitic and bioclastic carbonate banks ai
205		Weber	3	5.2	16	raster	done	21905	51002850104	weber3701	
206		Phosphoria	4	2.8	50	raster	done	24679	5270525845	phosp3701	Dolomitized grainstones and packstones
207		Nugget	1	19	54	raster	done	24679	66362221708	nugge3701	eolian sandstone
208		Entrada	0	5	47	raster	done	24410	7783206078	entra3701	quartzose sandstone
209		Dakota	5	11.5	47	raster	done	24679	15804822453	dakot3701	fine-grained mature quartzose sandstone
210		Frontier	5	11.7	51.5	raster	done	24679	34732186760	front3701	marine shelf sandstones, reservoirs cont
211		Blair	0	10	50	raster	done	24679	72679534621	blair3701	
212		Almond	18	7.9	47	raster	done	24679	13240190914	almon3701	
213		Lewis	28	9.8	47	raster	done	24679	25654421255	lewis3701	
214		Wasatch	0	15	55	raster	done	24679	1123868640	wasat3701	arkosic or lithic sandstones
215	3702	Nugget	0	19	54	222	done	7590	9779092557	nugge3702	eolian sandstone
216		Dakota	5	11.5	47	raster	done	7590	5738857921	dakot3702	fine-grained mature quartzose sandstone
217		Williams Fork	0	10	50		not in list			willi3702	
218		Almond	18	7.9	47	raster	done	4869	7562299242	almon3702	
219		Lewis	0	10	40	raster	done	5487	23067699827	lewis3702	
220		Lance	0	5.5	62	raster	done	5892	5661575510	lance3702	arkosic and lithic sandstones
221		Fort Union	0	12	58	raster	done	6284	25509568509	fortu3702	arkosic and lithic sandstones
222		Wasatch	0	15	55	raster	done	5892	24221532113	wasat3702	arkosic or lithic sandstones
233	3704	Madison	1	7.8	21	432	done	15727	28073188383	madis3704	oolitic and bioclastic carbonate banks ai
234		Morgan	1	3.5	65	460	done	7449	2838337683	morga3704	alternating marine and eolian envirnment
235		Nugget	0	19	54	466	done	15258	40885552485	nugge3704	eolian sandstone
236		Bear River	0	10	50	raster	done	1691	878701194	bearr3704	coal bearing sandstone
237		Dakota	21	9.2	51.7	raster	done	15727	12499875433	dakot3704	fine-grained mature quartzose sandstone
238		Frontier	15	10.5	55.7	raster	done	15727	31024248404	front3704	marine shelf sandstones, reservoirs cont
239		Mesaverde	7	18.4	56	raster	done	15294	60622307751	mesav3704	arkosic and lithic sandstones; feldspathi
240		Almy	0	10	50	raster	done	9796	26965448417	almy_3704	
241	3705	Almond	18	7.9	47	raster	done	11283	16433774167	almon3705	
242		Almy	0	10	50	raster	done	3612	21249719797	almy_3705	
243		blair	0	10	50	raster	done	4346	16429518118		
244		Dakota	26	9.6	50.7	raster	done	28380	18654312485	dakot3705	
245		Entrada	0	5	47	115	done	4543	901161854	entra3705	
246		Fort Union	4	11.4	57	1300	done	28991	95115600239	fortu3705	
247		Frontier	15	10.5	55.7	raster	done	28380	66158221727	front3705	
248		Lance	0	5.5	62	1600	done	16488	33765762534	lance3705	
249		Lewis	0	10	40	1050	done	14759	58353726344	lewis3705	

Figure 4. Results from Carbon Sequestration Volume modeling.

GIS Support for Terrestrial Sequestration Efforts

The South Dakota School of Mines and Technology (SDSMT), under Karen Updegraff, serves as the lead for terrestrial carbon sequestration evaluations, including greenhouse gas (GHG) sources and sinks, and development of the terrestrial database for the Big Sky Carbon Atlas. Characterization of MT, ID, and SD is complete and characterization of WY is currently in progress under supplemental funding to SDSMT and UWy.

GHG sources: The primary sources of greenhouse gases in Montana, Idaho, and South Dakota are compared in Figure 5. In 2002 the region's emissions of CO_2 were averaging about 25 MMTCE, not including Wyoming, which translates into per capita emissions ranging from a high of 13MTCE in South Dakota to 3 MTCE in Montana. In Montana and Wyoming, refining and other energy and heavy industries constitute the largest GHG source category; in Idaho, imported electricity accounts for the largest category of emissions. Potential emissions from future development of the vast fossil-fuel resources are conservatively estimated to be an order of magnitude higher, depending on transmission lines and other energy demand factors. Livestock-related GHG emissions exceed 15% of South Dakota emissions.

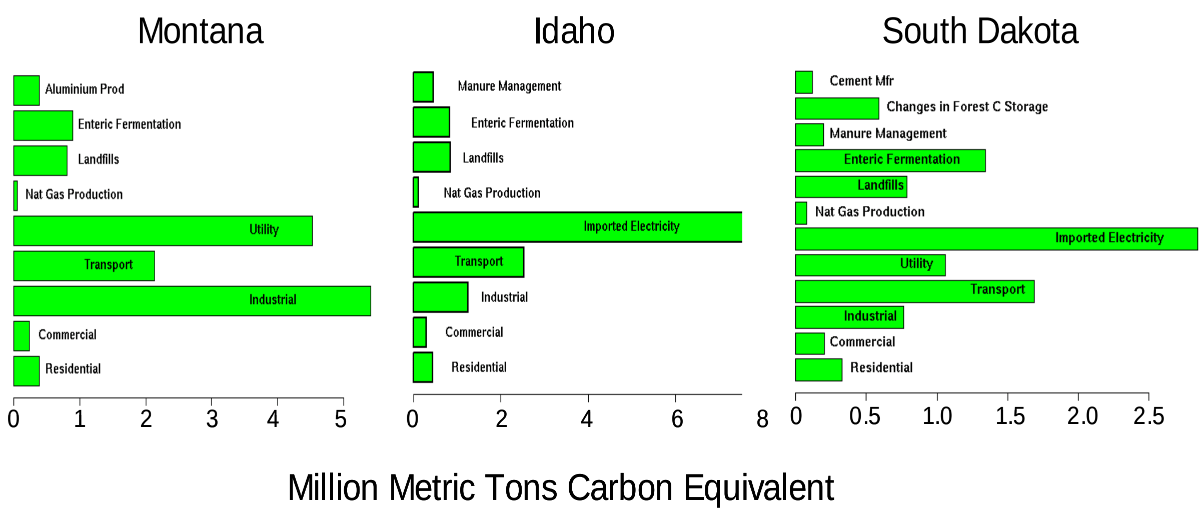


Figure 5. Primary Greenhouse gas emission sources in MT, ID, and SD.

GHG Sinks: GIS components of the terrestrial sink evaluation include climate, soil and land use databases. One hundred years of climate data from National Climate Data Center station records were averaged for each of up to 10 climate zones in each state, to produce zone-average files containing monthly max/min temperatures and precipitation since 1895. In addition, zone-specific statistical data on climate variability were provided to Century's stochastic climate generation subroutine, which we used to simulate climate after 2003.

Soil texture grids derived from SSURGO or STATSGO soil databases were developed for each state, then statistically aggregated to approximately 20 representative soil texture classes. Century simulations are highly sensitive to soil texture, so although it was impractical to model every actual soil map unit in the state, the classes we use represented the range of soil textures found in the state. Each class was weighted by the actual area of land to which it applied in each county.

Land management data were extracted from the 1997 Census of Agriculture (USDA 1997). Land in Farms data, for total areas of harvested cropland and grazing (pasture) land, and from the Conservation Technology Information Center (CTIC 2004) data for 2002 on land enrolled in the CRP and cropland under no-till management. These data were compiled on a county basis and are summarized in Table 2.

Table 2. Agricultural land areas, in km^2.

State	*Crop-Conv Till*	*Crop-No till*	*Grazing*	*CRP*	*Total*
Idaho	19,479	1,087	23,325	3,244	47,135
Montana	39,801	4,226	141,882	10,884	196,793
South Dakota	51,986	14,664	105,440	5,752	177,842

Five different management scenarios, ranging from continuous grassland to continuous conventionally-tilled cropland, were applied to spatial "cells" developed by intersecting climate and soil texture grids at the county level. The management types applied in our default (business-as-usual, or BAU) scenario were based on current agricultural land use statistics. The results of CENTURY modeling for each soil-climate-land use combination were applied to the appropriate cell, and the cells (up to 20 per county) were summed to obtain county-level estimates of current soil carbon flux rates. These were further summed to obtain state estimates (Figure 6).

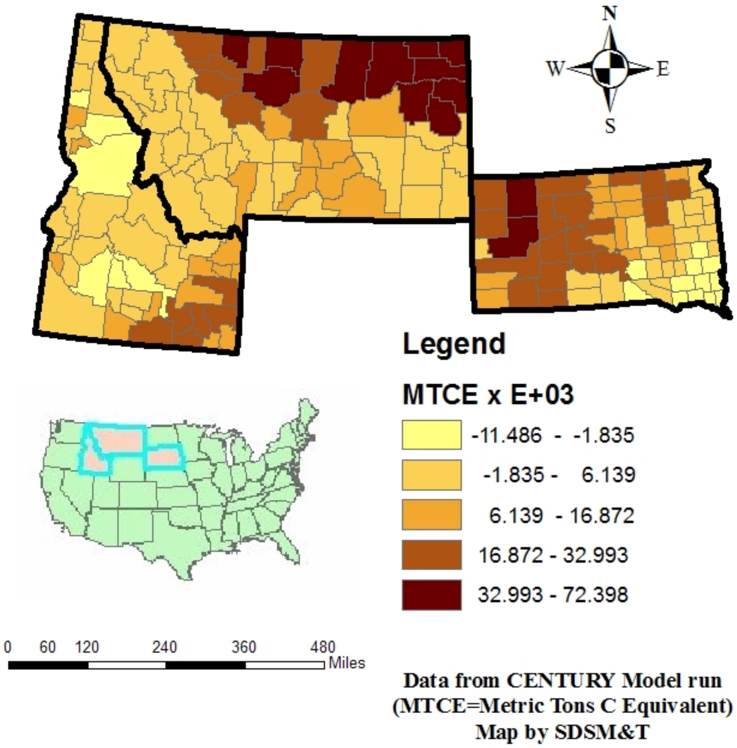


Figure 6. Current estimated annual soil carbon fluxes in Big Sky States (ID, MT, and SD).

The cellular nature of the data enables us to explore the effect of changes in the status quo, for example, an increase in the rate of no-till adoption or CRP enrollment, or a decline in CRP enrollment. Estimates for a limited suite of scenarios are included in the GIS database.

Montana has the largest agricultural land base, but South Dakota has by far the largest area of harvested cropland. As a result, South Dakota offers the largest potential for terrestrial sink enhancement due to agricultural land management, particularly through conversion to no-till.

Infrastructure Data

Los Alamos National Laboratory (LANL), under Paul Rich, has prepared infrastructure data for the states of MT, WY, ID, and SD.

Road and highway data and railroad data for the four states were derived from the SDC Feature Classes "highways.sdc" and "rail100k.sdc", respectively, supplied with ESRI ArcInfo Workstation 9.0.

Pipeline data for the four states was extracted from the Office of Pipeline Safety's National Pipeline Mapping System, to which LANL has a license. Metadata have been created for these data sets. These data is considered to be “Official Use Only” (OUO), and comes with the following disclaimer:

> *"I understand that any and all data/information obtained from the Office of Pipeline Safety's National Pipeline Mapping System is sensitive security information and I agree that it will be treated as DOT proprietary information. I agree to: restrict disclosure of and access to this data/information to persons with official state and local government responsibility; to not redistribute the data/information; and to refer requests by other persons for such information to the Associate Administrator for Pipeline Safety. I also agree to maintain a list of those persons that have been provided access to this information."*

Electrical powerline data are currently being extracted and processed, based on a LANL-owned nationwide dataset.

Big Sky Data Warehouse and Data Coordination

Montana State University (MSU), under Todd Kipfer, serves as the lead for the Big Sky Data Warehouse and data coordination.

Planning and Initial Implementation: The Big Sky Carbon Sequestration Partnership Data Warehouse was established in January 2005 at the Big Sky Institute at MSU. GIS expert Aaron Jones was hired to assist Todd Kipfer at MSU. Initial efforts have focused on establishing a base architecture for managing Big Sky Partnership data and providing access to that data via an ESRI ArcIMS interactive mapping application and a live data link to NatCarb (Figure 6).

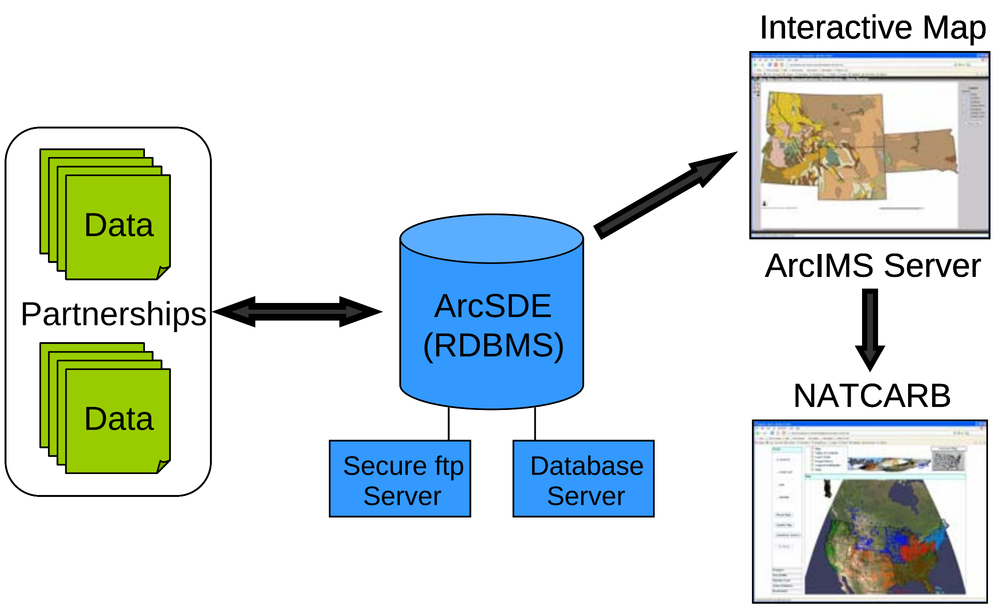


Figure 6. Web-based access to Big Sky data and integration with other partnerships and NatCarb is provided via ArcSDE and ArcIMS.

Witkowski et al. (2003) provided a key reference for determining the initial data architecture in the geodatabase and in anticipating how work flow will occur via ArcSDE. In addition, ESRI's Modeling our World and Building a Geodatabase have each proven instructive in envisioning how the Big Sky Data Warehouse might best be construed once data holdings have progressed to a point where we can expect to support site-specific decisions concerning CO2 transfer and storage.

For the Big Sky Partnership, we established a new application/database server with ArcIMS 9, MS SQL Server 2000 SP3, and ArcSDE 9 running on Windows 2003 Server with Apache and Tomcat. The server hardware consists of a dual Xeon server with a redundant SCSI disk array. Backup is maintained by tape and server to server backup strategies.

The initial setup was slowed by configuration issues. We ran into a couple of significant undocumented configuration issues that prevented the generation of ArcIMS services based on ArcSDE data. Through a combination of trial and error and close collaboration with ESRI technical support, we arrived at a stable installation and configuration of all IMS Server components on Monday, March 14th, and additionally gained an in depth understanding of the latest iteration of ArcIMS/ArcSDE/MS SQL Server architecture.

Data Coordination: A secure FTP site was established as a vehicle for harvesting large datasets (e.g., STATSGO data) from collaborators. Initial offerings of geologic and terrestrial data were relayed to us by Randy Lee (Idaho National Laboratory) and Patrick Kozak (South Dakota School of Mines and Technology).

We are working to fill data gaps by working with Partnership collaborators or directly obtaining the data from other sources. County-level soils data are expected to arrive shortly from Patrick Kozak at SDSMT. We need to obtain field-level oil and gas data. The Plains partnership may yet share some potential sources for field-level oil and gas data in areas where our partnerships geographically overlap. Field-level data for Wyoming are currently being revised by the Utah Geological Survey (Barry Beidiger, pers. comm.). We've obtained the requisite authorization (from Phyllis Ranz at University of Wyoming) to use this data as soon as it is prepared.

Metadata are needed for all Partnership data, and we are working to identify, compile and serve metadata for existing geologic and terrestrial datasets. While metadata for a majority of these data were either incomplete or absent in the data provided through INL and SDSMT, data lists were received for both geologic and terrestrial content, the latter of which does include references which should prove useful in appropriating some of the terrestrial metadata from the original sources. Currently, complete metadata is in hand only for the ESRI data used for base layers. We recently attended a USGS NBII sponsored workshop at LDEO on metadata standards and tools. This training will augment efforts to secure and provide FGDC-compliant metadata for our data holdings.

We are now in the process of integrating and standardizing a composite master data list (Appendix A) for the Data Warehouse holdings to better support current and future Partnership activities.

Interpartnership Coordination and Links with NatCarb, DOE, and National Cyberinfrastructure Efforts

Los Alamos National Laboratory (LANL), under Paul Rich, serves as overall coordinator of the Big Sky GIS effort, and as the lead for interpartnership coordination and links with NatCarb DOE, and national carbon cyberinfrastructure efforts.

Interpartnership Coordination and Links with NatCarb: Big Sky GIS personnel participated in period GIS Working Group teleconferences, which provided the primary means of communication with counterparts in other partnerships. In addition Big Sky GIS personnel from LANL (Paul Rich) and MSU (Todd Kipfer and Aaron Jones) attended an Interpartnership/NatCarb meeting in Lawrence, KS (February 1-2, 2005). The meeting focused on building partnership links with NatCarb and on GIS coordination during phase 2.

The following goals were formulated for GIS coordination during phase 2:

- Participate in inter-partnership planning and ongoing communication to ensure that key carbon sequestration data layers and tools are consistent, complete, and available (methodology, quality…).
- Contribute to building the national carbon cyberinfrastructure, an integrated computing environment that provides access to information, models, problem solving capabilities, and communication concerning carbon science and technology.
- Coordinate with key federal and DOE GIS efforts.

This will be implemented through the following activities:

- Participate in formulation of a **national carbon cyberinfrastructure plan** with input from diverse stakeholders and based on sound design.
- Participate in **GIS coordination meetings** and regular **GIS teleconferences**.
- Make data available via the **NatCarb** distributed network of carbon sequestration databases (http://www.natcarb.org).
- **Share key GIS resources** (methods, design, data sources, tools…) with other partnerships and NatCarb via the partnership/NatCarb e-mail list, web posting, and other effective means of communication.
- Resolve issues (gaps, overlaps, errors, inconsistencies…) required to produce a complete **regional carbon sequestration atlas** for each partnership.
- Follow **federal requirements** concerning geospatial data documentation, in particular by producing Federal Geographic Data Committee (FGDC) compliant metadata (http://www.fgdc.gov/metadata/metadata.html).
- Register geospatial data with the **Geospatial One-Stop** (GOS), the primary U.S. geoportal (http://www.geodata.gov/gos), mandated as part of the president's E-Government agenda.
- Contribute to building a department-wide **DOE Geospatial Science Pprogram** in conjunction with the DOE Office of the Chief Information Officer (contact Rosita Parkes, rose.parkes@hq.doe.gov) DOE Geospatial Science Steering Committee (contact David Morehouse, dmorehou@eia.doe.gov) and the DOE GIS User Group (contact James Bollinger, james02.bollinger@srs.gov).

Links with DOE and National Efforts: An oral presentation and posters concerning carbon cyberinfrastructure were presented at the American Geophysical Union Chapman Conference on "The Science and Technology of Carbon Sequestration", January 16-20, 2005, San Diego, CA (Rich et al. 2005, Keating et al. 2005A). Under separate funding, presentations were made concerning complex-wide GIS efforts (Bollinger et al. 2004, Rich et al. 2004), and a draft proposal was submitted to the DOE Office of the Chief Information Officer to build a DOE Geospatial Science Program (Bollinger et al. 2005). Also under separate funding, a related publication concerning Enterprise GIS design (Witkowski et al. 2005) was submitted for peer review, and two manuscripts now in draft form will be submitted soon, one concerning data sharing and the Geospatial One-Stop (Goodchild et al. 2005) and another concerning relations between GIS and cyberinfrastructure (Goodchild and Rich 2005). We are in the process of preparing a presentation for the NETL-sponsored Fourth Annual Conference on Carbon Capture and Sequestration (Keating et al. 2005B).

Outreach

Outreach efforts focused primarily on ongoing enhancements of the Big Sky website (http://www.bigskyco2.org), in conjunction with Pamela Tomski (EnTech Strategies) and Leslie Jones (MSU).

Big Sky Phase 2 Proposal

LANL, under Paul Rich, and INL, under Randy Lee, coordinated preparation of the GIS component of the Big Sky phase 2 proposal, with contributions from MSU, UWy, SDSMT, and state GIS coordinators from MT, SD, WY, and ID.

We proposed a phase 2 Big Sky GIS effort with five major elements:

- **Big Sky Knowledge Base:** consisting of A) the ***Big Sky Carbon Atlas*** of key data layers (geologic, terrestrial, infrastructure, and reference); B) the ***Big Sky Model Warehouse and Scenario Library*** (key model parameters and results); C) the ***Big Sky Metadata Library*** (data and model documentation); and D) ***knowledge base links*** to move data in and out of the knowledge base among the many project elements (MMV, process models, system dynamics models, etc.) (figure 7),
- **Big Sky Data Warehouse:** consisting of the Big Sky data, web-based management and visualization tools, and a distributed server infrastructure (web, map server, spatial database, and links to partners) to make the Big Sky Knowledge Base available via the internet;
- **Big Sky Decision Support Tools:** building on existing GIS capabilities to analyze and visualize contents of the knowledge base.
- **Interpartnership, NatCarb, and Geospatial One-Stop Coordination:** involving inter-partnership planning and ongoing communication to ensure that data layers and tools are consistent (quality, methodology…), complete, and available.
- **Links with Education and Outreach:** involving communication of carbon science and project results using interactive map-based visualization approaches.

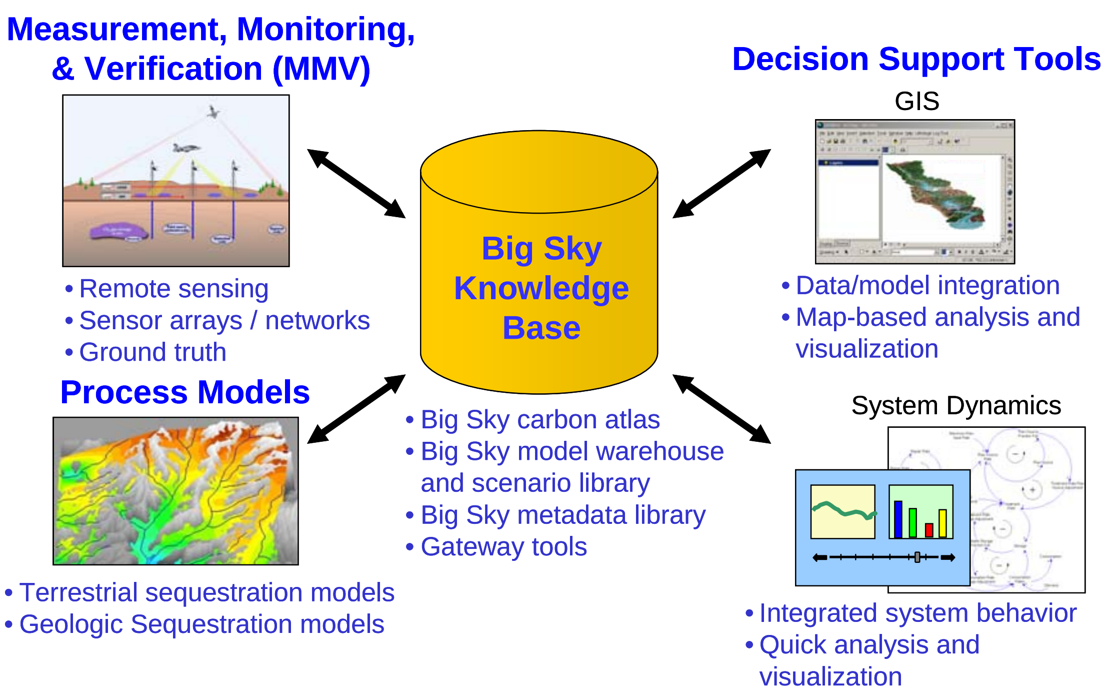


Figure 7. A GIS-based decision support framework integrates all project elements of the Big Sky phase 2 proposal.

The following were established as lead roles for the phase 2 Big Sky GIS effort:

- **LANL:** coordination and design lead; decision support co-lead (contact: Paul Rich)
- **INL:** geologic database co-lead; decision support co-lead (contact: Randy Lee)
- **MSU:** terrestrial database co-lead, data warehouse lead (contact: Todd Kipfer)
- **UWy:** geologic database co-lead; terrestrial database co-lead (contact: Jeff Hamerlinck)
- **State of MT:** state GIS links lead (contact: Stewart Kirkpatrick)

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Conservation Technology Information Center. 2004. National Crop Residue Management Survey; Conservation Tillage Data. (http://www.ctic.purdue.edu/CTIC/CRM.html . Verified 11 Jan. 05.)

USDA. 1997. Census of Agriculture. National Agricultural Statistics Service. (http://www.nass.usda.gov/census/index1997.htm. Verified 17 Aug 04.)

Witkowski, M.S., P.M. Rich, and G.N. Keating. 2003. A prototype for enterprise GIS. Los Alamos National Laboratory Report, LA-14027, Los Alamos, NM.

Presentations, Publications, and Proposals

Presentations at National Meetings:

Keating, G.N., T.L. Riggs, P.M. Rich, M.S. Witkowski, and H.S. Viswanathan. 2005A. GIS-Based Decision Support for Carbon Sequestration. Chapman Conference on The Science and Technology of Carbon Sequestration, January 16-20, 2005, San Diego, CA. LA-UR-04-7595.

Keating, G.N., P.M. Rich, M.S. Witkowski, and H.S.Viswanathan. 2005B. GIS knowledge integration for carbon sequestration: the cyberinfrastructure approach. to be presented at the Fourth Annual Conference on Carbon Capture and Sequestration, May 2-5, 2005, Alexandria, VA.

Rich, P.M., G.N. Keating, T.L. Riggs, and M.S. Witkowski. 2005. A vision for carbon cyberinfrastructure. Chapman Conference, The Science and Technology of Carbon Sequestration, January 16-20, 2005, San Diego, CA. LA-UR-04-7594.

Rich, P.M., T.L. Riggs, M.S. Witkowski, and G.N. Keating 2004. Toward enterprise GIS design for DOE. Invited talk for DOE GIS User Group Meeting. at ESRI International User Conference, San Diego.

Bollinger, J.S., S.M. Hargrove, Rich, P.M., L. Brady-Sabeff, D. Collette, A. Guber, M. Klein, J. Kuiper, J. Lee, R. Lee, K. Mickus, D. Morehouse, K. Moore, A. Ramsdell, S. Rush, J. Stewart, H. Walker, R. Wells. 2004. The DOE GIS Core Team. DOE Annual Information Management Conference, Columbus, OH.

Publications Submitted and In Manuscript:

Goodchild, M.F., P. Fu, and P.M. Rich. 2005. Geographic information sharing: the case of the Geospatial One-Stop portal. manuscript to be submitted for peer review.

Goodchild, M.F. and P.M. Rich. 2005. Space, time, and the emerging cyberinfrastructure. manuscript to be submitted for peer review.

Witkowski, M.S., P.M. Rich, and G.N. Keating. 2005. Enterprise GIS: definition, requirements, and metrics of success. submitted for peer review.

Proposals Submitted:

Department of Energy, Office of the Chief Information Officer. submitted February 2005. $3M requested for FY05. "DOE Geospatial Science Program". Draft plan for ramp-up funding for new DOE Geospatial Science program, goal $20-30M/yr across DOE complex. J. Bollinger, P. Rich, D. Morehouse, and S. Hargrove (Co-PIs). pending.

Department of Energy, NETL. submitted March 2005. $17.97M requested for FY06 to FY09. "Big Sky Regional Carbon Sequestration Partnership - Phase II", S. Capablo (PI).

IDAHO Filename	Data model	LAYER NAME	Description	Source
bid_bndclip	vector	**ID - State Boundary**	State boundary	ESRI
bid_counties	vector	**ID - Counties**	County boundaries	ESRI
bid_fedlands	vector	**ID - Federal Lands**	Federal lands	ESRI
bid_indlands	vector	**ID - Tribal Lands**	Tribal lands	ESRI
bid_mjwater	vector	**ID - Major Water Bodies**	Major water bodies	ESRI
bid_rds	vector	**ID - Major Roads**	Major Roads (including US and state hwys)	ESRI
bid_rivers	vector	**ID - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bidshdrlf	raster	**ID - Shaded Relief**	Shaded relief (1km res.)	ESRI
gid_pr1700g	vector	**ID - Play 1700**	Idaho-Snake River Downwarp Province (17) Boundary	NOGA
gid_pr1701g	vector	**ID - Play 1701**	Miocene Lacustrine (Lake Bruneau)	NOGA
gid_pr1702g	vector	**ID - Play 1702**	Pliocene Lacustrine (Lake Idaho)	NOGA
gid_pr1703g	vector	**ID - Play 1703**	Pre-Miocene	NOGA
gid_pr1704g	vector	**ID - Play 1704**	Older Tertiary	NOGA
gid_provinces	vector	**ID - NOGA Provinces**	Oil and gas province boundaries	NOGA
gid_regions	vector	**ID - NOGA Regions**	Oil and gas region boundaries	NOGA
tid_aveprecip1895-2003	vector	**ID - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	…
tid_climdivs	vector	**ID - Climatic Divisions**	Climatic divisions	EPA
tid_co2sources	vector	**ID - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
tid_countydc	vector	**ID - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**ID - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**ID - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**ID - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
tid_cropland	vector	**ID - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**ID - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**ID - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**ID - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
tid_livestock	vector	**ID - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**ID - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**ID - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
tid_bd	raster	**ID - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
tid_cl	raster	**ID - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
tid_sa	raster	**ID - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
tid_si	raster	**ID - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…

MONTANA Filename	Data model	LAYER NAME	Description	Source
bmt_bndclip	vector	**MT - State Boundary**	State boundary	ESRI
bmt_counties	vector	**MT - Counties**	County boundaries	ESRI
bmt_fedlands	vector	**MT - Federal Lands**	Federal lands	ESRI
bmt_indlands	vector	**MT - Tribal Lands**	Tribal lands	ESRI
bmt_mjwater	vector	**MT - Major Water Bodies**	Major water bodies	ESRI
bmt_rds	vector	**MT - Major Roads**	Major Roads (including US and state hwys)	ESRI
bmt_rivers	vector	**MT - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bmtshdrlf	raster	**MT - Shaded Relief**	Shaded relief (1km res.)	ESRI
gmt_pr2700g	vector	**MT - Play 2700**	Montana Thrust Belt Province (27) Boundary	NOGA
gmt_pr2701g	vector	**MT - Play 2701**	Imbricate Thrust Gas	NOGA
gmt_pr2800g	vector	**MT - Play 2800**	North-Central Montana	NOGA
gmt_pr2805g	vector	**MT - Play 2805**	Devonian-Mississippian Carbonates	NOGA
gmt_pr8806g	vector	**MT - Play 2806**	Tyler Sandstones	NOGA
gmt_pr8807g	vector	**MT - Play 2807**	Fractured-Faulted Carbonates in Anticlines	NOGA
gmt_pr8808g	vector	**MT - Play 2808**	Jurassic-Cretaceous Sandstones	NOGA
gmt_pr2809g	vector	**MT - Play 2809**	Shallow Cretaceous Biogenic Gas	NOGA
gmt_pr2900g	vector	**MT - Play 2900**	Southwest Montana	NOGA
gmt_pr2901g	vector	**MT - Play 2901**	Crazy Mountains and Lake Basins Cretaceous Gas	NOGA
gmt_pr2903g	vector	**MT - Play 2903**	Nye-Bowler Wrench Zone Oil and Gas	NOGA
gmt_pr3100g	vector	**MT - Play 3100**	Williston Basin	NOGA
gmt_pr3101g	vector	**MT - Play 3101**	Madison (Mississippian)	NOGA
gmt_pr3102g	vector	**MT - Play 3102**	Red River (Ordovician)	NOGA
gmt_pr3103g	vector	**MT - Play 3103**	Middle and Upper Devonian (Pre-Bakken-Post Prairie Salt)	NOGA
gmt_pr3105g	vector	**MT - Play 3105**	Pre-Prairie Middle Devonian and Silurian	NOGA
gmt_pr3106g	vector	**MT - Play 3106**	Post-Madison trhough Triassic Clastics	NOGA
gmt_pr3107g	vector	**MT - Play 3107**	Pre-Red River Gas	NOGA
gmt_pr3110g	vector	**MT - Play 3110**	Bakken Fairway	NOGA
gmt_pr3300g	vector	**MT - Play 3300**	Powder River Basin	NOGA
gmt_pr3302g	vector	**MT - Play3302**	Basin Magin Anticline	NOGA
gmt_pr3303g	vector	**MT - Play3303**	Leo Sandstone	NOGA
gmt_pr3304g	vector	**MT - Play 3304**	Upper Minnelusa Sandstone	NOGA
gmt_pr3305g	vector	**MT - Play 3305**	Lakota Sandstone	NOGA
gmt_pr3306g	vector	**MT - Play 3306**	Fall River Sandstone	NOGA
gmt_pr3307g	vector	**MT - Play 3307**	Muddy Sandstone	NOGA
gmt_pr3308g	vector	**MT - Play 3308**	Mowry Fractured Shale	NOGA
gmt_pr3309g	vector	**MT - Play 3309**	Deep Frontier Sandstone	NOGA
gmt_pr3310g	vector	**MT - Play 3310**	Turner Sandstone	NOGA
gmt_pr3311g	vector	**MT - Play 3311**	Niobrara Fractured Shale	NOGA
gmt_pr3312g	vector	**MT - Play 3312**	Sussex-Shannon Sandstone	NOGA
gmt_pr3313g	vector	**MT - Play 3313**	Mesaverde-Lewis	NOGA
gmt_pr3315g	vector	**MT - Play 3315**	Biogenic Gas	NOGA
gmt_pr3350g	vector	**MT - Play 3350**	Powder River Basin - Shallow Mining-Related	NOGA
gmt_pr3351g	vector	**MT - Play 3351**	Powder River Basin - Central Basin	NOGA
gmt_pr3400g	vector	**MT - Play 3400**	Bighorn Basin	NOGA
gmt_pr3402g	vector	**MT - Play 3402**	Basin Margin Anticline	NOGA
gmt_pr3403g	vector	**MT - Play 3403**	Deep Basin Structure	NOGA
gmt_pr3405g	vector	**MT - Play 3405**	Sub-Absaroka	NOGA
gmt_pr3406g	vector	**MT - Play 3406**	Phosphoria Stratigraphic	NOGA
gmt_pr3417g	vector	**MT - Play 3417**	Shallow Tertiary-Upper Cretaceous Stratigraphic	NOGA
gmt_provinces	vector	**MT - NOGA Provinces**	Oil and gas province boundaries	NOGA
gmt_regions	vector	**MT - NOGA Regions**	Oil and gas region boundaries	NOGA

MONTANA Filename	Data model	LAYER NAME	Description	Source
tmt_aveprecip1895-2003	vector	**MT - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	…
tmt_climdivs	vector	**MT - Climatic Divisions**	Climatic divisions	EPA
tmt_co2sources	vector	**MT - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
tmt_countydc	vector	**MT - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**MT - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**MT - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**MT - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
tmt_cropland	vector	**MT - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**MT - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**MT - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**MT - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
tmt_livestock	vector	**MT - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**MT - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**MT - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
tmt_bd	raster	**MT - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
tmt_cl	raster	**MT - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
tmt_sa	raster	**MT - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
tmt_si	raster	**MT - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…

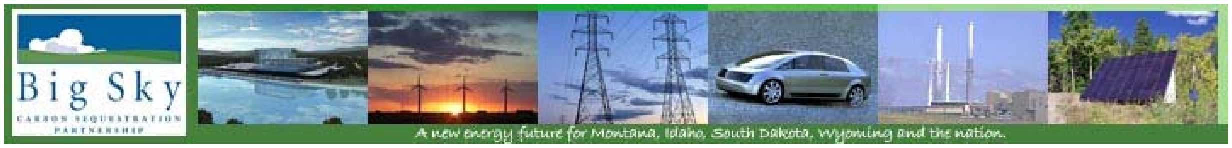
S. DAKOTA Filename	Data model	LAYER NAME	Description	Source
bsd_bndclip	vector	**SD - State Boundary**	State boundary	ESRI
bsd_counties	vector	**SD - Counties**	County boundaries	ESRI
bsd_fedlands	vector	**SD - Federal Lands**	Federal lands	ESRI
bsd_indlands	vector	**SD - Tribal Lands**	Tribal lands	ESRI
bsd_mjwater	vector	**SD - Major Water Bodies**	Major water bodies	ESRI
bsd_rds	vector	**SD - Major Roads**	Major Roads (including US and state hwys)	ESRI
bsd_rivers	vector	**SD - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bsdshdrlf	raster	**SD - Shaded Relief**	Shaded relief (1km res.)	ESRI
gsd_pr3100g	vector	**SD - Play 3100**	Williston Basin	NOGA
gsd_pr3101g	vector	**SD - Play 3101**	Madison (Mississippian)	NOGA
gsd_pr3102g	vector	**SD - Play 3102**	Red River (Ordovician)	NOGA
gsd_pr3103g	vector	**SD - Play 3103**	Middle and Upper Devonian (Pre-Bakken-Post Prairie Salt)	NOGA
gsd_pr3302g	vector	**SD - Play 3302**	Basin Magin Anticline	NOGA
gsd_provinces	vector	**SD - NOGA Provinces**	Oil and gas province boundaries	NOGA
gsd_regions	vector	**SD - NOGA Regions**	Oil and gas region boundaries	NOGA

S. DAKOTA Filename	Data model	LAYER NAME	Description	Source
tsd_aveprecip1895-2003	vector	**SD - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	
tsd_climdivs	vector	**SD - Climatic Divisions**	Climatic divisions	EPA
tsd_co2sources	vector	**SD - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
tsd_countydc	vector	**SD - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**SD - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**SD - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**SD - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
tsd_cropland	vector	**SD - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**SD - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**SD - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**SD - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
tsd_livestock	vector	**SD - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**SD - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**SD - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
tsd_bd	raster	**SD - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
tsd_cl	raster	**SD - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
tsd_sa	raster	**SD - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
tsd_si	raster	**SD - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…

WYOMING Filename	Data model	LAYER NAME	Description	Source
bwy_bndclip	vector	**WY - State Boundary**	State boundary	ESRI
bwy_counties	vector	**WY - Counties**	County boundaries	ESRI
bwy_fedlands	vector	**WY - Federal Lands**	Federal lands	ESRI
bwy_indlands	vector	**WY - Tribal Lands**	Tribal lands	ESRI
bwy_mjwater	vector	**WY - Major Water Bodies**	Major water bodies	ESRI
bwy_rds	vector	**WY - Major Roads**	Major Roads (including US and state hwys)	ESRI
bwy_rivers	vector	**WY - Rivers and Streams**	Rivers and streams (generalized)	ESRI
bwyshdrlf	raster	**WY - Shaded Relief**	Shaded relief (1km res.)	ESRI
gwy_pr3300g	vector	**WY - Play 3300**	Powder River Basin	NOGA
gwy_pr3302g	vector	**WY - Play 3302**	Basin Magin Anticline	NOGA
gwy_pr3303g	vector	**WY - Play 3303**	Leo Sandstone	NOGA
gwy_pr3304g	vector	**WY - Play 3304**	Upper Minnelusa Sandstone	NOGA
gwy_pr3305g	vector	**WY - Play 3305**	Lakota Sandstone	NOGA

WYOMING	Data			
Filename	model	LAYER NAME	Description	Source
gwy_pr3306g	vector	**WY - Play 3306**	Fall River Sandstone	NOGA
gwy_pr3307g	vector	**WY - Play 3307**	Muddy Sandstone	NOGA
gwy_pr3308g	vector	**WY - Play 3308**	Mowry Fractured Shale	NOGA
gwy_pr3309g	vector	**WY - Play 3309**	Deep Frontier Sandstone	NOGA
gwy_pr3310g	vector	**WY - Play 3310**	Turner Sandstone	NOGA
gwy_pr3311g	vector	**WY - Play 3311**	Niobrara Fractured Shale	NOGA
gwy_pr3312g	vector	**WY - Play 3312**	Sussex-Shannon Sandstone	NOGA
gwy_pr3313g	vector	**WY - Play 3313**	Mesaverde-Lewis	NOGA
gwy_pr3315g	vector	**WY - Play 3315**	Biogenic Gas	NOGA
gwy_pr3350g	vector	**WY - Play 3350**	Powder River Basin - Shallow Mining-Related	NOGA
gwy_pr3351g	vector	**WY - Play 3351**	Powder River Basin - Central Basin	NOGA
gwy_pr3400g	vector	**WY - Play 3400**	Bighorn Basin	NOGA
gwy_pr3402g	vector	**WY - Play 3402**	Basin Margin Anticline	NOGA
gwy_pr3403g	vector	**WY - Play 3403**	Deep Basin Structure	NOGA
gwy_pr3405g	vector	**WY - Play 3405**	Sub-Absaroka	NOGA
gwy_pr3406g	vector	**WY - Play 3406**	Phosphoria Stratigraphic	NOGA
gwy_pr3417g	vector	**WY - Play 3417**	Shallow Tertiary-Upper Cretaceous Stratigraphic	NOGA
gwy_pr3500g	vector	**WY - Play 3500**	Wind River Basin	NOGA
gwy_pr3501g	vector	**WY - Play 3501**	Basin Margin Subtrhrust	NOGA
gwy_pr3502g	vector	**WY - Play 3502**	Basin Margin Anticline	NOGA
gwy_pr3503g	vector	**WY - Play 3503**	Deep Basin Structure	NOGA
gwy_pr3504g	vector	**WY - Play 3504**	Muddy Sandstone Stratigraphic	NOGA
gwy_pr3515g	vector	**WY - Play 3515**	Shallow Tertiary-Upper Cretaceous Stratigraphic	NOGA
gwy_pr3518g	vector	**WY - Play 3518**	Cody and Frontier Stratigraphic	NOGA
gwy_pr3550g	vector	**WY - Play 3550**	Wind River Basin-Mesaverde	NOGA
gwy_pr3600g	vector	**WY - Play 3600**	Wyoming Thrust Belt	NOGA
gwy_pr3601g	vector	**WY - Play 3601**	Moxa Arch Extentsion	NOGA
gwy_pr3604g	vector	**WY - Play 3604**	Absaroka Thrust	NOGA
gwy_pr3606g	vector	**WY - Play 3606**	Hogsback Thrust	NOGA
gwy_pr3607g	vector	**WY - Play 3607**	Cretaceous Stratigraphic	NOGA
gwy_pr3700g	vector	**WY - Play 3700**	Southwestern Wyoming	NOGA
gwy_pr3701g	vector	**WY - Play 3701**	Rock Springs Uplift	NOGA
gwy_pr3702g	vector	**WY - Play 3702**	Cherokee Arch	NOGA
gwy_pr3703g	vector	**WY - Play 3703**	Axial Uplift	NOGA
gwy_pr3704g	vector	**WY - Play 3704**	Moxa Arch-LaBarge	NOGA
gwy_pr3705g	vector	**WY - Play 3705**	Basin Margin Anticline	NOGA
gwy_pr3707g	vector	**WY - Play 3707**	Platform	NOGA
gwy_pr3750g	vector	**WY - Play 3750**	Greater Green River Basin-Rock Springs	NOGA
gwy_pr3751g	vector	**WY - Play 3751**	Greater Green River Basin-Iles	NOGA
gwy_pr3752g	vector	**WY - Play 3752**	Greater Green River Basin-Williams Fork	NOGA
gwy_pr3753g	vector	**WY - Play 3753**	Greater Green River Basin-Almond	NOGA

WYOMING Filename	Data model	LAYER NAME	Description	Source
gwy_pr3754g	vector	**WY - Play 3754**	Greater Green River Basin-Lance	NOGA
gwy_pr3755g	vector	**WY - Play 3755**	Greater Green River Basin-Fort Union	NOGA
gwy_provinces	vector	**WY - NOGA Provinces**	Oil and gas province boundaries	NOGA
gwy_regions	vector	**WY - NOGA Regions**	Oil and gas region boundaries	NOGA
gwy_CO2OilGasArealFields	vector	**WY - Oil and gas fields**	Wyoming Oil and Gas fields	…
gwy_refineries	vector	**WY - Refineries**	Refineries	…
gwy_CMBArealFields	vector	**WY - Coalbed-methane fields**	Coalbed-methane fields	…
twy_aveprecip1895-2003	vector	**WY - Ave. Precip. 1895-2003 (cm)**	Annual mean precipitation in cm, averaged over 1895 through 2003, by climatic division	…
twy_climdivs	vector	**WY - Climatic Divisions**	Climatic divisions	EPA
twy_co2sources	vector	**WY - CO2 sources (tons per year)**	Point sources of C02 release (in tons per year)	NATCARB
twy_countydc	vector	**WY - Est.yearly C02 capture: default (MTCE)**	MgC_yr_def=projected yearly carbon sequestration for state (default scenario-current) in MTCE	CENTURY model run
"	vector	**WY - Est.yearly C02 capture: +25% CRP (MTCE)**	MgC_yr_nt = projected yearly carbon sequestration for state (25% increase in no-till, based on current no-till acreage) in MTCE	CENTURY model run
"	vector	**WY - Est.yearly C02 capture: 25% to no-till (MTCE)**	MgC_yr_crp = projected yearly carbon sequestration for state -25% increase in CRP acreage (based on current CRP, land drawn from current grazing land) in MTCE	CENTURY model run
"	vector	**WY - Est.yearly C02 capture: 25% CRP to no-till (MTCE)**	MgC_yr_crp2nt= projected yearly carbon sequestration for state (25% of current CRP acreage (based on current CRP converted to no-till crop management) in MTCE	CENTURY model run
twy_cropland	vector	**WY - Tillage cropland (sq.m)**	Crop_CT_M2=conventional tillage cropland for state in square meters	USDA, CTIC
"	vector	**WY - No-till cropland (in sq.m)**	Crop_NT_M2=no-till cropland for state in square meters	USDA, CTIC
"	vector	**WY - Conservation Reserve Program (sq.m)**	Crop_M2=state's cropland currently enrolled in the Conservation Reserve Program in square meters	USDA, CTIC
"	vector	**WY - Grazing, pasture, rangeland (sq.m)**	Grazing_M2=grazing, pasture and rangeland for state in square meters	USDA, CTIC
twy_livestock	vector	**WY - CH4 release: manure mgmt (MTCE)**	CH4_Manure=yearly methane emissions for state from manure management in MTCE	1997 Ag Census
"	vector	**WY - CH4 release: enteric ferment. (MTCE)**	CH4_Enteric= yearly methane emissions for state from enteric fermentation in MTCE	1997 Ag Census
"	vector	**WY - N20 release: manure mgmt (MTCE)**	N2O_Manure=yearly nitrous oxide emissions for state from manure management in MTCE	1997 Ag Census
twy_bd	raster	**WY - Soils: bulk density (% integer)**	Soils - bulk density (STATSGO, and SSURGO where present; ID, MT, and SD only)	…
twy_cl	raster	**WY - Soils: bulk density - clay (% integer)**	Soils - bulk density: clay percent integer values	…
twy_sa	raster	**WY - Soils: bulk density - sand (% integer)**	Soils - bulk density: sand percent integer values	…
twy_si	raster	**WY - Soils: bulk density - silt (% integer)**	Soils - bulk density: silt percent integer values	…



Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 8:
Report on Evaluation of Terrestrial Sinks

Attachment A: Evaluation of Cropland Terrestrial Sinks for the Big Sky Region
Attachment B: Rangeland Terrestrial Sinks Forestry
(see separate file for PDF document)
Attachment C: Forest and Agroforestry Opportunities for Carbon Sequestration in the Big Sky

July 2005

U.S. Department of Energy (DOE)
National Energy Technology Laboratory (NETL)
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9/26/03 thru 9/25/05

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Deliverable 8 – Attachment A
Evaluation of Cropland Terrestrial Sinks for Big Sky Region

This report summarizes efforts to date on assessing the terrestrial sinks for the Big Sky region. The assessments are done in terms of both technical potential and economic potential. Technical potential provides the most optimistic estimate of the size of the terrestrial sinks, assuming that all land use management was changes to the management regime that sequestered the maximum amount of soil carbon. The economic potential examines the amount of carbon that would be sequestered from land use changes taking into account the "cost' of changing the existing land use management to a management regime that would sequester larger amounts of carbon. In theory, the economic assessment is a realistic means of capturing both the potential size of the sinks and the opportunity cost of sequestering carbon. This research is supported by the DOE/NETL/Partnership grant and through the USDA/CASMGS grant.

PART I: Technical Assessment, Methods, and Results

GIS components of the terrestrial sink evaluation were represented aerially as continuous surfaces summarized by county; these include climate, soil, and land use databases.

One hundred and eight years of climate data from National Climate Data Center station records were averaged for each of up to 10 climate zones in each state so as to produce zone-average files. In addition, zone-specific statistical data on climate variability were used to simulate climate after 2003.

Soil texture grids derived from SSURGO or STATSGO soil databases were developed for eachstate, then statistically aggregated to approximately 20 representative soil texture classes. Land management data were extracted from the 1997 Census of Agriculture and from the Conservation Technology Information Center. These data were compiled on a county-level basis and are summarized in Table 1.

Table 1. Agricultural land areas, in km^2.

State	***Crop-Conv Till***	***Crop-No till***	***Grazing***	***CRP***	***Total***
Wyoming	8,881	142	127,357	1,134	137,514
Idaho	19,479	1,087	23,325	3,244	47,135
Montana	39,801	4,226	141,882	10,884	196,793
South Dakota	51,986	14,664	105,440	5,752	177,842

The CENTURY Model

Terrestrial sequestration technical potential was estimated by applying results of the CENTURY model, a point-based protocol for predicting carbon stock changes, over counties in accord with alternative land management scenarios. Initially, the sets of point-based predictions are generated based on unique combinations between different management scenarios, climatic zones and soil texture classes. These results are then applied across individual counties, respective to the relevant climatic zone and to the extent of within-county management class areas as estimated in proportion to areas of within-county soil texture classes. To obtain the county-level estimated annual soil carbon flux rates, predicted carbon stock changes were then summed across all management classes within each county (Figure 1).

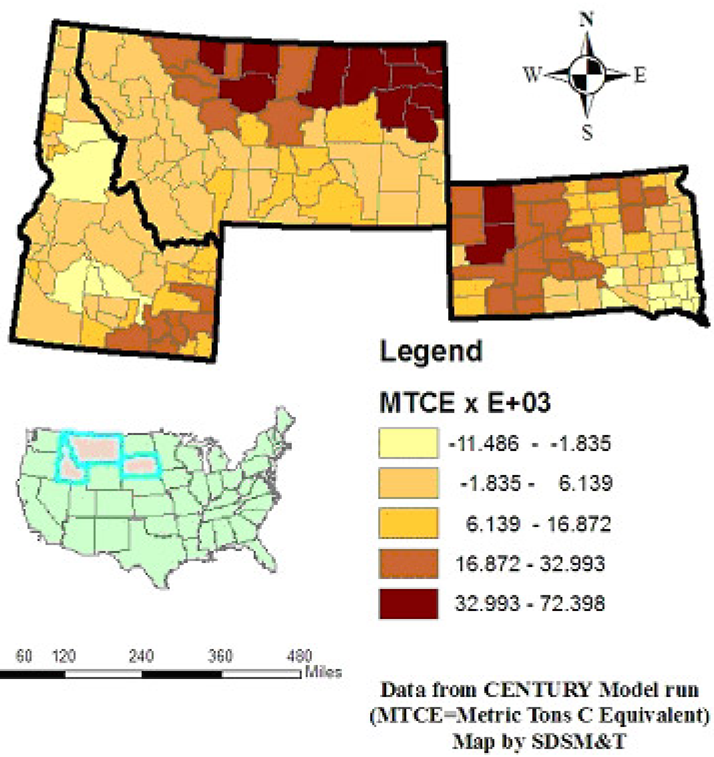

Figure 1. Current estimated annual soil carbon fluxes in Big Sky states (ID, MT, and SD).

GIS-based modeling has enabled the iterative exploration of effects from changes to the status quo in land use/management such as altered rates of no-till adoption or CRP enrollment. The CENTURY model has already afforded significant insights into the spatially-variable prospects for terrestrial sequestration; as one general example, results have confirmed that South Dakota (the state with by far the largest area of harvested cropland) offers the largest potential for terrestrial sink enhancement due to improved agricultural land management, particularly through conversion to no-till. Estimates of sequestration potential for a limited suite of scenarios are currently included in the GIS database of the Big Sky Carbon Warehouse.

Results

Montana has the largest agricultural land base, but South Dakota has by far the largest area of harvested cropland (Table 1). As a result, South Dakota offers the largest technical potential for terrestrial sink enhancement due to cropland management, but Wyoming and Montana may provide greater potential benefits due to improved rangeland management.

Statewide simulation preliminary results for current and potential agricultural management scenarios are summarized in Table 2. Increasing CRP areas by 25% at the expense of conventionally tilled lands enhances agricultural sinks by 4-9% over 40 years of simulation. An increase in no-till area appears to offer the greatest potential for enhancing agricultural sinks in South Dakota, which has more cropland than the other states. The much lower gains resulting from increased no-till in Montana, Idaho and Wyoming are due in part to the very small areas currently classified as no-till. On the other hand, Wyoming and South Dakota realize the largest gains from a hypothetical 50% reduction in grazing pressure across all grazing lands. It is not clear why Montana, with a larger rangeland area than SD, does not realize at least a comparable benefit. Literature indicates that forage condition responds in a complex way to the interaction of grazing pressure and climate (under wetter conditions pasturelands can sustain more intensive grazing without losing productivity); however, it is unlikely that Century is capable of simulating this interaction effectively, therefore grazing results should be treated as preliminary.

Table 2. Predicted 40-year average annual C stock change (MTCE) for different scenarios. Percent change from current in parentheses.

State	***Current***	***+25% CRP***[1]	***-50% Grazing***[2]	***+25% No-Till***[3]
Idaho	287,124	312,968 (9%)	283,087(-1%)	289,071 (1%)
Montana	788,544	818,251 (4%)	883,797 (12%)	801,317 (2%)
South Dakota	706,193	748,105 (6%)	846,748 (20%)	931,406 (32%)
Wyoming	43,050	46,742 (9%)	104,093 (142%)	43,323 (1%)

1. 25% increase in current CRP area, deducted from current conv till land.
2. Grazing intensity reduced by about 50% on all grazing land.
25% increase based on *current* no-till area, deducted from current conv. till land (i.e. 0% current no-till resulted in 0% increase).

Table 3. Role of agriculture in state GHG budgets.

	Idaho	***Montana***	***South Dakota***	***Wyoming****
	State Annual Estimates for 2000 in MMTCE			
Fossil/Industrial Emissions	15.93	13.1	11.37	21.46
Forest LUC	-3.26	-8.41	0.59	-0.04
Agriculture – Soil C	-0.29	-0.79	-0.66	-0.04
Agriculture – Net	1.87	1.32	3.04	0.64
TOTAL NET	12.39	3.9	11.26	21.37
*Preliminary data				

Note that in SD the LULUCF offset reduces gross emissions by about 1%, due entirely to agricultural soils; in MT there is a 70% offset due almost entirely to forest growth; in ID there is a 22% offset. largely due to forest growth, and in WY there is almost no LULUCF offset against an emissions load attributable in large part to utility emissions and energy production (Table 3).

PART II: <u>Economic Methods and results</u>

In a market for greenhouse gases, the competitiveness of US agricultural producers as suppliers of carbon-credits depends on the marginal costs and quantities of soil carbon (C) that can be sequestered. Economic and ecosystem models can be used together to estimate the marginal costs of soil C sequestration and the quantity of C-credits that can be sequestered within a given region.

<u>Approach.</u> The economic approach to the analysis of the potential to sequester soil C links biophysical data and models with economic data and models on a site-specific basis. In this way, the analysis can account for the spatial heterogeneity of biophysical conditions (soil C sequestration rates) and economic decisions (land use) and how these conditions interact to determine the marginal cost of sequestering C in soil. We apply an integrated assessment approach to quantify the costs of sequestering C from changes in land use and management practices in the dryland grain production systems of the Northern Plains region of the United States which encompasses the Big Sky region. In this region, changes in land use such as conversion of crop land to permanent grass, and changes in management practices such as use of reduced fallow, may be economically feasible where afforestation—the conversion of non-forest land to forest—is not. We compare the relative efficiency of sequestering soil C for two alternative policies relevant to the Northern Plains region: one that provides producers with payments for converting crop land to permanent grass (similar to the Conservation Reserve

Program in the United States), and one that provides payments to farmers to switch from a crop-fallow rotation or permanent grass to a continuous cropping system. These policies are similar to ones proposed in recent U.S. legislation. Our analysis shows that the economic efficiency of C sequestration and the size of the sinks depends on site-specific opportunity costs of changing practices, the rates of soil C sequestration associated with changing practices, and the policy design.

Assuming that agricultural producers are initially utilizing those land use and management practices that yield the highest economic return, it follows that producers will adopt different practices that increase soil C if and only if there is a perceived economic incentive to do so. While there are many possible ways to design policies to sequester soil C, we have adopted the basic structure of a soil C contract program, where soil C can be purchased by either the government or a private entity. Within a given region, let a contract pay the farmer g^{is} dollars per hectare per year for T years to change from management practice *i* to management practice *s* that sequesters additional soil C. Letting the total increase in soil C over the time period t = 0 to T from switching from *i* to *s* be $\Delta c^{is} = c_T^{s} - c_0^{i}$, the average increase is $\Delta c^{is}/T = c^{is}$ (metric tons per hectare per year). Although the time path for the increase in the stock of soil C in response to the adoption of improved practices is non-linear, the path is often approximated linearly with the annual average rate of soil C increase (e.g., see the soil C rates discussed in Watson et al.). Furthermore, because it is not practical to measure soil C rates accurately on an annual basis, we assume that these average annual rates are what would be actually measured and used in soil C contracts.

The per hectare capitalized value of the contract to the farmer to switch from *i* to *s* is

$$\sum_{t=1}^{T} g^{is} (1+r)^{-t} = g^{is} D(r,T), \qquad (1)$$

where D(r,T) denotes the present value of $1 at interest rate r for T periods. The value of a C contract to the government or other purchaser of carbon depends on the soil C rate parameter c^{is} and the time period over which the practices are adopted. If the buyer of the carbon can sell the C for *p* dollars per metric ton, it follows that the value of the contract to the buyer is

$$\sum_{t=1}^{T} p\, c^{is}(1+r)^{-t} = p\, c^{is} D(r, T). \qquad (2)$$

The equivalence of (1) and (2) implies that $g^{is} = pc^{is}$. If a program pays farmers g^{is} dollars per hectare per year for soil C sequestration, then the implicit price per metric ton being paid by the government or any other buyer of soil C is equal to g^{is}/c^{is} . Under the assumption of static price expectations for carbon, the payment per hectare per year to the farmer is equal to the value of the C sequestered per hectare per year. More generally, if prices are constant but the rate of increase in soil C varies with time, then it follows that $pk = g^{is}$, where $k = \sum_t c_t^{is} (1+r)^{-t}/D(r,T)$.

Producers will switch production practices if and only if the profits per hectare of their profit-maximizing practices are less than the alternative practices plus the payment per hectare. Let the total amount of agricultural land in a region be *A* hectares, and let the share of land in a given region that is entered into C contracts for switches from i to s be $z^{is}(g)$, where we have assumed that $g^{is} = g$ for all *i*, *s* that result in a positive amount of soil C accumulation and $g^{is} = 0$ otherwise. This region would sequester $C(g) = T \sum_i \sum_s c^{is} z^{is}(g) A$ metric tons of C, or $C(g)/T$

metric tons of C per year. The region's marginal cost function for sequestering soil C, $M(C)$, can then be defined as the correspondence between p and $C(g)$.

When a producer switches to alternative practices as part of the program the reduction in profitability, net of the payment, is the opportunity cost of entering into the contract. Given site-specific data on net returns, the opportunity costs differ across regions and thus an economic production model of land-use choices is needed to determine the share of land that would be entered into a specific type of contract as payment levels increase. An upward-sloping marginal cost curve for soil C in a region reflects the fact that different land units have different opportunity costs.

Given $M(C)$, the corresponding total cost can be calculated by integrating under the marginal cost curve adding any fixed transactions costs. Revenue generated by producers selling C contracts is equal to $R = pC(g)$ and the net benefit to producers is the usual producer surplus measure. In the case of a government payment program that pays farmers \$$g$ per hectare the total cost to the government is revenue R.

The integrated assessment approach to assess the cost of agricultural soil C sequestration involves linking the output of two disciplinary models—an econometric-process simulation model and a crop ecosystem model—to quantify the responses of farmers to economic incentives to sequester soil C. The econometric-process model, which is discussed below, simulates expected returns to alternative production systems on a site-specific basis, in response to incentives provided through a policy that pays farmers to change land use or management practices. These expected returns are used to simulate the farmer's choice of production system for a given land unit. This simulation model utilizes the stochastic properties of the economic production models and sample data, so its output can be interpreted as providing a statistical representation of the population of land units in a given region. The crop ecosystem model provides estimates of the levels of soil C and productivity (yields) associated with each production system. Following the marginal cost presentation, simulated changes in production systems are combined with simulated changes in soil C to compute the implied marginal costs, government costs, and producer surplus associated with policies in given regions. Thus, the integrated assessment model provides answers to policy questions about the effects of different payment schemes on the quantity of carbon sequestered and the marginal cost of sequestering soil C, and how the costs vary spatially. This approach also provides a basis for estimating the value of using government-based carbon payments as a part of the policy options to offset greenhouse gas emissions.

Econometric-Process Model of Production System Choice

In previous work, an econometric-process model was developed to model a producer's intensive- and extensive-margin production decisions. The motivation for the development of the econometric-process approach was the need to link economic analysis of production systems to site-specific bio-physical simulation models to assess the economic and environmental impacts of changes in policies, technologies, or biophysical conditions (Antle et al. 1999; Antle and Capalbo 2001a). Site-specific data are used to estimate the economic production models which are then incorporated into a simulation model that represents the decision making process of the farmer as a sequence of discrete and continuous land use and input use decisions. This discrete/continuous structure of the econometric-process model is able to simulate decision making both within and outside the range of observed data in a way that is consistent with economic theory and with site-specific biophysical constraints and processes.

The economic model is specified as follows: the production process of activity i at site j in period t is defined by a non-joint production function $q_{ijt} = f(\mathbf{v}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{it})$ where **v** is a vector of variable inputs, **z** is a vector of allocatable quasi-fixed factors of production and other fixed effects, and **e** is a vector of bio-physical characteristics of the site (soils, topography, climate, etc.) (random terms are suppressed here for notational convenience). For expected output price p_{ijt}, the profit function is $\pi_{ijt} = \pi_j(p_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{it})$. If a crop is not grown, the land is in a conserving use with a return of π_{hjt}. Define $\delta_{ijt} = 1$ if the i^{th} crop is grown at j at time t and zero otherwise. The land-use decision on site j at time t is

(3) $$\max_{(\delta_{i1t}, \dots, \delta_{int})} \sum_{i=1}^{n} \delta_{ijt}\, \pi_i(p_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{it}) + (1 - \sum_{i=1}^{n} \delta_{ijt})\, \pi_{hjt}.$$

The solution takes the form of a discrete step function

(4) $\delta^*_{ijt} = \delta i(\mathbf{p}_{it}, \mathbf{w}_{it}, \mathbf{z}_{it}, \mathbf{e}_{it}, \pi_{hjt})$,

where $\mathbf{p}_{jt}$ is a vector of the p_{ijt} and likewise for the other vectors. Using Hotelling's lemma, the quantity of the i^{th} output on the j^{th} land unit is given by

(5) $q_{ijt} = \delta^*_{ijt}\, \partial\pi_i(p_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{it})/\partial p_{ijt} = q_{ijt}(\mathbf{p}_{jt}, \mathbf{w}_{jt}, \mathbf{z}_{jt}, \mathbf{e}_{jt}, \pi_{hjt})$.

Variable input demands are likewise given by

(6) $\mathbf{v}^*_{ijt} = -\delta^*_{ijt}\, \partial\pi_i(p_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{it})/\partial\mathbf{w}_{ijt} = v_{ijt}(\mathbf{p}_{ijt}, \mathbf{w}_{ijt}, \mathbf{z}_{ijt}, \mathbf{e}_{ijt}, \pi_{hjt})$.

The econometric process approach combines the econometric production model represented by the supply and demand functions given in (5) and (6) with the process-based representation of the discrete land-use decision represented by (3) and (4). The model simulates the producer's crop choice, and the related output and costs of production at the field scale over time and space. This simulation structure utilizes the stochastic properties of the econometric models and the sample data, so its output is interpreted as providing a statistical representation of the population of land units in the region.

By operating at the field scale with site-specific data, the simulation can represent spatial and temporal differences in land use and management, such as crop rotations, that give rise to different economic outcomes across space and time in the region. Moreover, because of the detailed representation of the production system, the econometric-process model can be linked directly to the corresponding simulations of the crop ecosystem model to estimate the impacts of production system choice on soil C. Each field in the sample is described by area, location, and a set of location-specific prices paid and received by producers, and quantities of inputs. Using sample distributions estimated from the data, draws are made with respect to expected output prices, input prices, and any other site-specific management factors (e.g., previous land use). The econometric production models are simulated to estimate expected output, costs of production, and expected returns. The land-use decision for each site is made by comparing expected returns for each production activity. These spatially and temporally explicit land-use decisions are combined with simulated outputs of the crop ecosystem model to assess changes in soil C.

Biophysical Process Model

The crop ecosystem model known as Century is utilized to represent the processes controlling crop growth, water, nutrient, and organic matter dynamics that determine the productivity of agricultural ecosystems (Parton et al. 1994; Paustian, Elliott, and Hahn, 1999). Century is a generalized biogeochemical ecosystem model which simulates C (i.e., biomass), nitrogen and other nutrient dynamics. It includes submodels for soil biogeochemistry, growth and yield submodels for crop, grass, forest and savanna vegetation and simple water and heat balance. For use in agricultural and grassland ecosystems, the model incorporates a large suite of management options including crop type and rotation, fertilization, tillage, irrigation, drainage, manuring, grazing, and burning. The model employs a monthly time step and the main input requirements (in addition to management variables) include monthly precipitation and temperature, soil physical properties (e.g., texture, soil depth) and atmospheric nitrogen.

For the current application, soils and climate data for each of the sub-MLRAs are used as Century model inputs in addition to management variables such as crop type and rotation, fertilization and tillage practices. The Parameter_elevation Regressions on Independent Slopes Model (PRISM) data set was used to determine weather-related data. Information on current management systems is from the 1995 survey of Montana producers, augmented with the USDA National Agricultural Statistics Service (NASS) database, the National Resources Inventory (NRI) database, and county_level databases of the National Association of Conservation Districts (NACD). Soil characteristics are determined using the Advanced Very High Resolution Radiometer (AVHRR) database (USGS_Earth Resources Observation System (EROS) Data Center), the State Soil Geographic Database (STATSGO) and the NRI database. Baseline projections of soil C are made using historical climate and land-use records. These projections are compared to NASS records of county-level crop yields and changes in soil C derived from the Century database of native and cultivated soils. The initial land-use allocation from the 1995 Montana survey was used to calculate base C levels for each sub-MLRA.

The variability in the levels of soil C predicted by the Century model across the six major crop producing sub-MLRAs and production systems in Montana is shown in Figure 2. Simulations of the crop-fallow, continuous cropping, and permanent grass production systems with the Century model show that the equilibrium levels of soil C under a crop-fallow rotation range from 3–7 MT per hectare less than continuous grass over a twenty year horizon, and that soil C levels under permanent grass range from 1–5 MT per hectare less than under continuous cropping depending upon sub-MLRA. In sub-MLRA 52-low, soil C levels under permanent grass compare favorably with soil C levels under a continuous cropping system. The variability across sub-MLRAs reflects the heterogeneity in biophysical and climatic conditions, which translates into different equilibrium levels of soil C for the production systems.

Simulation of Soil C Levels and Costs

The economic simulation model selects the land use that maximizes expected returns for each sample field for each policy scenario that is investigated. When using this model to address soil C sequestration analysis, the net returns are augmented by the per hectare payment, *g,* to switch to management and land uses that would sequester additional carbon. The economic simulation is executed over a time horizon (approximately 20 years) sufficient to reach an equilibrium for each policy setting *g*. The land-use patterns are then summarized for each sub-MLRA for each policy setting in the form of proportions $z^{is}(g)$ of land reallocated from activity i to activity s. The Century model is used to simulate the soil C levels and annual averate rates for each land use in each sub-MLRA over a given time horizon. Given the land-use changes within each sub-MLRA based on maximizing expected returns, we calculate the levels of soil C sequestered and the resulting C sequestration costs using the procedures discussed earlier.

Simulation Results: Land-use Changes, Soil C Levels, and C Sequestration Costs

We present the empirical results for changes in land use, changes in soil C levels, and the costs of sequestering soil C for two policy scenarios: a policy for conversion of crop-land to permanent grass (PG) which gives producers a fixed annual per hectare payment; and a policy that pays producers on a per-hectare basis for fields switched to continuous cropping (CC). A precedent exists for using compensation schemes to enhance the environmental benefits from use of agricultural land. Existing agricultural policies, such as the Conservation Reserve Program (CRP), provide producers with per-acre payments in return for changes in land use and management that provide environmental benefits. The proposed revisions to the Food Security Act of 1995 would offer farmers the option of participating in a voluntary, incentive-based conservation program in exchange for compensation. Alternative policy designs for sequestering carbon, such as per ton payment schemes, are discussed in Antle et al. (2001).

Under the PG policy scenario, the producer could choose to enter a field into permanent grass and receive a payment above and beyond the payment for land in CRP. The level of the CRP payments used in the simulation model is set at the average level of CRP payments in Montana in the mid 1990s ($37.50 per acre or $93.75 per hectare). The PG policy is simulated for *additional* payments ranging from zero (the base case) to $125 per hectare by increments of $12.50 per hectare. Land is enrolled for a period of twenty years, and all cropland and pasture land is eligible for payment. This policy scenario reflects a payment design that is similar to other land retirement programs such as the CRP that are currently being used in agriculture and is comparable to payments schemes utilized in other studies of C sequestration (Plantinga, Mauldin, and Miller, 1999; Stavins, 1982).

The CC policy provides per hectare payments for switching from a crop-fallow or permanent grass system to a continuous cropping system. Producers are offered payments that range from a low of $5 per hectare per year and increase by $5 increments to $50 per hectare per year. Clearly, only land that is switched from crop-fallow or grass to continuous cropping results in an increase in soil C that is attributable to the policy. However, if the policy pays only farmers who switch from crop-fallow or grass to continuous cropping and does not include payments to farmers who already use continuous cropping, it creates an incentive for those farmers to switch temporarily to crop-fallow and then back to continuous cropping. Thus, two variations on the CC scenario could be considered: all fields continuously cropped could be eligible for payments, regardless of their previous cropping history (*nontargeted CC payments*); or only fields with a history of crop-fallow or grass could be eligible for continuous cropping payments (*targeted CC payments*). Both the targeted and nontargeted policies would result in the same *net* increase in soil C, and the same changes in land use and opportunity costs of sequestering C, but the costs of the policy borne by the government and the resulting producer surplus would be greater under the non-targeted program as a result of the additional fields eligible for payments. A simulation of the model with the payments set equal to zero generates a baseline estimate of the land use and soil C levels for each sub-MLRA for both policies. The economic simulation model was executed for each field in the data set using observed initial conditions for land use and prices set at mean levels to reflect long-run averages over the past decade. The land-use alternatives simulated in the model were winter wheat, spring wheat, and barley in either a continuous cropping or crop-fallow rotation, and permanent grass. The baseline land-use patterns indicate that permanent grass is a more attractive alternative relative to continuous cropping in sub-MLRAs 58A-high, 58A-low, and 53A-high. These areas in the eastern and southeastern part of the state have lower levels of moisture relative to the more productive areas sub-MLRAs 52-high and 52-low. In these latter two areas, continuous cropping accounts for approximately 50% more land acreage than permanent grass.

Simulated Changes in Land Use and Soil C Levels

Figure 3 shows the changes in land use under each policy for each sub-MLRA as payment levels increase. For the PG policy, as payment levels increase the *additional* share of land in permanent grass increases from less than 20% to approximately 25 to 45% within each sub-MLRA (Figure 3a). The baseline shares of land in permanent grass range from a high of 33 to 35% in sub-MLRA 58A-high and 58A-low to under 7% in sub-MLRA 53A-high. The differences in land use in permanent grass across the sub-MLRAs reflect the effects of spatial heterogeneity on the opportunity cost of grain production.

Recall that the crop-fallow and continuous systems yield similar net returns on average; thus the baseline allocation of land in crops is about evenly divided between the two in the sample. This implies that a relatively small payment could induce farmers to switch land from crop-fallow to continuous cropping. Baseline shares of total acreage in continuous cropping ranges from 13% in sub-MLRAs 58A-high to approximately 18% in the other four areas. Figure 2b shows the response of land-use changes to payment levels under the CC policy. All sub-MLRAs exhibit a similar pattern of land-use change under the CC policy, reflecting the fact that the opportunity cost of switching from crop-fallow or grass to a continuous cropping system is fairly similar across the sub-MLRAs.

The effects of these changes in land use on the changes in the equilibrium levels of soil C after 20 years are shown in Figure 4 for each sub-MLRA for each payment level. The amount of soil C sequestered varies depending upon the land area, land use, and the relative productivity of each cropping system to sequester soil C. Under both policies, the largest change in soil C sequestered in response to changes in payment levels occurs within sub-MLRAs 52-high and 52-low which comprise an average of 50% more acreage than the other areas. Comparing across policies, a greater amount of soil C is sequestered under the CC policy relative to the PG policy within each sub-MLRA. The increases in soil C become smaller as payment levels increase, reflecting the diminishing rates of land-use changes shown in Figure 2.

On a *per hectare basis*, the average amount of carbon sequestered under the highest PG policy payment is fairly constant across the sub-MLRAs at about 0.4MT/hectare. For the CC policy, the highest payment level results in average levels of C sequestration per hectare per sub-MLRA that range from 0.8 to 1.1 MT/hectare. Over the six sub-MLRAs considered, the total C sequestered ranges from 1.75 to 4.84 MMT under the PG policy, and from 4.80 MMT to 17.7 MMT under the CC policy.

Costs of Sequestering Soil C

To compare the relative efficiency of the two policies, the marginal cost curves for each sub-MLRA are constructed as discussed above. The per hectare payment levels are divided by the area-specific and activity-specific carbon sequestration rates to obtain the implicit price per metric ton of carbon. This is arrayed with the amount of carbon sequestered over the twenty-year time period, where the amount of carbon sequestered is a function of the opportunity cost and site-specific land-use decisions. Alternative ways of displaying the marginal costs would be to array the costs per metric ton and the *annual* carbon sequestration or to use a *discounted* carbon quantity. Use of annual carbon sequestration quantities could be misleading because there is an upper bound on the total amount of carbon that can be sequestered in each sub-MLRA (saturation), and thus the resulting annual amounts would depend upon how many years one wants to consider. Likewise, discounting the carbon levels assumes that we know the relevant social rate of discount and time horizon. Moreover, for comparisons of our results to the biophysical estimates of soil C potential in the literature cited above it is necessary to use undiscounted measures of soil C.

The simulated marginal cost curves for the both the PG and CC policies embody the combined effects of site-specific land-use changes, soil C productivity differences, and differences in the payment levels (Figure 5). For the PG policy, the spatial differences in land area, opportunity cost of alternative land uses, and carbon sequestration rates cause a corresponding heterogeneity among the marginal cost curves. For the CC policy, the relative homogeneity of changes in land-use patterns shown in Figure 3 means that the observed differences in marginal costs of C sequestration are explained largely by the spatial differences in the productivity of the soils to produce soil C and by the size of the sub-MLRA.

The relative efficiency of the PG and CC policies can be seen by comparing the marginal cost of producing a given level of soil C. As an example, to sequester an additional .75 MMT of C in each sub-MLRA under a PG policy, the marginal costs start at $150/MT and increase to over $500/MT of C. Under the CC policy, .75 MMT of C could be sequestered for less than $50/MT even in the less efficient production areas. In general, our results show that for each sub-MLRA and for all C levels, the PG policy is far less efficient than the CC policy. Furthermore, the patterns of land-use change under the CC policy mean that the marginal cost curves under the CC policy are more elastic relative to the PG cost curves. Above $150/MT, these CC marginal cost curves turn steeply upward in response to the limitations on the quantity of soil C that can be sequestered when all acreage is in continuous cropping.

Table 4 presents a comparison of the quantity of soil C sequestered over the twenty year time horizon and undiscounted government costs and estimates of producer surplus, aggregated across all sub-MLRAs. In order to sequester approximately 7 MMT of C (more precisely 6.76 MMT in the PG scenario and 7.61 MMT in the CC scenario), the PG policy would involve government outlays that are more than ten-fold larger than the CC policy, and total costs that are nearly twice as high. From taxpayers' point of view the CC policy is far superior to the PG policy, providing much more soil C sequestered for a given government cost. From producers' point of view, the PG policy provides much larger income transfers to them per metric ton of soil C sequestered. These differences in the efficiency of the two policies can be measured at either the aggregate level or on a sub-MLRA basis. Over all sub-MLRAs, the efficiency gains associated with sequestering approximately 7 MMT of C using the CC policy rather than the PG policy amounts to over $430/MT of C at the margin.

The effects of spatial heterogeneity on government costs and benefits to producers are illustrated in Table 5 which compares similar data for sub-MLRAs 52-high and 58A-low. Within the payment levels considered in the simulation model, the CC policy always sequesters more C than the PG policy and the marginal costs per MT of C are lower. As payment levels are raised beyond the $125/hectare under the PG policy, the increases in soil C are minimal, as less productive land is switched into grass at a decreasing rate. Such an intensive switch to permanent grass may actually cause a decline in the overall soil C levels if the acreage is taken from the land that was continuously cropped. For the CC policy, payments in excess of $50/hectare do not add appreciably more soil C because the share of land in continuous cropping at payment levels of \$50/hectare is at least 90% of the cropland acreage.

Conclusions

Previous published studies of C sequestration have considered the conversion of agricultural land to forests. There are important reasons to consider the economic feasibility of using crop land to sequester C: first, there are large areas of agriculture with substantial technical potential to sequester C in soil that are not suitable for afforestation; second, changing agricultural practices to sequester soil C is likely to bring subsidiary environmental benefits associated with reduced soil erosion and enhanced productivity; and third, changing agricultural practices does not have the potentially large, and often negative, regional economic impacts that are associated with land retirement programs.

We developed a conceptual framework for analysis of the economic potential for C sequestration in agricultural soils which shows that the economic efficiency of soil C sequestration depends on site-specific opportunity costs of changing practices and on the rates of soil C sequestration associated with changing practices. Our analysis of dryland grain production systems in the Northern Plains shows how site-specific land-use decisions change in response to policy incentives, and how this induces changes in soil C within a given region. The analysis shows that a policy providing payments for converting crop land to permanent grass is a relatively inefficient means to increase soil C, with marginal costs per MT of C ranging from \$50/MT to over \$500/MT. In contrast, payments to adopt continuous cropping were found to produce increases in soil C at a marginal cost ranging from \$12 to \$140 per MT of C even in the less productive regions of the northern Great Plains. For this policy, the average costs do not exceed \$50 per MT of C.

Several caveats should be mentioned in concluding which may affect the costs of soil C. First, if the duration of contracts for soil C sequestration were extended beyond the time period T needed to reach the saturation of soil C, the estimated costs would increase. Second, in this analysis the entire opportunity cost associated with changing agricultural practices was attributed to a single environmental benefit—sequestering C. In many cases, changes in land use and management practices produce multiple environmental benefits, such as reduced soil erosion, improved water quality and wildlife habitat, and visual amenities. If additional environmental benefits were incorporated into an analysis of soil C, the relative economic efficiency of alternative land use and management options could be different, and other options to sequester soil C may become more competitive with non-agricultural reductions in GHG emissions.

Finally, it is important to note that agriculture is both a sink for C as well as a major emitter of CO_2 and two other potent greenhouse gases, nitrous oxide and methane (McCarl and Schneider; Robertson, Paul, and Harwood). Ideally policies to mitigate GHG emissions would reward sinks and tax sources according to their global warming potential (GWP), wherein methane is estimated to be about 21 times more potent than a unit of CO_2, and nitrous oxide is estimated to be about 310 times more potent (IPCC). Both methane and nitrous oxide are also likely to be influenced by land use and other management practices. An efficient GHG policy would provide incentives according to GWP that accounted for the total mixture of emission and sequestration fluxes of GHG caused by a farmer's altered land use and management practices. To do so one could replace the C rate in our analytical framework with a measure of GWP, and introduce a policy that would provide a positive payment for a reduction in GWP and a tax on actions that increase GWP. While this generalization is straightforward in principle, implementing it poses formidable measurement problems because methods and models to quantify nitrous oxide and methane emissions are not as well developed as those for C. Nevertheless this does appear to be the direction that policy will move as the needed science and data are developed.

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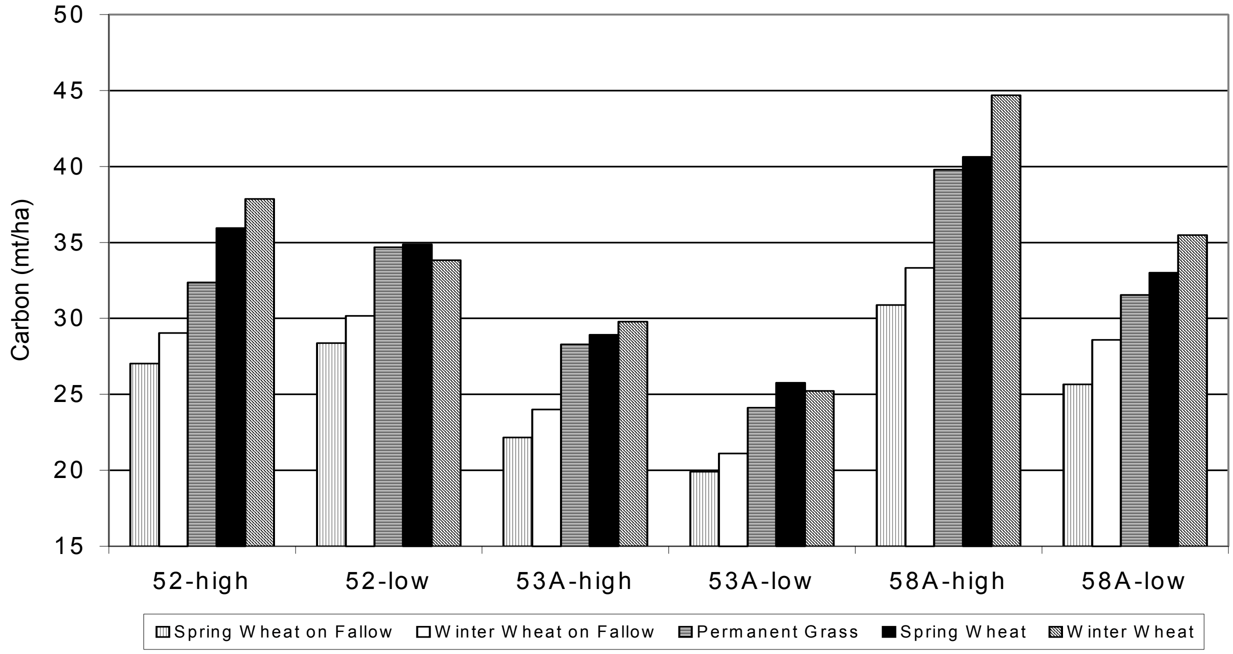
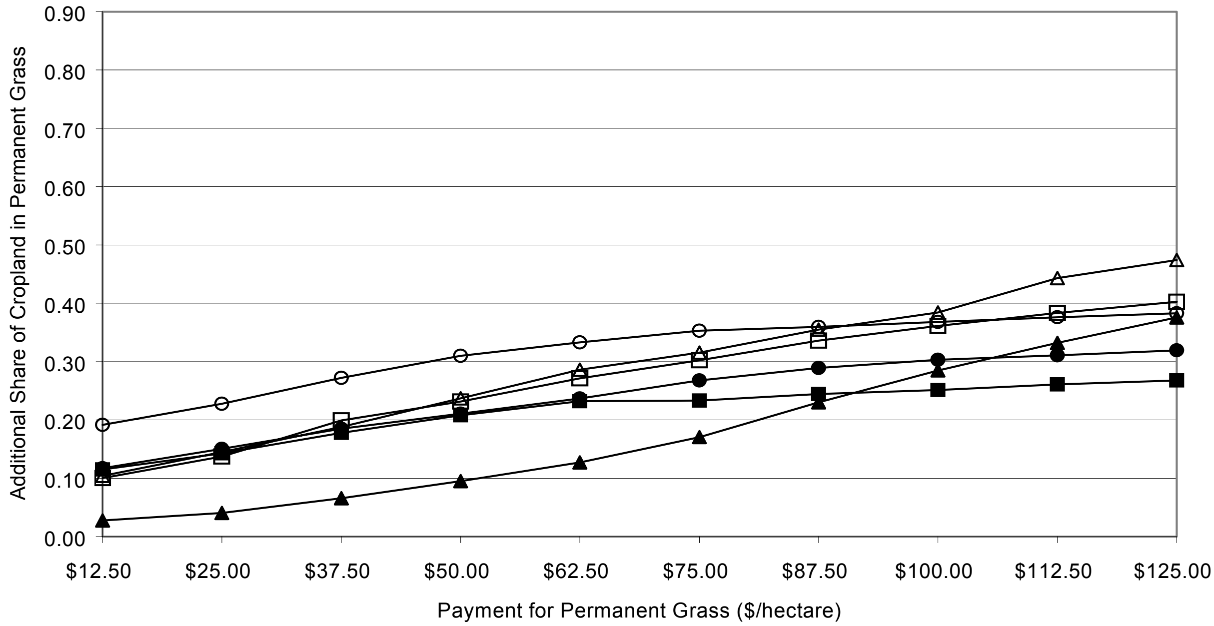
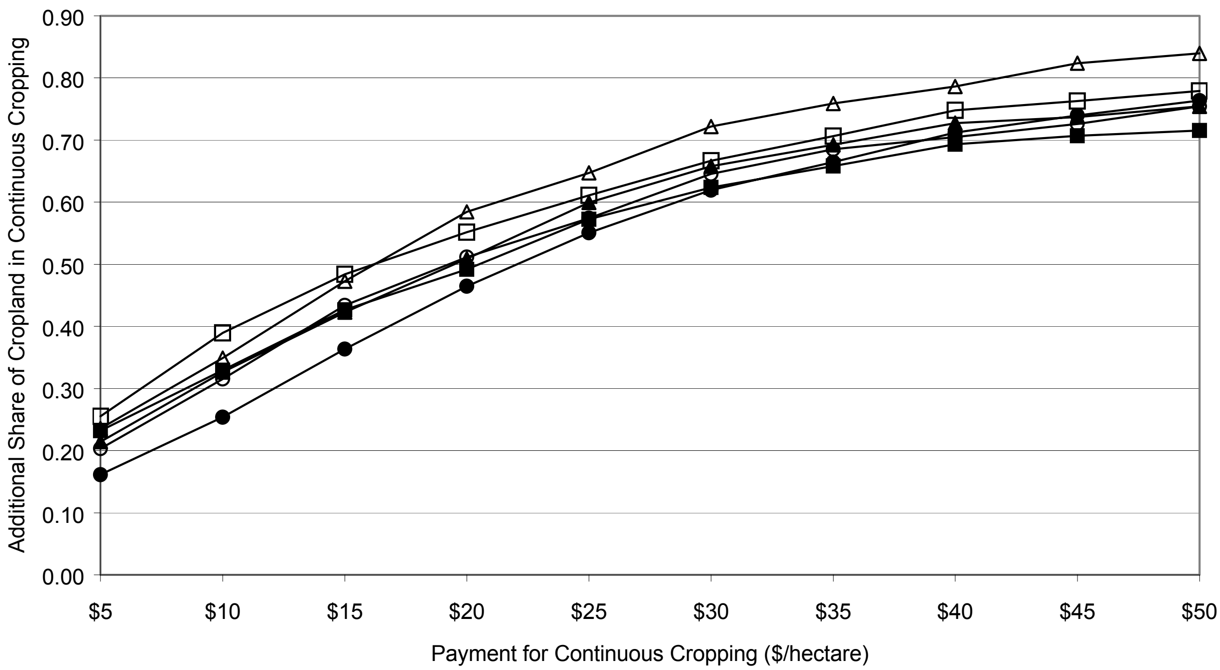


Note: Soil C levels for barley are the same as spring wheat.

Figure 2. Soil C levels predicted by Century model for cropping systems in Montana



(a) Permanent Grass Payment Policy



(b) Continuous Cropping Payment Policy

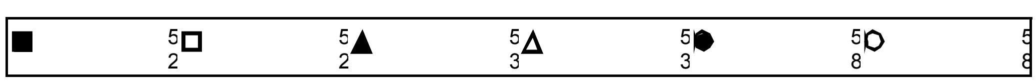
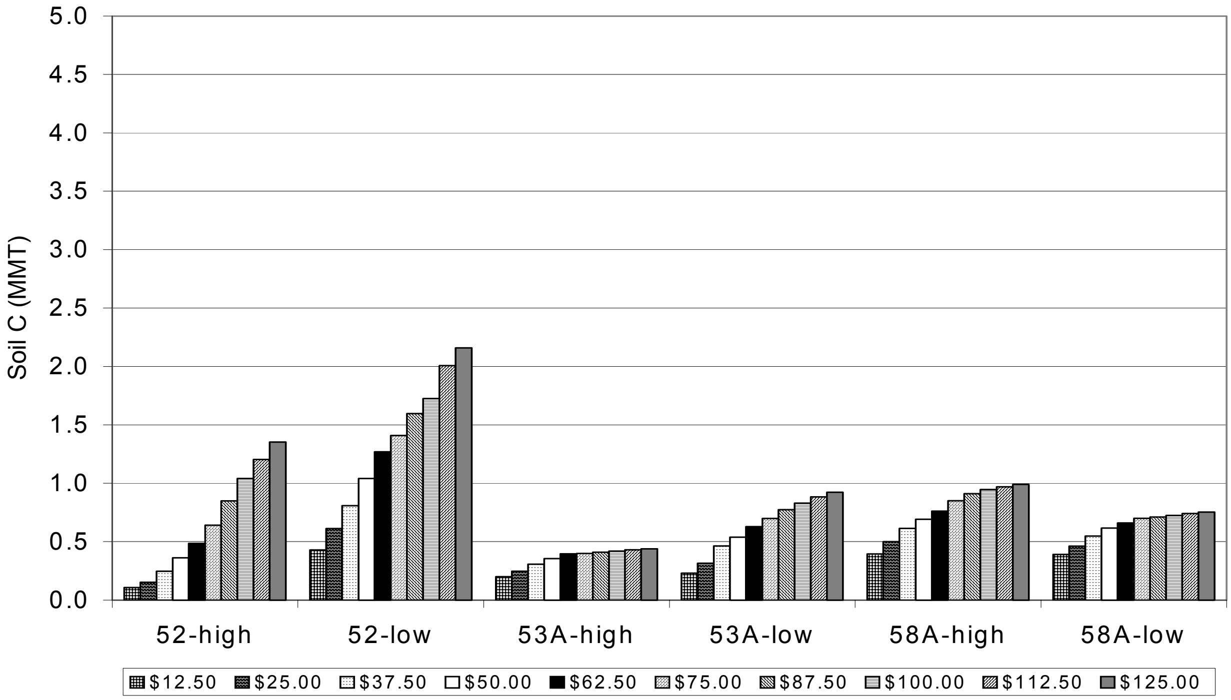
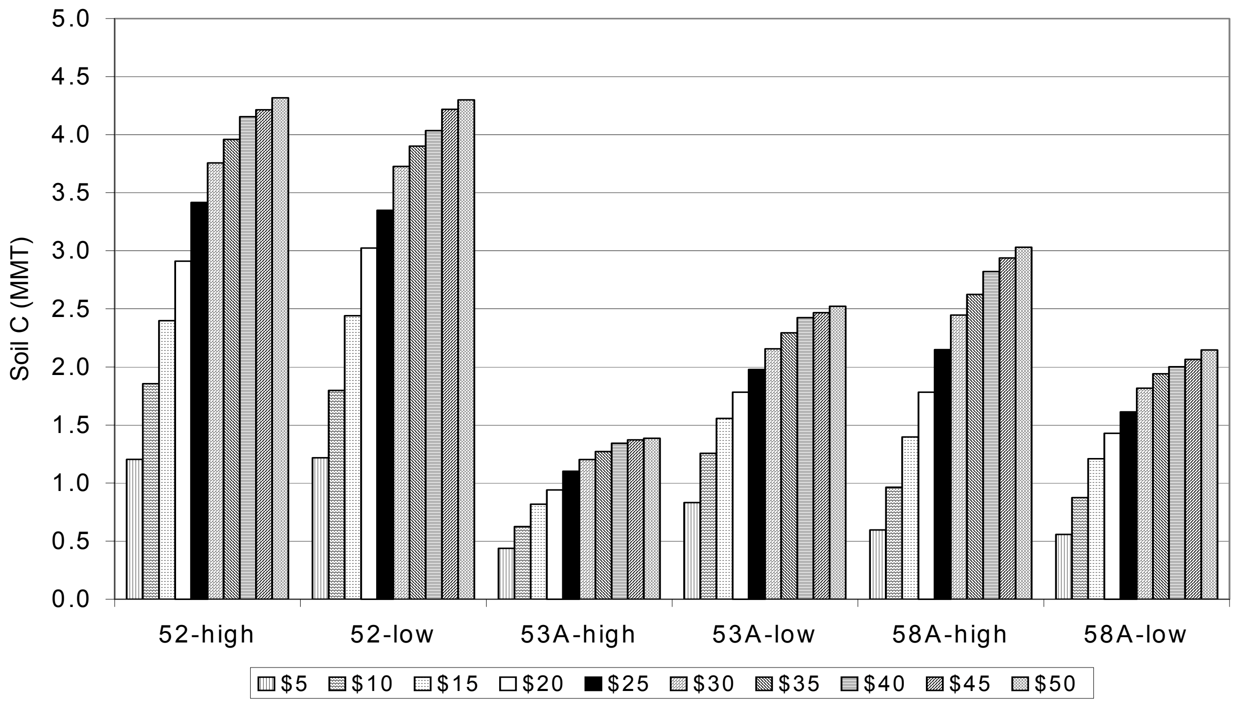


Figure 3. Changes in land-use shares by sub-MLRA and policy scenario

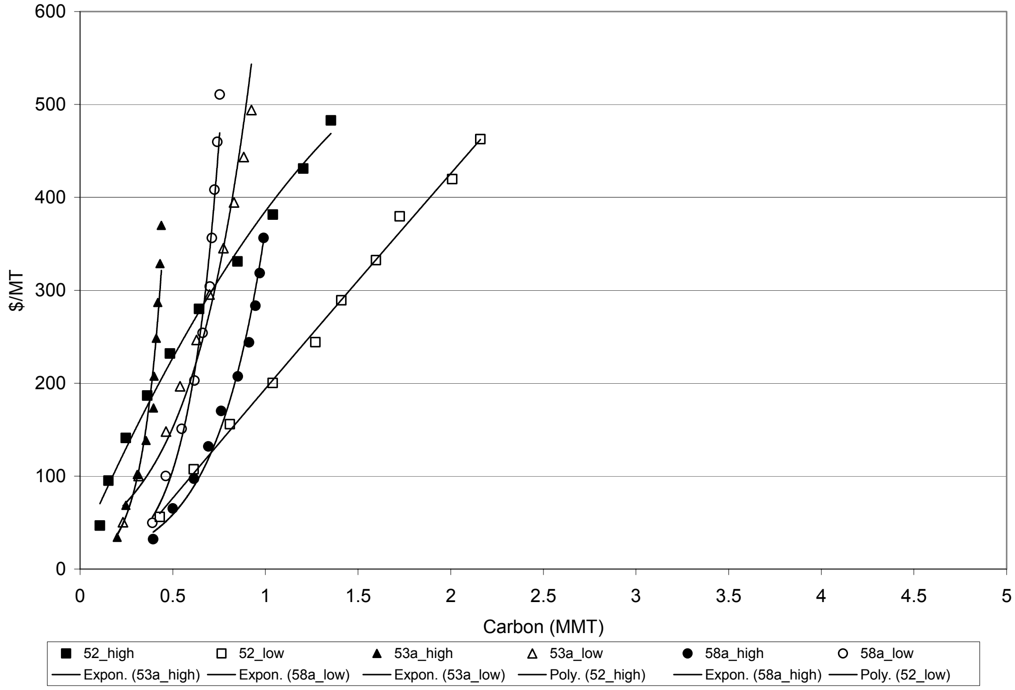


(a) Permanent Grass Payment Policy

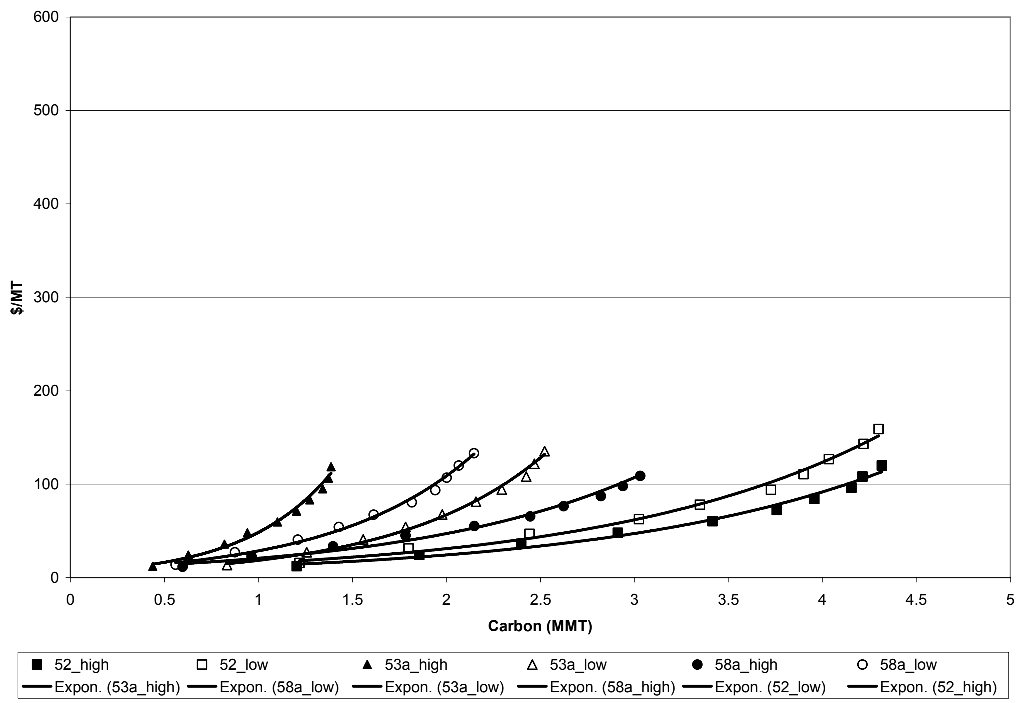


(b) Continuous Cropping Payment Policy

Figure 4. Changes in soil C by sub-MLRA and policy scenario



(a) Permanent Grass Payment Policy



(b) Continuous Cropping Payment Policy

Figure 5. Marginal cost for soil C by sub-MLRA and policy scenario

Table 4. Levels of Carbon Sequestered, Costs to Government, and Producer Surplus, by Policy Scenario for All Sub-MLRAs

A. Permanent Grass Payment Policy

Payment Level ($/hectare/year)	Quantity of Soil C Sequestered (MMT)	Cost to Government (Million $)	Producer Surplus (Million $)
$25	2.37	216.9	81.3
$50	3.71	670.2	325.1
$75	4.82	1305.3	673.0
$100	5.82	2121.5	1135.4
$125	6.76	3084.0	1674.4

B. Continuous Cropping Payment Policy

Payment Level ($/hectare/year)	Quantity of Soil C Sequestered (MMT)	Cost to Government (Million $)	Producer Surplus (Million $)
$10	7.61	201.7	66.4
$20	12.22	647.1	303.4
$30	15.54	1226.3	639.6
$40	17.28	1818.6	1063.5
$50	18.25	2404.9	1531.2

Table 5. Simulation of Land-use Changes, Carbon Sequestration Levels, and Costs for Sub-MLRAs 52-high and 58a-low

A. Permanent Grass Payment Policy*

Area	Payment Level ($/hectare/year)	Change in Share of Land in Permanent Grass	Quantity of Soil C Sequestrated (MMT)	Marginal Cost of Carbon Sequestrated ($/MT)	Average Cost of Carbon Sequestrated ($/MT)	Government Costs (million $)	Producer Surplus (million $)
MLRA 52-high	$25	0.04	0.15	95	67	14.6	4.2
	$50	0.10	0.37	186	123	67.6	22.9
	$75	0.17	0.64	279	185	179.7	60.7
	$100	0.28	1.04	381	247	396.7	138.8
	$125	0.37	1.35	482	294	653.4	255.4
MLRA 58A-low	$25	0.23	0.46	100	55	46.2	20.4
	$50	0.31	0.62	203	76	125.3	78.0
	$75	0.35	0.70	304	95	213.0	146.2
	$100	0.37	0.73	408	105	296.3	219.4
	$125	0.38	0.75	510	117	384.7	294.8

B. Continuous Cropping Payment Policy**

Area	Payment Level ($/hectare/year)	Change in Share of Land in Continuous Cropping	Quantity of Soil C Sequestrated (MMT)	Marginal Cost of Carbon Sequestrated ($/MT)	Average Cost of Carbon Sequestrated ($/MT)	Government Costs (million $)	Producer Surplus (million $)
MLRA 52-high	$10	0.33	1.86	24	16	44.7	14.3
	$20	0.51	2.91	48	24	139.6	67.0
	$30	0.66	3.76	72	34	271.0	143.1
	$40	0.73	4.15	96	40	399.3	235.5
	$50	0.75	4.32	120	42	518.1	337.6
MLRA 58A-low	$10	0.32	0.88	27	18	23.7	7.2
	$20	0.51	1.43	54	28	77.2	37.0
	$30	0.65	1.82	81	39	146.4	74.7
	$40	0.70	2.00	107	44	213.8	124.9
	$50	0.75	2.15	133	50	285.9	177.8

*Baseline share of land in permanent grass: MLRA 52-high=0.07, MLRA 58A-low= 0.36
**Baseline share of land in continuous cropping: MLRA 52-high=0.15, MLRA 58A-low=0.13 Total hectares: MLRA 52-high=0.68 million, MLRA 58A-low=0.36 million

Forest and Agroforestry Opportunities for Carbon Sequestration in the Big Sky

A contribution to

The Big Sky Carbon Sequestration Partnership

by

R. Neil Sampson
Matt Kamp
The Sampson Group, Inc.
February 10, 2005

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Executive Summary

The Big Sky Carbon Sequestration Project is attempting to characterize the carbon sequestration potential in the agricultural and forest areas of the 4-state region, comprising Idaho, Montana, South Dakota and Wyoming. This study addresses the portion of that potential related to agroforestry practices and biomass production on agricultural lands, as well as afforestation of marginal agricultural soils and changing the management of existing private forests. None of these opportunities are overwhelmingly large, as one would expect in a region characterized by a high proportion of federal land, vast areas of arid and semi-arid ecosystems, and widely scattered production areas. But they could be important contributors to state, regional, and national efforts to mitigate greenhouse gas emissions in the near term, as these management practices are available immediately, with mature technologies that are widely known to landowners and technical agents in the region. In the event that carbon sequestration were to gain some market value, these opportunities could become a badly-needed supplement to income in a region dependent on agriculture and forestry for much of its rural economy.

Table 1 illustrates the estimates produced by the study. These estimates have a high degree of uncertainty, in that while most of the practices are well established, the policies and incentives to implement them are not. An example is found in the agroforestry practice of field windbreaks. The values of field windbreaks for soil erosion reduction, soil moisture retention, fuel use reduction, and farm yield protection have been known for decades, and there have been federal cost-sharing incentives since the 1930's. But there are still thousands of acres where windbreak protection would be beneficial, but remains undone. Farmers have resisted the existing incentives, and it is not yet clear how an added incentive tied to carbon sequestration would make a significant difference.

Table 1 contains estimates that reflect the total physical area in the region that is suitable for each practice. While these lands are available in the physical sense, they do not reflect actual implementation. The "potential area" is an author's estimate of what is most likely to be realized over the next 5-10 years unless much additional work is done to produce the policy, economic, and institutional support needed to assure increased success.

Table 1. Summary of carbon sequestration potential in agroforestry, biomass, and forestry, Big Sky Region.

Practice	Available Area (1,000 Ac)	Potential Area (1,000 Ac)	Potential Mitigation ($TgCO_2e/yr$)*
Afforestation	34,000	3,400	4 – 6
Forest Management	10,900	6,200	1.5 – 2
Field Windbreaks	594	300	1.0 – 1.5
Riparian Forest Planting	1,500	750	2.0 – 2.5
Biomass for co-firing	10,500	330	0.25 – 3

* Tg = terragrams = million metric tonnes

Table 1 suggests a total agroforestry, biomass, and forest opportunity in the range of 9 – 15 $TgCO_2e$ per year on the non-federal lands of the region. In comparison, USDA currently estimates that the forests of the region (including federal forests) are sequestering around 41 $TgCO_2e$ per year (Table 8). Thus, while 9-15 will not represent a huge national or global impact, it would mean that activities on private lands could increase regional sequestration by 25 to 35 percent. That, accompanied by the many other environmental values associated with improved carbon sequestration practices, would seem substantial.

Background of the Study

The Sampson Group, Inc. is a contributor to the Big Sky Carbon Sequestration Partnership, working together with other institutions and organizations under sponsorship of the U.S. Department of Energy to coordinate a study of the carbon sequestration opportunities in the region encompassing the states of Idaho, Montana, and South Dakota (www.bigskyco2.org). Wyoming has recently joined the partnership, as well, thus data for Wyoming have been included in this study.

This study is designed to contribute to the task of evaluating the terrestrial sequestration potential in regional ecosystems through forestry, agroforestry, and bioenergy opportunities.

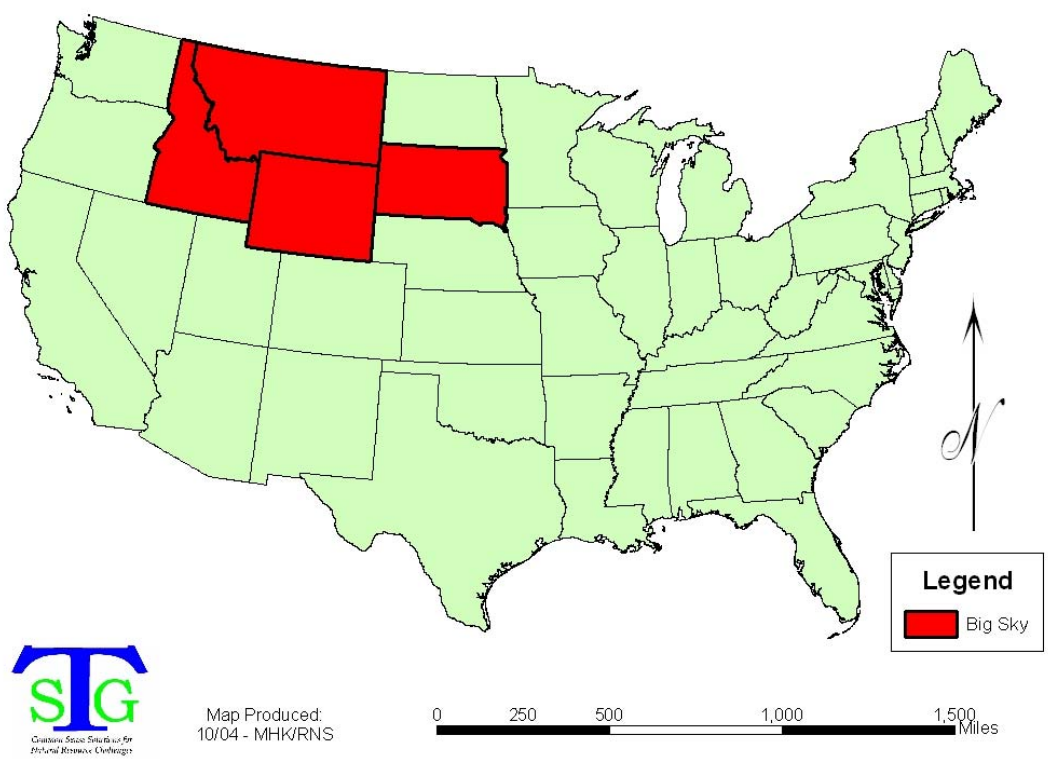

Figure 1. The Big Sky Region covers the states of Idaho, Montana, South Dakota, and Wyoming.

The Big Sky Land Base

The Big Sky region, for the purposes of this paper, consists of the states of Idaho, Montana, South Dakota, and Wyoming (Figure 1). Large areas of arid and semi-arid grazing and croplands are common on the eastern and southern sides of the region, while forested mountainous areas characterize the west. Average annual precipitation rates are highly variable (Figure 2), and even more locally variable in mountainous forest areas where topography and micro-climatic change significantly affect growing conditions.

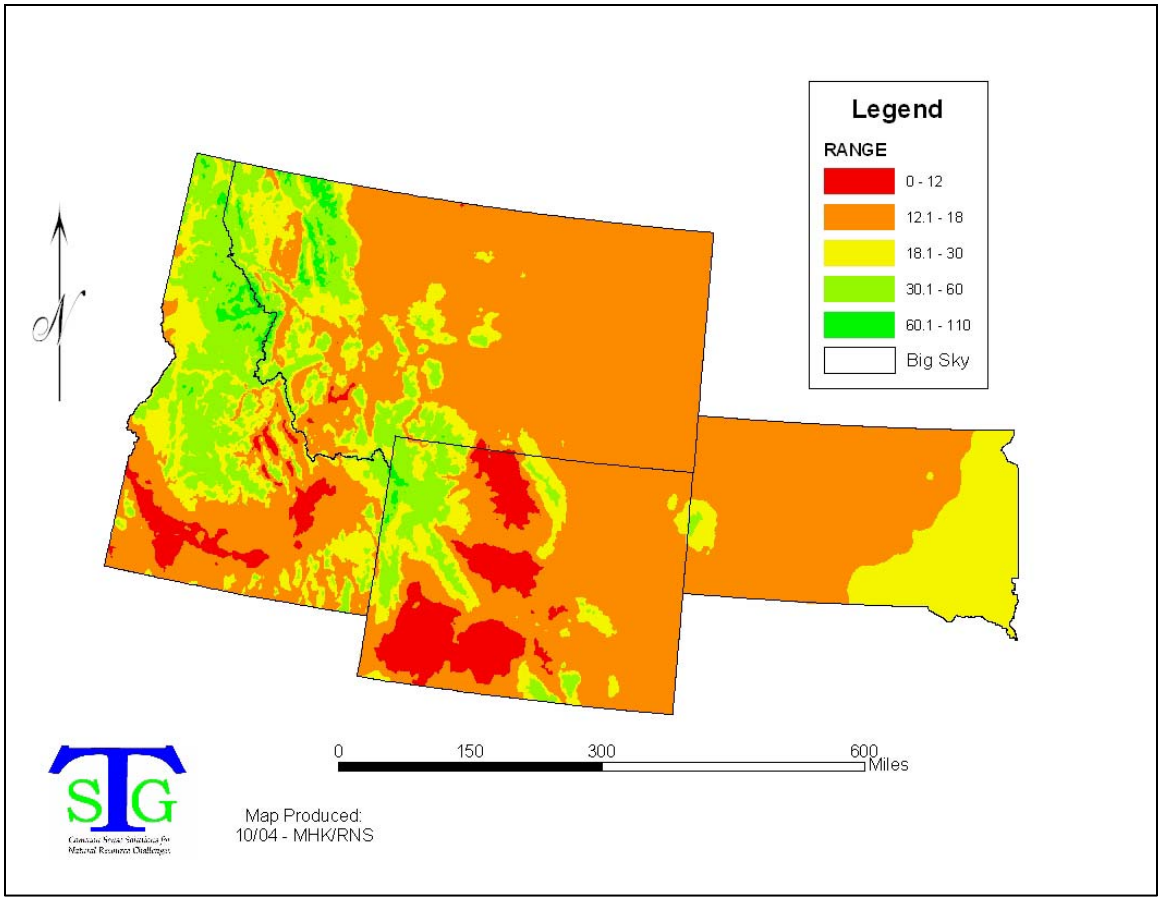

Figure 2. Average annual precipitation, in inches, Big Sky Region. Source: PRISM

The region is 40% federal land (Table 2; Figure 3). These lands are included in the federal Greenhouse Gas Inventory (USDA 2004) that is outlined below (Tables 7 & 8), but are excluded from the estimates of potential opportunity for the creation of additional GHG reductions through state or market programs for carbon sequestration. The exception to this was in the analysis of potential for biomass fuels, where the federal forest land was included as a potential source of woody biomass.

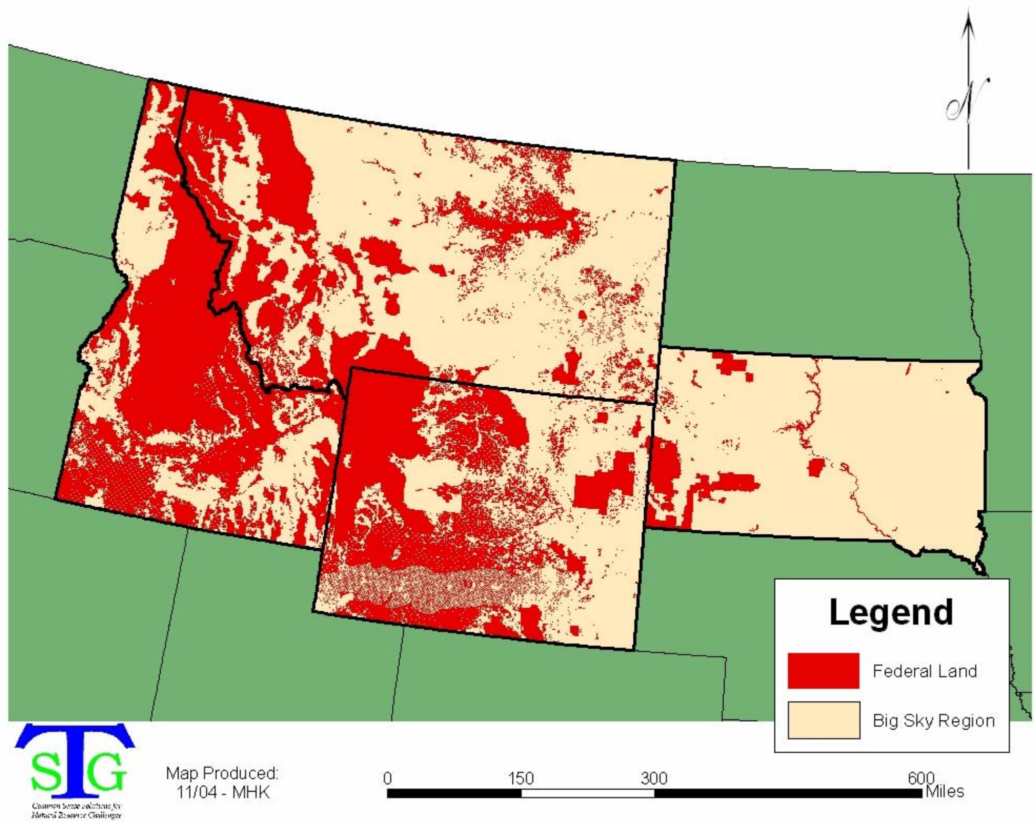

Figure 3. Federal land in the Big Sky Region.

This analysis focuses on the 161 million acres of rural, non-federal land in the region, estimating the potential for increasing carbon sequestration through forestry, agroforestry, and bioenergy strategies.

Table 2. Surface area of nonfederal and federal land and water areas, by state, 1992

			Nonfederal Land			Total
State	Federal Land	Water	Developed	Rural	Total	Surface area
	------------------------------- 1,000 acres --					
Idaho	33,480.9	552.2	690.0	18,764.4	19,454.4	53,487.5
Montana	27,089.7	1,052.5	758.6	65,209.2	65,967.8	94,110.0
South Dakota	3,107.9	874.4	957.9	44,417.8	45,375.7	49,358.0
Wyoming	28,748.0	430.9	662.8	32,761.1	33,423.9	62,602.8
Total Big Sky	92,426.5	2,910.0	3,069.3	161,152.5	164,221.8	259,558.3

Source: USDA-NRCS 2000; 1997 NRI, Table 1, National Summary.

The current (1992) use of non-federal rural land is indicated in Table 3. We used the 1992 NRI data (as corrected in 1997) (USDA-NRCS 2000) for this analysis since the only available land use/land cover geographic data was developed in 1992 (USGS 1998). The NRI data provides an independent source against which to test the GIS-derived estimates of potential land use change for improving carbon sequestration. The GIS-derived estimates were derived by identifying areas of non-forested land as shown by the 1992 National Land Cover Data (NLCD) (USGS 1998) that occurred on general soil types that supported native forest cover, as shown by the STATSGO general soil map (USDA-NRCS 2004). For a fuller explanation of how the potential land use change estimates were derived, see Appendix A. Both the NRI and NLCD for 2002 are in development, and the analysis could be fairly easily updated when both become available for use.

Table 3. Land use of non-federal land, 1992, by state.

State	Cropland	CRP	Pasture	Range	Forest	Other rural land	Total rural land
				(1,000 acres)			
Idaho	5,600.0	823.7	1,299.0	6,517.2	4,019.9	533.2	18,793.0
Montana	15,035.0	2,781.3	3,406.6	36,982.0	5,413.6	1,404.5	65,023.0
South Dakota	16,436.7	1,756.8	2,199.7	22,078.9	524.1	1,477.3	44,473.5
Wyoming	2,271.9	251.7	935.3	27,312.1	1,030.2	1,006.1	32,807.3
Big Sky Total	39,343.6	5,613.5	7,840.6	92,890.2	10,987.8	4,421.1	161,096.8

Source: USDA-NRCS 2000; 1997 NRI, Table 2, National Summary.

Much of the cropland (19%) in the region is irrigated (Table 4). The opportunities identified in this paper for converting marginal crop and pasture land to forest are limited to non-irrigated cultivated cropland where soils and climate conditions could support forest growth. Irrigation is too expensive to be used for growing forest (with the possible exception of fast-growing hybrids), and this land would be too arid for trees if the irrigation was discontinued, so irrigated cropland was not considered an opportunity for conversion. Non-cultivated cropland is largely meadow hayland, hayland, vineyards, or orchards, so was also not considered a high opportunity for conversion. While the non-irrigated cropland area is large, only a portion lies in climate zones where trees are adapted. The GIS analysis used to identify those climate zones is described in Appendix A.

Table 4. Cropland use, by state, 1992

State	Cultivated Cropland			Non-cultivated Cropland			Total
	Irrigated	Non-irrigated	Total	Irrigated	Non-irrigated	Total	
				(1,000 Acres)			
Idaho	2,862.2	1,793.0	4,655.2	633.0	311.8	944.8	5,600.0
Montana	884.4	11,597.9	12,482.3	1,193.0	1,359.7	2,552.7	15,035.0
South Dakota	420.9	13,983.7	14,404.6	61.4	1,970.7	2,032.1	16,436.7
Wyoming	456.5	518.5	975.0	962.9	334.0	1,296.9	2,271.9
Big Sky Total	4,624.0	27,893.1	32,517.1	2,850.3	3,976.2	6,826.5	39,343.6

Source: USDA-NRCS 2000; 1997 NRI, Table 3, National Summary.

Land use change has not been a major factor in the region since 1982, as illustrated in Table 5. Virtually all of the Conservation Reserve land that has been established has come from cropland, and this land retirement was the main factor in a cropland reduction of about 3.5 million acres (8.2%) over the past 15 years. Both the total area (~ 11 million acres) and the individual sample plots on nonfederal forest land have been essentially unchanged since 1982 (the margin of error in the 1982 and 1997 total estimates is around 500,000 acres, so the changes shown are not statistically significant).

Implementation of the most recent signup in the CRP program has resulted primarily in the conversion of cropland to grassland, as shown in Table 6. Even in the counties where conversion to trees looks biologically possible, the amount of CRP land planted to trees has been very low. These factors suggest that conversion of marginal cropland to trees is a difficult "sell" in this region, even in those counties where trees are a logical option. This is not a recent phenomenon, nor is it limited to this region. Esseks et al. (1992) found that farmers outside the Southeast, where forest production is a common practice on private lands, were generally unwilling to commit to the permanence of forest cover and opted, instead, for the land use flexibility of planting a grass cover.

One possibility, largely unused to date, is the potential for the Conservation Reserve Enhanced Program (CREP) for establishing riparian forests as a means of enhancing water quality.

Table 5. Land Cover/Land Use Change, 1982-1997, Big Sky Region.

Land Cover/Use in 1982	Land Cover/Use in 1997: Cropland	Pasture-land	Range-land	Forest Land	CRP Land	Other Rural Land	Devel-oped Land	Water & Federal Land	Total in 1982
	(1,000 Acres)								
Cropland	**35,609**	1,599	218	9	5,066	219	221	182	43,122
Pastureland	1,682	**5,618**	162	19	153	54	93	46	7,825
Rangeland	2,037	625	**91,373**	159	207	134	202	320	95,055
Forest Land	13	19	176	**10,458**	0	18	86	201	10,972
CRP Land	0	0	0	0	**0**	0	0	0	0
Other Rural Land	77	83	86	41	12	**3,925**	21	16	4,261
Developed Land	13	5	23	6	0	2	**2,768**	0	2,816
Water & Federal Land	169	65	393	209	0	27	0	**94,643**	95,507
Total in 1997	39,600	8,011	92,430	10,901	5,438	4,380	3,391	95,408	259,558

Source: NRCS 2000 (1997 NRI). Note: Acreage in bold is unchanged from 1982 to 1997.

Table 6. Conservation Reserve Program Acres, Big Sky States, by Cover Type, Signup #26, 2003

State	Total CRP	Grass		Trees	
	Acres		*Percent*	*Acres*	*Percent*
Big Sky Region	129,985	127,847	98.4%	2,138	1.6%
Idaho	53,750	51,829	96.4%	1,921	3.6%
Montana	50,255	50,242	100.0%	13	0.0%
South Dakota	25,980	25,776	99.2%	204	0.8%
Wyoming	0				

- ## Greenhouse Gas Emission Inventory

The U.S. Department of Agriculture has conducted a comprehensive assessment of greenhouse gas emissions and sinks in U.S. agriculture and forests (USDA 2004). Estimates are provided at State, regional, and national scales, categorized by management practices where possible. The estimates are consistent with those published by EPA in the official Inventory of U.S. Greenhouse Gas Emissions and Sinks that was submitted to the United Nations Framework Convention on Climate Change in April 2003. For the Big Sky Region, cropland soils were estimated to be an annual sink of 5.4 $TgCO_2e$ (Table 7), while forests (not counting soils or forest products) were estimated to be a sink of 40.8 $TgCO_2e$ per year (Table 8). (Tg stands for teragrams, or million metric tons.)

Table 7. State estimates of soil carbon changes in cropland and grazing land in 1997 by major activity categories.

State	Plowout of grassland to Annual cropland[1]	Cropland manage-Ment	Other Crop-land[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land man-agement	CRP	Manure applica-tion	Cultiva-tion of organic soils	Net soil carbon Emissions[4]
						Tg CO_2e					
Idaho	1.1	-0.07	0	-1.03	-0.04	-0.26	-0.04	-0.59	-0.34	0.07	-1.19
Montana	1.91	-0.59	0	-1.28	-0.07	-0.48	0	-1.8	-0.08	0.11	-2.28
South Dakota	4.07	-0.18	0	-2.9	-0.04	-0.44	0.07	-1.39	-0.31	0.07	-1.04
Wyoming	0.51	-0.07	0	-0.62	-0.04	-0.29	0	-0.37	-0.04	0	-0.92
Big Sky Totals	7.59	-0.91	0	-5.83	-0.19	-1.47	0.03	-4.15	-0.77	0.25	-5.43

Negative numbers indicate net sequestration.

[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).

[2] Perennial/horticultural cropland and rice cultivation.

[3] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.

[4] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

Source: Appendix Table B-11, USDA 2004.

Tg = terragrams = million metric tonnes

Table 8. State summaries of forest area, total area, forest non-soil stocks (2002), forest non-soil stock change (2001), and forest products stock change (2001).

State	Forest Area	Total Area	Forest non-soil stocks	Forest non-soil stock change	Products stock change
	1,000 ha		*Tg CO_2 e*	*Tg CO_2 e/yr*	
Idaho	8,760.0	21,646.0	4,145.0	-12.1	-3.4
Montana	9,426.0	23,291.6	3,938.0	-21.5	-2.3
South Dakota	655.0	1,618.5	192.0	0.6	-0.2
Wyoming	4,449.0	10,993.5	1,897.0	-7.8	-0.2
Big Sky Totals	23,290.0	57,549.6	10,172.0	-40.8	-6.1

Source: Appendix Table C-1, USDA 2004

• Forestry Opportunities for Carbon Sequestration in the Big Sky

• *Afforestation*

We define the biological opportunity for afforestation as all non-federal, non-forest land (primarily cropland and grassland) identified in the 1992 NLCD data in areas where the STATSGO soil survey (USDA-NRCS 2004) identifies woodland as being the native vegetation (Figure 4). See Appendix A (Tables A-1 and A-2 for the classifications used.) That estimate may overstate the real biological opportunity, since some of those sites have been degraded by soil erosion to the point where an ecological type change has occurred that may prevent successful re-establishment of trees. That overestimation has been taken into account by discounting the estimates of feasible afforestation from the estimate of total suitable land. The amount of discount was based on the current land use and the forest type suitability (Appendix Table A-6).

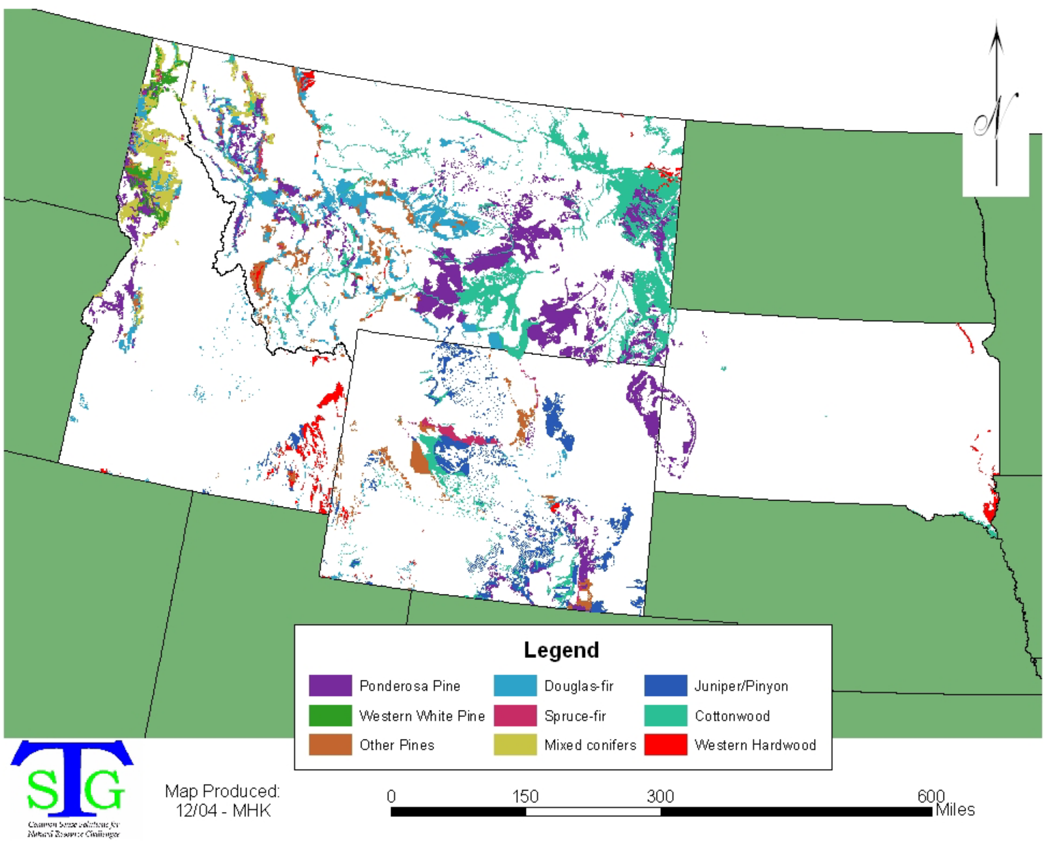

Figure 4. Potential forest types on non-federal lands, as indicated by general soil type (STATSGO).

To develop estimates of the impact of afforestation, tables were developed by state indicating the current non-forest area that coincided with a native forest type. These were then combined in a regional table (Appendix Table A-3). See Appendix A for a description of the analytic methods used. Average annual forest growth estimates were developed from Birdsey (1996) (Appendix Table A-4). Estimates of potential timber volume growth were developed by multiplying the acreage of land available to be afforested times the average annual growth rate of the appropriate forest type.

The estimates of potential timber volume growth were converted to carbon dioxide equivalents by the factors published by Birdsey (1992, 1996). When the specific factors are applied to the species in the region, they range from 88 to 127 lbs CO_2e per ft^3 of timber grown.

The resulting biological opportunity is around 44.6 TgCO_2e per year (Appendix Table A-5) on the region's non-federal lands. This estimates the upper limit of potential afforestation impact. This would represent a significant impact, more than doubling the amount of sequestration currently occurring in the forests of the region (Table 8). If the estimate of available, suitable acres (34.3 million) is reasonable, however, the estimated sequestration rate is about 1.3 tCO_2e per acre per year. That is conservative, as there are existing default factors, such as those used by the Chicago Climate Exchange, that run in the range of 1.4 to 1.5 tCO_2e per year.

Since it is anticipated that only a small portion of the potential will be realized (and that it will be realized at a different rate for different existing land uses and timber types, see Table A-6), a final table (Table A-7) was constructed based on an author's estimate of the potential for conversion, based on experience in the region. These factors can be debated by experts in the region and changed to reflect other opinions. The impact of this calculation was to reduce the biological potential estimate by nearly 90%. In other words, we think it reasonable for the region to seek a goal of sequestering about 10% of the total biological opportunity available for afforestation (Table A-7).

On this basis, we estimate that the potential for additional carbon sequestration from an effective afforestation program in the 4-state Big Sky Region is in the range of 5 TgCO_2e per year. The range of uncertainty in the estimate is significant, running from near zero to an upper estimate of some 15-20 TgCO_2e per year. That would suggest an increase in the range of 10 to 50% compared to what is currently sequestered in all the region's forests (Table 8). Given that Table 8 includes millions of acres of federal forestlands, such a potential increase from the limited amount of non-federal forests is fairly significant. An economic supply curve could be constructed that would estimate the prices that might be required to realize the quantities within this range, but that is beyond the scope of this paper.

- ***Forest Management***

The analysis for forest management opportunity is based on data from the 1997 National Resources Inventory (NRI) that, for the first time, included an attribute for woodland species on the non-federal lands (USDA-NRCS 2000). Here, the land that was forest in 1997 was tabulated by forest type. There are no data on forest age or condition, how intensively these forests are currently being managed, or what opportunities might exist to improve that management through practices like enrichment planting (to fill understocked stands), thinning to improve health and growth in overstocked stands, or fertilization. The carbon dynamics in these forests can also be changed by lengthening the growing rotation on managed forests to provide larger trees, and larger wood products that last longer in use (Row 1996).

Table 9 contains 1997 estimates of non-federal forest by species groups as one basis for understanding the potential for carbon sequestration through improved forest management.

Table 9. Forest species groups on non-federal land, by state, 1997.

Group	Species	Idaho	Montana	S Dakota	Wyoming	Total
				1,000 acres		
1	Ponderosa Pine	462.0	1,116.7	346.5	660.7	2,585.9
2	Lodgepole Pine	47.0	662.7		49.3	759.0
3	Douglas Fir	1,272.5	2,335.0		23.8	3,631.3
4	Fir; Spruce	122.0	439.6		98.2	659.8
4	Hemlock; Sitka Spruce	658.0	-			658.0
4	Spruce; Fir		8.2			8.2
5	Larch	946.1	296.1			1,242.2
5	Western White Pine	60.7	16.2			76.9
6	Pinyon; Juniper	5.4	-			5.4

7	Elm; Ash; Cottonwood		40.6	89.4	3.2	133.2
8	Aspen; Birch		54.4	10.1	15.9	80.4
8	Oak; Pine			40.1	10.7	50.8
8	Western hardwoods	248.4	192.6	26.6	107.4	575.0
9	Noncommercial	3.6	90.5	5.0	32.9	132.0
9	Non-stocked	122.1	178.2	0.6	2.0	302.9
	Total non-federal forest	3,947.8	5,430.8	518.3	1,004.1	10,901.0

Source: 1997 NRI (USDA-NRCS 2000)

The next question that arises is the extent to which the existing forests can be managed differently to increase carbon sequestration. Not knowing the level of current management intensity, we applied general factors across the area, recognizing that on any one forest, the departures from average will likely be significant.

There are some forest types that are more likely to be managed for improved growth and productivity than others. One example would be ponderosa pine versus pinyon pine. Ponderosa is widely managed for timber and other forest values, while pinyon is generally a scattered forest across broad areas that are primarily used for grazing land by private landowners. Thus, pinyon/juniper is one forest type that is unlikely to be managed to increase carbon sequestration. Most of the western hardwoods in the Big Sky Region probably fall into this category, as well. Based on these factors, the forest types were divided into three classes on the probability that state or regional carbon sequestration programs would be likely to impact forest management (Table 10).

As a general rule, the average annual carbon sequestration impact from changing forest management is quite low (Table 10). Lengthening harvest rotations, thinning and weeding for improved species adaptation and forest health, inter-planting to achieve optimum stand density, and fertilization all can change forest growth dynamics, but the region's forest types are fairly slow-growing, and changing management does not impact the annual change in standing biomass rapidly. The result is fairly low estimates of potential annual impact from forest management. The large area involved, almost 10 million acres in the "high" and "medium" categories, result in fairly significant estimates of potential impact. The bottom line of 1.5 to 2 $TgCO_2e$/yr, would represent a change of some 3-5 percent in the region's currently estimated annual forest sequestration (Table 8).

- **Table 10. Non-federal forest land, Big Sky Region, with estimates of the management opportunities for increasing carbon sequestration**.

		Management Opportunity*		
Species Group	1000 Acres	High	Medium	Low
Ponderosa Pine	2,585.9	2,585.9		
Other Pines	759.0		759.0	
Douglas-fir	3,631.3	3,631.3		
Fir-spruce	1,326.0		1,326.0	
Mixed conifers	1,319.1		1,319.1	
Pinyon/juniper	5.4			5.4
Cottonwood	133.2			133.2
Western Hardwood	706.2			706.2
Non-stocked	434.9			434.9
Total	10,901.0	6,217.2	3,404.1	1,279.7
* Rated by authors on the basis of the likelihood that landowners will manage them for long-term timber or carbon sequestration goals.				
tCO_2e/acre/year		0.25	0.1	0
Sequestration Opportunity		1,554.3	340.4	-
Total Annual Sequestration Opportunity (1000 tCO_2e)				1,894.7

• Agroforestry Opportunities

• *Field Windbreaks*

The analysis for field windbreak needs and opportunities is based on data from the 1997 NRI (USDA-NRCS 2000). We used the NRI to identify all non-irrigated cropland with an erosion index (EI) of 5 or higher that did not have windbreaks or cross-wind stripcropping established in 1997 (Table 11). These lands may have other erosion control practices such as conservation tillage, vegetative soil traps, or other herbaceous wind barriers, but there is a good indication that windbreaks would be a helpful addition to the wind erosion control strategy on many of them, and the carbon sequestration impacts would be an added benefit to the landowners and the environment. (Soils with EI values over 5 are erodible, and USDA classifies those with EI values over 8 as highly erodible (USDA-NRCS 2000)).

For those erodible dry croplands, we estimated that field windbreaks occupying 5% of the cultivated surface area would be a realistic goal for the establishment of needed windbreaks (Brandle et al., 1992a). At an average one-row windbreak width of 16½ feet, such a windbreak would occupy 2 acres per mile. At 8 to 10-foot spacing between trees, there would be 530 to 660 trees per mile. The carbon sequestration rate was estimated at 3 tCO_2e per acre per year (Table 11, see Table 12 for representative species). No credit was given for the emissions reductions inherent in the soil conservation effect of windbreaks, or the reduction in cultivated area and associated fuel and fertilizer use, etc. What is clear, however, is that field windbreaks offer significant ancillary environmental benefits in addition to their impact on carbon sequestration (Brandle et al., 1992b). Work is currently underway at the University of Nebraska to develop more definitive tables of sequestration in windbreaks, and could become available for use in the near future (Table 12, Zhou and Brandle, unpub.).

• Table 11. Croplands with a wind erosion index (EI) greater than 5, and annual carbon sequestration from establishing windbreaks on 5 percent of those that lacked stripcropping or windbreaks in the 1997 NRI.

Category	Idaho	Montana	South Dakota	Wyoming	Big Sky
			1,000 acres		
Cultivated Cropland, Wind EI > 5	2,823.1	12,350.9	3,584.9	870.1	19,629.0
Dry Cultivated (DC) Cropland, EI > 5	172.8	11,534.1	3,535.0	467.0	15,708.9
DC Cropland, EI > 5, with no Stripcropping	164.6	8,711.1	3,452.9	217.9	12,546.5
DC Cropland, EI > 5, with no Stripcropping or Windbreaks	164.6	8,682.9	2,818.3	217.9	11,883.7
Windbreaks on 5%	8.2	434.1	140.9	10.9	594.2
tCO_2e/acre/year	3.0	3.0	3.0	3.0	3.0
$TgCO_2e$/year	0.025	1.3	0.42	0.033	1.78

Table 12. Estimated sequestration rates for 3 common windbreak species.

Species	KgC/tree/yr	Lb/tree/yr	Trees/acre	tC/ac/yr	tCO_2e/ac/yr
Green Ash	5	11.02	264	1.32	4.85
Austrian Pine	4	8.82	264	1.06	3.88
Eastern Redcedar	1.5	3.31	330	0.50	1.82

After Zhou and Brandle, unpub.

- ***Riparian Forest Establishment***

Many of the private lands with soils adapted to forest establishment are in riparian areas, particularly in the drier areas of the region. A close inspection of the forest-growing soils (Figure 4) shows many linear patterns, particularly with the western hardwood types. These patterns outline stream valleys for the most part, and the forest opportunities there are significant. The ancillary environmental benefits to water quality and wildlife habitat are also important in these riparian areas. Table A-3 indicates 1.5 million acres of western hardwood sites in the region, which is one indicator of the riparian forest opportunity. Yields will respond in these areas due to favorable soil and moisture conditions, leading to an estimated carbon sequestration gain of 2 – 2.5 $TgCO_2e$ per year if one-half of these lands were planted to species such as cottonwood, willow, and other adapted local species with yields of around 3 tCO_2e per acre per year.

• Biomass Energy Opportunities

The use of biomass as a substitute for fossil fuel (primarily coal) is an excellent opportunity to replace fossil carbon emissions with renewable fuels that grow and sequester carbon in the same general time as the emissions occur. Thus, the use of biomass is often referred to as an offset for fossil emissions (Klass 1998; Sampson et al. 1992).

Biomass for fuel can be harvested from existing forests, particularly those that are overstocked and need thinning. Thinning that removes small trees and ladder fuels can be a major contributor to helping these forests become less susceptible to uncharacteristic wildfires, improving forest health, and opening up overcrowded forests for additional biological diversity (Sampson et al. 2001).

While it is possible to build power plants that rely solely on biomass fuels, another opportunity lies in co-firing biomass in existing coal-burning power plants. Research indicates that firing with up to 10 percent biomass is technically feasible and provides reductions in pollution emissions, including carbon dioxide emissions (Payette and Tillman 2004). Biomass, while having several environmental advantages, can also be used effectively in co-firing despite supply variations due to things like annual weather or harvest conditions. The coal plant is not dependent on the biomass, so if a yield shortfall occurs, the plant is not forced to cut back on production.

One of the key economic limitations in biomass energy production is the transportation costs involved in moving heavy, low-value fuels large distances. For that reason, many authors suggest that a radius of about 50 miles is reasonable in calculating the region that can feasibly supply biomass fuel to an existing power plant (Klass 1998).

Figure 5 shows the existing coal-fired power plants in the Big Sky Region, according to the 2002 version of the eGRID database produced by the Environmental Protection Agency (USEPA 2003). A GIS analysis estimated the 1992 land cover/land use within a 50-mile radius of each plant. This analysis included federal lands, because federal lands in the region are in serious need of thinning to restore forest health and fire adaptability (Sampson et al. 2001).

Growing short-rotation crops like hybrid poplar or willow on agricultural land produces biomass yields in the range of 4-10 dry tons per acre per year (Tuscan 2000). Switchgrass should produce about 4 dry tons per acre per year on dry croplands in eastern South Dakota (Graham et al. 1996). Limited rainfall will preclude its growth west of there, according to the ORNL data (Graham et al. 1996). Thinning overcrowded forests produces one-time biomass yields of around 15 tons per acre

(Sampson et al. 2001). Although heat values vary considerably with the moisture content of biomass fuel, we assumed that 1 bone dry ton (BDT) of biomass would produce 1 MWH of electricity. Thus, around 8,700 BDT of biomass is needed to produce 1MWH for a year.

There is a significant difference in these biomass sources, however. Farm-produced biomass (switchgrass or short-rotation woody crops such as hybrid poplar) should yield around 4 tons per acre per year on a sustained basis. Thinning overcrowded forests is largely a one-time biomass removal, since converting the forests to a more sustainable condition will result in fewer small and uneconomic stems in the future (Sampson et al. 2001). There will be future production that may need removal by mechanical means, but the average per-year production rate will be slow. Thus, a power plant dependent on forest thinning needs an available acreage that is some 25-30 times larger than what is needed for its annual consumption.

Table 12. Estimates of land required, land available, and proportion needed to provide biomass sufficient for co-firing to replace 10% of the current MWh produced by coal-burning power plants in the Big Sky Region.

Plant No.	State	Name	2000 annual coal net generation (MWh)	Biomass to replace 10% of MWh[1] (BDT)	Land Required		Land Available		Proportion Needed	
					Crop-land[2]	Forest[3]	Cropland[4]	Forest[5]	Crop-land	Forest
1	ID	AMALGAMATED SUGAR CO LLC NAMPA FACTORY	42,436.9	4,244	1,061	283	403,505	317,587	0%	0%
2	ID	THE AMALGAMATED SUGAR CO LLC	28,238.3	2,824	706	188	897,829	22,657	0%	1%
3	MT	COLSTRIP + COLSTRIP ENERGY LP	14,715,206.9	1,471,521	367,880	98,101	318,606	538,893	115%	18%
4	MT	CORETTE	1,161,874.8	116,187	29,047	7,746	1,134,961	393,154	3%	2%
5	MT	LEWIS & CLARK	323,757.0	32,376	8,094	2,158	1,810,108	25,179	0%	9%
6	SD	BEN FRENCH	166,314.0	16,631	4,158	1,109	320,936	1,104,604	1%	0%
7	SD	BIG STONE	3,504,262.0	350,426	87,607	23,362	1,171,048	513	7%	4554%
8	WY	DAVE JOHNSTON	5,661,946.0	566,195	141,549	37,746	10,206	117,212	1387%	32%
9	WY	GENERAL CHEMICAL + JIM BRIDGER	16,380,196.4	1,638,020	409,505	109,201	7,671	13,848	5338%	789%
10	WY	OSAGE	245,439.0	24,544	6,136	1,636	48,978	349,676	13%	0%
11	WY	LARAMIE RIVER 1 + LARAMIE RIVER 2 & 3	12,440,471.0	1,244,047	311,012	82,936	495,047	222,950	63%	37%
12	WY	NAUGHTON	5,311,532.0	531,153	132,788	35,410	26,470	241,123	502%	15%
13	WY	NEIL SIMPSON + NEIL SIMPSON II + WYODAK	3,534,324.0	353,432	88,358	23,562	64,957	71,524	136%	33%

[1] Estimated on the basis of 1 BDT yielding 1 MWH of power.
[2] Estimated sustainable yields of 4 BDT biomass per acre per year with grass or woody crops
[3] Estimated one-time yield of 15 BDT per acre of otherwise non-merchantable wood during thinning.
[4] Total row crops, small grains, and fallow from NCLD within 50 miles of plant.
[5] Total evergreen forest within 50 miles of plant. (Omits deciduous and mixed forests as unlikely sources.)

This analysis suggests that there are significant differences between locations as to the possibility of co-firing biomass from agricultural or forest sources. Some (i.e. 1 and 2) are located in the midst of irrigated agricultural areas where production costs might be too high to support biomass production. Forest resources are plentiful within 50 miles, and may be a better opportunity. Some plants (i.e. 3,8,9,11,12, and 13) would clearly be too large to be considered for agricultural inputs since they are so large in comparison with the available cropland nearby. Others (3,7,8,9,11,12, and 13) would overwhelm surrounding forest resources because of their size. Some of the smaller plants (i.e. 1,2,4,5,6, and 10) may be potentials for consideration as a co-firing opportunity.

Those six plants were responsible for annual emissions of 2.5 $TgCO_2e$ in 2000, according to the eGRID data, so if co-firing were feasible on all of them, a reduction of some 0.25 $TgCO_2e$ per year may be realized. While it is unlikely that all of this could be realized by co-firing, the estimate could also under-estimate the future opportunities if the current trend toward building new fossil-fired power plants were to include biomass co-firing as part of initial design, or if new technologies or economic conditions make construction of dedicated biomass plants feasible.

Figure 5. Existing coal-fired power plants, with 50-mile radius indicated.

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Appendix A. The Geographic Information System (GIS) Analysis for Afforestation Opportunity

Data Sources

Three primary data sources were used in this analysis. This included a vector layer containing the location of Federal lands, the U.S. Geological Survey National Land Cover Data (NLCD) raster coverages and State Soil Geographic (STATSGO) vector data. These layers were downloaded via the Internet from federal sources. Each layer was in the same projection system and measurement units (Albers Conical Equal Area, meters).

To obtain the location of Federal lands within the scope of the project, the *Federal Lands and Indian Reservations* vector file was downloaded from www.nationalatlas.gov. This is a federal website supported by the United States Department of the Interior that provides a platform to download federally produced GIS data sets. This layer contains polygons of the federally owned or administered lands throughout the United States. For the purposes of this study it was determined that federal lands were not eligible for afforestation, but Indian reservations could be. Therefore, the Indian Reservations were removed from this layer before it was used as a filter to remove Federal land.

The USGS National Land Cover Data (NLCD) was downloaded by state from *http://www.usgs.gov*. This data was derived from Landsat satellite TM imagery (circa 1992) and is provided in a Geo-TIFF format with a 30-meter resolution. Each cell contains a numeric value that represents a certain land cover based upon the NLCD Classification System.

State Soil Geographic (STATSGO) data were downloaded by state from http://www.nrcs.usda.gov. This vector layer and its related tabular data provide locations of current and potential forests by forest type based on soil types and descriptions. Use of this layer helps identify areas containing soils suitable for growing trees.

Scale/Accuracy

Data accuracy is always a concern when performing spatial analyses using multiple data layers from multiple sources. Data accuracy and scale of each layer was considered before the analysis was performed.

According to the metadata of the Federal Lands data, it was produced for analysis “at scales appropriate for 1:2,000,000-scale data.” This is a small scale, so accuracy would be a concern if this data were used in analyses conducted at much larger scale. However, this analysis was conducted at the state level and, given the large size of the western states within the scope of our project, the use of this federal lands layer was considered appropriate.

The NLCD layers were produced with a 30 by 30 meter cell-size (or resolution). Therefore, each cell represents 900 square meters or 0.222 acres. These data were produced with the highest level of detail of any data used in this analysis and were appropriate for our state-level analysis.

According to its metadata, STATSGO data was “designed primarily for regional, multistate, river basin, state, and multi-county planning, managing and monitoring,” so was considered appropriate for this analysis.

Procedures

The GIS analysis was conducted in several steps. The first step determined existing areas on non-federal lands that would be available for afforestation on the basis of current use (mainly cropland or pasture). The second step determined soil and climate situations suitable for afforestation based on the STATSGO data. The third step combined the outputs of the first two steps to compute a *Final Suitability* layer. Finally, the tabular data were converted from acres of potential forest into estimates of sequestration by primary forest groups, based on projected average annual yields of timber converted into its equivalent carbon dioxide sequestration impact.

Step 1- NLCD land cover on non-federal lands

The Federal Lands layer was first clipped to the Big Sky states within the scope of the project: Idaho, Montana, Wyoming and South Dakota. The polygons associated with the Indian Reservations and null values were then removed from the resulting federal land layers, since the Indian Reservations are considered potential cooperating lands for the purposes of this study. Each state-clipped federal land layer was converted to a raster grid with the same resolution (30m) and extent of the NLCD layer associated with each particular state. The resulting grids were then reclassified, so that the cells containing federal land held a value of zero and all other cells contained a value of one.

A raster calculation within each state multiplied the reclassified federal lands grids and the NLCD grids. The resulting grids contained a value of zero where federal lands exist and the previous value of the NLCD classification in all other areas.

Not all NLCD classes are available for afforestation (Table A-1). Areas already classified as forests, and areas such as urban, wetlands, etc., were excluded from the analysis. In order to isolate the suitable areas, the non-federal NLCD grids were reclassified to remove the cells that contained unsuitable values. The result provided maps and area estimates of the non-federal land within each state that is potentially available for afforestation based on NLCD classifications (Figure 4). (Note: this map contains areas unsuited for forests due to soil and climate conditions.)

Table A-1. NLCD classes identified as suitable/non-suitable for afforestation on the basis of 1992 land use or cover.

Suitable				Non-Suitable	
Code	Description	Comments		Code	Description
33	Transition Areas	Poss. Clearcuts		11	Water
51	Shrubland	good on suitable soils		12	Perennial Ice/Snow
61	Orchards/Vineyards/Other			21	Low Intensity Residentail
71	Grasslands/Herbaceous	good on suitable soils		22	High Intensity Residentail
81	Pasture/Hay			23	Commercial/Industrial/Transporation
82	Row Crops			31	Bare Rock/Sand/Clay
83	Small Grains			32	Quarries/Strip Mines/ Gravel Pits
84	Fallow			41	Deciduous Forest
				42	Evergreen Forest
				43	Mixed Forest
				85	Urban/Recreational Grasses
				91	Woody Wetlands
				92	Emergent Herbaceous Wetlands

Step 2- STATSGO suitability

For step two, the STATSGO data layers and their associated tabular data were analyzed for each state. To determine areas that are suitable for growing trees the 'woodland' table was joined to the base STATSGO layers. By doing so, the attributes identify polygons with soil and climate characteristics appropriate for growing trees. Only these areas in each state were included in further analysis.

The 'woodland' table also provides a native forest type based upon the soil and climate features. To simplify our analysis, we grouped the STATSGO forest types into nine groups (Table A-2). The federal lands were then removed, by clipping the forest group polygons to the non-federal lands layer created from the original Federal lands data. The resulting layer contained the areas of non-federal land that are suitable for afforestation based upon the STATSGO data (Figure 4).

Table A-2. Grouping of primary species in STATSGO soils data into major forest type groups.

Code	Group	Species included in Group
1	Ponderosa Pine	Ponderosa pine
2	Western White Pine	Western White Pine
3	Other Pines	Lodgepole pine, limber pine
4	Douglas-fir	Douglas-fir
5	Spruce-fir	Engelmann spruce, subalpine fir, white spruce, mountain hemlock
6	Mixed conifers	Grand fir, western larch, western redcedar
7	Pinyon/juniper	Utah juniper, oneseed juniper, pinyon, singleleaf pinyon
8	Cottonwood	Black cottonwood, narrowleaf cottonwood, plains cottonwood, eastern cottonwood
9	Western Hardwood	Bur oak, white oak, quaking aspen, silver maple

Step 3- Final Suitability

The final map layer identified areas available for afforestation by the NLCD (current cover is not forest) and potentially suited to forests according to STATSGO. These layers were combined by converting the STATSGO suitability layers to grids with the same resolution (30m) and extent of the NLCD suitability layers associated with each particular state. Each cell of the new STATSGO grids contained the forest type code (created in step 2) for the potential forest spatially associated with each particular cell.

This forest-type grid was then reclassified so that all cells containing a forest-type were given a value of 1 and all other cells contained a value of zero. A raster calculation was then performed between this reclassified grid and the NLCD suitability grid. This created a new layer that contained the NLCD codes in the areas determined suitable for growing trees by the STATSGO data.

In order to determine area estimates of potential afforestation by forest types, the original forest type grid values need to be incorporated with the NLCD values. This gives the area of potential afforestation by 1992 land cover and potential forest type. Another raster calculation is done between the suitable soil forest types and the original NLCD grid that contained the non-forest values.

Unfortunately, these grid values could not be simply added together, because the results would contain integers with potentially non-unique or overlapping values. In order to maintain the integrity of both the NLCD values and the forest group values, NLCD values were multiplied by 100 and then the forest type values were added to that number. The result was a grid with each cell identified by a four-digit number. The first two digits referred to the NLCD code associated with that cell, the third number was a zero (meaning nothing, but a place holder or separator) and the fourth number contained the forest type code associated with that cell. (Thus, a grid cell with an attribute of 7101 indicated an area of current grassland with the soil and climate potential to grow ponderosa pine.)

Step 4. Developing afforestation and carbon sequestration estimates

The final suitability grid was entered into a spreadsheet model and analyzed for potential afforestation acreage estimates within each state. Since each grid represents 900 m^2, multiplying the number of grids by 900 and dividing the result by 4047 converted the area to acres. A cross-tabulation produced a table showing current cover and potential forest type. These estimates were developed for each state and rounded to 1,000 acres to avoid the appearance of high precision. Table A-3 gives the results for the 4-state Big Sky Region – an estimate of some 34.3 million non-federal acres that are not now in forest, but that are biologically capable of supporting forest growth.

Table A-3. Area potential for afforestation, Big Sky Region

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood	Total
					1,000 acres					
Transition Areas	11.0	19.5	4.4	28.9	7.0	131.7	0.0	1.1	0.0	**203.6**
Shrubland	1,372.8	64.2	610.6	819.4	152.6	206.0	2,477.4	1,607.5	524.3	**7,834.8**
Orchards/Vineyards/Other	-	0.3	-	2.5	-	0.0	-	-	-	**2.8**
Grasslands/Herbaceous	6,807.4	72.6	1,641.9	2,233.8	312.8	165.3	1,627.7	5,130.3	466.7	**18,458.4**
Pasture/Hay	378.2	36.7	74.8	130.0	1.8	68.8	212.7	685.0	217.6	**1,805.6**
Row Crops	17.8	0.2	3.9	5.8	0.2	0.1	89.2	184.8	210.8	**512.8**
Small Grains/Fallow	1,379.9	108.5	104.4	480.5	0.8	198.6	98.9	3,007.9	118.6	**5,498.2**
TOTAL	**9,967.0**	**302.0**	**2,440.0**	**3,701.0**	**475.3**	**770.5**	**4,505.9**	**10,616.6**	**1,538.1**	**34,316.3**

Table A-4. Estimated average yields for major forest types, Big Sky Region.

Code	Group	Average Yield	Notes	lbs. total CO_2e per ft^3 timber*
		ft^3/acre/year		
1	Ponderosa Pine	25	Birdsey Table 32	100.4
2	Western White Pine	25	Birdsey Table 32	100.4
3	Lodgepole pine	27	Birdsey Table 34	111
4	Douglas-fir	29	Birdsey Table 31	88.4
5	Fir-spruce	39	Birdsey Table 33	92.5
6	Mixed conifers	29	Birdsey Table 31	92.5
7	Pinyon/juniper	10	Author's estimate	111
8	Cottonwood	30	Birdsey Table 25	126.9
9	Western Hardwood	50	Birdsey Table 26	126.9

*Factors for lbs. C per cubic foot and multiplier to total tree C taken from Birdsey (1996). Multiplied by 3.67 to produce CO_2e.

The final steps in the calculation were to estimate forest yields in terms of carbon sequestration. Yield estimates (in average ft^3 of timber per acre per year for a 50-year growing period) were taken from Birdsey (1996) where available, and estimated by the authors for species not covered in Birdsey (Table A-4). If improved local data are found, they can be readily substituted into the spreadsheet model for updating.

The estimated yields were then multiplied times the areas estimated in Table A-3 (in thousands of acres), and the product multiplied by the pounds of total CO2e (Table A-4), then divided by 2204 to convert to thousands of tonnes, and divided again by 1000 to convert to million metric tonnes of CO_2e ($TgCO_2$e). The results were the biological estimates. (Table A-5).

Table A-5. Estimated annual biological carbon sequestration from afforestation opportunities, Big Sky Region.

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood	Total
					$TgCO_2e$ per year					
Transition Areas	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
Shrubland	1.6	0.1	0.8	1.0	0.2	0.3	1.2	1.9	1.1	8.1
Orchards/Vineyards/Other	-	0.0	-	0.0	-	0.0	-	-	-	0.0
Grasslands/Herbaceous	7.7	0.1	2.2	2.6	0.5	0.2	0.8	8.9	1.3	24.4
Pasture/Hay	0.4	0.0	0.1	0.2	0.0	0.1	0.1	1.2	0.6	2.7
Row Crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	1.0
Small Grains/Fallow	1.6	0.1	0.1	0.6	0.0	0.2	0.0	5.2	0.3	8.2
TOTAL	11.3	0.3	3.3	4.3	0.8	0.9	2.3	17.4	4.0	44.6

Note: All estimates smaller than 0.05 Tg rounded off to zero.

Table A-6 estimates the impacts of an afforestation program based on current cover and potential forest. These reductions were made as an author's estimate, and could be changed on the basis of regional expert review and comment or further studies such as a supply curve related to possible future carbon credit prices. Such a study was beyond the scope of this paper.

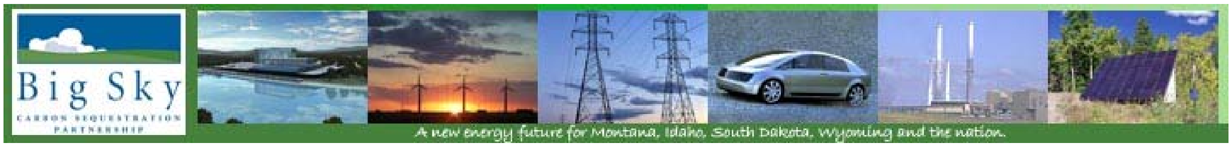
Table A-6. Estimated potential for conversion, as a percent of suitable land.

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood
					percent				
Transition Areas	10%	10%	10%	10%	0%	10%	0%	10%	10%
Shrubland	10%	10%	10%	10%	0%	10%	0%	10%	10%
Orchards/Vineyards/Other	2%	2%	2%	2%	0%	2%	0%	2%	2%
Grasslands/Herbaceous	10%	10%	10%	10%	10%	10%	0%	10%	10%
Pasture/Hay	10%	10%	10%	10%	10%	10%	0%	10%	10%
Row Crops	10%	10%	10%	10%	0%	10%	0%	10%	10%
Small Grains/Fallow	20%	20%	20%	20%	0%	20%	0%	20%	20%

The final estimate (Table A-7) was derived by multiplying the area suitable for conversion (Table A-3) times the percentage factors in Table A-6. The result was an estimate of potential annual carbon sequestration in the range of 5 $TgCO_2e$ per year in the Big Sky Region.

Table A-7. Estimated average annual carbon sequestration from afforestation opportunities, Big Sky Region

Potential Forest → / Current Cover ↓	Ponderosa Pine	Western White Pine	Other Pines	Douglas-fir	High Elev. Conifers	Other Conifers	Pinyon/ Juniper	Cotton-wood	Western Hardwood	Total
	$TgCO_2e$ per year									
Transition Areas	0.0	0.0	0.0	0.0	-	0.0	-	0.0	0.0	0.0
Shrubland	0.2	0.0	0.1	0.1	-	0.0	-	0.2	0.1	0.7
Orchards/Vineyards/Other	-	0.0	-	0.0	-	0.0	-	-	-	0.0
Grasslands/Herbaceous	0.8	0.0	0.2	0.3	0.1	0.0	-	0.9	0.1	2.4
Pasture/Hay	0.0	0.0	0.0	0.0	0.0	0.0	-	0.1	0.1	0.3
Row Crops	0.0	0.0	0.0	0.0	-	0.0	-	0.0	0.1	0.1
Small Grains/Fallow	0.3	0.0	0.0	0.1	-	0.0	-	1.0	0.1	1.6
TOTAL	1.3	0.0	0.3	0.5	0.1	0.1	-	2.3	0.4	5.0



Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 8: Report on Evaluation of Terrestrial Sinks

Attachment B: Rangeland Terrestrial Sinks Forestry

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Big Sky Partnership
The Northern Rockies and Great Plains Regional Carbon Sequestration Partnership_MLRAs
Appendix 1

Summary of MLRA Attributes for Montana, Idaho, and South Dakota

% of region	MLRA	NAME	Area km^2	Area mi^2	States
	10	Upper Snake River Lava Plains and Hills (10A proposed)	44,870	17,330	Idaho and Oregon
	11	Snake River Plains (11A and 11B proposed)	35,250	13,610	Idaho and Oregon
	12	Lost River Valleys and Mountains	16,380	6,320	Idaho
	13	Eastern Idaho Plateaus	21,010	8,110	Idaho
	43	Northern Rocky Mountains	282,650	109,130	Idaho, Montana, Oregon, Washington, and Wyoming
	44	Northern Rocky Mountain Valleys	32,320	12,480	Idaho, Montana, and Washington
1/2 north	46	Northern Rocky Mountain Foothills	52,070	20,110	Montana and Wyoming
	52	Brown Glaciated Plain	52,110	20,120	Montana
2/3 west	53 A	Northern Dark Brown Glaciated Plains	30,740	11,870	Montana and North Dakota
1/3 south	53 B	Central Dark Brown Glaciated Plains	44,980	17,370	North Dakota and South Dakota
	53 C	Southern Dark Brown Glaciated Plains	13,870	5,350	South Dakota
1/3 south	54	Rolling Soft Shale Plain	58,100	22,430	Montana, North Dakota, and South Dakota
	55 C	Southern Black Glaciated Plains	20,240	7,810	South Dakota
	58 A	Northern Rolling High Plains; Northern Part	105,620	40,780	Montana and Wyoming
1/2 south	58 D	Northern Rolling High Plains; Eastern Part	10,000	3,860	North Dakota and South Dakota
	60 A	Pierre Shale Plains and Badlands	23,600	9,110	Nebraska, South Dakota, and Wyoming
	60 B	Pierre Shale Plains; Northern Part	5,600	2160	Montana
	61	Black Hills Foot Slopes	8,400	3,240	South Dakota and Wyoming
	62	Black Hills (home of Rocky Racoon)	9,200	3,550	South Dakota and Wyoming
	63 A	Northern Rolling Pierre Shale Plains	29,610	11,430	South Dakota
1/2 north	64	Mixed Sandy and Silty Tableland	28,400	10,970	Nebraska, South Dakota, and Wyoming
1/3 north	66	Dakota-Nebraska Eroded Tableland	12,400	4,800	Nebraska and South Dakota
1/2 west	102 A	Rolling Till Prairie	38,600	14,900	Minnesota and South Dakota
	102 B	Till Plains	43,790	16,910	Iowa, Minnesota, South Dakota, and Nebraska

Land use

3/5 federal, 90% range, 5% (along streams) irrigated for potatoes, small grains, pasture
1/2 federal - mostly range, annual grasses have invaded much of the rangeland, 1/4 irrigated potatoes
mostly all federal, high mountain slopes are forested, grass - shrubs on slopes and valleys are grazed
1/4 federal, 1/2 range, 1/4 dryfarm - wheat, ~10% irrigated -alfalfa, ~10% forested mt. slopes
Nearly all this area is federally owned, less than 2% cropped, Mostly forest -lumbering and mining
farms and ranches.1/2-1/3 native range (grass-shrub) , 1/3 irrigated - Potatoes, sugar beets, and peas
1/5 federal, 1/2 range of short and mid grass, 1/5 dryfarm (northeast side) wheat
Most of the land in the east is in range/ one-half of the total area is cropped (west) spring wheat
1/2+ dryland farm mostly spring wheat / sloping soils are in native grass range
1/2+ is dryfarmed -.winter wheat chief cash crop. Corn, grain, sorghum, oats, and alfalfa also grown sloping soils are in range.
2/3 dryland Spring wheat is the chief crop / flax, oats, barley, and alfalfa also grown / more sloping soil in native grass range
1/3 dry frarmed wheat/ 3/5 native grass and shrub grazed /
70% dryland farm.- Corn, small grains, and alfalfa main crops / 1/4 native range and tame pasture alone steeper slopes
Most in native grasses and shrubs grazed by cattle and sheep / rest dryland farming in wheat / sugar beets, alfalfa along river
4/5 ranches in native grasses and shrubs grazed by cattle and sheep 10-15% dryland wheat and alfalfa
Most of it is in native grasses and is used for grazing livestock / Badlands National Monument is a large tourist attraction.
Most of it is rangeland used for grazing livestock
Native grass is used mainly for livestock grazing. / the less sloping parts are farmed mainly to alfalfa and small grains
Black Hills National Forest used for mining, recreation, and hunting./Some timber / summer grazing
area is used mainly for livestock production and cash-grain farming / Dry-farming soils not suited to cultivation is destroying the native grassland
3/5 rangeland cattle / 1/3 crop cash grain and winter wheat / corn and sugar beets are irragated crops
Most of this area is in native grasses that are grazed by cattle
70 % is cropland Corn, soybeans, alfalfa, flax, spring wheat, and oats are the principal crops /
70% cropland Corn, soybeans, grain sorghum, alfalfa, and oats are the principal crops./ Urban development is expanding

Elevation	Precipitation	Temperature	Freeze free days
400 to 2,000 m	250 to 500 mm.	4 to 13 C	60 to 165 days
600 to 1,700 m	175 to 325 mm	5 to 11 C	90 to 170
1,400 m valleys to 3,100 m mt.crests.	175 to 275 mm valleys 625 mm mountains	3 to 7 C valleys	80 to 110 days valleys
1,400 to 2, 000 m plains and plateaus	300 to 625 mm	4 to 7 C	50 to 120
400 to 2,400 m	625 to 1,525 mm	2 to 7 C	45 to 120 days
600 to as much as 2,100 m	300 to 400 mm in most of the area	4 to 8 C	100 to 120 days
1,100 to 1,800 m in north	300 to 500 mm	6 to 7 C	90 to 125 days
600 to 1,400 m	250 to 375 mm	3 to 7 C	100 to 130
600 to 900 m	300 to 350 mm	3 to 5 C	110 to 125 days
400 to 700 m	425 to 475 mm	7 to 9 C	130 to 150 days
500 to 600 m	350 to 425 mm	1 to 7 C	110 to 130 days
500 to 1100 east to west	325 to 450	4 to 7 C	110 to 135
400 to 600	50 to 525 mm	7 to 9 C	l30 to 155 days
900 to 1,800 m east to west	300 to 500 mm	4 to 7 C.	120 to 140 days
700 to 1,000 m east to west	325 to 375 mm	4 to 7 C	120 to 130 days.
800 to 1,100 m	300 to 400 mm	7 to 9 C	130 to 150 days
900 to 1,000 m on uplands	300 to 350 mm	4 to 7 C.	110 to 125 days
900 to 1,200 m	375 to 450 mm	6 to 9 C	110 to 140 days
1,100 to 2,000 m	450 to 650 mm	3 to 7 C	80 to 130 days
400 to 500 m bottom 500 to 900 m upland	375 to 475 mm	7 to 9 C	130 to 160 days
900 to 1,200 m	375 to 450 mm	7 to 9 C	~140 days.
600 to 900 m	450 to 550 mm	8 to 10 C	130 to 160 days
300 to 400 m lowlands 400 to 500 m uplands	500 to 600 mm	6 to 9 C	120 to 140 days
300 to 400 m bottpm 400 to 500 m uplands	500 to 650 mm	9 to 11 C	135 to 165 days

Water

supplies small mostly untapped - low to moderate precipitation is adequate for dryfarming
Ground water is plentiful around major rivers - scarce on sites far from the major rivers
moderate precipitation for grass/shrubs on slopes, valleys depend on the streamflow
limited amount precip. for dryfarming and grazing
Moderate precipitation and many perennial streams and lakes provide ample water
Perennial streams principle source.
Presipitation too low for crops in some parts/ adequate for grain and forage in others
Most of the area depends on precipitation for water for range and crop
mostly moisture is inadequate for good crop production /
Most years, moisture is inadequate for maximum crop production.
most years moisture is inadequate for maximum crop production
most years moisture is inadequate for maximum crop production
most years precipitation is inadequate for maximum crop production
low and erratic precipitation is the principal source of water for agriculture.
low and erratic precipitation is the principal source of water for agriculture
limited precipitation, production of cultivated crops is marginal.
limited precipitation, the growing of cultivated crops is marginal
Most of the soils suitable for cultivation are dry during much of the growing season.
Precipitation, perennial streams, springs, and shallow wells provide adequate water for domestic use
In most years precipitation is inadequate for maximum plant growth
Most of the area depends on the rather low and erratic precipitation for water
limited precipitation makes farming a risk
In many years precipitation is inadequate for maximum production
Precipitation is the principal source of moisture for crops some year it is inadequate

Irrigation

Streams provide enough irrigation water along the major valleys
ground water around major rivers is used extensively for irrigation
about 1% mostly for hay and pasture
Ground water is scarce except near the large streams
Streams and reservoirs supply water to adjoining MLRA's for irrigation
Ground water is abundant some used for irrigation
1-2% irrigated (valleys) major rivers provide most water for irrigation
The Milk River provides irrigation water to its flood plains
only a small acreage is irrigated by the Missouri river
irrigated cropland is mostly along a narrow band of the Missouri river
only a small acreage is irrigated around the Missouri river
irrigation is available in quantity only from the Missouri River
Water from reservoirs on the Missouri River is used for irrigation
Strips along the Yellowstone River and main tributaries are irrigated.
no irrigation some wells provide water for stock
Few places have shallow-water wells for domestic use.
Water for livestock comes mainly from runoff that flows into dams
Domestic wate mostly from f streams, shallow wells, and springs.
moisture is adequate for normal plant growth. No irrigation
reservoirs on the Missouri River are on the eastern border
Ground water is scarce and of poor quality in most of the area
The Niobrara River is the only perennial stream.
Shallow wells iand small ponds principle water supply for for livestock
irrigation is increasingly along major rivers

Dominat soil	Vegetation type
Xerolls and Argids moderately fine textured to fine textured	shrub-grass association
Orthids, Argids, and Orthen	shrub-grass vegetation
Orthids, Orthents, Aquolls, and Xerolls (valleys)	desert shrub, shrub-grass, and forest vegetation
Xerolls and Borolls	grass-shrub vegetation
Ochrepts and Andepts	conifer forests
Orthids, Borolls, and Argids medium to fine textured	conifer forests and grassland vegetation
Borolls, Orthents, and Fluvents medium to fine textured	grass valleys/foothills, forest higher elevations
Borolls, Orthents, Argids, and Fluvents medium to fine textured	grass land vegetation
Borolls. deep, well drained, and medium textured	natural prairie vegetation
Ustolls. They are deep, well drained, and medium textured	natural prairie vegetation
Borolls. They are deep, well drained, and medium textured	natural prairie vegetation
Borolls. moderately deep - deep, loamy and clayey	natural prairie vegetation
Ustolls. deep, well to moderately well drained, sandy to clayey.	natural prairie vegetation
Orthents, Orthids, Argids, Borolls, and Fluvents. medium to fine textured, shallow to deep	grassland vegetation
Orthents, Orthids, Argids, and Borolls. They are medium to fine textured and well drained	mixed prairie vegetation
Orthids. They are moderately deep and deep and fine textured	natural mixed prairie vegetation
Orthids and Orthents. They are moderately deep and deep and fine textured	natural mixed prairie vegetation
Orthents. They are deep to shallow and fine textured to medium textured	open grassland, forest, and savanna vegetation
Boralfs. They have a frigid or cryic temperature regime	open to dense forest vegetation
Ustolls and Orthents fine textured and very fine textured	transition between mixed and true prairie vegetation.
Ustolls. They are medium textured and formed in loess or in alluvium	mixture of short, mid, and tall grasses
Ustolls. moderately and deep, medium and moderately coarse textured	mixed prairie vegetation
Borolls. They are deep and loamy and silty	true prairie vegetation
Ustolls. They are deep and silty and loa	true prairie vegetation

Potential Vegetation
Big sagebrush and bluebench wheatgrass are dominant on moderate to deep soils
Big sagebrush, winterfat, shadscale, Indian ricegrass, needleandthread, Thurber needlegrass, and Sandberg bluegrass grow on the lower Snake River Plains
Indian ricegrass, needleandthread, shadscale, gardner saltbush, and scarlet globemallow are major species in the valleys
Bluebunch wheatgrass and big sagebrush are dominant.
western white pine, ponderosa pine, lodgepole pine, western redcedar, western larch, hemlock, Douglas-fir, subalpine fir, and spruce are common
Bluebunch wheatgrass, rough fescue, Idaho fescue, and bearded wheatgrass are the major species of the grassland
Bluebunch wheatgrass, rough fescue, Idaho fescue, and western wheatgrass are the major grass species /Ponderosa pine, Rocky Mountain juniper higher up
Bluebunch wheatgrass, needleandthread, western wheatgrass, green needlegrass, and basin wildrye are dominant species.
western wheatgrass, needleandthread, green needlegrass, and blue grama. Little bluestem / important species on sloping and thin soils
Western wheatgrass, blue grama, needleandthread, and green needlegrass are dominant species
western wheatgrass, needleandthread, green needlegrass, and blue grama   Little bluestem important on sloping thin soils
Western wheatgrass, blue grama, needleandthread, and green needlegrass are dominant species / Prairie sandreed and little bluestem on shallow soils
western wheatgrass, green needlegrass, needleandthread, and porcupinegrass. Big bluestem is an important species on soil with restricted drainage
Western wheatgrass, bluebunch wheatgrass, green needlegrass, and needleandthread are dominant species /in east littlebluestem replaces bluebunch wheatgrass
western wheatgrass, green needlegrass, blue grama, and buffalograss /Little bluestem and sideoats grama grow on shallow soils
western wheatgrass, green needlegrass, blue grama, and buffalograss /Little bluestem and sideoats grama grow on shallow soils
western wheatgrass, green needlegrass, and blue grama. Little bluestem and sideoats grama grow on shallow soils.
little and big bluestem, green needlegrass, western wheatgrass, and needleandthread / Bur oak grows throughout the area
Black Hills spruce grows at higher elevations // Kentucky bluegrass, poverty oatgrass, Richardson needlegrass, and Canada wildrye are common under story grasses
Green needlegrass, western wheatgrass, needleandthread, porcupinegrass, little bluestem, and big bluestem are the major species
Blue grama, western wheatgrass, threadleaf sedge, sideoats grama, little bluestem, prairie sandreed, switchgrass, sand bluestem, and needleandthread are the major species
Little bluestem, prairie sandreed, green needlegrass, and needleandthread are dominant species / Sideoats grama and plains muhly are important on shallow soils.
big and little bluestem, porcupinegrass and green needlegrass / Needleandthread and prairie dropseed are important species on the steeper soils
big and little bluestem, indiangrass, porcupinegrass, and green needlegrass. Needleandthread and prairie dropseed are important species on the steeper soils

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

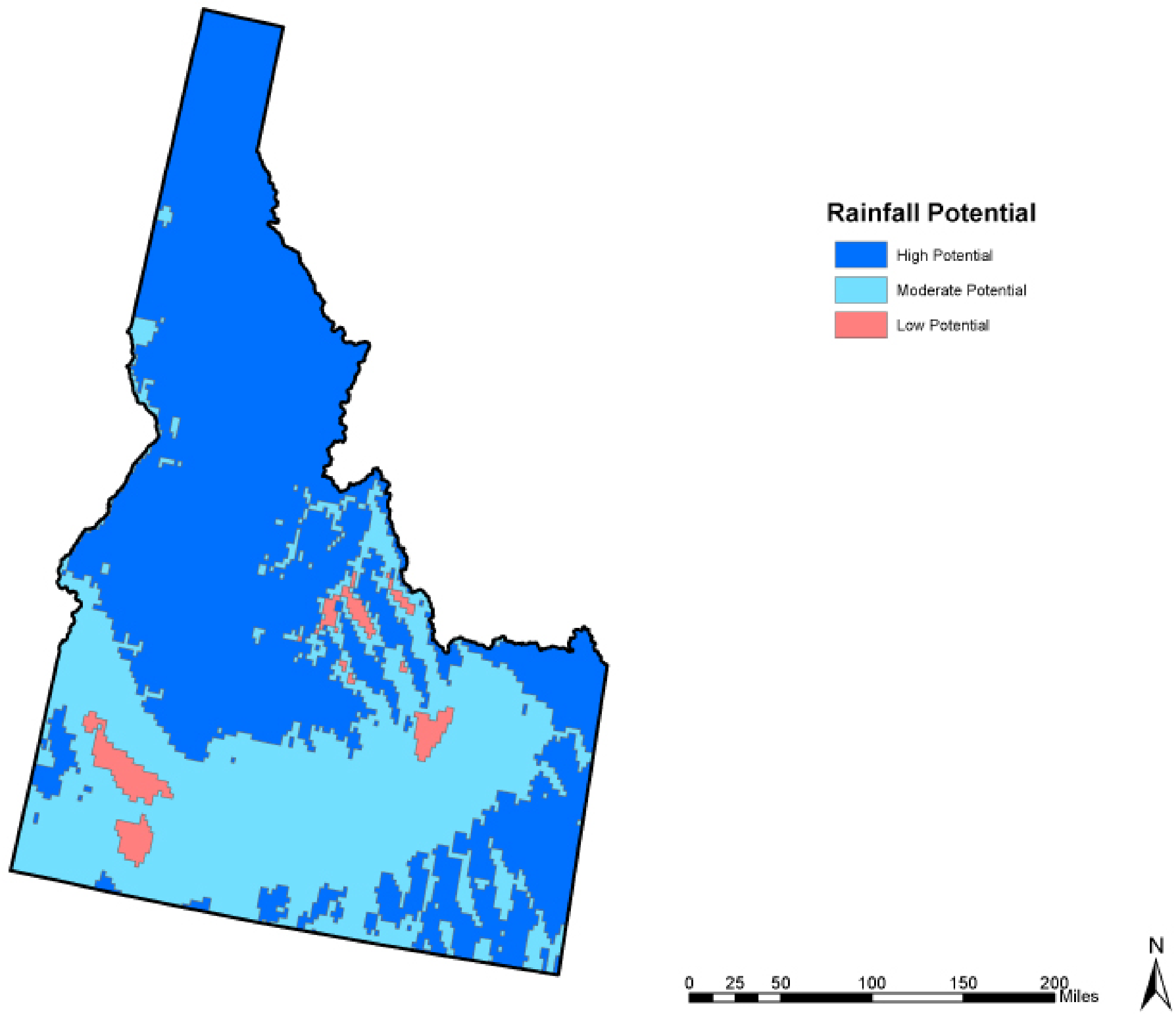


Figure 1. Spatial classification of climatic potential for Idaho. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year. Areas classified as Low Potential have between 130 and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

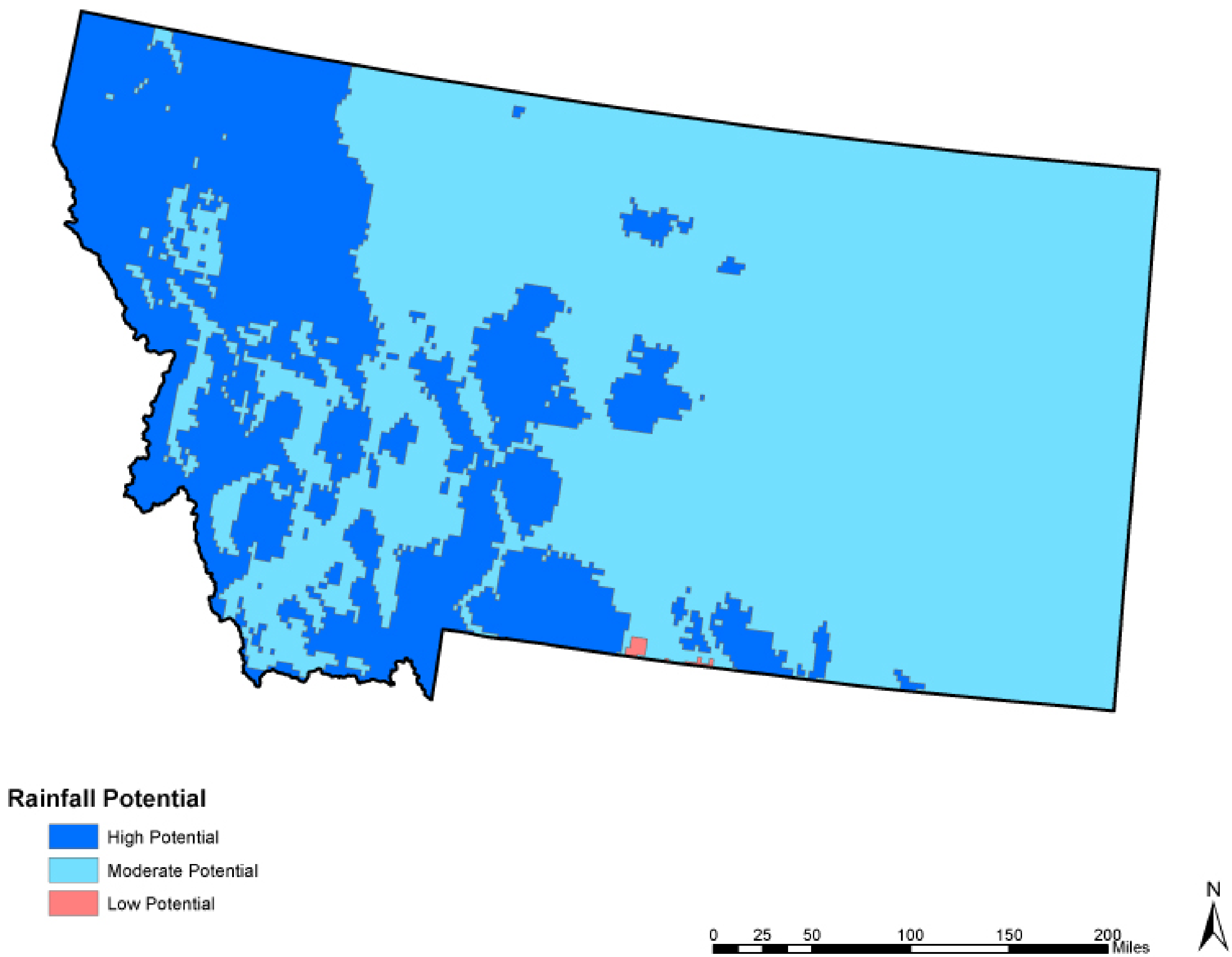


Figure 2. Spatial classification of climatic potential for Montana. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year. Areas classified as Low Potential have between 130 and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

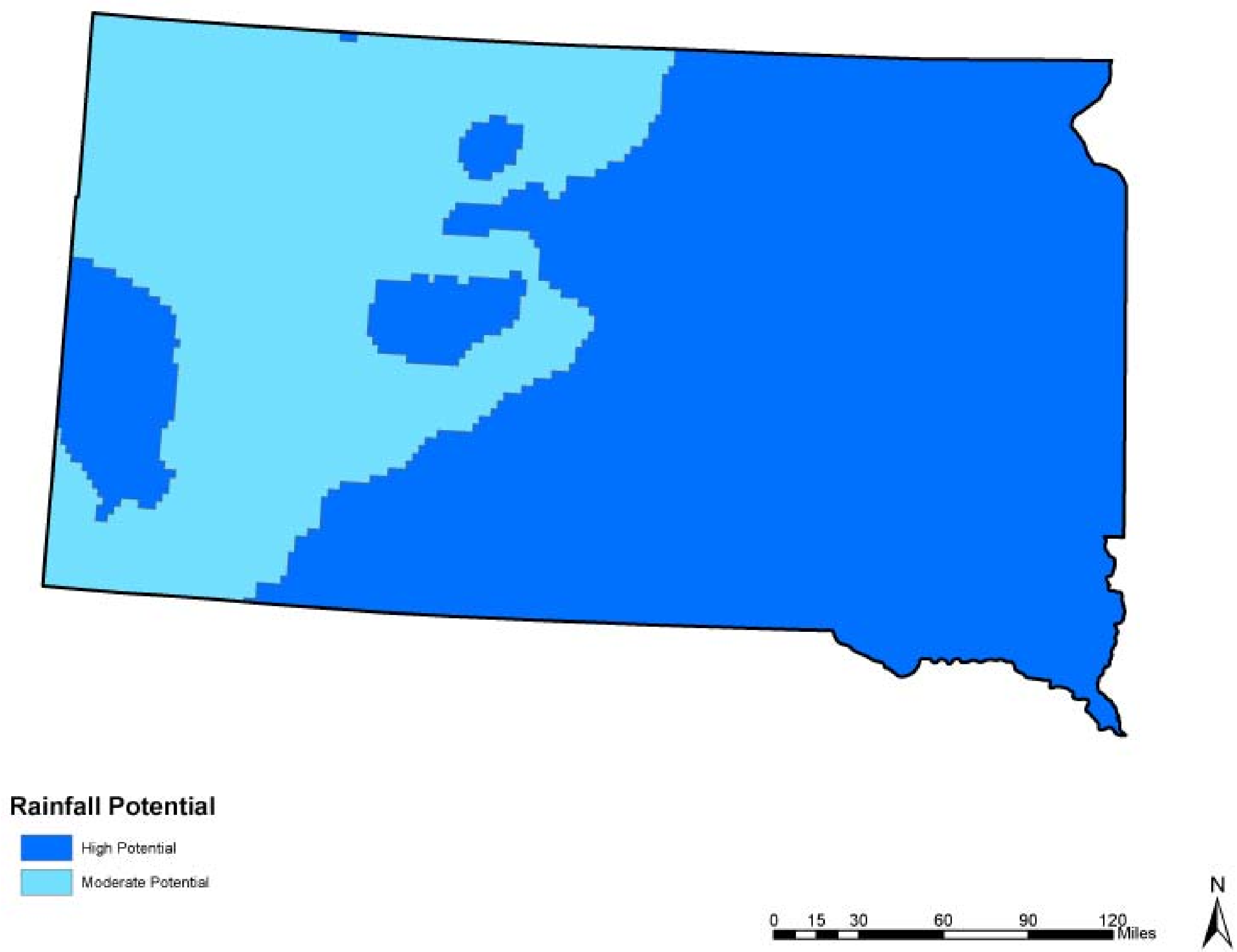


Figure 3. Spatial classification of climatic potential for South Dakota. Areas classified as High Potential have greater than 460mm of precipitation per year. Areas classified as Moderate Potential have between 230 and 460 mm of precipitation per year.

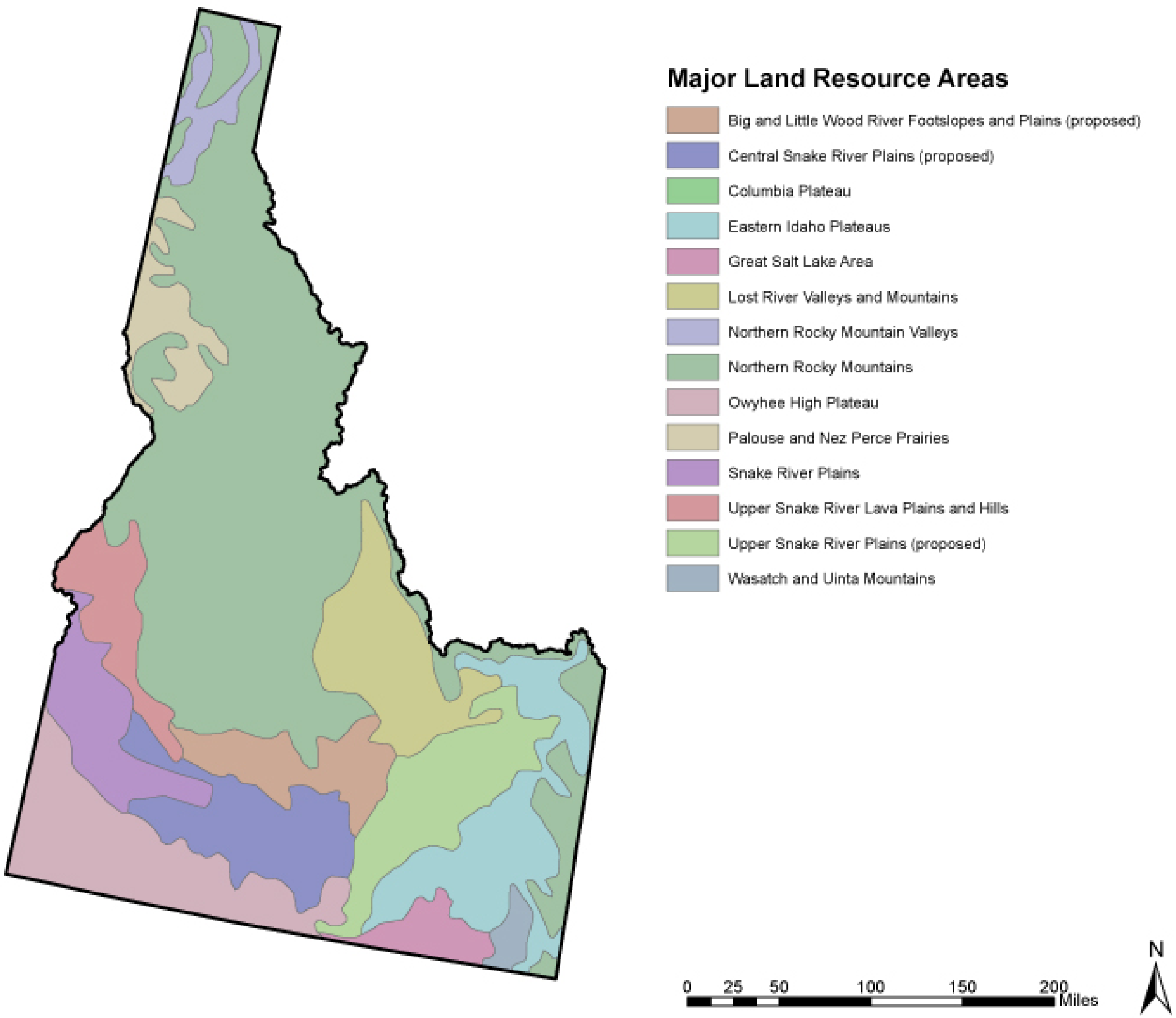


Figure 4. Major land resource areas (MLRAs) within the state of Idaho.

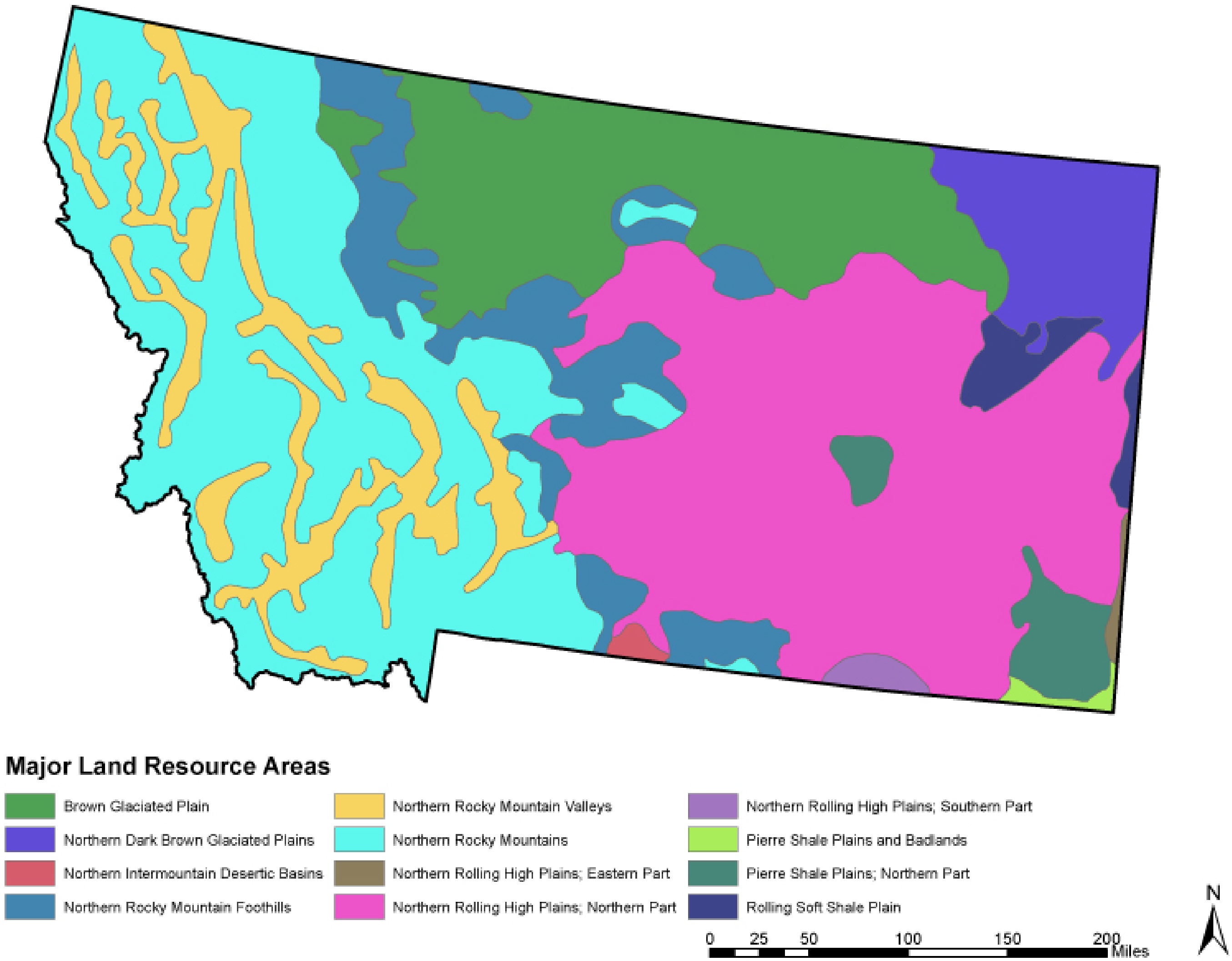


Figure 5. Major land resource areas (MLRAs) within the state of Montana.

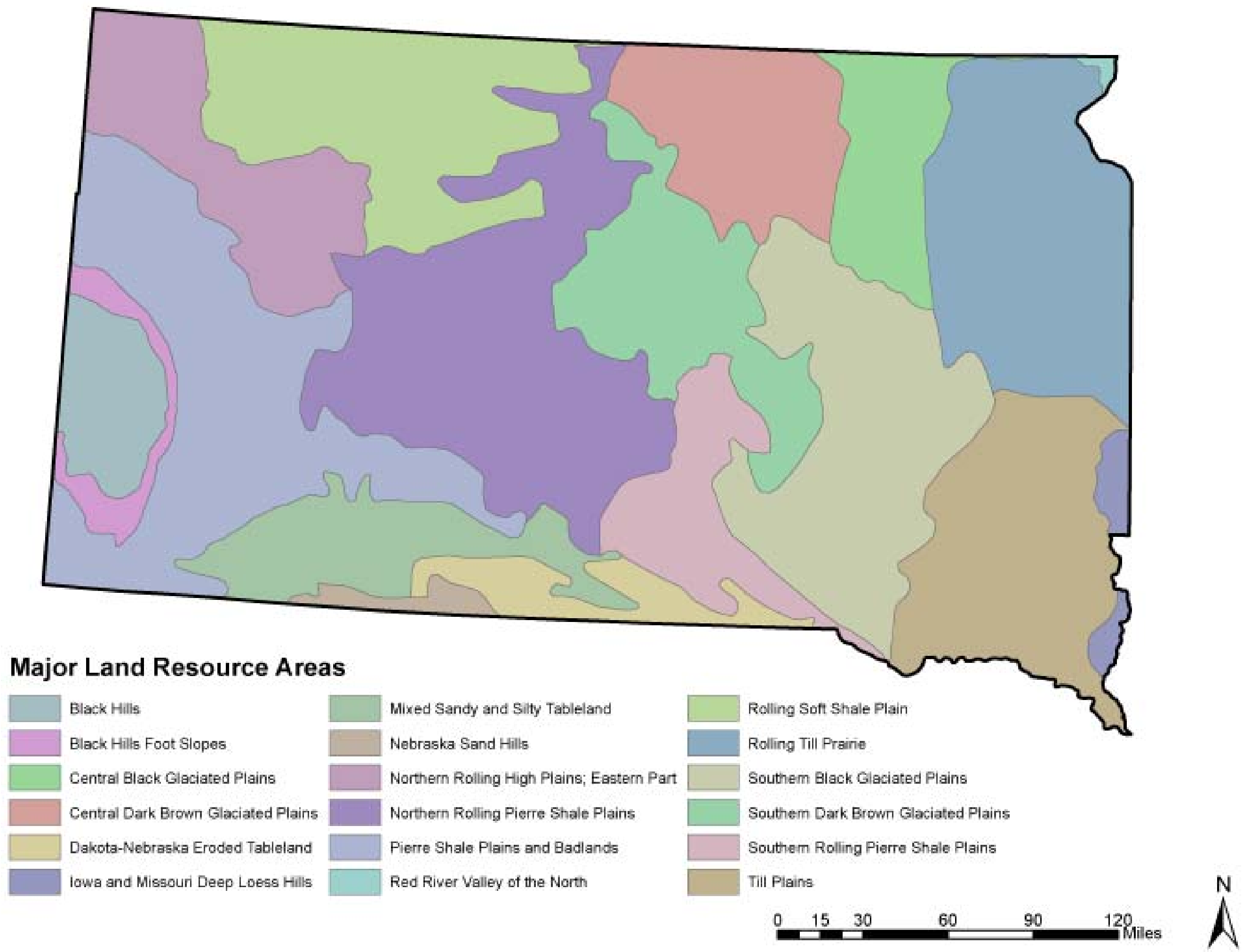


Figure 6. Major land resource areas (MLRAs) within the state of South Dakota

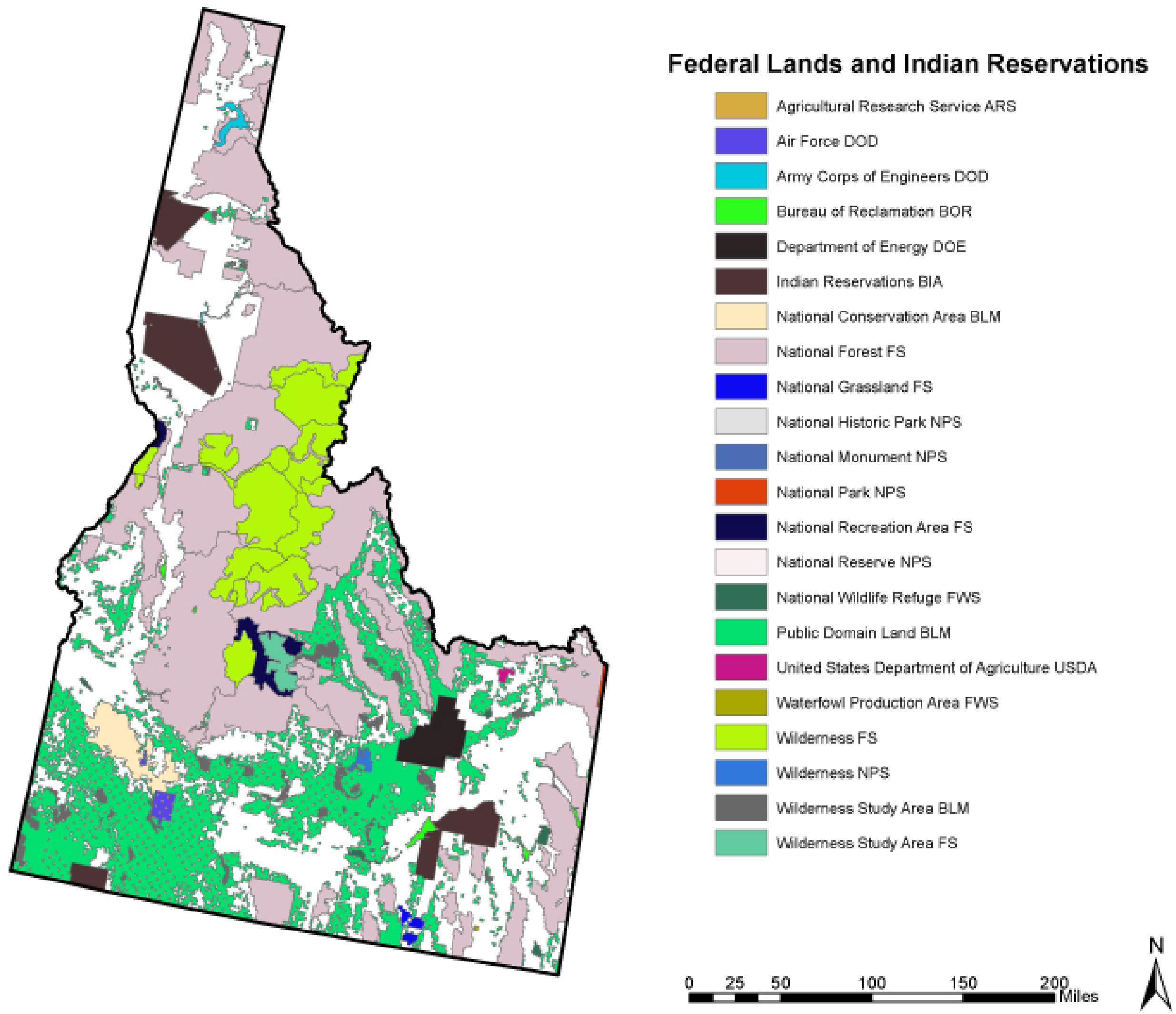


Figure 7. Federal lands and Indian reservations within the state of Idaho.

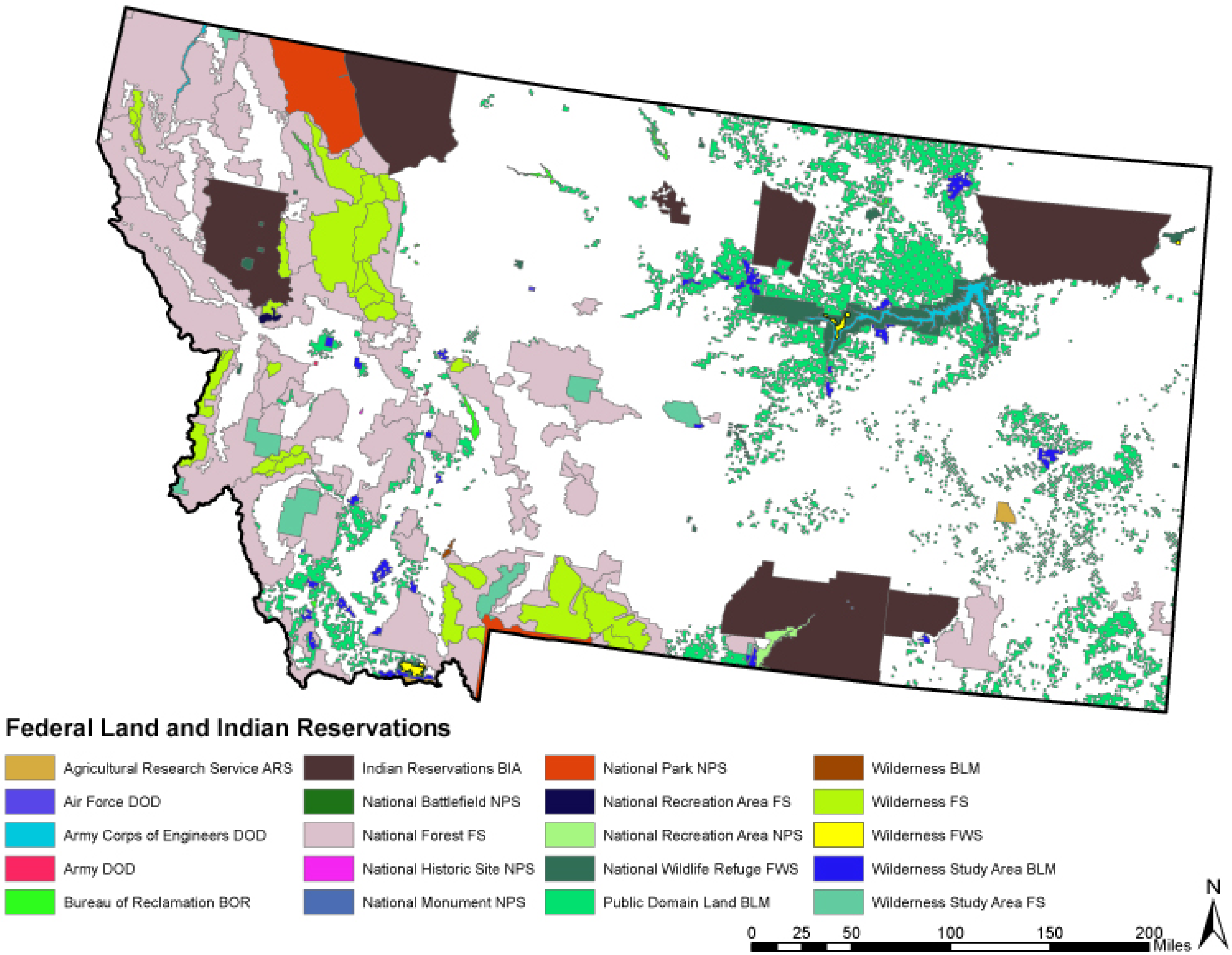


Figure 8. Federal lands and Indian reservations within the state of Montana.

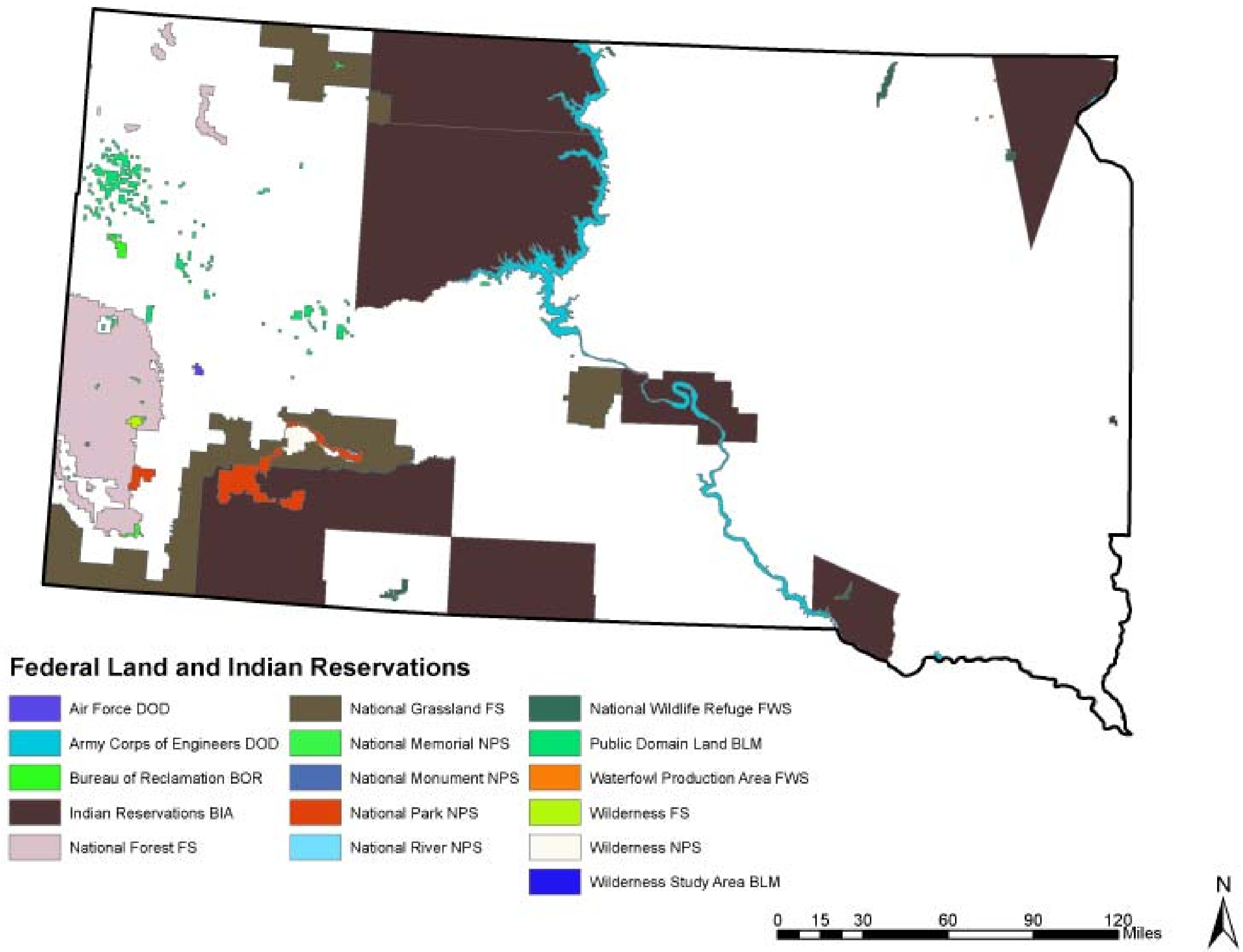


Figure 9. Federal lands and Indian reservations within the state of South Dakota

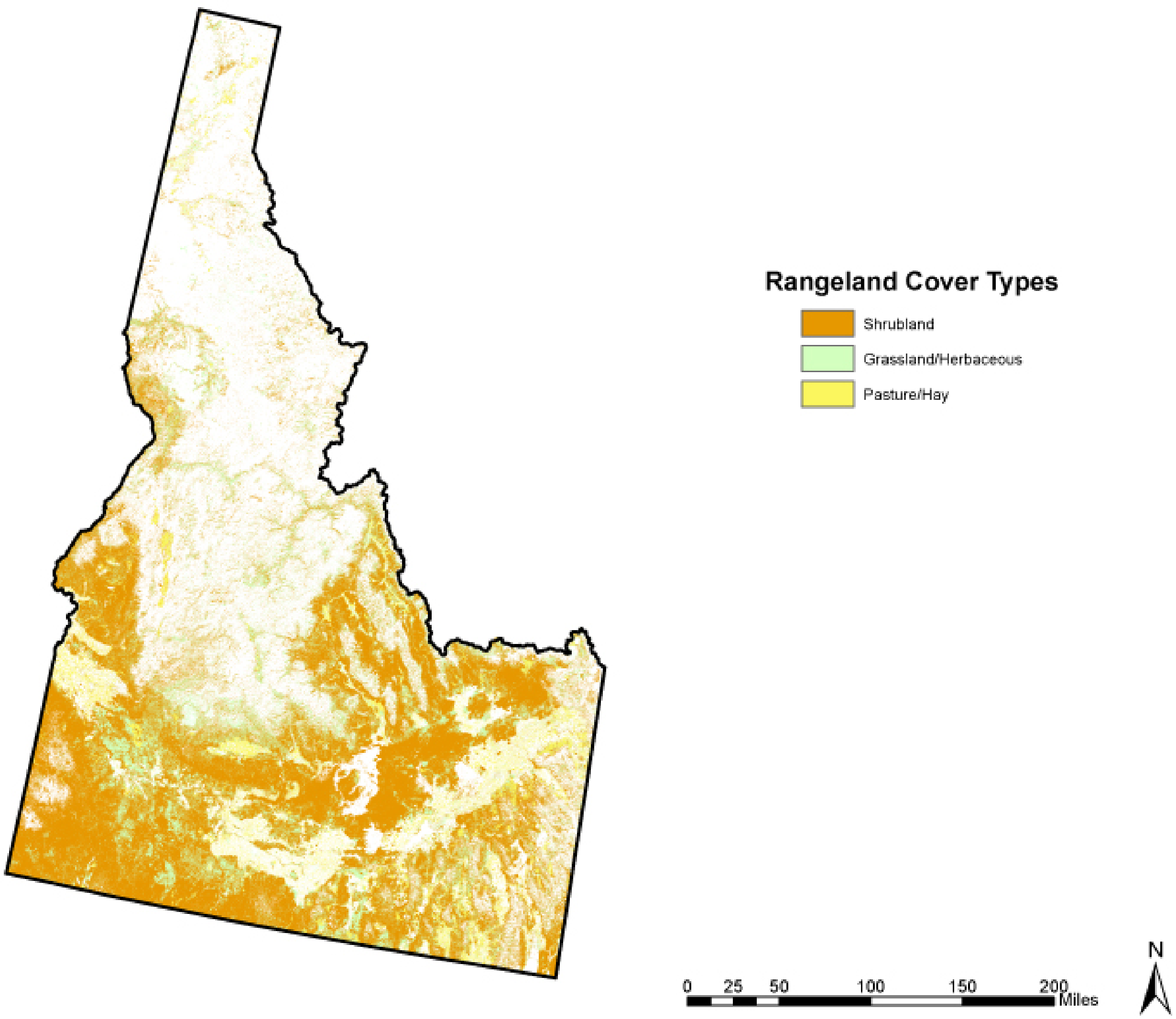


Figure10. Rangeland cover types for the state of Idaho as classified by the National Land Cover Database.

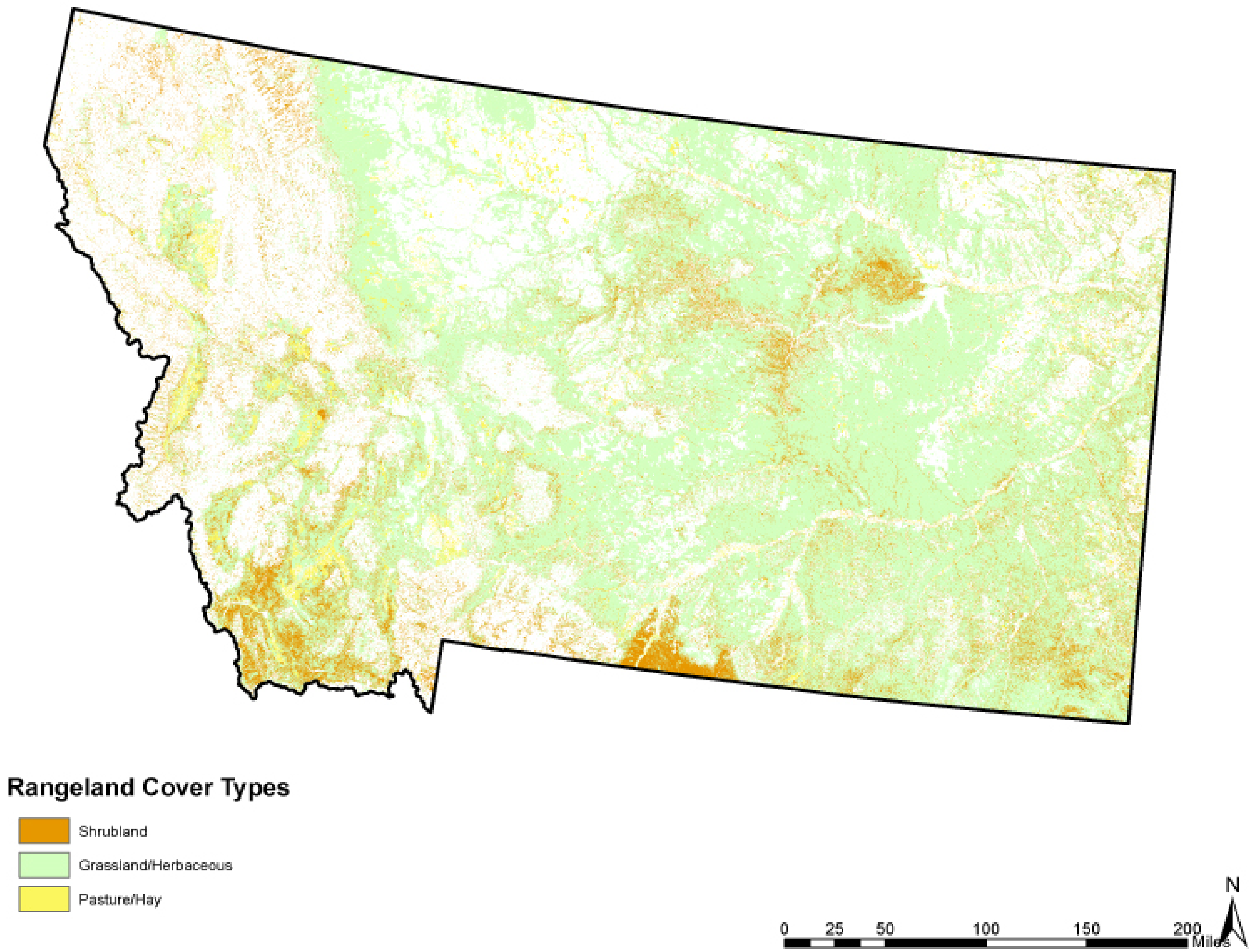


Figure 11. Rangeland cover types for the state of Montana as classified by the National Land Cover Database.

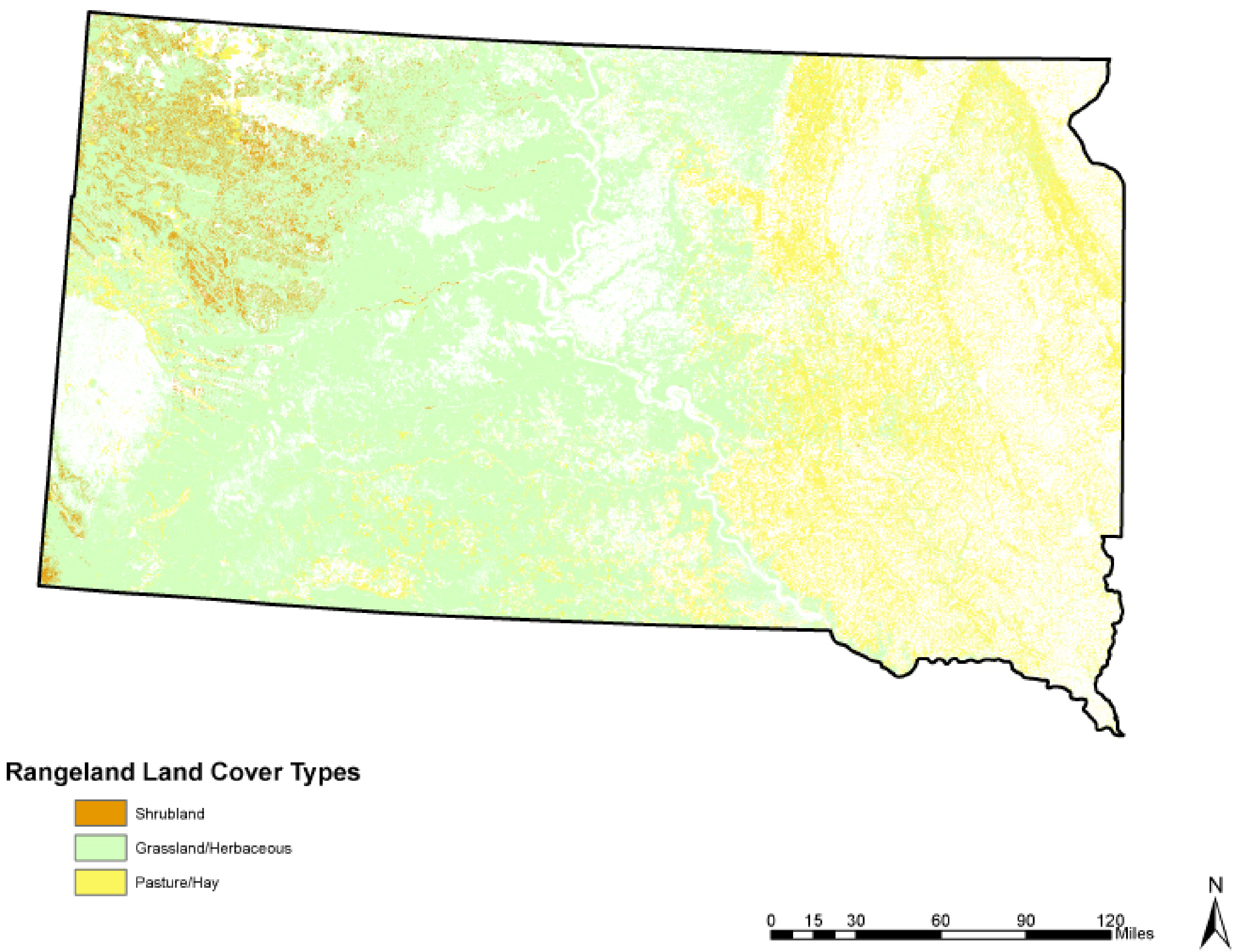


Figure 12. Rangeland cover types for the state of South Dakota as classified by the National Land Cover Database.

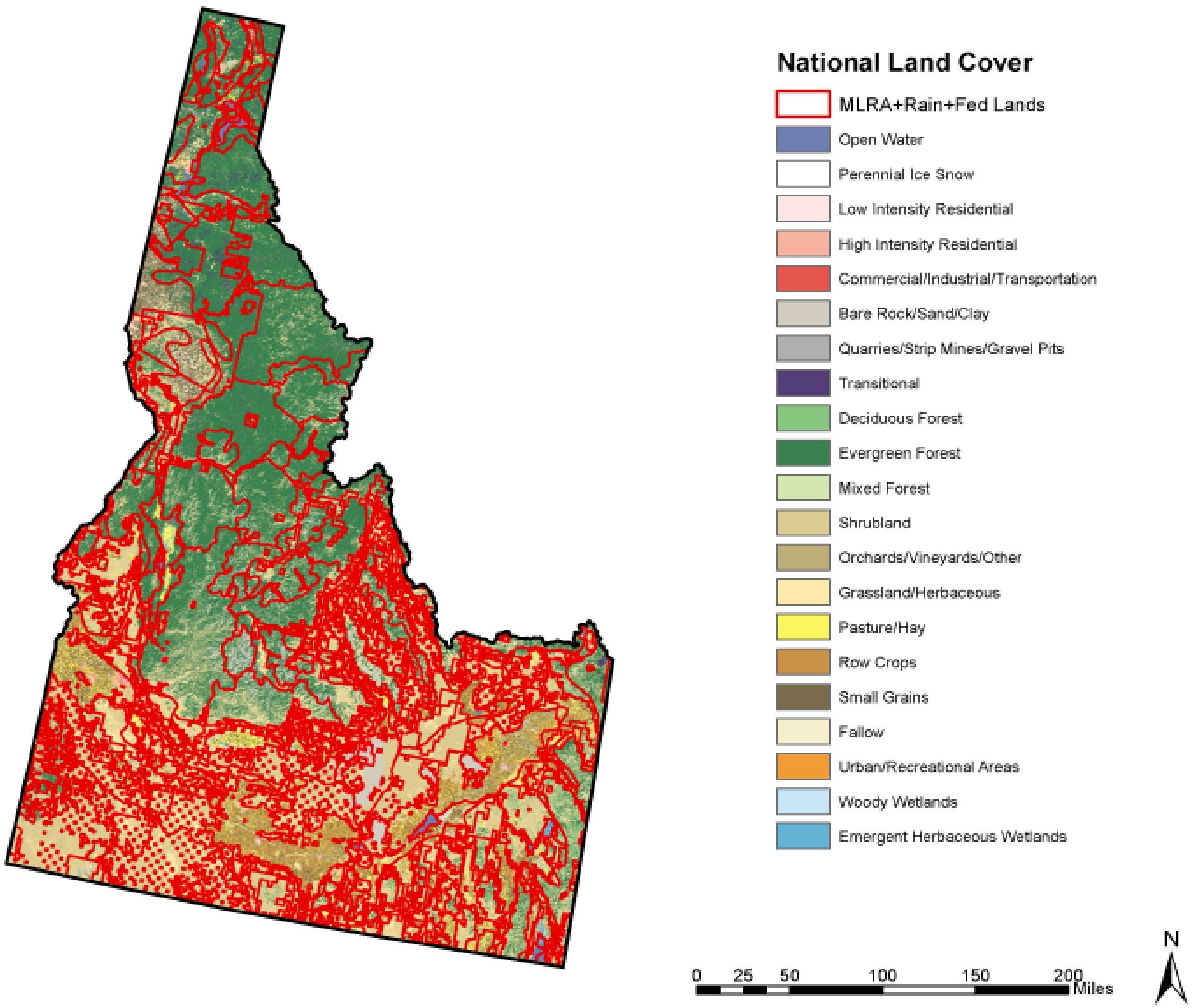


Figure 13. Sampling units (red lines) used in the spatial cross tabulation for the state of Idaho. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation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

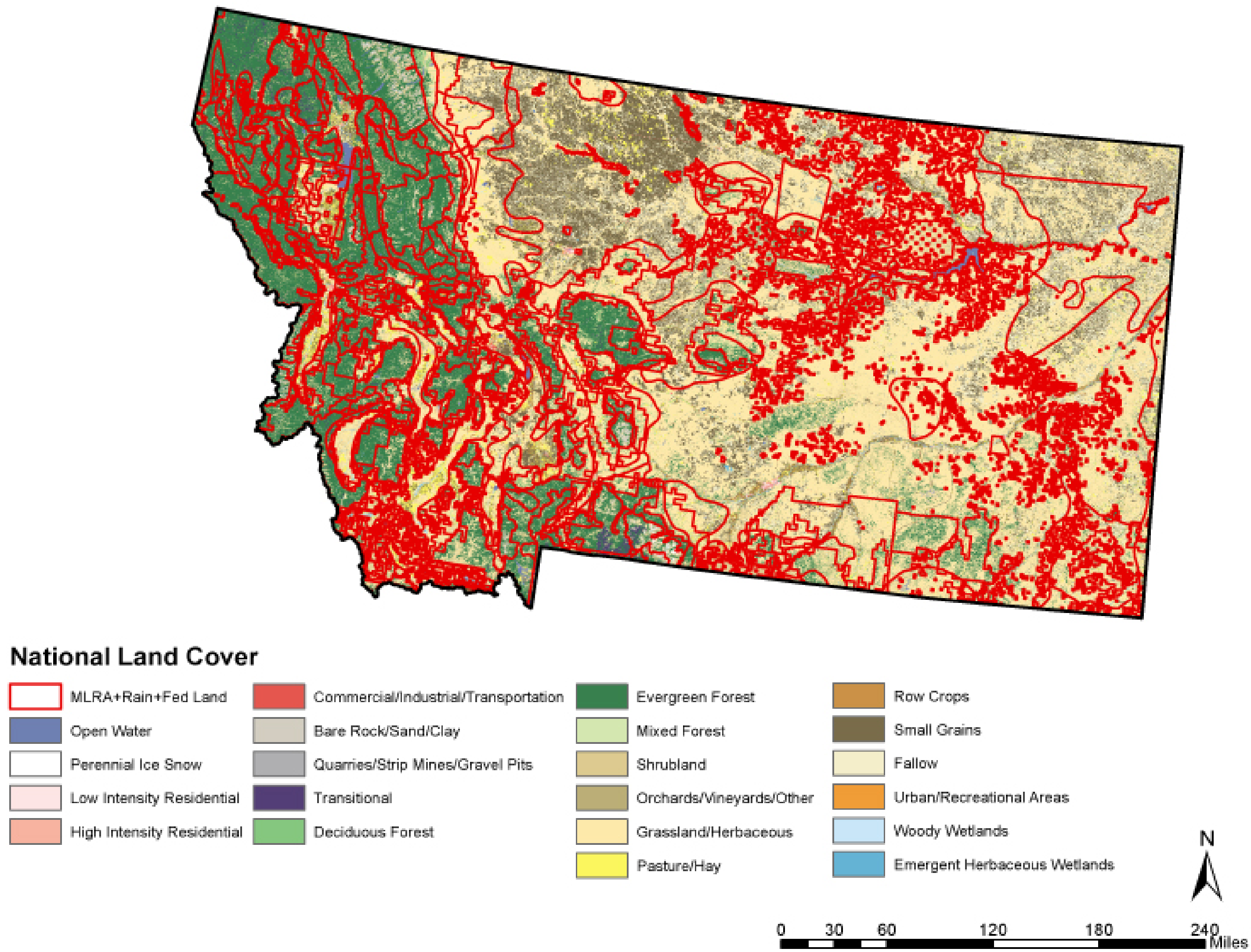


Figure 14. Sampling units (red lines) used in the spatial cross tabulation for the state of Montana. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation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

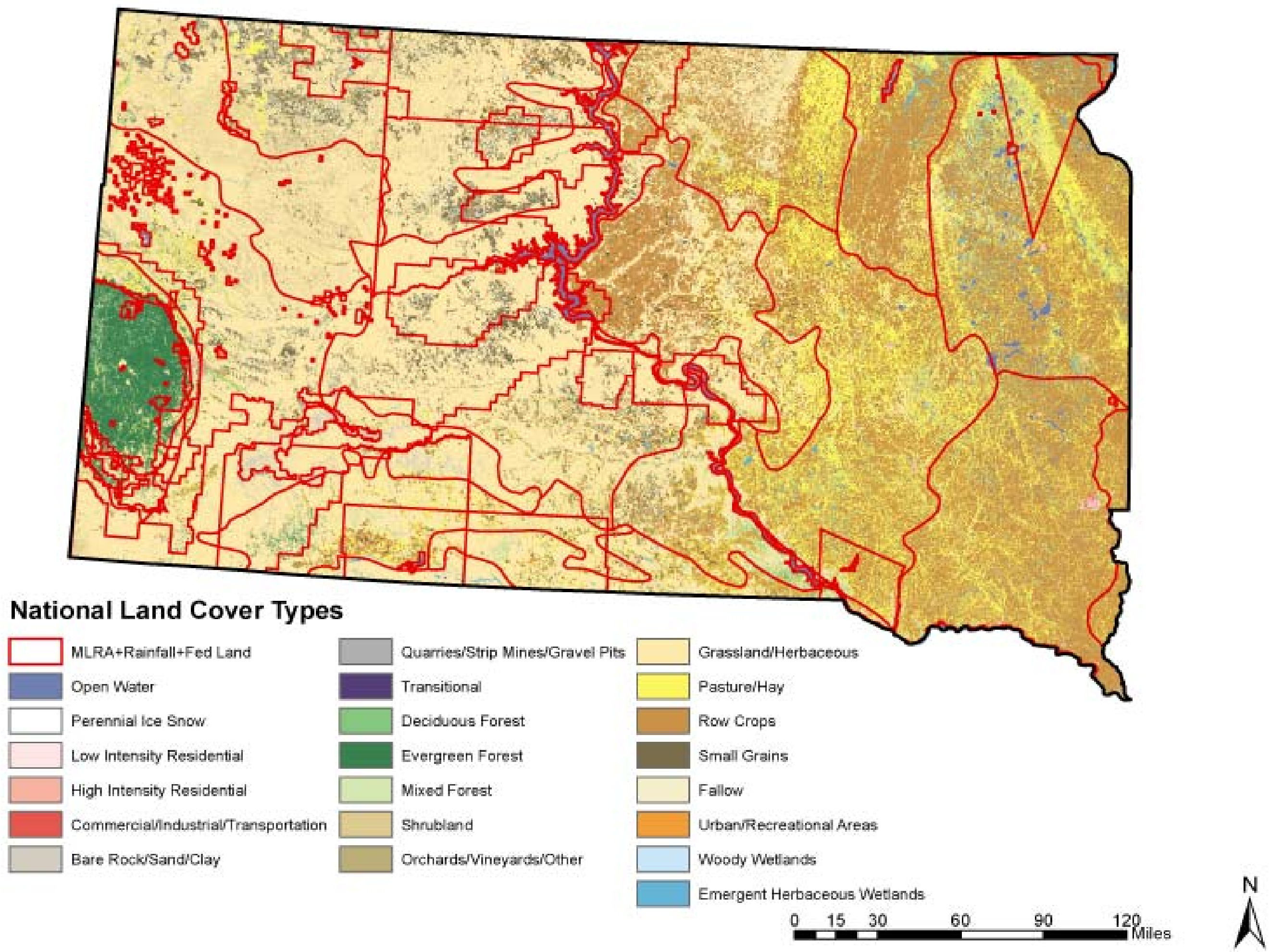


Figure 15. Sampling units (red lines) used in the spatial cross tabulation for the state of South Dakota. The sampling units represent the intersection of the Major Land Resource Areas, climatic potential, and Federal Lands and Indian Reservations map coverage that were used in the spatial cross-tabulation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

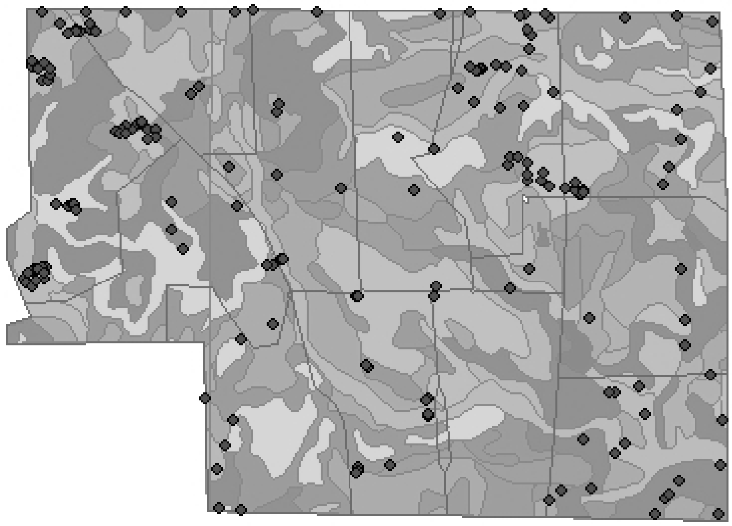


Figure 16. Distribution of sample points for Throckmorton Ranch placed over soil map and pasture boundaries.

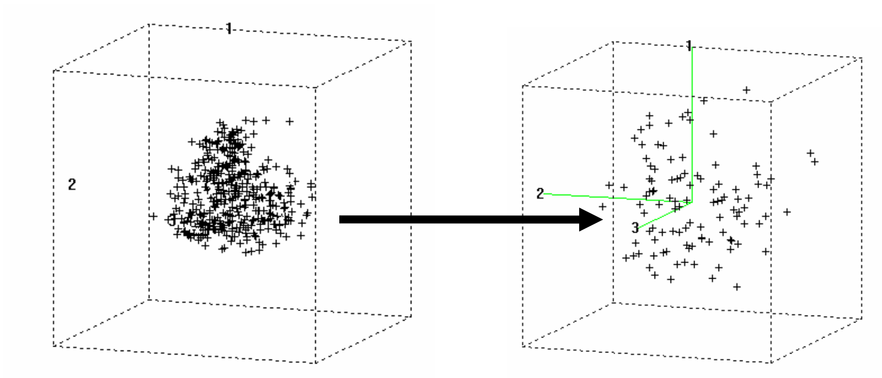


Figure 17. Selection of spectrally unique samples used to reduce laboratory costs and to choose samples that represent the range of population variance for equation development. From a total of 460 samples (left box) this procedure identified 107 spectrally unique samples (right box).

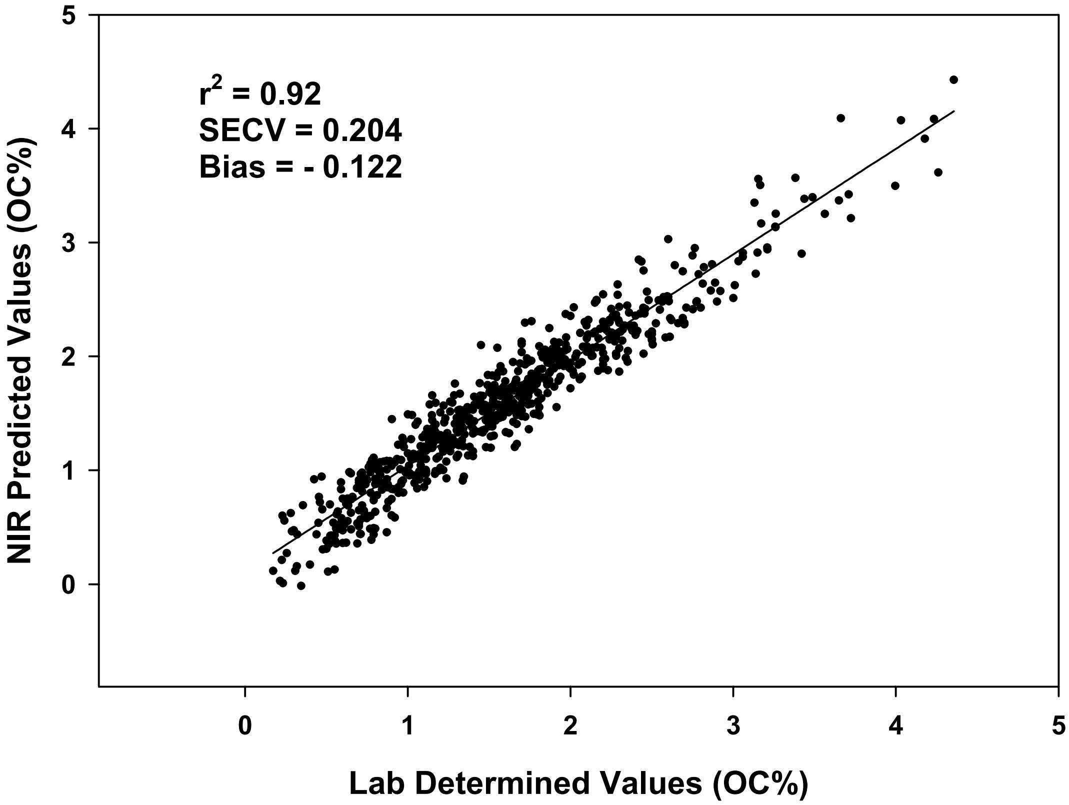


Figure 18. NIR cross validation prediction results for organic carbon using soils from diverse locations. (n = 661)

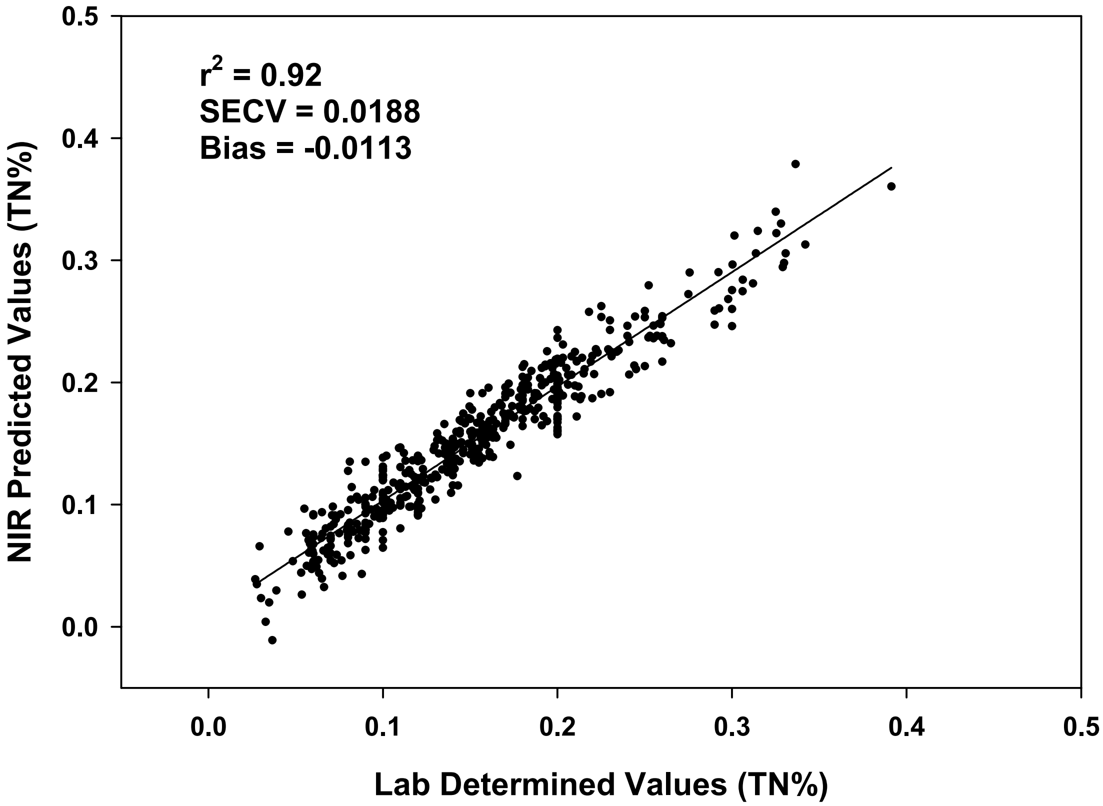


Figure 19. NIR cross validation prediction results for total nitrogen using soils from diverse locations (n = 502)

Table 1. Rangeland (ha) by land cover class and sums of the classes for Major Land Resource Area (MLRA) and land tenure class grouped according to Climatic Potential for carbon sequestration in Idaho. Percent of total reflects the percent of total rangeland occupied by the MLRA and Land Tenure class within the climatic potential grouping.

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Rangeland Totals	Percent of Total
High Climatic Potential (>460 mm)						
Big and Little Wood River Footslopes and Plains (proposed)	Federal	56,622	29,421	757	86,799	2.0
	Private or Non-Federal	27,243	15,017	92	42,352	1.0
Central Snake River Plains (proposed)	Federal	4,557	949	1	5,507	0.1
	Private or Non-Federal	829	336	41	1,207	0.0
Eastern Idaho Plateaus	Federal	193,563	63,495	3,173	260,231	6.0
	Indian Reservations	57,725	15,120	2,216	75,061	1.7
	Private or Non-Federal	314,950	105,948	75,772	496,670	11.4
Great Salt Lake Area	Federal	86,118	24,887	2,657	113,663	2.6
	Private or Non-Federal	44,230	20,983	23,323	88,536	2.0
Lost River Valleys and Mountains	Federal	164,767	82,669	261	247,697	5.7
	Private or Non-Federal	5,438	2,154	204	7,796	0.2
Northern Rocky Mountain Valleys	Federal	1,056	1,293	1,664	4,013	0.1
	Indian Reservations	0	0	0	0	0.0
	Private or Non-Federal	12,363	14,279	22,716	49,358	1.1
Northern Rocky Mountains	Federal	859,135	708,934	8,928	1,576,996	36.1
	Indian Reservations	18,552	16,882	3,180	38,614	0.9
	Private or Non-Federal	163,864	89,391	57,616	310,872	7.1
Owyhee High Plateau	Federal	136,813	21,248	85	158,146	3.6
	Indian Reservations	8,475	1,437	1	9,914	0.2
	Private or Non-Federal	68,598	7,731	665	76,994	1.8
Palouse and Nez Perce Prairies	Federal	2,418	1,595	6	4,019	0.1
	Indian Reservations	27,561	29,561	1,422	58,544	1.3
	Private or Non-Federal	27,529	21,288	1,764	50,581	1.2
Snake River Plains	Federal	3,687	68	0	3,756	0.1
	Private or Non-Federal	3,157	92	0	3,249	0.1
Upper Snake River Lava Plains and Hills	Federal	157,056	38,725	662	196,443	4.5
	Private or Non-Federal	226,480	47,414	13,631	287,525	6.6
	Federal	6,396	963	106	7,465	0.2
Upper Snake River Plains (proposed)	Indian Reservations	766	203	267	1,236	0.0
	Private or Non-Federal	7,107	2,884	4,075	14,066	0.3
Wasatch and Uinta Mountains	Federal	34,583	13,187	61	47,831	1.1
	Private or Non-Federal	25,893	8,698	5,444	40,035	0.9
	Sub Total	**2,747,530**	**1,386,853**	**230,791**	**4,365,174**	

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Rangeland Totals	Percent of Total
Moderate Climatic Potential (230 to 460 mm)						
Big and Little Wood River Footslopes and Plains (proposed)	Federal	360,770	39,236	1,796	401,803	6.3
	Private or Non-Federal	102,483	43,547	41,038	187,068	3.0
Central Snake River Plains (proposed)	Federal	454,674	173,426	5,770	633,870	10.0
	Private or Non-Federal	123,744	90,003	120,472	334,219	5.3
Columbia Plateau	Private or Non-Federal	254	161	0	415	0.0
Eastern Idaho Plateaus	Federal	51,017	9,328	2,619	62,963	1.0
	Indian Reservations	37,630	12,363	4,195	54,189	0.9
	Private or Non-Federal	140,491	57,646	79,381	277,519	4.4
Great Salt Lake Area	Federal	51,368	23,305	1,955	76,627	1.2
	Private or Non-Federal	22,751	14,359	28,563	65,674	1.0
Lost River Valleys and Mountains	Federal	447,226	100,518	6,059	553,802	8.7
	Private or Non-Federal	83,993	42,639	37,332	163,964	2.6
Northern Rocky Mountains	Federal	157,023	82,342	3,006	242,371	3.8
	Indian Reservations	173	23	0	195	0.0
	Private or Non-Federal	56,930	22,603	8,798	88,331	1.4
Owyhee High Plateau	Federal	1,032,573	160,837	3,007	1,196,417	18.9
	Indian Reservations	35,668	7,698	1,398	44,764	0.7
	Private or Non-Federal	194,881	33,059	13,933	241,873	3.8
Palouse and Nez Perce Prairies	Federal	1,780	624	0	2,404	0.0
	Indian Reservations	5,851	5,000	0	10,852	0.2
	Private or Non-Federal	22,538	10,783	0	33,321	0.5
Snake River Plains	Federal	250,264	95,717	3,502	349,483	5.5
	Private or Non-Federal	93,020	33,739	93,506	220,265	3.5
Upper Snake River Lava Plains and Hills	Federal	38,711	10,245	326	49,283	0.8
	Private or Non-Federal	115,130	26,065	11,503	152,698	2.4
Upper Snake River Plains (proposed)	Federal	394,244	82,842	2,973	480,059	7.6
	Indian Reservations	17,718	9,136	6,485	33,339	0.5
	Private or Non-Federal	162,794	85,580	122,121	370,495	5.8
Wasatch and Uinta Mountains	Federal	1,237	295	86	1,619	0.0
	Private or Non-Federal	5,737	2,328	3,317	11,382	0.2
	Sub Total	**4,462,675**	**1,275,446**	**603,141**	**6,341,262**	
Low Climatic Potential (130 to 230 mm)						
Central Snake River Plains (proposed)	Federal	8,437	2,317	6	10,759	2.3
	Private or Non-Federal	1,269	401	33	1,703	0.4
Lost River Valleys and	Federal	94,558	24,520	2,340	121,418	26.2

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Rangeland Totals	Percent of Total
Mountains	Private or Non-Federal	15,689	10,758	17,262	43,708	9.4
Northern Rocky Mountains	Federal	6,229	2,053	217	8,498	1.8
	Private or Non-Federal	1,129	506	395	2,030	0.4
Owyhee High Plateau	Federal	68,142	21,819	84	90,044	19.4
	Private or Non-Federal	3,705	1,029	1	4,735	1.0
Snake River Plains	Federal	81,218	46,044	3,122	130,384	28.1
	Private or Non-Federal	13,744	10,617	6,208	30,569	6.6
Upper Snake River Plains (proposed)	Federal	18,605	748	1	19,355	4.2
	Sub Total	**312,724**	**120,809**	**29,670**	**463,203**	
	Grand Total	**7,522,930**	**2,783,108**	**863,602**	**11,169,640**	

Table 2. Total hectares of rangeland cover types identified in Major Land Resource Areas (MLRA) in Idaho.

MLRA NAME	Rangeland (ha)
Northern Rocky Mountains	2267908
Owyhee High Plateau	1822887
Eastern Idaho Plateaus	1226633
Lost River Valleys and Mountains	1138385
Central Snake River Plains (proposed)	987265
Upper Snake River Plains (proposed)	926014
Snake River Plains	737706
Big and Little Wood River Footslopes and Plains (proposed)	718021
Upper Snake River Lava Plains and Hills	685948
Great Salt Lake Area	344500
Palouse and Nez Perce Prairies	159720
Wasatch and Uinta Mountains	100866
Northern Rocky Mountain Valleys	53371
Columbia Plateau	415

Table 3. Rangeland (ha) by land cover class and sums of the classes for Major Land Resource Area (MLRA) and land tenure class grouped according to Climatic Potential for carbon sequestration in Montana. Percent of total reflects the percent of total rangeland occupied by the MLRA and Land Tenure class within the climatic potential grouping.

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
High Climatic Potential (>460 mm)						
Brown Glaciated Plain	Indian Reservations	1,044	47,497	383	48,924	1.3
	Private or Non-Federal	154	6,993	59	7,206	0.2
Northern Intermountain Desertic Basins	Federal	1,798	2,606	0	4,404	0.1
	Private or Non-Federal	1,639	1,934	0	3,573	0.1
Northern Rocky Mountain Foothills	Federal	11,102	42,284	39	53,425	1.5
	Indian Reservations	30,045	138,512	5,937	174,495	4.8
	Private or Non-Federal	51,449	464,005	15,309	530,763	14.6
Northern Rocky Mountain Valleys	Federal	47,410	53,485	3,318	104,213	2.9
	Indian Reservations	3,492	15,622	2,129	21,243	0.6
	Private or Non-Federal	65,074	185,917	47,999	298,990	8.2
Northern Rocky Mountains	Federal	574,907	776,050	4,591	1,355,548	37.4
	Indian Reservations	30,912	107,895	6,724	145,531	4.0
	Private or Non-Federal	166,339	567,570	15,946	749,855	20.7
Northern Rolling High Plains; Northern Part	Federal	147	323	0	469	0.0
	Indian Reservations	11,539	72,612	1,957	86,108	2.4
	Private or Non-Federal	3,139	17,532	1,053	21,724	0.6
Northern Rolling High Plains; Southern Part	Federal	171	2,228	12	2,411	0.1
	Private or Non-Federal	1,359	15,404	299	17,062	0.5
	Sub Total	**1,001,720**	**2,518,468**	**105,755**	**3,625,943**	
Moderate Climatic Potential (230 to 460 mm)						
Brown Glaciated Plain	Federal	43,303	649,228	3,950	696,481	4.0
	Indian Reservations	16,450	374,909	7,319	398,679	2.3
	Private or Non-Federal	90,151	1,533,435	125,049	1,748,636	9.9
Northern Dark Brown Glaciated Plains	Federal	3,284	11,916	175	15,375	0.1
	Indian Reservations	32,783	173,152	3,429	209,364	1.2
	Private or Non-Federal	103,209	389,768	37,846	530,823	3.0
Northern Intermountain Desertic Basins	Federal	20,040	3,574	0	23,614	0.1
	Private or Non-Federal	24,763	6,049	1,423	32,235	0.2
Northern Rocky Mountain Foothills	Federal	31,919	57,980	172	90,071	0.5
	Indian Reservations	26,924	210,946	5,485	243,355	1.4
	Private or Non-Federal	72,222	983,168	58,110	1,113,500	6.3
Northern Rocky Mountain Valleys	Federal	51,065	84,188	4,337	139,590	0.8
	Indian Reservations	8,313	53,955	30,467	92,735	0.5
	Private or Non-Federal	177,486	728,161	222,278	1,127,925	6.4
Northern Rocky Mountains	Federal	146,928	189,265	2,490	338,683	1.9
	Indian Reservations	15,034	39,315	10,493	64,841	0.4

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
	Private or Non-Federal	199,634	654,437	54,658	908,728	5.2
Northern Rolling High Plains; Eastern Part	Federal	4,620	10,355	52	15,027	0.1
	Private or Non-Federal	11,434	35,177	2,490	49,102	0.3
Northern Rolling High Plains; Northern Part	Federal	310,851	1,340,477	3,688	1,655,017	9.4
	Indian Reservations	54,433	436,462	15,263	506,158	2.9
	Private or Non-Federal	648,515	5,506,180	145,777	6,300,471	35.8
Northern Rolling High Plains; Southern Part	Federal	2,479	10,565	45	13,090	0.1
	Indian Reservations	501	2,426	0	2,927	0.0
	Private or Non-Federal	25,141	104,513	1,723	131,377	0.7
Pierre Shale Plains and Badland	Federal	9,238	25,657	107	35,002	0.2
	Private or Non-Federal	6,909	65,461	2,117	74,487	0.4
Pierre Shale Plains; Northern Part	Federal	50,877	149,794	724	201,395	1.1
	Private or Non-Federal	86,067	449,058	10,616	545,740	3.1
Rolling Soft Shale Plain	Federal	227	2,763	138	3,128	0.0
	Private or Non-Federal	34,437	224,796	24,914	284,147	1.6
	Sub Total	**2,309,237**	**14,507,129**	**775,335**	**17,591,700**	
Low Climatic Potential (130 to 230 mm)						
Northern Intermountain Desertic Basins	Federal	9,260	535	20	9,815	33.5
	Private or Non-Federal	8,516	1,594	1,047	11,156	38.0
Northern Rocky Mountain Foothills	Federal	5,554	185	40	5,778	19.7
	Private or Non-Federal	471	7	0	478	1.6
Northern Rocky Mountains	Federal	1,780	254	0	2,034	6.9
	Indian Reservations	72	6	0	77	0.3
	Sub Total	**25,652**	**2,581**	**1,106**	**29,339**	
	Grand Total	**3,336,609**	**17,028,178**	**882,196**	**21,246,983**	

Table 4. Total hectares of rangeland cover types identified in Major Land Resource Areas (MLRA) in Montana.

MLRA NAME	Rangeland
Northern Rolling High Plains; Northern Part	8,569,948
Northern Rocky Mountains	3,565,297
Brown Glaciated Plain	2,899,925
Northern Rocky Mountain Foothills	2,211,864
Northern Rocky Mountain Valleys	1,784,696
Northern Dark Brown Glaciated Plains	755,562
Pierre Shale Plains; Northern Part	747,135
Rolling Soft Shale Plain	287,276
Northern Rolling High Plains; Southern Part	166,867
Pierre Shale Plains and Badlands	109,489
Northern Intermountain Desertic Basins	84,797
Northern Rolling High Plains; Eastern Part	64,128

Table 5. Rangeland (ha) by land cover class and sums of the classes for Major Land Resource Area (MLRA) and land tenure class grouped according to Climatic Potential for carbon sequestration in South Dakota. Percent of total reflects the percent of total rangeland occupied by the MLRA and Land Tenure class within the Climatic Potential grouping.

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
High Climatic Potential (>460 mm)						
Black Hills	Federal	126	63,784	11,469	75,379	1.1
	Private or Non-Federal	60	19,915	1,942	21,917	0.3
Black Hills Foot Slopes	Federal	19	10,776	689	11,483	0.2
	Private or Non-Federal	713	64,476	25,848	91,037	1.4
Central Black Glaciated Plains	Federal	0	278	1,638	1,916	0.0
	Indian Reservations	0	177	1,575	1,751	0.0
	Private or Non-Federal	45	40,388	171,125	211,558	3.2
Central Dark Brown Glaciated Plains	Private or Non-Federal	1,424	319,620	237,937	558,981	8.3
Dakota-Nebraska Eroded Tableland	Indian Reservations	0	152,108	19,518	171,626	2.6
	Private or Non-Federal	0	132,641	46,360	179,002	2.7
Iowa and Missouri Deep Loess Hills	Private or Non-Federal	1	1,618	31,220	32,839	0.5
Mixed Sandy and Silty Tableland	Federal	0	1,489	1,546	3,036	0.0
	Indian Reservations	0	264,652	44,531	309,184	4.6
	Private or Non-Federal	0	181,193	47,756	228,949	3.4
Nebraska Sand Hills	Federal	0	368	0	368	0.0
	Indian Reservations	0	43,193	1,426	44,618	0.7
	Private or Non-Federal	0	69,855	897	70,751	1.1
Northern Rolling Pierre Shale Plains	Federal	97	85,743	1,456	87,295	1.3
	Indian Reservations	1,556	235,250	1,848	238,655	3.6
	Private or Non-Federal	1,176	758,973	41,274	801,423	11.9
Pierre Shale Plains and Badlands	Federal	8	2,085	437	2,530	0.0
	Indian Reservations	0	77,028	8,188	85,216	1.3
	Private or Non-Federal	1,151	139,081	17,957	158,189	2.4
Red River Valley of the North	Federal	0	11	17	28	0.0
	Indian Reservations	0	3	1,620	1,624	0.0
	Private or Non-Federal	0	0	190	190	0.0
Rolling Soft Shale Plain	Indian Reservations	286	98,987	2,147	101,420	1.5
	Private or Non-Federal	0	796	416	1,213	0.0
Rolling Till Prairie	Federal	0	382	1,218	1,600	0.0
	Indian Reservations	1	21,170	113,190	134,360	2.0
	Private or Non-Federal	89	60,265	510,783	571,137	8.5
Southern Black Glaciated Plains	Federal	0	1,212	496	1,709	0.0
	Indian Reservations	0	15,080	54,100	69,180	1.0
	Private or Non-Federal	466	151,138	733,494	885,098	13.2
Southern Dark Brown Glaciated Plains	Federal	0	785	14	799	0.0
	Indian Reservations	30	15,325	161	15,516	0.2
	Private or Non-Federal	399	429,966	150,230	580,595	8.6

NRCS Major Land Resource Area	Land Tenure	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Rangeland Totals	Percent of Total
Southern Rolling Pierre Shale Plains	Federal	27	4,694	1,024	5,745	0.1
	Indian Reservations	75	86,247	11,763	98,085	1.5
	Private or Non-Federal	27	286,624	87,998	374,649	5.6
Till Plains	Federal	0	1,018	1,482	2,501	0.0
	Indian Reservations	0	371	822	1,193	0.0
	Private or Non-Federal	11	33,390	448,383	481,784	7.2
	Sub Total	**7,788**	**3,872,157**	**2,836,184**	**6,716,129**	
Moderate Climatic Potential (230 to 460 mm)						
Black Hills	Federal	303	2,524	53	2,881	0.1
	Private or Non-Federal	631	4,036	46	4,713	0.1
Black Hills Foot Slopes	Federal	878	34,954	686	36,518	0.7
	Private or Non-Federal	3,594	39,465	1,743	44,802	0.8
Central Dark Brown Glaciated Plains	Federal	0	17	0	17	0.0
	Private or Non-Federal	137	64,316	7,275	71,728	1.3
Mixed Sandy and Silty Tableland	Federal	0	10,346	64	10,410	0.2
	Indian Reservations	0	183,648	5,698	189,345	3.5
	Private or Non-Federal	0	9	5	15	0.0
Northern Rolling High Plains; Eastern Part	Federal	6,582	14,982	461	22,026	0.4
	Indian Reservations	399	13,283	0	13,681	0.3
	Private or Non-Federal	207,120	802,760	16,546	1,026,425	18.8
Northern Rolling Pierre Shale Plains	Federal	296	57,655	1,690	59,641	1.1
	Indian Reservations	3,225	383,905	833	387,962	7.1
	Private or Non-Federal	739	557,318	4,603	562,659	10.3
Pierre Shale Plains and Badlands	Federal	24,426	531,493	12,968	568,887	10.4
	Indian Reservations	0	154,950	3,880	158,830	2.9
	Private or Non-Federal	105,203	935,981	68,558	1,109,742	20.4
Rolling Soft Shale Plain	Federal	21,382	121,743	3,273	146,399	2.7
	Indian Reservations	27,392	653,331	6,522	687,244	12.6
	Private or Non-Federal	69,753	210,147	31,554	311,454	5.7
Southern Dark Brown Glaciated Plains	Federal	2	3,114	107	3,223	0.1
	Private or Non-Federal	10	27,258	2,694	29,962	0.5
	Sub Total	**472,070**	**4,807,234**	**169,260**	**5,448,564**	
	Grand Total	**479,858**	**8,679,391**	**3,005,444**	**12,164,693**	

Table 6. Total hectares of rangeland cover types identified in Major Land Resource Areas (MLRA) in South Dakota.

MLRA NAME	Rangeland
Northern Rolling Pierre Shale Plains	2,137,636
Pierre Shale Plains and Badlands	2,083,394
Rolling Soft Shale Plain	1,247,729
Northern Rolling High Plains; Eastern Part	1,062,133
Southern Black Glaciated Plains	955,986
Mixed Sandy and Silty Tableland	740,938
Rolling Till Prairie	707,097
Central Dark Brown Glaciated Plains	630,725
Southern Dark Brown Glaciated Plains	630,095
Till Plains	485,477
Southern Rolling Pierre Shale Plains	478,480
Dakota-Nebraska Eroded Tableland	350,628
Central Black Glaciated Plains	215,226
Black Hills Foot Slopes	183,841
Nebraska Sand Hills	115,738
Black Hills	104,890
Iowa and Missouri Deep Loess Hills	32,839
Red River Valley of the North	1,842

Table 7. Rangeland (ha) for each state in the Big Sky Project by climatic potential (annual precipitation) and land tenure class. Federal lands are not included since they will most likely not be included in carbon sequestration programs.

Land Tenure Class	Idaho	Montana	South Dakota	Big Sky Region Totals
High Climatic Potential (>460 mm)				
Indian Reservations	183,369	476,300	1,272,428	1,932,096
Private or Other Non-Federal	1,469,240	1,629,173	5,249,313	8,347,725
Moderate Climatic Potential (230 to 460 mm)				
Indian Reservations	143,339	1,518,059	1,437,063	3,098,461
Private or Other Non-Federal	2,147,225	12,847,170	3,161,500	18,155,895
Low Climatic Potential (130 to 230 mm)				
Indian Reservations	0	77	0	77
Private or Other Non-Federal	82,745	11,635	0	94,380
Totals	**3,943,172**	**16,470,702**	**11,120,304**	**31,534,178**

Table 8. Prediction statistics for the independent validation set predicted from the equation derived from the 107 analyzed samples and cross validation results obtained from combining the validation set with the calibration set. Values are percentages.

	Independent Validation				Cross Validation Combined Set				
Property	n	RSQ	SEP	BIAS	n	Mean	SD	SECV	RSQ
Inorganic Carbon	25	0.966	0.211	-0.060	120	1.85	2.11	0.279	0.98
Total Carbon	25	0.918	0.329	-0.016	120	3.46	1.90	0.313	0.97
Organic Carbon	25	0.859	0.278	0.090	120	1.63	0.73	0.266	0.87
Total Nitrogen	25	0.945	0.018	0.006	118	0.17	0.012	0.016	0.94

Table 9. Cross Validation Results for Final NIR Throckmorton Equation.

Property	n	Mean	SD	SECV	RSQ
IC	186	1.71	1.83	0.297	0.97
TC	188	3.32	1.75	0.323	0.97
OC	185	1.56	0.64	0.251	0.85
TN	118	0.17	0.012	0.016	0.94

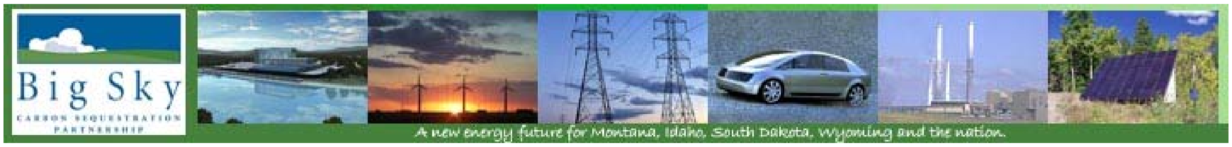
Table 10. Cross Validation Results for Second General Organic Carbon and Total Nitrogen Equation

Property	n	Mean	SD	SECV	RSQ
Organic Carbon	1110	2.10	1.10	0.36	0.89
Total Nitrogen	951	0.20	0.093	0.034	0.86

Table 11. Cross validation predictions of selected carbon fractions.

Property	n	Mean*	SD	SECV	RSQ	Bias
Glomalin	111	0.51	0.36	0.122	0.89	-0.07
POM	142	0.95	1.02	0.556	0.71	-0.33
Amino sugar	131	201.54	71.26	33.26	0.78	19.96
B -glucosaminidase	138	26.32	18.61	10.73	0.67	-6.44
B- glucosidase	130	75.94	46.76	29.10	0.61	-17.46

*units for glomalin and POM are mg g^{-1} and µg g^{-1} for amino sugar, B -glucosaminidase and B- glucosidase.



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Carbon Sequestration: A Handbook

Version 2.0 -- 2004

The National Carbon Offset Coalition

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FOREWORD TO THE REVIEW DRAFT

This review draft of the NCOC Handbook (Version 2.0) 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.

It is an expanded version of Version 1.0, that was designed primarily to explain the development of carbon sequestration project plans. Hopefully, we have retained that element while expanding our coverage of marketing concepts and opportunities.

The first 4 parts of the Handbook explain the organizational context within which we work on carbon sequestration projects. That context is continually changing, so while the explanations in here may reflect how the carbon market existed in the past, it may not reflect the current situation. Those who need to understand current details are urged to rely on credible sources from the World Wide Web.

The final parts of Version 2.0 are designed to help project planners and landowners in the development of actual project plans. Those details, too, will necessarily change as markets mature. See the NCOC website at www.ncoc.us for current details.

NCOC is an organization that seeks to expand the frontiers of funding for improved management of agricultural and forest lands. Our basic goal is to promote resource conservation while assisting in the development of expanded economic opportunities for private landowners and managers. We hope this handbook contributes to that goal.

Associated with the handbook are Excel workbooks designed to assist in the calculation of carbon sequestration amounts and economic feasibility. We encourage you to download these workbooks from the website and assess them alongside the handbook to see if the combination is effective. For further information about the Excel workbooks or to provide comments on them, contact Neil Sampson at rneilsampson@cs.com.

Finally, we would greatly appreciate any comments on this handbook. If you find areas that are confusing, or that lack information that you need to understand, plan, or implement a carbon sequestration project, please let us know. The handbook will remain largely a loose-leaf construction, available on the Web, and updated as good ideas or new facts emerge. As you will see in reading through it, there are areas where the final information or sources are still not known. This handbook, like most of the factors surrounding carbon sequestration projects, is a work in progress. You can be an important part of this development, and we welcome your contribution.

Sincerely,

Ted Dodge, Manager and Project Broker, National Carbon Offset Coalition
Neil Sampson, Technical Advisor, National Carbon Offset Coalition.
August 13, 2004

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Part I. Background and Context

A. The International Setting

International concern over the causes and consequences of environmental change go back over three decades. The United Nations Environmental Program (UNEP) was founded in 1972. In 1985, the ozone hole over Antarctica was discovered, and it became clear that human activity was having impact on the global environment. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was created. It has since involved over 3,000 of the world=s scientists in a series of studies designed to help identify scientific and technical aspects of the climate change issue. IPCC findings were instrumental in encouraging 154 nations to sign the U.N. Framework Convention on Climate Change at the first AEarth Summit@ in Rio de Janeiro in 1992. That launched a continuing process, where the nations who signed the Protocol meet in a series of AConference of Parties@ or COP meetings. Today, there have been 10 COP sessions and they continue on a regular basis. The 3rd produced what is known as the AKyoto Protocol,@ which called for legally binding reductions in emissions.

The Kyoto Protocol introduced the concept that sequestering CO_2 through the creation of carbon sinks in agriculture and forestry could be counted against a Party=s commitments for reducing emissions. It was agreed that the first commitment period would be 2008 through 2012, and the target would be the amount of emission compared to 1990 emissions. In the initial agreement, the U.S. agreed to cut overall emissions 7% below 1990 levels, the European Union agreed to cut to 8% under 1990, Canada and Japan agreed to 6% cuts. The details of exactly how those cuts would be achieved were left to further negotiation and decisions to be made in future COP meetings.

After the Kyoto Protocol was adopted, the IPCC was asked to produce a special report on the scientific and technical issues involved in implementing the articles pertaining to carbon sinks in agriculture and forestry (Watson et al. 2000). That special report pointed out that the inclusion of full accounting for the carbon exchanges between the earth and atmosphere would capture a major aspect of the issue, but that there were very important decisions to be made regarding how these activities would be defined and how the accounting systems would work.

The 6th COP, which concluded in Bonn, Germany, in July of 2001, made several important decisions in regard to agriculture and forestry.[1] The definitions of afforestation, reforestation, and deforestation were linked to a change in land use. By linking to a change in land use, the normal forest harvest and regeneration cycle is not considered part of Kyoto accounting. That is critical in making any national reporting system feasible.

In addition, COP 6 decided that broadly-defined activities such as Aforest management,@ Acropland management,@ Agrazing land management,@ and Arevegetation@ may be used in the first commitment period if a Party chooses to do so. If those activities are chosen, the Party will need to demonstrate that the activities have occurred since 1990, and are human-induced. This is an important step in implementing

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[1] **For current information on UNFCCC activities and the full copy of COP documents, see *www.unfccc.int.***

Article 3.4 of the Kyoto Protocol, and is consistent with the scientific and technical findings in the IPCC Special Report.

Throughout the international discussions of climate change, one of the major concerns has been the well-documented increase of carbon dioxide (CO_2) in the atmosphere over the past century. Carbon dioxide is among several atmospheric compounds (generally called greenhouse gases) that have the effect of reflecting heat waves and preventing them from leaving the earth's atmosphere. This heat-trapping effect is responsible for the moderate climate on earth, but any significant increase could, it is proposed, cause climate change that could disrupt many natural and human systems on earth. Studies have shown that the increase in greenhouse gases is largely due to the burning of fossil fuels and deforestation in the tropics.

While the most direct and effective means of slowing the increase in greenhouse gases is to reduce fossil fuel burning and tropical deforestation, neither of these can be done easily or rapidly under present social and economic conditions. As a result, in addition to those efforts, other means of reducing emissions and/or increasing the transfer of CO_2 from the atmosphere into stable terrestrial systems have been encouraged. Two of the most effective ways of doing that are to increase the sequestration of stable carbon compounds in agricultural soils and forests.

Throughout the negotiations on the Kyoto Protocol, proposals have been made to allow countries to use carbon sequestration in soils and forests as one of the means of helping reduce their total carbon emissions. The topic has been controversial, as opponents felt it offered an "easy out" compared to the more difficult challenges of reducing fossil fuel use and slowing tropical deforestation. Other questions have been raised about the effectiveness or permanence of soil and forest sinks, and whether or not they should be compared to reduced fossil emissions. The United States, while it was actively engaged in the Kyoto process, argued strongly for the inclusion of soil and forest sinks in the international accounting system. What has emerged from the continuing negotiations is, in general, consistent with the prior positions of the U.S.

The United States, citing concerns that the international agreement was not well balanced, did not set realistic goals, and did not include developing countries, decided not to ratify the Kyoto Protocol after COP 6, and withdrew from the process of implementing it. While the decision to withdraw has been widely criticized by supporters of the agreement, the United States continues to pursue policies to mitigate climate change outside the restrictions of the protocol. The Protocol, having now been signed by the required number of Parties, goes into effect in early 2005. The impact it will have on carbon sequestration projects, particularly in the U.S., is highly uncertain at this time.

B. U.S. Policy

After making the decision not to ratify the Kyoto Protocol, the United States has continued to work toward a unilateral GHG mitigation program. At this point, the decision has been made to make the program a voluntary one, without mandatory emissions reductions or the institution of a formal cap-and-trade system.

The continued international negotiating process on the Protocol has, however, influenced the development of rules and guidelines for the creation of emission reductions and credits within the U.S. program. This is due to several reasons, including the fact that many U.S. companies operate globally. As a result, they will be dealing with

Kyoto-related rules and guidelines in parts of their operation, and it is in their interest to encourage the U.S. to be reasonably consistent with those global rules so that their activities can be more effectively managed. The Kyoto rules have also prompted some prospective buyers and sellers to seek out novel and innovative methods to reduce carbon emissions, especially through terrestrial sequestration projects, not only within the U.S. but also in other parts of the world.

In February 2002, President Bush committed the United States to reducing America's greenhouse gas intensity – the ratio of emissions to economic output – by 18 percent during the next decade. He also challenged the Department of Energy to develop improvements in the voluntary greenhouse gas reporting system under Section 1605(b) of the Energy Policy Act of 1992 so that it could become part of a market-based approach to achieving greenhouse gas emission reductions. At the same time, the President directed the Secretary of Agriculture, in consultation with DOE and EPA, to develop rules and guidelines for carbon sequestration projects on agriculture and forestlands. Drafting is under way, with the target of a new and expanded 1605(b) registry in 2005. That registry, described in preliminary form in Part 3A, can become a critical component of incorporating agricultural and forestry projects in a national GHG reduction program.

Federal cost-sharing programs are likely to be important components of any U.S. approach, as well. In June 1993, Agriculture Secretary Ann M. Veneman announced major program initiatives in federal forest and agriculture conservation programs to encourage practices that store carbon and reduce greenhouse gases.

The Department planned to invest almost $3.9 billion in agriculture and forest conservation on private land in 2004, an increase of $1.7 billion over 2001 levels. Due to the increase in conservation investments and a focus that includes carbon sequestration efforts, USDA estimates these actions would reduce and sequester a total of more than 12 million metric tons of greenhouse gas emissions (measured in carbon equivalent terms) annually by 2012. That amount is 12 percent of the Bush Administration's national goal.

USDA announced that it would consider greenhouse gas management practices in the Environmental Quality Incentives Program (EQIP), the Conservation Reserve Program (CRP) and the Forest Land Enhancement Program (FLEP). Federal budget cuts have, however, dramatically curtailed these ambitious plans. The FLEP program has been essentially killed by cuts in the FY 2005 budget. Those decisions may be reversed by Congressional action, but the final resolution of the funding for these programs remains unknown at this time (August, 2004).

C. Meeting emission limits through reductions or mitigation

A basic requirement for the creation of market opportunities for carbon credits is the imposition of some sort of limit, or cap, on greenhouse gas emissions. This might be similar to the cap and trade program[2] established in the U.S. under the Acid Rain Program[3].

The imposition of emission reductions on industry, provided it is coupled with an emissions trading scheme such as the SO_2 program, would create a new challenge for industry, and a new opportunity for landowners. The regulated company will seek the most cost-effective ways to reach its emissions target. Those might come from technical improvements it could make internally, to switch fuel sources, improve efficiencies, or otherwise lower emissions to target levels. If, however, mitigation credits were available at a lower cost from another firm that was below its own target, it could purchase those "surplus" credits from that company. Finally, it could purchase mitigation credits by funding an agricultural or forest project that would create increased carbon sequestration in an agreed-upon amount for an agreed-upon time. Achieving these latter mitigation trades would require the emergence of a market where buyers and sellers could meet and establish prices for efficient sales.

Carbon offset markets are unlike typical markets for consumer goods, which often function with little or no regulatory interference beyond the requirements established for fair trading and open information exchange. Carbon trading markets depend on the government to establish emission limits and rules, and provide current and future emitters with some level of permits. The number of permits issued, and their distribution among different industries or companies within an industry creates the initial supply and demand conditions upon which the market begins to operate. At that point, trading begins to seek the most economically efficient way of adjusting the initial allocation so that all parties can meet their new emission requirements.

As the trading proceeds, there will be continued interaction between buyers, sellers and the regulatory authority. The regulatory authority not only establishes the property rights, it also sets and enforces the environmental standards or targets. Once the property rights and regulatory standards are in place, the buyer and sellers can engage in environmental trades. *"To understand the economic forces at work in the environmental trades they should actually be viewed as three-party transactions involving active participation among buyers, sellers and trade regulators"* (King and Kuch, 2003).

Demand for carbon sequestration units will also be created in the international arena once the Kyoto Protocol comes into effect and nations have completed the process of capping their greenhouse gas emissions. Industries in those countries that face a high cost of reducing their emissions may buy carbon offsets from lower-cost sources to meet their obligations under the Protocol. Whether or not projects in the U.S. will be eligible to participate in these international schemes is still unknown.

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[2] The "cap" puts a ceiling on emissions and each allowance authorizes one ton of SO_2 emissions. Limiting the number of available allowances ensures the cap's integrity. Allowances are allocated among sources based on emission performance standards and representative fuel use. At the end of each year, every source must have enough allowances to cover its emissions for that year. Unused allowances may be sold, traded, or saved (banked) for future use. (http://www.epa.gov/airmarkets/articles/clearingtheair.pdf)

[3] The overall goal of the Acid Rain Program is to achieve significant environmental and public health benefits through reductions in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx), the primary causes of acid rain. To achieve this goal at the lowest cost to society, the program employs both traditional and innovative market-based approaches for controlling air pollution. In addition, the program encourages energy efficiency and pollution prevention. (http://www.epa.gov/airmarkets/articles/clearingtheair.pdf)

A cap and trade carbon program will probably not emerge within the U.S. until the federal government (or several of the states) decides to move beyond the existing voluntary approach. At the moment, there is considerable activity within the states. Since January, 2000, about one-third of the states have either enacted legislation or issued executive orders designed to reduce GHG emissions (Rabe 2002). While many of these were directed at curbing emissions, a few have direct relevance to increasing carbon sequestration in agriculture and forestry. Given the current level of activity, both within the states and internationally, it appears that some sort of emissions limits will soon affect many industries.

D. Carbon sequestration projects as a mitigation option

If a cap and trade system is established, either at the state, federal, or international level, it is likely that one of the options available to emitters will be to purchase mitigation credits created by agriculture or forestry projects. These projects can be designed to increase the amount of carbon stored in soils or woody plants. By removing this additional carbon from the atmosphere and storing (sequestering) it for a period of time, the projects can help mitigate the impacts of the industry's emissions.

Carbon stored in agriculture and forest ecosystems is usually measured in four Apools.@ They are:

$ Above- and below-ground woody material in live trees
$ Litter, understory plants, and small debris on the forest floor
$ Dead snags and large woody debris
$ Soil organic compounds (not counting large roots or surface debris)

As carbon flows in and out of any particular pool, the total amount (*stock*) of carbon in that pool will change. Thus, one method of estimating the effectiveness of a project in sequestering carbon is to measure the carbon in each pool at one point in time, typically measured on a per unit area basis (e.g. tons per acre), then re-measure it again at some later date (Watson et al. 2000). The net change in carbon stock in all pools—the ecosystem—reflects sequestration if stocks increase or emission if stocks decrease. In some situations, the net change in some pools could increase while there is a decrease in other pools. For sequestration to occur the sum of all increases must be greater than the sum of the decreases.

While improving agricultural and forestry practices to reduce emissions or sequester carbon has met with wide acceptance on the basis of their impact on environmental conservation and ecosystem sustainability, there have been a number of challenges to their long-term value as mitigation efforts to offset greenhouse gas emissions from industrial sources. It is important, therefore, for projects seeking recognition for their emissions reduction or carbon-sequestering value to demonstrate that they have achieved real reductions in atmospheric GHG's, that those reductions can be maintained for an appropriate time period, and that an independent observer can verify project claims if necessary.

Even where measurements are conducted, monitored, and verified in a technically competent manner, there are several important issues in terms of the "equivalency" between emitted greenhouse gases and the carbon sequestered in projects. To achieve real environmental benefits, the projects must achieve greenhouse gas offsets that truly offset the impact of the industrial emissions.

Some of the issues involved that will need to be addressed in agriculture and forestry projects designed for mitigation trading will include:

$ Additionality B This term refers to the amount of increases in the carbon pools that were the result of human activity rather than normal change in ecosystems over time. This is often a non-issue in agricultural or tree planting projects, where everything is the result of human action. It can, however, become an issue in the management of existing forests or grasslands, where the environment can be expected to change with or without intentional management.

$ Leakage B This is another term stemming from the international debates. It refers to the fact that some projects may cause indirect or unintended changes on non-project land that will either increase or decrease the carbon on that non-project land. Where project action creates these off-site effects, the project results need to be adjusted accordingly in order to reflect the net effect of the project on the environment.

$ Duration or Permanence – These terms refer to the fact that soil or wood carbon can be lost back to the atmosphere if management practices change or a disaster strikes. The project needs to identify major risks and establish ways to address them.

$ Monitoring, verification, and reporting B Buyers will need assurance that the project and its practices are functioning as planned. Some monitoring and reporting can be done on an annual basis by the landowner. Periodically, it will be necessary to develop measurements through soil sampling, timber cruising, or other accepted forms of developing carbon estimates. The frequency of these measurements will usually be established either by public policy or buyer demands, but will probably be every 5 years or so for woody plants and every 10 years or so for soil carbon. Most contracts also require periodic verification audits by an independent 3rd party to increase credibility.

$ Transparency B the methods and calculations used to establish the amount of carbon credits involved should be clear. For most buyers or policy makers, calculating the amount of carbon credits in a Ablack box@ computer model won=t be acceptable unless the results can be reproduced by other methods.

E. Options for addressing issues in carbon sequestration projects

Additionality and Baselines

Additionality is the amount of net carbon sequestered when one calculates the amount resulting from the project activities as compared to the amount without the project activity. There have been several ways proposed to arrive at this calculation, but as yet there are no fully agreed or universal guidelines. Some of the ways that have been proposed (and, in most cases, are in use somewhere) are:

- A "base year." Normally used for carbon sequestration projects, this would be a measure of the carbon stock at the time the project activity was begun. It serves as the reference point from which future measurements are compared to calculate the amount of carbon sequestered over a period of time.
- A "historic baseline." This would use the records covering a past time period to estimate the average annual rate of emissions or sequestration that occurred before the project was initiated. This could be done, for example, with records of fuel usage, regional records of deforestation, or documented forest growth records.

- A "business as usual" baseline. This involves the creation of a forward-looking model to predict what would occur in the absence of project action. To arrive at the estimate, one normally creates a "base case" or "reference case," which projects a most likely future for the project area. From that reference case, one constructs the carbon "baseline" that would have resulted.

While these methods sound straightforward on the surface, there are any number of assumptions and methods that can be used to calculate both the reference and project cases. It can be readily seen that, to achieve the maximum carbon credit for the project, it is necessary to produce a minimum reference case and a maximum project case. This leads to fears that project developers will "game" the system and attempt to achieve credit for carbon that is either not present, or that would have been present with or without the project. This has led to several different approaches and suggestions, including:

- *Limit to easy situations.* Some programs have limited their consideration to projects where base case or baseline calculation is relatively straightforward, such as afforestation, reforestation, conversion of cropland to grass, or implementation of conservation tillage. On these, the baseline assumption can be that carbon stocks would have changed little or none without the project, and the carbon increases on the land can be readily modeled and actually measured. A more difficult case might be forest management, where a project proposes to improve the management of a forest to enhance growth. The forest growth between two time periods is partly the result of natural change, and partly the result of the manager's actions. There is no scientifically credible way to separate these two effects, so if carbon credits are limited to those caused solely by management action, any claim can be suspect.
- *Use a base year approach.* The Chicago Climate Exchange (CCX)[4] approach for large forestry projects is to use a base year approach. An inventory of the reporting entities' entire forest carbon stocks establishes a starting point, and all change that occurs beyond that year is considered to be the result of management. While this includes natural growth factors, it also includes such management activities as thinning, harvesting, and reforestation. The net change over the entire forest estate is what is measured, which recognizes that forest management can (often with good ecological and economic justification) result in biomass declining for a period of time as well as increasing. Thus, management that supports and maintains an increase in the carbon stocks on a forest is, in fact, a reflection of management choice.
- *Provide clear guidelines.* Some systems require that a project go beyond what is required by law or regulation in order to be additional. Therefore, in states that require reforestation in their state forest practice act, a mandatory reforestation project would not qualify.
- *Provide calculation methods and tools*. Projects submitted to the National Carbon Offset Coalition are asked to provide calculations using standard tables developed by NCOC. For those who wish to use it, an Excel workbook is available to aid in

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[4] Chicago Climate Exchange is a self-regulatory exchange that administers the world's first multi-national and multi-sector marketplace for reducing and trading greenhouse gas emissions (See Part 2). CCX represents the first voluntary, legally-binding commitment by a cross-section of North American corporations, municipalities and other institutions to establish a rules-based market for reducing greenhouse gases. (http://www.chicagoclimatex.com/)

calculating both soil and wood carbon for both reference and project cases. Use of the standard method by all project developers allows NCOC to readily check all calculations and assure itself that different projects have used consistent methods.

The DOE also provides Excel software for both field forest and urban forest plantings to assist in calculating what is termed "net effect," for inclusion in the 1605(b) report. It is therefore assumed that the software calculates a reference case, but it is not clear what that case contains, since only the net figure is illustrated.

- *Ask for narrative explanation.* In the previous version of the 1605(b) program, reporters were asked to explain the method used to arrive at the reference case. The program distinguished between a "basic" reference case, defined as an actual historical record of sequestration for a year or period of years, and a "modified" reference case, which is a projection of the sequestration that would have occurred in the absence of the project. Almost all of the existing project reports have used the modified case. The reporters are then asked to explain in a narrative how they arrived at the project calculations.
- *Use general tables and discount for uncertainty.* In the CCX, general growth tables published in the scientific literature have been adopted for use in calculating additionality for agriculture and small forestry projects, and the indicated amounts have then been discounted fairly severely to allow for the uncertainty between general estimates and specific projects. This produces a project calculation that is conservative at the outset, but which can be adjusted later if measurements indicate that different results are actually being achieved.
- *Adopt default values.* For conservation tillage projects, the CCX has consulted scientific experts to set regional default values. Projects are then credited with that value per acre each year that they maintain their tillage plan. Values are selected to be conservative, with the thought that a wide range of projects should produce an average value equal to or greater than the estimate. These values may or may not be sensitive to different soil and climatic conditions within the region. Usually, they are not, but reflect broad regional averages.
- *Adopt regional baselines.* Although no program has yet adopted regional baselines to our knowledge, this has been suggested as one way of approaching the problem of estimating the amount of forest growth that would have occurred in the absence of a forest management project. In this approach, the regional growth data produced by the Forest Service's Forest Inventory and Assessment program would be used as the baseline for the different types of forest in each forest region. Those data reflect the measured growth rates by forest type achieved by all owners, across all soils and sites in the region. A project that could, through periodic measurements or other credible means, demonstrate that its growth rates were above the regional baseline could, under this idea, claim that difference as a carbon credit produced by project action. (Note that increased growth could also be partly due to better-than-average soil and site conditions, leaving some uncertainty in this estimate.)
- *Model potential regional changes*. In some of the forest protection projects done for the UtiliTree[5] program, computer models such as GEOMOD[6] have been used to

[5] See discussion of UtiliTree projects in Part 2.

produce projections of future deforestation based on a geographic analysis of deforestation trends in the recent past, as reflected by remote imagery. These models, that can assign statistical weights to the various physical, cultural, and economic factors that are associated with past deforestation, build future projections based on how those same factors will drive deforestation pressure within the project area. That deforestation pressure, if unchecked by project action, reflects a credible reference case.

Leakage

Leakage is the term applied to off-site impacts caused by a project. While there have been many studies as to its possible impact on project calculations, there are very few established programs that include guidelines for including leakage estimates. There are several ways that it might be addressed, including:

- *Ignore it.* This may eventually be unacceptable, but several programs today offer little or no guidance, so it is likely that leakage has effectively been ignored.
- *Rename it.* There is no mention of leakage in the original 1605(b) guidelines, for example, although the term "indirect emissions" and "unintended effects" are clearly designed to get project reporters to calculate effects that occur outside project boundaries. There appear to be no instructions on how this might be done consistently across reports.
- *Establish simple guidelines.* For the CCX at the present time, a project that indicates that the reporting entity is maintaining a sustainable forest (i.e. not destroying forest elsewhere while claiming credit for planting a new one) is adequate evidence of no leakage.
- *Decision Tree.* Provide a "decision tree" that project planners can utilize to help them understand whether leakage is likely to exist in their project and, if so, whether it is significant. Several technical papers exist that could help suggest ways to do this.
- *Establish Standard Discounts.* Perhaps in connection with the decision tree, a registry could provide discount percentages (i.e. given these indications of leakage, discount the project calculations __% to arrive at the reported amount.)

Duration (permanence)

Because the carbon in agricultural and forestry projects is stored in woody vegetation and soils, there is always the possibility that it might be lost, either through intentional management actions or natural events such as wildfire. While recognizing that few, if any, things in nature are truly permanent, it has also been effectively argued that these projects buy important time. The need, therefore, is to properly calculate the value of carbon sequestered over differing time periods, as well as protect against premature losses.

[6] GEOMOD is a dynamic land use simulation model, developed by Systems Ecologist Charles Hall and graduate students at SUNY ESF that predicts the rate and spatial pattern of land conversion, particularly that which is anthropogenically-derived.

Many liability rules have been suggested in order to account for non-permanence of carbon credits generated through land based sequestration activities. They include:

- Ton-year accounting where carbon sequestration is valued on the basis of both the number of tons sequestered and years over which it is sequestered (Noble et al. 2000; Herzog, et al 2003).
- Utilize 'Temporary Certified Emission Reductions', which are only valid over the lifetime of a project or a forest plantation and expire thereafter. The buyer of a temporary credit has to bear the liability of finding a follow-on credit (Chomitz and Lecocq 2003).
- Account for the average carbon that can be stored under a certain project or a given forest plantation, such that the stochastic carbon stocks are averaged over a predefined period of time, which could be the project's lifetime or the ending date of a contractual agreement.
- Consider the carbon offset credits to be permanent, so that any emissions are deducted from the emission reductions and the liability for failure to ensure permanence or to deliver the promised number of credits lies with the seller of these credits.

Implementing these options has been done in project contracts by several methods, such as:

- *Seek Long Term Easements.* Some programs have been based on very long (80 to 100 year) or even perpetual conservation easements. These easements establish guidelines for the use of the land, and are designed to maintain the project's integrity over the term of the easement. There are obvious limitations to the ability of an easement to eliminate the loss of carbon in natural events or disasters, so while an easement might prevent the clearing of a forest for another land use, it wouldn't prevent the forest from burning in a wildfire.
- *Record Annual Amounts.* In the 1605(b) program, reporters are encouraged to update the amounts sequestered, by project, on an annual basis. For afforestation and reforestation, annual amounts can be calculated in the associated Excel software as a "net amount" based on forest growth tables provided in the supporting materials. The software calculates the net amount as a uniform annual amount for years 1 through 20, so it appears that it must calculate a mean annual growth increment (MAI) for years 0-20. The CCX credits conservation tillage projects on an annual basis, based on a default value established by the Exchange.
- *Establish fixed crediting periods.* Current guidelines for CDM (Clean Development Mechanism) projects under the Kyoto Protocol call for two approaches: A) a maximum of 7 years which may be renewed at most two times; or, B) a maximum of 10 years with no option of renewal.
- *Short, renewable contracts.* NCOC is experimenting with approaches to flexible short-term, renewable contracts. Thus, a landowner might establish a sequestration project with an anticipated duration of 50 years, but only register a 5-year contract based upon the MAI (mean annual increase of carbon) for the first 5 years. At the end of the contract, the actual carbon is measured, adjustments made if needed, and the contract is re-negotiated for another period (i.e. from 5 to 15 years) at the new MAI (which, in a young growing forest, will be significantly higher). The short contracts are designed to protect all parties in the transaction from major differences between calculated and measured amounts, as well as allow responsiveness to future price levels if the projects are involved in market transactions.

- *Create Portfolios of Projects.* NCOC creates portfolios of various projects to increase diversity and reduce the risk of losing stored carbon. The system anticipates using actual measurements of forest carbon (probably on 5-year intervals) to “true up” project estimates. If some projects under-perform projections, others may over-perform, maintaining the integrity of the total amount reported in the portfolio.
- *Create a protection fund.* Where projects produce credits that are sold in a market transaction, their loss would be a financial loss to the buyer who could no longer claim them. An insurance pool that contains un-claimed, but legitimate, carbon credits could provide replacements. Another option would be a program that could reimburse the loser financially through insurance. The NCOC has worked with insurance companies to create an insurance program patterned after existing crop insurance programs used in agriculture, but this has yet to be implemented.

Monitoring and Verification

To the extent that sequestered carbon or emission reduction attains a value (i.e. a “creditable” tonne), it becomes a commodity. Unlike other commodities, however, it does not move physically from the control of the supplier to the control of the buyer. Instead, what moves is a certificate or statement proclaiming the existence, stability, and legitimacy of the claim. To be fully credible, that claim must be subject to monitoring and verification. This has led to several approaches, including:

- *A Monitoring Plan.* All of the systems involving credit sale or trade require that a monitoring and verification plan be submitted as part of the project plan. While there appears to be no single approach at this time, there seems to be a trend toward a tiered approach. NCOC guidelines require an annual report from the landowner, stating that the project is still intact and that the management plan remains in effect. That is supplemented by periodic monitoring, in most cases carried out by a local public agency such as a conservation district or county forester, or a consultant. That monitoring may take the form of a visual inspection or, in some cases, plot measurements to ascertain tree growth. In some plans, those measurements are planned at year 5, then periodically (2-5 years) thereafter. In the event of term contracts, there will be actual measurements at the end of the term to ascertain values. Soil sampling has generally been proposed at year 10 and at 10-year intervals to recognize its higher cost and the slower rate of change anticipated.
- *Verification.* Auditing of the program, including a sample of the field projects, is foreseen in all programs involving carbon credit sale or trading. It has not been a part of the voluntary 1605(b) program and, given the cost involved, seems unlikely to become a requirement in a voluntary program. Forest certification is an increasingly common part of forest management, particularly for large owners. NCOC recognizes that the third-party audits conducted for forest certification provide independent verification of landowner claims involving timber growth and system sustainability. Such certification also assures that other environmental (as well as economic and social) issues have been addressed in the forest’s management.

Transparency and Credibility

Project reports that feature fully transparent measurements and calculations will be more readily accepted than those where the calculation of reported amounts cannot be determined from the available material. Some of the following issues may be important to address:

- *Project plan.* All trading systems require a written project plan that contains explicit information about the "who, what, when, where, and how" aspects of the project. Those plans need to be on file and available for program auditing when that is required.
- *Stocking rate.* In agroforestry and afforestation projects, different species are planted at different physical spacing, and there can be significant mortality during the planting year. Project developers need to conduct survival surveys after the first year and, where the remaining live trees do not meet minimum stocking guidelines, plant new trees to fill in gaps and bring the stand to acceptable stocking levels.
- *Methods of calculation.* Transparency is enhanced when the methods of calculation are clearly apparent to reviewers. Where claimed sequestration rates are outside established ranges, planners should submit detailed calculations. Where the results of proprietary models cannot be reproduced in open models, there should be some method of adjusting to more credible and transparent figures.
- *Pools measured.* Carbon can be sequestered into several "pools," including above- and below-ground biomass, soil carbon, forest floor, and understory growth. For credible reporting, all pools measured should be indicated, and the method of establishing current (baseline) carbon stocks in each pool should be shown. For unmeasured pools, there should be some technical assurance that there will not be significant reduction in carbon stocks as a result of the project activity.
- *GHG Gases reported.* While the measurement of carbon stocks offers are relatively effective way of measuring the transfer of CO_2 between the atmosphere and the land, a project could affect the emission of other GHG gases that are much more difficult, or impossible, to measure. This may require a project developer to consider how (and whether) those other emissions should be reported. It is anticipated that most registries will have rules that must be followed. The California Climate Action Registry, for example, allows a forest entity to report only carbon stocks and CO_2 emissions for the first years, but from the fourth year onward, they are required to report emissions of all five GHG's in the Kyoto Protocol. Calculation and reporting methodologies are yet to be developed.
- *Location.* Sequestration projects differ from many industrial emission reduction projects in that they are tied to a wide geographic area rather than a point location. A transparent registry will provide geographic location data for agricultural and forestry projects. Planners should provide the geographic coordinates of an adequate set of points to describe the project polygon or polygons. This reduces the risk of duplicate reporting, facilitates monitoring, and could eventually allow better understanding of cumulative impacts in regions where projects become a significant part of the landscape. (This does not need to be the location of an activity, such as conservation tillage, within an agricultural project. By showing the project boundaries, however, it reduces the chance that another project (i.e. a land conversion) could be reported within the same land area.)

- *Credit ownership.* The right to report credits as emission offsets (or sell or trade them in an eventual market system) will often be separated from the ownership of the land or emission source upon which the credits are produced. NCOC, for example, requires a sale document from the landowner to establish NCOC's right to report or sell the credits, as do all the systems involving credit sale or trade. A transparent registry will have rules for annual reporting that only allow the owner of record for the year involved to report the credits. Associated with requirements for geo-locating each project, it may be useful to document the landowner of the land where the credits actually reside.

F. Energy substitution as a means of mitigating emissions

The concept of growing crops and trees for energy has been used for ages. Wood was a common source of energy before fossil fuels came into the arena. The concept of using biomass fuels for energy has emerged in the international climate change mitigation discussions as a potential source for further reducing emissions. In addition to sequestering carbon, trees and other biomass can be used as an energy source in place of fossil fuels. Fuels from biomass or renewable sources are often referred to as 'biofuels' and may include woodfuel, charcoal, livestock manure, biogas, biohydrogen, bioalcohol, microbial biomass, agricultural wastes and by-products, and energy crops.

Where trees and biomass are used as an energy source the carbon dioxide that is released can be netted out by the next cycle of growth, thus providing a zero net change in atmospheric greenhouse gas levels. In addition, biomass energy production produces far lower levels of environmental pollution from sulphur and nitrogen componds compared to fossil fuels. For example, making biodiesel from soybeans reduces net emissions nearly 80%[7].

The US currently has 10 gigawatts of installed capacity for generating greenpower based on direct combustion. Green electricity requires customers to pay a premium on their electricity bill to support investment in renewable energy technologies or to purchase electricity generated using biomass (or other renewable resources) in restructured electricity markets.

While the technologies for making energy from biomass are relatively new and continue to emerge, the interest in these type of projects is high, driven by the many environmental benefits that can be obtained from them. Biopower generation in the US includes co-firing of biomass in existing coal-fired boilers, gasification combined cycle systems, fuel cell systems and modular systems. Some of the processes and systems involved include:

- Direct combustion of biomass with excess air, producing hot flue gases that are used to produce steam in the heat exchange sections of boilers. The steam is used to produce electricity in steam turbine generators[8].
- Co-firing biomass in high-efficiency coal fired boilers as a supplementary energy source[9].
- Biomass gasification by heating in an oxygen-starved environment to produce a medium or low calorific gas. This "biogas" is then used as fuel in a combined cycle

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[7] http://www.eere.energy.gov/biomass/environmental.html
[8] http://www.eere.energy.gov/RE/bio_biopower.html
[9] http://www.eere.energy.gov/RE/bio_biopower.html

power generation plant that includes a gas turbine topping cycle and a steam turbine bottoming cycle[10].

- Biomass pyrolysis where biomass is exposed to high temperatures in the absence of air, causing the biomass to decompose. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide).
- Anaerobic digestion where organic matter is decomposed by bacteria in the absence of oxygen to produce methane and other byproducts. The primary energy product is a low to medium calorific gas, normally consisting of 50 to 60 percent methane.
- Modular power systems are small energy producers that can be used in farm systems to provide power at or close to customers' sites.
- Combined heat and power (CHP) facilities are used most commonly at present to provide biopower. They are usually located at forest product industry sites and achieve high efficiencies by using both the power and the excess heat from burning the biomass.

Biomass energy resources include many forms of organic material that are available on a renewable basis. Energy crops and trees, agricultural food and feed crops, agricultural crop waste and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes and other waste materials fall under this category. Some of the fuel types are described as:

- Biomass energy crops are trees and perennial grasses grown specifically to provide raw materials (feedstocks) for energy producers and industry.[11] They include herbaceous crops such as switchgrass, miscanthus, bamboo, sweet sorghum, tall fescue, kochia, wheatgrass, and woody crops like hybrid poplar, hybrid willow, silver maple, eastern cottonwood, green ash, black walnut, sweetgum, and sycamore. Fast growing trees can be grown and coppiced on a short cycle of three to seven years. Coppicing refers to cutting trees and shrubs to ground level, from which they re-grow from the stump into a clump of stems.[12]
- Agricultural feedstocks include cornstarch and corn oil, soybean oil and meal, wheat starch and other vegetable oils used to yield sugars, oils, and extractives.
- Aquatic crops like algae, kelp, seaweed and marine microflora are used to produce thickeners and food additives, algal dyes and biocatalysts[13].
- Agricultural crop residues such as stalks, leaves, and other biomass that has not been harvested or removed from commercial fields such as corn stover, wheat straw and rice straw.
- Forest residues include non-merchantable biomass removed from commercial harvesting sites, pre-commercial thinning, or dead and decaying trees.
- Municipal waste includes waste paper, cardboard, wood or yard waste, or any other form of biomass waste from residential, commercial and institutional garbage.

[10] http://www.eere.energy.gov/RE/bio_biopower.html
[11] http://bioenergy.ornl.gov/papers/misc/cropenv.html
[12] http://www-saps.plantsci.cam.ac.uk/trees/glossary.htm#Coppice
[13] Biocatalysts are used in bioprocessing under extreme environments

- Animal waste, largely from confined animal feeding operations, where waste disposal can become a major pollution control problem, can be used to generate energy through direct combustion or methane generation.

There are many ways in which biomass can be used as energy and/or industrial feedstocks. They include:

- Biofuels, including liquid fuels such as ethanol, methanol, biodiesel, or Fischer-Tropsch diesel, and gaseous fuels such as hydrogen and methane[14]. Ethanol is currently the most widely used biofuel with the US having a current capacity of producing 1.8 billion gallons per year using starch crops like corn. Biodiesel can be produced from soybean, rapeseed, animal fats, waste vegetable oils and microalgae oils. Advances in biotechnology are expected to bring about continued improvement and efficiency in biochemical conversion processes.
- Biochemicals and Biomaterials[15] are commercial or industrial products, other than food and feed, derived from biomass. They include chemicals, plastics, fibers, and structural materials. Several of these products can be used to replace products and materials traditionally derived from petrochemicals, however many still require development of new and improved processing technologies.

Increased use of bioenergy will reduce dependence on imported oil and improve local, regional and national energy self-sufficiency. In 2002, fossil fuels supplied 86% of the energy consumed in the United States,[16] with more than half (65%) of the petroleum being imported. A move toward a sustainable economy based on domestic biomass energy sources could produce many economic benefits for the US economy, including:

- Reduction in trade deficits – energy related petroleum products account for over one-fourth of the total US trade deficit and each $1 billion of trade deficit costs the U.S. 27,000 jobs;[17]
- Job creation, especially in rural areas – new plants mean construction, maintenance and support efforts;
- Increased revenue from selling greenpower, especially through locally operated smaller biopower facilities;
- Increased revenue for farmers and forest owners from energy crops;
- Reduced costs of biomass waste disposal;
- Increased revenue from biomass based chemicals and infrastructure material;
- Sustainable production from marginal land without the threat of land damage due to soil erosion;
- Development of new processing, distribution, and service industries in rural communities;
- Reduced use of landfills;
- Decrease in depletion of domestic petroleum reserves;

[14] http://www.eere.energy.gov/RE/bioenergy.html
[15] http://www.eere.energy.gov/RE/bioenergy.html
[16] http://www.eere.energy.gov/biomass/biomass_benefits.html
[17] http://www.eere.energy.gov/biomass/economic_growth.html#trade

- Reduced cost of maintaining an uninterrupted flow of oil from the Gulf region, in terms of military expenditures;
- Reduced harmful impacts that fluctuations in petroleum prices can have on the US economy; and,
- Reduced public health costs – reduction in air pollution from vehicular emissions would reduce public health costs from eye irritation, respiratory and cardiovascular illnesses, and cancer.

In terms of environmental benefits, bioenergy technologies can have the following impacts:

- Reduced emission of nitrogen oxides, sulfur dioxides, and other air pollutants associated with fossil fuel use;
- Very low or no net carbon dioxide emissions;
- Soil erosion control;
- Better nutrient retention;
- Stabilization of river banks and stream banks;
- Watershed stability;
- Improved groundwater quality;
- Improved surface water runoff quality;
- Improvement in availability of wildlife habitat;
- Improved biodiversity;
- Relatively low input of fertilizers and pesticides compared to many agricultural crops;
- Environmental sustainability;
- Are non-toxic and biodegradable;
- Reduced risk of petroleum product spills; and
- Reduced odors associated with conventional disposal or land applications.

The future will likely see the emergence of integrated bioenergy systems like biorefineries that function similar to petroleum refineries. These are likely to produce a few basic biomass products initially and later expand to sophisticated multi-product operations that maximize the use of the biomass resources.

Part 2 – Carbon Trading and Marketing

A. Background on Environmental Markets

Greenhouse gas emissions like any other form of pollution are generally side effects of activities that impact other people, but the polluter never compensates the affected parties or the affected parties do not pay the polluter to stop polluting. This implies that there are certain costs to the society that are not paid for by anyone. Many policies have been proposed for internalizing these "external" environmental costs. Some suggest the use of market based economic incentives and others advocate the use of "command and control" regulatory instruments. Market based mechanisms include taxing polluters with something like a carbon tax or setting up of a system for trading environmental permits or rights, such as the right to emit carbon. Command and control mechanisms on the other hand require polluters to adhere to some sort of emission standards that may put a cap on the total emissions from a source or might require the use of a prescribed technology that would inhibit innovation or research.

In the1980's environmental taxes were seen as a substitute for command and control approaches that could lead to reduced government intervention and a more prominent role for economic incentives to change polluter behavior. The use of taxes often turns out to be politically unpopular, especially in case of environmental issues. Some of the problems associated with environmental taxes are:

- It is not easy to determine the level of taxes that accurately reflect the real environmental cost of producing or consuming a product or resource.
- If certain environmental resources do not have substitutes, like fossil fuels, the higher production costs (due to taxes) are passed on to consumers. This discourages consumption of the resource but may not lead to cleaner production of commodities that use that resource.
- Environmental taxes can damage the competitive advantage of a critical national industry unless a tax benefit is directed to eco-efficient enterprises in the same industry.
- Environmental taxes may be regarded more as a revenue generation tool for the government by both industry and the community than as a genuine tool for dealing with environmental problems unless the revenues raised are spent directly on environmental activities, or to reduce taxes on employment or capital.
- If taxes or charges represent only a small portion of outlays on a particular product or service, their effects may not be sufficient to alter behaviour.[18]

Command and control mechanisms can thwart the growth of new technologies that might be more efficient in abating pollution and can also prevent the flow of environmental/pollution rights to entities who value them the most. Some problems with command and control mechanisms are:

- It is not always easy to determine the 'optimum' target or technological standard, especially with non-marketable goods, such as water and air, which would help achieve the appropriate environmental targets.

[18] http://www.deh.gov.au/industry/corporate/taxes.html

- In case of a command and control approach, firms have no incentives to reduce pollution beyond what is required by the standard.
- If penalties for violating standards are too low then enforcement will be weak and the environmental standard might not be achieved.
- The standards under a command and control approach need to be adjusted frequently in order to be effective under new information and risks, however in practice legislation tends not to keep up with change.
- Since mandatory standards do not allow the entities to choose the production or consumption activity to meet the standard, command and control mechanisms tend not to drive the marginal cost of compliance to the minimum.
- Standards might prove to be politically unpopular if they are stringent and industries are adversely affected.

While command and control mechanisms have been more widely used in the past than market based mechanisms, policy makers have become more open to the use of market based environmental tools in recent decades (Stavins 1998). Markets for trading environmental rights have been advocated by researchers and economists since the 1960's, when Ronald Coase proposed a conceptual and practical framework for the possibility of trading environmental rights as a mechanism to deal with environmental problems. The Coase theorem was that if transaction costs are zero, so that the trading parties make an agreement that is mutually beneficial, any initial definition of property rights leads to an efficient outcome. The problem is that transaction costs are almost never zero where the environment is concerned and carrying out a mutually beneficial trade could be so costly that trade wouldn't occur at all.

Establishment of a trading market is one step towards minimizing the transaction costs for buyers and sellers of GHG emissions rights. But trading implies that one party owns rights that another party finds desirable to obtain, and 'property rights' are usually not well defined where environmental goods like clean air and clean water are concerned. The right could be held either by the polluter or by the affected parties. Therefore, the establishment of a trading market requires government to establish emission rights. This is normally done by assigning emission permits to all of the emitting sources in a particular sector or industry. There are many issues involved in allocating the initial emission limits and permits.[19]

Once industries are assigned rights to emit greenhouse gases and the initial property rights are defined and enforced, any industry with excess emission rights can sell them in the market, and the market serves to minimize the relevant transaction costs. Markets automatically create and assign the highest value to emission rights by putting them in the hands of people who value them the most.

Permit trading suffers it's own set of problems. Some researchers argue that permit trading gives private corporations a "license to pollute". However, an overall cap would usually accompany a trading system so that the total permits issued by the government achieve the environmental standards and trading ensures that the market locates the lowest cost opportunity for reducing emissions. A second issue raised with regard to emissions trading is that it allows polluters to buy their way out of their responsibility to reduce emissions. Emissions trading markets put a price on emissions, thus making it

[19] See, for example, www.pewclimate.org/global-warming-in-depth/all_reports/

costly for firms to emit. This provides an incentive to invest in cleaner technologies where they are more cost effective than buying emission rights.

It does not matter where the carbon dioxide emissions are reduced as long as the overall reduction target is achieved at minimum cost. A cap and trade mechanism provides the two pronged benefit of allowing the regulatory authority to achieve the environmental target and offering the affected parties flexibility to select the production or consumption option that minimizes the cost of achieving a particular level of environmental quality. In case the government chooses to auction the initial permits, it can create a new revenue stream that can be used to reduce negative economic effects.

B. Lessons from Sulfur Dioxide Trading

A tradable permit system for sulfur dioxide was introduced with the Acid Rain Program established under Title IV of the 1990 Clean Air Act Amendments. The Acid Rain Program set out to reduce total U.S. SO_2 emissions by 50 percent, or 10 million tons, below 1980 levels. These reductions were to be achieved through a two-phase plan that involved tightening of the restrictions placed on fossil fuel-fired power plants.

Phase I began in 1995 and affected 263 units at 110 mostly coal-burning electric utility plants located in 21 eastern and Midwestern states[20]. Later, 182 more were added, bringing the total number of affected units to 445 under Phase I. The year 2000 saw the beginning of Phase II, which led to tightening of annual emissions limits imposed on large plants with higher emissions and also placed emission caps on smaller, cleaner plants fired by coal, oil, and gas, bringing over 2,000 units under the program.

Under the SO_2 tradable permits program each allowance authorizes the holder of the allowance one ton of emissions. The cap on emissions is enforced by limiting the number of available allowances, so that the desired reduction in SO_2 levels is achieved. EPA used the emission performance standards and representative fuel use records during the baseline period from 1985-87 to allocate allowances among various sources of emissions. At the end of each year, every source must have enough allowances to cover its emissions for that year.

This system achieves cost efficiency by allowing sources to buy and sell allowances as their situation warrants. Thus any source with an excess of allowances or any source that can reduce emissions at a lower cost can sell them to those for whom it is cheaper to buy allowances than reduce emissions themselves. Any unused allowances may be saved or banked for future use. Besides trading allowances, the sources are free to install any new technology or switch fuels to cover their emissions if it is cheaper to do so as compared to buying allowances. The aim is to equalize the marginal cost of reducing emissions across all sources thereby driving them to the minimum.

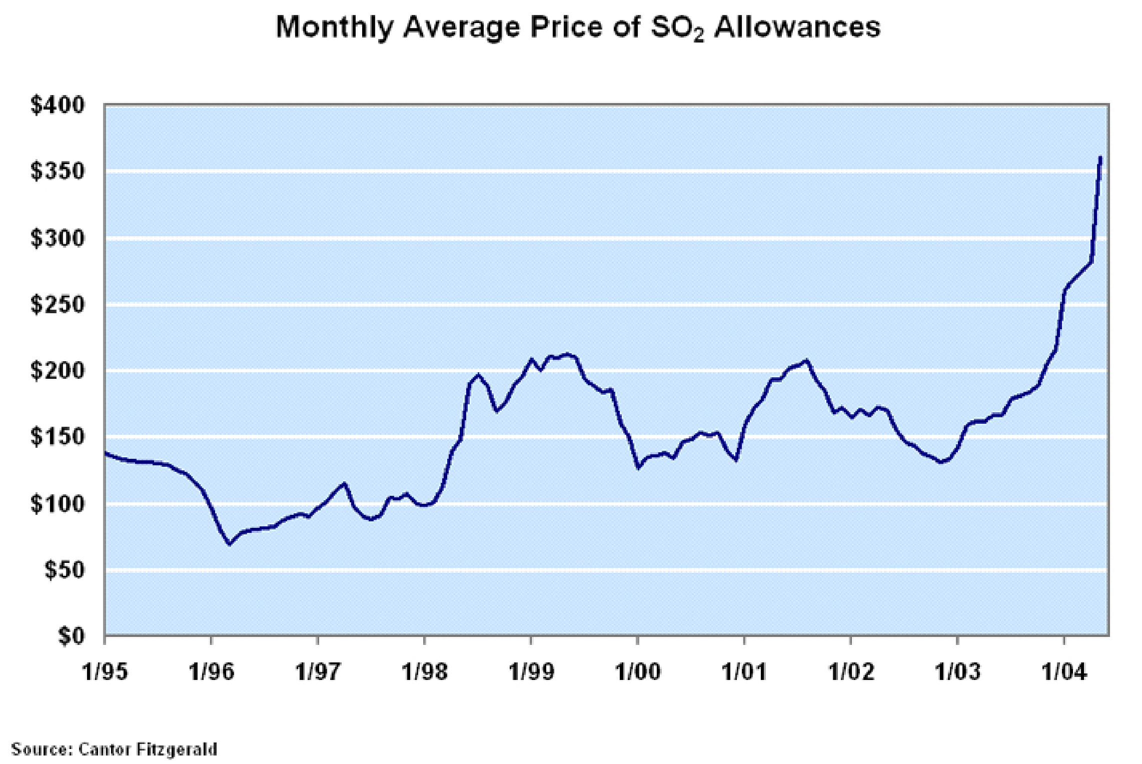
EPA ensures compliance by continuously monitoring sources for the tons of SO_2 emitted and placing a penalty of $2000 per ton on emissions in excess of the total allowances held by a source, with a further requirement that sources surrender allowances in future years to cover excess emissions (Stavins 1998).

The resulting SO_2 markets have not only led to cost savings in dealing with the acid rain problem but also achieved the environmental target of reducing SO_2 concentrations. By 1999, the SO_2 emissions from Phase I units were 29 Percent below the allowable level; and 45 percent lower than emissions from those same plants in 1990 (US EPA

[20] http://www.epa.gov/airmarkets/arp/overview.html#phases

2000). The costs of meeting SO_2 reduction goals have been much lower than what were estimated at the beginning of the program, as reflected in the price of permits, which also reflects the marginal cost of abatement. The price of allowances was initially estimated to be around $400-1000 per ton, but it had declined to less than $150 per ton by the end of 1999. The price was $131 per ton at the 2000 allowance auction, and prices remained in the $130 to $200 range through 2002 (Figure 2.1). The runup in prices during 2003 has continued in 2004, apparently reflecting a new supply-demand relationship as energy production has continued to climb while much of the supply of available allowances has been utilized.

Figure 2.1. Allowance Prices (1995-2004)



Source: http://www.epa.gov/airmarkets/trading/so2market/alprices.html

The SO_2 tradable permit system illustrates the importance of flexibility in the banking of unused permits and the freedom to adopt the least cost means of reducing emissions. In addition to giving away permits based on historical baselines, EPA also auctions them to allow producers to meet any additional requirements. The revenue from these auctions can be used to reduce other taxes in the economy thereby further reducing the overall cost of the permit system.

The simplicity of the SO_2 trading system lies in the fact that permits were allocated based on historical data, trading rules are unambiguous, individual trades do not require prior government approval and baselines are absolute rather than relative. Continuous monitoring and high penalties have ensured compliance with the program.

Energy utilities have an incentive to reduce SO_2 emissions and prevent pollution under the tradable permit system since for each ton of SO_2 that a utility avoids emitting, one fewer allowance must be retired. Thus utilities that reduce emissions through energy efficiency and renewable energy are able to sell, use, or bank their surplus allowances[21].

C. Experience in Carbon Emissions Trading

The Kyoto Protocol includes three flexible mechanisms that the capped countries can use in order to meet their carbon reduction goals. The flexibility mechanisms are basically three different ways of trading emissions, which allow countries and/or firms the flexibility to select the most cost effective mechanism for achieving the mandatory carbon reduction standards. The three flexibility mechanisms include:

- International Emissions Trading: This represents a basic buyer-seller transaction between any two Annex B Countries[22].
- Joint Implementation: Entities can create Emission Reduction Units (ERUs) by developing and financing projects that reduce emissions in an Annex B country
- Clean Development Mechanism: This mechanism provides a way for increasing the collective emissions cap of Annex B Countries by creating offset decreases in non-Annex B[23] countries.

The United States has decided to reduce GHG emissions unilaterally, thus none of the above mechanisms would apply unless the US decides to enter the international market for GHG credits.

Emissions trading can take on different forms where agents buy and sell contractual obligations or permits that represent specified amounts of carbon-related emissions: 1) which may be emitted[24]; 2) which may be abated (energy efficient technology and renewable energy)[25]; or 3) which may represent offsets against emissions, such as carbon sequestration[26].

Even though formal GHG trading markets have not been established, trading has taken place within the US and also in other parts of the world because industries predict that they will be required in the future to undertake measures for addressing the impacts of GHG emissions on climate change. Since GHG markets are likely in the future, companies are hedging their risk exposure to potential limitations on CO_2 emissions by purchasing emission credits. Entities are trading emissions reductions in the current unregulated markets and these reductions represent either reductions in actual emissions, avoidance of potential emissions, or the creation of emission offsets (e.g. carbon

[21] http://www.epa.gov/airmarkets/arp/overview.html#impetus

[22] Annex B countries are the 39 emissions-capped industrialized countries and economies in transition listed in Annex B of the Kyoto Protocol. Legally-binding emission reduction obligations for Annex B countries range from an 8% decrease (e.g., various European nations) to a 10% increase (Iceland) in relation to 1990 levels during the first commitment period from 2008 to 2012. (http://www.co2e.com/common/glossary.asp#A)

[23] Countries not included in Annex B of the Kyoto Protocol. Non-Annex B countries do not currently have binding emission reduction targets. (http://www.co2e.com/common/glossary.asp#N)

[24] http://www.climate.org.ua/glossary/glossary_e.html

[25] www.envirotools.org/glossary.shtml

[26] http://www.forest.nsw.gov.au/env_services/carbon/trading/Default.asp

sequestration). Companies are buying GHG reductions in the anticipation that regulatory authorities will accredit these reductions when formal trading markets are established.

Some of the reasons why companies are engaging in early trading are:

- They believe that the issue of climate change mitigation is real and here to stay.
- They are taking action now to mitigate the negative impacts of GHG emissions, and preparing their business to participate in future market trading.
- They believe that the issue of climate change is going to be an integral part of future business and financial risk management.
- By participating in early GHG trades companies are trying to get a head start in the competition in an emerging emissions trading market.
- Early trading helps build institutional capacity, invest in credible emissions reduction and influence the development of formal GHG trading markets.
- By participating early the companies can reap financial benefits of investing in emissions reductions when it is relatively cheap to do so.
- Trading provides early experience in using markets to meet compliance requirements.
- Early trading provides an opportunity for positive public relations and building a strong image of environmental responsibility.

GHG trading could be especially cost efficient because carbon dioxide and other greenhouse gases come from a huge diversity of sources. The costs of meeting national or international targets will vary widely across different sectors of the economy and across regions. In that situation, a market for GHG permits can drive the production of carbon credits to sectors where it costs the least to produce them. The SO_2 trading program has demonstrated that once the institutional framework and incentives are in place, players in the private sector will bring together trading partners and reveal costs and prices.

Several factors will be required for the development of an active market in carbon credits. Some are being developed today; some still lie in the future. While these developments may have little or no impact on the manner in which sequestration projects are planned, they will control how effectively a landowner can market their carbon credits through the NCOC.

The limiting factor in the market today is the lack of buyers. While there is widespread agreement that some form of limits on greenhouse gas emissions may be necessary to prevent unwanted climate changes, those limits are not in widespread effect in 2004. There are discussions in Europe, in the U.S. Senate, and in some U.S. states, but formal limits for the U.S. are not in effect.

D. The Chicago Climate Exchange (CCX)

The Chicago Climate Exchange (CCX) is a self-regulatory exchange that administers a voluntary, legally-binding pilot program for reducing and trading GHG emissions in North America. The program began live on-line trading of GHG emission allowances in 2003. CCX has 55 members, including major corporations, trading firms, non-governmental organizations, and public entities such as cities and universities. Members with direct emissions commit to reduce GHG emissions by 1% per year over the years 2003 to 2006, thus achieving a total reduction of 4% below their baseline average emissions in 1998-2001. A member whose emissions exceed its commitment can reduce emissions directly, purchase emission allowances from other CCX members who are below their commitment target, or purchase offsets. Those that reduce emissions below the commitment level can either sell their excess allowances on the exchange or bank them for use in future years.

CCX has contracted with the National Association of Securities Dealers (NASD) to provide regulatory services. NASD will assist in the registration, market oversight, and compliance procedures for CCX members, as well as provide auditing services to verify claimed baselines, measurements, and offset project verifications. Offset project verification, done by CCX-approved verifiers, is required for all offset projects to ensure environmental integrity.

As the only rules-based and standardized GHG emissions trading system in North America, CCX provides its members an opportunity to participate in building the institutions and shaping the policies that may eventually guide a national or international GHG trading system. Trades are conducted rapidly and efficiently through a web-based system that is designed to keep transaction costs to a minimum.

CCX provisions relative to NCOC

NCOC is currently seeking an eligible partner (commercial or trading firm) so that NCOC portfolios (groups of projects) can be eligible for CCX trading. If that effort is successful, NCOC will construct portfolios of projects for CCX, using the following CCX rules and guidelines. These are listed here so that project planners are aware of the special requirements involved in qualifying for an offset sale on the CCX.[27]

In order to qualify as an aggregator for CCX, an organization such as NCOC and its marketing partner must:

1. Accept initial registration forms from owners of CCX-eligible projects;
2. Assemble project reports from project owners, retain copies of project verification records;
3. Submit offset registration fees to CCX;
4. Have sole authority to access the Registry Accounts holding the offsets issued to project it represents and to access the CCX trading platform as an authorized trader; and,
5. Execute sales on the CCX trading platform on behalf of project owners and distribute sales proceeds to project owners in accordance with the terms agreed between the Aggregator and Project Owners.

The terms of the business and legal relationships between Aggregators and Project Owners are left to the discretion of those parties.

The minimum trading unit on the CCX is one Exchange Offset, which equals 100 tCO_2e (or 100 CSU's, as defined by NCOC, See Part 4B). Each Exchange Offset will be identified by annual Vintage (the year it is eligible under CCX rules to be used for compliance with the CCX emission reduction schedule)

Projects involving forestation or forest enrichment by plantings or natural regeneration initiated after Jan 1, 1990, on land not forested or on forestland that had been degraded or unforested on Dec 31, 1989, may earn Exchange Forestry Offsets (XFO's). XFO's are based on the annual increase in carbon stocks realized during the

[27] Note: These are CCX rules as of July, 2004. They are subject to change by CCX without notice.

years 2003, 2004, 2005, and 2006, measured in metric tonnes of carbon dioxide (CO_2) equivalent.

XFO's are based on increases in carbon in above-ground living biomass. The owner retains rights to all non-included carbon pools.

Project owners must demonstrate that their forest holdings outside the Project area are sustainably managed. For non-CCX members, this can be established by attestation and provision of evidence that the Project Owner sustainably manages its non-Project forest carbon stocks and that its non-project forest holdings are not converted to non-forest uses.

Projects on privately-owned land need to be placed in protective status via:

a. Establishment of a long-term conservation easement providing that the Project land is to be maintained as forest for the duration of the easement;
b. Transfer of ownership of land to a land trust, qualifying NGO, or governmental body, provided such transfer establishes legal protection that the project land is to be maintained as forest; or
c. Other means that the CCX Committee on Offsets and the CCX Committee on Forestry may recommend as acceptable.

The Project Owner retains full legal ownership of all rights associated with the mitigation of Greenhouse Gases that might accrue:

a. On lands or via activities not included in the CCX-registered Project
b. In excess of the quantity of Exchange Offsets issued by CCX; or
c. Before or after the 2003-2006 period

Methods of measurement are the same as for the forest products sector. Small and Medium-Sized Projects (less than 12,500 tCO_2e per year) can use the CCX Accumulation Tables if they involve plantings of over 250 stems per acre. Small & Medium Projects must document the quantity of trees involved, acreage included, description of planted tree species and the tree ages, sizes and planting density at the time of Project Registration.

The Registration Filing must include a signed attestation by the Project Owner(s) that the forest Project has long-term carbon storage as a primary purpose. Owners are required to provide documentary evidence of the legal protection status of forest parcels included in a Project, if applicable. Owners may manage Project forests (thinning, pruning, fertilizing, selective harvest). Loss of carbon stocks associated with any management must be reflected in the Project performance reports.

Projects must contribute to a 20% Reserve Pool, maintained either by CCX or the Aggregator. The Pool remains the property of the Owner, and will be released in 2006 if not needed to cover Carbon reductions or losses. The Owner must report actual increases and decreases in Carbon Stocks.

Projects must be verified by a CCX-Approved Verifier and Owners must provide access to Project lands and documents for purposes of verification audits.

Any decrease in Project carbon stocks will result in cancellation of Offsets held in the Reserve Pool. The Owner must replace those losses to replenish the Pool. If the losses exceed what was in the Pool, the Owner must provide coverage.

E. Natsource

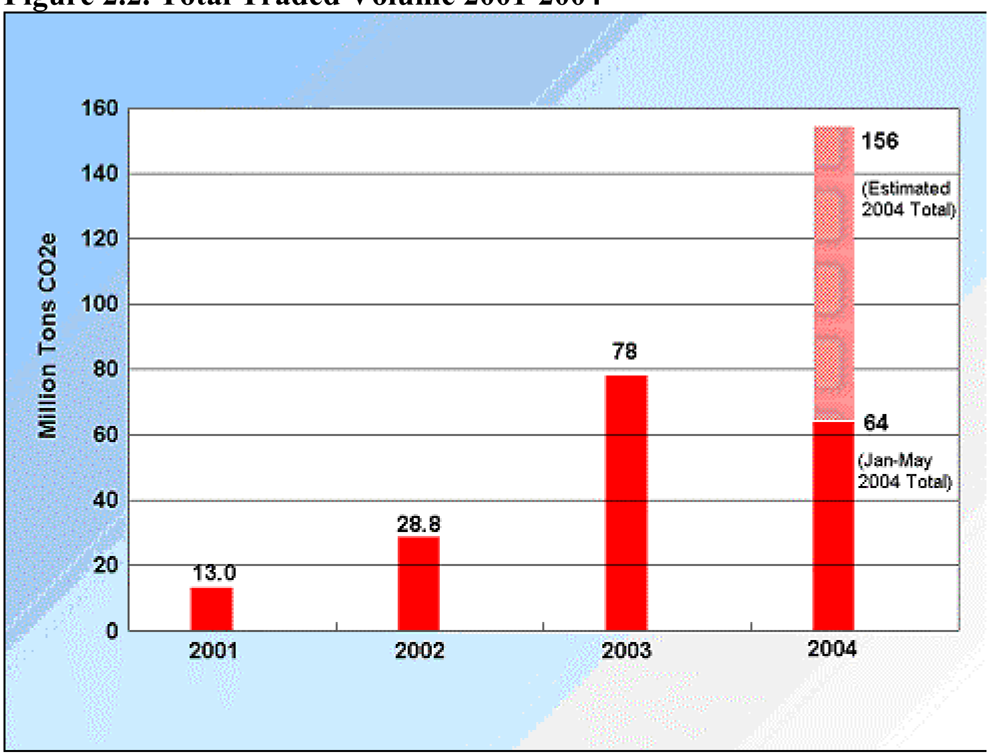
Natsource is a consultancy and environmental brokerage firm that provides services such as market and policy development assistance, price discovery, matching buyers and sellers, and organizing and constructing trade deals in the GHG emissions market. Natsource provides a platform for buyers and sellers to come together, negotiate and agree upon a mutually beneficial trade under strict confidentiality. In 2001, Natsource brokered the first transactions in allowances from the UK and Danish greenhouse gas emissions trading programs—the world's first greenhouse gas trading systems[28].

The Natsource team of brokers and policy advisors in energy and environmental markets helps clients with strategic planning efforts at the beginning of the negotiation process until the close of a trade and in the process helps them to "capitalize on opportunities and minimize risk[29]" at an early stage of market development.

According to LexisNexis, a division of Reed Elsevier Inc., Natsource brokered the purchase of 3.6 million metric tons of emission reductions for $17 million by Japan's Chugoku Electric Power in early June (2004) and these reductions were the first purchased from the Greenhouse Gas-Credit Aggregation Pool operated by Natsource.

Natsource's Environmental Action Desk has announced that it will donate for retirement 2,600 tons (more than 5,000,000 pounds) of CO_2 and 5 tons of SO_2 as part of an agreement made with EcologyFund.com and the Environmental Law and Policy Center to reduce pollution that contributes to global warming and acid rain[30].

Figure 2.2. Total Traded Volume 2001-2004



Source: http://www.gcsi.ca/ggtpr.html (*Note: 2004 illustrative estimate based on doubling of 2003 volumes.*)

[28] http://www.ieta.org/Library_Links/IETAEnvNews/Cogen.PDF
[29] http://www.natsource.com/markets/index.asp?s=22
[30] http://www.eadenvironmental.com/news/index.asp?n=301

Figure 2.2 demonstrates that the traded volumes increased from around 29 million tons in 2002 to approximately 78 million tons in 2003. Approximately 64 million tons were traded in the first four months of 2004[31]. Market trading volumes are expected to exceed 150 million tons for 2004 in anticipation of the European Union Emissions Trading Scheme, slated to start in January 2005.

Natsource suggests various transaction structures of GHG trading deals that buyers and sellers can enter into in order to increase trading benefits and reduce risks:

- **Immediate Settlement**: After the 'title' to the GHG reductions is transferred to the buyer, the seller receives the payment within 3 to 5 business days.
- **Forward Settlement**: GHG credits are delivered in the future with payments made either upon delivery or immediately at a discounted rate.
- **Streams:** Streams of GHG credits from consecutive vintage years may be traded using immediate or forward settlement, thus allowing the buyer to acquire the emission reduction credits of the vintages that he/she believes to be most important and seller to receive a stream of revenues for credits produced over the long term.
- **Options:** Options give the buyer of an option the right but not the obligation to buy GHG credits at a specified price for a specified premium, thus helping buyers and sellers hedge price risks.
- **Inter-pollutant and Inter-commodity Swaps:** Swaps are beneficial to those buyer who might, for example, have a surplus of GHG credits but a deficiency of Sulfur Dioxide credits by allowing trading of these two commodities, or another commodity such as power or coal for GHG emission reduction credits.
- **Bundling:** Reductions in GHG's may be bundled together with other goods such as coal or wholesale power.
- **Contract liability clauses:** This provides a guarantee to the buyer that any early emission reduction credits that are being transferred in the future will remain valid under future regulations by getting an assurance of money return with interest or substitution of valid credits from another project.
- **Portfolio building:** A portfolios of a variety of greenhouse gas reduction mechanisms that meet different quality, location, and vintage criteria can help reduce risk through diversification.

F. CO2e

This is a brokerage and consultancy firm similar to Natsource who claims to go beyond matching sellers and buyers of GHG emission credits by helping change the risk characteristics and tax effectiveness of the transactions through 'appropriate structuring'. Their services are associated with brokering related to greenhouse gases, renewable energy and other environmental products, sourcing and delivery of emissions offsets, financial structuring of wholesale and retail instruments to achieve tax effectiveness and better risk management, consulting for carbon commerce related to strategy development, analysis, verification, legal, accounting, insurance and other professional services and marketplace development and trading and risk management software which they deliver in association with eSpeed, Inc.

[31] http://www.gcsi.ca/ggtpr.html

CO2e.com, LLC is part of the Cantor Fitzgerald group created in association with PricewaterhouseCoopers and powered by eSpeed^{SM}. CO2e brings together a group of global experts and firms like PricewaterhouseCoopers, Innovest Strategic Value Advisors, CH2M Hill and ICF Consulting to provide these services. CO2e provides a 24 hour global platform for emissions trading through it's website http://www.co2e.com. Their website offers two means of entering the emissions market place, through their Trading Floor which can be used to build bids or make offers or through CO2e Portfolio Builder which is an analysis and development tool.

CO2e trades in 'emissions reductions', which refer to cuts in actual emissions, prevention of potential emissions, or the removal and storage of atmospheric carbon in biological sinks like forests, tree plantations and agricultural lands. It does not trade in carbon 'credits' which refer to emission rights generated against any reduction, removal or abatement of emissions that have been certified or approved by a regulatory authority, because GHG markets are still evolving and current trades are taking place on voluntary basis without any regulatory approval.

As described by www.CO2e.com, a typical trade of greenhouse gases would usually entail the following steps:

- Explanation of the methodology by which reduction in emissions is taking place (e.g. technological improvement, changes in production process, afforestation, sequestration in agricultural soils, etc.);
- Explanation of the methodology employed for verification, and liability for verifying the reductions in greenhouse gases;
- A report explaining how the reduced emissions qualify as 'additional' to those that would occur otherwise;
- Explanation of the seller's entitlement to ownership of the emissions reductions and the guarantee thereof;
- Explanation of various elements of a carbon trade in terms of the commodity that is being traded, the type of trade that is taking place, scheduled date of delivery of carbon reductions, payment for reductions, etc.; and,
- Explanation of the various liability rules and warranties in case of delivery or payment failure, and stipulations and requirements for the reductions to be accepted by future or current international and domestic regulatory bodies etc.

In order to buy and sell emissions reduction CO2e provides the users a platform to enter the Forward Market[32] or the Options Market[33] or to determine the appropriate market by visiting Market Instruments on their website. CO2e Portfolio Builder can be used to develop and test one or more trading strategies, in three major steps:

[32] A forward market deals in forward contracts, which are agreements to buy or sell an asset at a certain time in the future for a certain price. They generally constitute a private agreement between two entities including a mutually agreed delivery date. (http://www.co2e.com/common/glossary.asp#F)

[33] Options are contracts that give the option buyer the right but not the obligation to enter into a specific transaction purchase (a Call) or sale (Put) up to a certain date. The price (Strike Price), quantity and terms of delivery are locked in at the trade date. The expiration or exercise date (Strike Dates) is also locked in at that time, that is the date after which the option buyer's rights to enter into the transaction terminate. The option seller must live by the decision of the buyer, and is paid a premium for selling the optionality or flexibility to the buyer. (http://www.co2e.com/common/glossary.asp#O)

- Defining a Portfolio: the first step is to determine the 'Aggregate emissions gap', which is the difference between the entity's emissions target and the 'business as usual' emissions forecast over the five-year commitment period. The next step is to determine the default discount rate for discounting the future streams of carbon reductions from said project activity.
- Building the Portfolio: this step involves adding details to existing, internal and new projects in the portfolio.
- Analyze the Portfolio: this step consists of two types of analyses, the summary table and the summary chart.

Emissions reduction projects[34] at CO2e consist of three categories: Existing projects, Internal projects and New projects. Existing projects refer to "arms length[35]" emission reduction projects currently owned by a firm where the rights to emission reductions have been acquired from third parties. Internal projects refer to emission reduction projects that have been created through initiatives undertaken by the firm itself. New projects refer to "arms length" emission reduction projects that are not currently owned by a firm but the firm may choose to acquire them.

The CO2e Portfolio Builder analysis requires calculation of the historical and market costs of emission reduction projects, which are calculated as present value of future cash flows discounted at the appropriate discount rate. The price of emissions reductions are influenced by a variety of factors including regulatory uncertainty, project specifications, and technical risks, supply quantities, buyer outlook, and current market activity. Market prices are currently low because the demand for reductions hasn't yet caught up with their supply and especially because early reductions run the risk of not being recognized when formal carbon markets come into force.

The Portfolio Builder provides a convenient online tool for planning carbon transactions and executing them with the help of CO2e brokers. However, due to the uncertainty regarding future national and international regulatory setups and uncertainty regarding many provisions in the Kyoto Protocol itself, each individual portfolio suffers from unique risks and uncertainties. The CO2e website and the tools offered on it allow for updating, redefining and revisiting the portfolios to adjust for existing and emerging risks. Certain risks and uncertainties will always be associated with carbon projects even after a formal carbon market comes into effect.

G. The European Carbon Market

The European Council formally accepted the Emissions Trading Directive on July 2, 2003. The Directive laid out the framework for the European Emissions Trading Scheme (the 'European ETS')[36], which will launch the first international greenhouse-trading

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[34] Emission Reduction Project is a generic term that broadly refers to projects, investments, initiatives or instruments that generate or represent the reduction in the emission of, or sequestration of greenhouse gases. (http://www.co2e.com/common/faq.asp?intPageElementId=15230&intCategoryID=220)

[35] Arm's Length Transaction: A transaction in which the parties involved act independently of each other, and in which the mechanics of the transaction are handled as they would be between strangers. Sometimes the transaction is conducted by a mutually agreed upon third party, to ensure that one of the principal parties does not influence the other. (http://www.docloan.com/loans/loan_terms/Arms-Length-Transaction)

[36] http://www.thecarbontrust.co.uk/carbontrust/climate_change/iocc4_2_2_1.html

scheme covering 25 countries in the European Union in 2005. Their goal is to reduce emissions from the European Union by 8% below 1990 levels by the end of year 2012.

States in the EU have agreed to cap their emissions of greenhouse gases, and they are required to trade only carbon dioxide during the first phase (2005-2007), with the potential to include other gases in subsequent 5-year phases. The main sectors that are covered by the directive are power generation, steel, cement, ceramics, and pulp and paper. Activities in the first phase include energy activities, production and processing of ferrous metals, mineral processing and pulp and paper production. Additional sectors including chemicals, aluminum and transport may be taken into account for inclusion in subsequent phases of the scheme.

By April 2004, the operator of each installation in the member states was required to hold a greenhouse gas emissions trading permit for all installations included in the scheme. Under the directive operators are allowed to "pool" their targets and efforts to either abate or buy allowances to meet the joint targets in the first and/or second phases, provided they are all undertaking the same activity. In such a situation allowances will be issued to a nominated trustee for the group[37].

The EU ETS required that individual Member States submit National Allocation Plans (NAPs) for the first phase (2005-2007) to the European Commission by March 31, 2004. During the first phase, Member States are scheduled to allocate at least 95% of the allowances free of charge. They will then allocate at least 90% for the next phase beginning in 2008. Each national allocation plan is supposed to include a list of all installations covered and the expected quantities of allowances that are going to be allocated to each installation in the first phase of the scheme. Member states are required to allocate allowances to installations by February 28th of each year.

In order to keep track of all allowance transactions and to register allowances for accreditation, an electronic registry will be created in each Member State. Member States were required to complete the construction of their registries by September 30 2004, and are allowed to operate their registries jointly with one or more Member States. These registries will allow the flexibility for anyone to hold allowances, whether or not they are an operator of an installation included in the scheme. This establishes the platform for international trading of GHG credits.

A monetary penalty of €40 (approximately US$ 48.41 as of 06/23/2004) per tCO_2e[38] emitted in excess of the allowance held would be levied during the first phase of the scheme on all installations[39] that fail to surrender the required number of allowances. The penalty will be higher at €100 per excess tCO_2e emitted during the second and subsequent phases. Besides the fines levied in each phase, the installations that fail to meet their target will have to surrender sufficient allowances in the following year to make good their shortfall from the previous year in addition to the allowances required

[37] http://www.co2e.com/carbonbriefing/carbonbriefingview_eu.asp?categoryid=10146

[38] Carbon dioxide equivalent is the universal unit of measurement used to indicate the global warming potential (GWP) of each of the 6 greenhouse gases. It is used to evaluate the impacts of releasing (or avoiding the release of) different greenhouse gases. (http://www.co2e.com/common/glossary.asp#C)

[39] An "installation" means "a stationary technical unit where one or more activities listed in Annex I are carried out and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution". (http://www.co2e.com/carbonbriefing/carbonbriefingview_eu.asp?categoryid=10146)

for the current year. Operators[40] will be obliged to give up adequate allowances by April 30th of each year to cover the emissions of their installation.

Verification of emissions from activities that are included in the scheme via an independent process is required on a yearly basis where the verifier issues a full report on verification. Verification is required to ensure the validity of the measurements, calculations, emissions factors and related information in the monitoring report.

The price of carbon credits under the EU ETS will be driven by supply and demand, which in turn will depend on how these allowances are allocated initially before trading begins, the difference in abatement costs across various sectors and regions involved in trading, and the associated fines.

Formal guidance on the accounting treatment for EU allowances, which is to be prepared by the International Financial Reporting Interpretations Committee (IFRIC) of the International Accounting Standards Board (IASB), has been delayed until 2005 when it is hoped that the trading environment and relevant rules and regulations become clearer.

H. United Kingdom

The UK Emissions Trading Scheme was launched by DEFRA (Department for Environment Food and Rural Affairs) in April 2002 and represents the world's first economy-wide, inter-industry, national greenhouse gas emissions trading scheme. Thirty one organizations entered the scheme as 'direct participants' and undertook voluntary emission reduction targets to reduce their emissions against 1998-2000 levels, with the goal of delivering 11.88 million tonnes of additional carbon dioxide equivalent emission reductions over the life of the scheme (2002 - 2006)[41].

Companies can also enter the scheme through Climate Change Agreements, which are negotiated agreements between business and Government for pre-decided energy-related targets covering 6,000 companies. Those companies who meet their targets are eligible to get an 80% discount from the Climate Change Levy, which is a tax on the business use of energy. The scheme is open to anyone who opens an account on the UK registry. Participants can either buy allowances to meet their targets or sell emission reductions that are over and above their reduction targets.

The first year of trading saw emission reductions of 4.64 million tCO_2e against baselines by the Direct Participants and the second year saw emission reductions of nearly 5.2 million tCO_2e against baselines. DEFRA reported that 31 of the 32 Direct Participants remaining in the scheme complied with all the requirements of the scheme. In case of the Climate Change Agreements, 88% of participants met their targets and have been re-certified for their Climate Change Levy discounts.

Prices in the UK emissions trading market have ranged anywhere from around £4-6 to a peak of around £12.50 at the end of October 2002, and falling to below £2.50 in late January 2003.

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[40] An "operator" is defined as "any person who operates or controls an installation or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the installation has been delegated".
(http://www.co2e.com/carbonbriefing/carbonbriefingview_eu.asp?categoryid=10146)
[41] http://www.defra.gov.uk/environment/climatechange/trading/uk/index.htm

The UK emission-trading registry is an online system that maintains records and keeps account of the allocation, transfer of ownership and eventual retirement of greenhouse gas emission allowances.[42] The scheme requires that participants seeking to generate allowances for over-achieving their target must have their emissions verified by an independent organization accredited by the UK Accreditation Service.

In case a firm has not met its target by reducing its emissions or by buying allowances from other firms, it will be given a three-month reconciliation period within which to meet it's target, after which it will be subject to the following penalties:

- The financial incentive will not be paid to the firm.
- The number of allowances allocated for the next year will be reduced by the current shortfall plus a penalty factor of 1.3

In case of a failure to meet the full five-year emissions reduction target the firms will have to repay all the incentives received with interest for meeting earlier annual targets. The UK Government is proposing that after 2-3 years, for each commitment year, the penalty will be £20 per tCO_2e or twice the mean average market price of an allowance during the reconciliation period, whichever is the higher. When the £20 penalty comes into force, the penalty factor of 1.3 will be removed.[43]

UK Emissions trading registry website (http://etr.defra.gov.uk/default.asp) provides a user manual and other detailed guidance about opening the various accounts and engaging in the trading.

H. Existing Projects and Programs

CKST sale

The National Carbon Offset Coalition helped the Confederated Salish and Kootenai Tribes of Montana develop a carbon sequestration project involving the planting of ponderosa pine on 250 acres of land on the Tribe's land at Henry Peak. The land had been badly burned in a 1994 wildfire, and was not naturally regenerating due to the intensity of the fire and the lack of a seed source. The project was sold to the London office of Sustainable Forestry Management, Ltd. The project was estimated to generate some 47,492 tCO_2e, with the forest to be managed sustainably by the Tribe for 80 years[44].

UtiliTree and PowerTree

The Utilitree Carbon Company is a non-profit corporation established in 1994 by a partnership of 40 North American utility companies working through the Edison Electric Institute (EEI).[45] The members raised $3 million that has resulted in the installation of 10 forestry projects designed to offset emissions or sequester carbon. The projects consist of a diverse mix of rural tree planting, forest preservation, forest management and research efforts at both domestic (Louisiana, Mississippi, Arkansas and Oregon) and

[42] http://etr.defra.gov.uk/pdf/ETR_User_Manual.pdf
[43] The UK Emissions trading registry website (http://etr.defra.gov.uk/default.asp) provides a user manual and other detailed guidance about opening the various accounts and engaging in the trading.
[44] http://forests.org/articles/reader.asp?linkid=30879
[45] http://www.powertreecarboncompany.com/program.htm

international (Belize and Malaysia) sites. The estimated total carbon impact of the projects is projected to be some 3 million tCO_2e over 40-70 years.

In 2003, 25 companies established the PowerTree Carbon Company, LLC, a voluntary consortium of 25 leading U.S. electric power companies that have committed $3 million to establish six bottomland hardwood reforestation projects in the Lower Mississippi Alluvial Valley (LMAV) states of Louisiana, Mississippi, and Arkansas, with partners in the Federal government, conservation groups and landowners. As the trees grow, they will eventually capture more than 1.6 million tons of carbon dioxide (CO_2) from the atmosphere – as well as provide critical habitat. The pool of six projects will provide CO_2 management at a cost of less than $2 per ton. Participants will share the greenhouse gas benefits on a pro rata basis and may report these shares into the voluntary Energy Policy Act section 1605(b) database.

The PowerTree Carbon Company projects bring together a diverse group of national conservation entities (The Conservation Fund, The Nature Conservancy, Ducks Unlimited and the Wild Turkey Federation), regional and state conservation groups (Old South Woodlands, Central Arkansas Resources Conservation and Development Council, The Carbon Fund, Black Bear Conservation Committee, Friends of Red River and Mississippi Fish and Wildlife Foundation), local landowners, Federal agencies (the Department of Interior's Fish & Wildlife Service,, the Department of Agriculture's Natural Resources Conservation Service and the U.S. Forest Service), leading practitioners of tree planting and monitoring (Environmental Synergy, Inc. and Winrock International), and 25 leading power companies

The Global Climate Change Initiative (GCCI)

The Global Climate Change Initiative is a program of The Nature Conservancy (TNC), designed to protect forestland and reduce greenhouse gas emissions. In collaboration with several electric utilities, major manufacturing corporations, and non-governmental organizations, the program's projects include the Noel Kempff Mercado National Park project in Bolivia that has terminated logging rights on 1.5 million acres of tropical forest adjacent to the park, the Rio Bravo project in Belize that involves the conservation and sustainable management of 153,000 acres of forest, the Guaraqueçaba Environmental Protection Area in Brazil where several small projects seek to restore and protect about 55,000 acres of tropical forest, and the Midwest Forest Restoration project in Indiana and Ohio that will reforest parts of the Conservancy's Edge of Appalachia and Big Walnut Nature Preserves. In total, the GCCI claims to be protecting more than 1.7 million acres of forest.[46]

Pacific Northwest Direct Seed Association (PNDSA)

PNDSA is a producer-based organization, started in 2000 to support development and adoption of direct seed cropping systems through research coordination, funding and information exchange among a group of producers and university researchers from the states of Oregon, Idaho and Washington.

[46] http://nature.org/initiatives/climatechange/work/index.html

PNDSA entered into a contract with Entergy[47] in April 2002, who had committed to Environmental Defense to reduce their emissions. The contract is for a ten-year lease of CO_2 credits generated through the practice of direct seeding cropland in the Pacific Northwest[48]. The contract will result in an annual trade of 3,000 tCO_2e between PNDSA and Entergy for a total of 30,000 tCO_2e for the next ten years.

PNDSA brought together 77 member producers representing a total of 6,470 acres in production that is estimated to sequester 0.55 tCO_2e per acre per year. PNDSA received $75,000 to aggregate the base of growers for this sequestration project, and the growers are being paid to direct seed a designated acreage for the next ten years. Local Conservation Districts will monitor and verify whether the acreage has been direct seeded or not.

PNDSA chose to lease carbon credits instead of selling them so that the energy company only has a temporary control of the management of the land and the producers retain ownership of the C-credits at the end of the contract. The PNDSA can solicit additional land if any of the existing producer contracts default and the producers are restricted to a maximum of 100 acres in order to spread the risk of default and to protect the producers from committing too many acres too early in the development of the carbon sink market[49]. After the completion of producer contracts in November 2002 the producers received the money for C-credits. PNDSA is currently in the process of developing a verification agreement with local Conservation Districts who have producer contracts within their districts.

The PNDSA is one of the early movers in the implementation of a leasing strategy to aggregate agricultural producers in the development of a market for C-credits, which can play a major role in economic sustainability of American Agriculture. PNDSA aims to stimulate research to develop whole-farm accounting of carbon and carbon equivalent changes occurring as a result of direct seed cropping systems and have a yield of carbon equivalents for each farm based on the many environmental and management decisions that the farmer employs, which the farmer can market as C-credits.

Moreover, this project brings to light the ability of the private sector to manage a terrestrial carbon trade without federal mandates. With the goal of increasing the number of direct-seeded land in the Pacific Northwest, PNDSA is engaged in actively exploring opportunities for value-added agriculture. It is supporting efforts along with Environmental Defense that will help to establish values, measurement methods, and potential risks and gains of the carbon credit market.

[47] http://www.entergy.com/corp/
[48] http://www.directseed.org/
[49] http://www.directseed.org/

Part 3 – Registering Carbon Credits

A. The United States Registry – the 1605(b) Program

The National Voluntary Reporting of Greenhouse Gases Program, established by Section 1605(b) of the Energy Policy Act of 1992, offers an instrument for entities and individuals to report their GHG emissions and any reductions thereof as a result of voluntary action to avoid, abate or sequester green house gases. The registry has outlined general as well as sector specific guidelines for reporting GHG reductions through voluntary action which will allow the reporting entity to demonstrate that they have achieved the reductions. At present the industry specific guidelines have been developed for electricity supply, residential and commercial buildings, industry, transportation, forestry and agricultural sector.

The reporting forestry entities are free to either report entity-wide emissions reductions or project specific reductions. Unlike non-biological sectors the forestry sector must account for sequestration activities that result in removal of carbon in addition to simple reporting of emissions and avoided emissions. Carbon sequestration has to be measured as a net flow of carbon that results from withdrawal of carbon from the atmosphere when trees grow and emission of carbon when the trees are harvested to be used either as biomass fuel or are left to decay when they are not converted into long lasting wood products.

The registry guidelines provide accounting equations for calculating annual and average carbon flows for a forest entity or recommend the use of existing models to estimate carbon flows from forest activities. Since the registry provides a platform for documenting reductions in GHG emissions from voluntary actions, it requires the participants to establish reference cases or baselines against which they can evaluate their project performance or the performance of their organization.

On February 14, 2002, President Bush, in announcing a new approach for meeting the long-term challenge of climate change, directed the Secretary of Energy, in consultation with the Secretaries of Commerce and Agriculture, the Administrator of the Environmental Protection Agency (EPA), and other Departments and agencies, to propose improvements to the current program to ''enhance measurement accuracy, reliability and verifiability, working with and taking into account emerging domestic and international approaches.'' The President directed that DOE recommend proposed improvements to the GHG Registry within 120 days.

Also on February 14, 2002, the President directed the Secretary of Energy to recommend reforms ''to ensure that businesses and individuals that register reductions are not penalized under a future climate policy, and to give transferable credits to companies that can show real emissions reductions.'' The President also directed the Secretary of Agriculture, in consultation with EPA and DOE, to develop accounting rules and guidelines for crediting carbon sequestration projects.

The process of federal register publication, agency consultation, public meetings, and drafting new 1605(b) regulations has proceeded through 2004. Another round of public review and comment is anticipated some time in 2005, with DOE attempting to have the new guidelines in use for 2005 (or 2006, if the process lags much further behind). When the final rules have been adopted, much of the preceeding explanation may need revision. Users are encouraged to go directly to the DOE website for current information.

B. State and Regional Registries

California

The California Climate Action Registry is a non-profit voluntary registry for greenhouse gas (GHG) emissions, which allows members to document GHG emissions by using any year following 1990 as a base year. Besides having developed a general protocol they have also developed an industry specific protocol to provide guidance on GHG inventorying. At present the industry specific protocols are being developed for the forestry and the power sector.

Under the forestry sector any entity with at least 100 acres of trees is eligible to report their GHG emissions. The registry requires them to report both biological and non-biological GHG emissions. Guidelines for reporting non-biological emissions are included in the registry's General Reporting Protocol and the guidelines for reporting biological emissions are detailed in the Forest Sector Protocol.

For the first three years of reporting a forest entity is required to record only entity-level carbon stocks and CO_2 emissions and fourth year onwards they are required to report any of the other five greenhouse gases mentioned in the Kyoto Protocol that are relevant to the forestry sector. However, the methodologies for reporting other greenhouse gases are yet to be developed by the California Registry.

The registry distinguishes between a forest entity and a forest project, where a project may be a smaller area within the geographic boundary of a forest entity. The registry requires that any entity reporting project level emissions be also required to report entity-wide emissions, both biological and non-biological. Though the participants can choose to report both California and Nation-wide emissions, only California emissions are certifiable by the registry for the time being. The Registry requires third party certification of forest biological inventories by a State and Registry approved forest sector certifier only for inventories within the state of California. This is required to impart additional integrity and standardization to the records registered.

It also requires identification of geographic, organizational and operational boundaries for all forest entities. Geographically the emissions can be recorded in two ways, either as total carbon stocks and biological emissions within California or as total carbon stocks and biological emissions in U.S., separated into California and non-California inventories. Organizational boundaries refer to an entity's share of ownership or control of the sources (or potential sources) of biological emissions and forest carbon stocks that fall within an entity's chosen geographic boundaries[50]. In case of multiple ownership sources, the organizational boundary of each owner is determined on the basis of their equity share and they are required to report emissions from both commercial and non-commercial biological source.

Operational boundaries are defined as, "the boundaries that determine the direct and indirect [forest carbon stocks and biological] emissions associated with operations owned or controlled by the reporting company"[51]. Direct emissions refer to carbon stocks and emissions that are produced by sources that are owned and controlled by the reporting

[50] http://www.climateregistry.org/docs/PROTOCOLS/04.04.20%20Final%20Forest%20Sector%20Protocol.pdf

[51] World Resources Institute " The Greenhouse Gas Protocol: A corporate accounting and reporting standard (Revised edition) 2004. < http://www.wristore.com/ghgprotorev.html>

entity whereas indirect emissions refer to those stocks and emissions that occur due to the reporting entity's actions, but are produced by sources owned or controlled by another entity. Identification of operational boundaries to determine indirect emissions is not required by the registry at this point. In order to determine direct emissions the registry identifies certain "forest carbon pools" that might remove or emit carbon dioxide:

1) Aboveground live forest biomass;
2) below-ground live forest biomass;
3) dead forest biomass; and
4) forest soil.

The registry has established certain direct carbon pools that all forest entities are required to identify, inventory and report:

1) Tree bole (aboveground live biomass)
2) Tree Branches, leaves and needles (aboveground live biomass)
3) Tree roots (belowground live biomass)
4) Standing and lying dead wood (dead biomass)
5) Wood products (dead biomass)

Other direct carbon pools identified by the registry, 1) Herbaceous understory and shrubs 2) Soil/Litter, are reportable but not certifiable by the registry.

Participants are not required to establish baselines, which means that they will basically report their annual emissions and stocks. However establishing an entity-wide baseline will only provide credibility to the forest projects undertaken by the entity if it wants to sell the GHG offsets that it generates sometime in future through organizations like the National Carbon Offset Coalition.

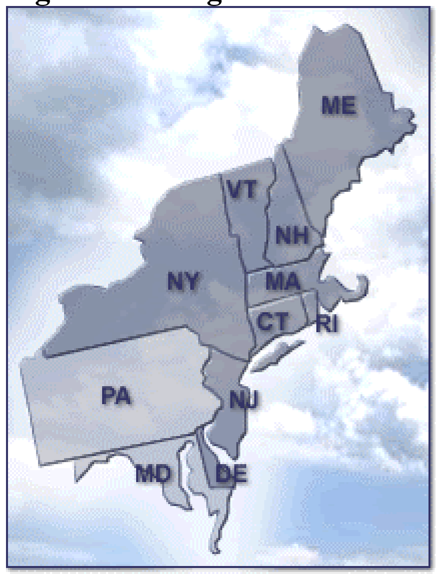
The requirements of the registry represent a complex set of rules and compliance requirements, starting from detailed description of forest practices and management scenarios, carbon stock accounting and calculation rules, quantification requirements and standards, sampling and inventorying methodologies, calculation of carbon stock in the identified carbon pools, to certification, monitoring and reporting requirements.[52]

Northeast Regional Greenhouse Gas Registry

Nine Northeastern and Mid-Atlantic states (Figure 3.1) have come together in a cooperative effort to mitigate carbon dioxide emissions through the Regional Greenhouse Gas Initiative (RGGI). Two additional states (Pennsylvania and Maryland) are observers to the process. It is not yet known if they will join as members in the future.

[52] http://www.climateregistry.org

Figure 3.1. Regional Greenhouse Gas Initiative



Source: http://www.rggi.org/

RGGI aims to set up a multi-state cap and trade program involving market-based emissions trading system for controlling greenhouse gas emissions and is scheduled to accomplish the design stage by April 2005. At present RGGI covers only carbon dioxide emissions from power plant in the region. Other sources of greenhouse gases and greenhouse gases other than carbon dioxide may be included in future. RGGI is closely monitoring the efforts of the Northeast States for Coordinated Air Use Management (NESCAUM) in designing a regional GHG registry, with the aim of possible integration of the two efforts in future.

NESCAUM started a Regional Greenhouse Gas Registry (RGGR) for the Northeast in October 2003 in an effort to provide infrastructure to the Northeast states for meeting their climate change obligations under the New England Governors-Eastern Canadian Premiers (NEG/ECP) Climate Change Action Plan, which was adopted in August 2001. The NEG/ECP report specifically recommended the creation of a regional GHG registry, which will utilize quantification and reporting practices based on the GHG Protocol[53], a multi-stakeholder collaboration led by the World Resources Institute and the World Business Council for Sustainable Development[54].

[53] The Greenhouse Gas Protocol Initiative (GHG Protocol) was established in 1998 to develop internationally-accepted accounting and reporting standards for greenhouse gas emissions from companies. It operates under the umbrella of the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI). (http://www.ghgprotocol.org/)

[54] The GHG Protocol corporate accounting and reporting standards have been used by the California Climate Action Registry, the World Economic Forum Registry, and many other climate initiatives. (http://www.rggr.us/)

Box 4.1. Green House Gas Protocol Initiative

The Greenhouse Gas Protocol Initiative, which was established in 1998, developed one of the most widely recognized and internationally accepted accounting and reporting standards for greenhouse gas emissions from companies. The Protocol represents an international, multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), governments and others, operated in collaboration by the World Business Council for Sustainable Development (http://www.wbcsd.ch/) and the World Resource Institute (http://www.wri.org/).

The Protocol provides calculation tools for both sector specific and cross sector emissions with step-by-step guidance and automated electronic worksheets to help users calculate greenhouse gas emissions. These tools are consistent with those prepared by the International Panel on Climate Change (IPCC). This Protocol has been utilized for national and international voluntary reduction programs, registries, national industry initiatives, trading programs and sector-specific protocols developed by a number of industry associations.

The registry is expected to be operational by October 2005. It will begin by providing general guidance for measuring and reporting emissions from all major sectors, followed by development of sector specific guidelines starting with the power sector. RGGR will assist in the following forms of reporting:

- Voluntary Reporting
- Mandatory Reporting required under particular state laws or regulations
- Regional Greenhouse Gas Initiative (RGGI) Reporting

The Registry's website lists some of the benefits of registries:

- Public Recognition of voluntary emissions reduction initiatives
- Credibility and Consistency of data which is collected using transparent, standardized, and appropriate methodologies
- Baseline Protection for entities pursuing proactive voluntary reductions initiatives
- Inventory Quality and Completeness for comprehensive and accurate inventory data
- Support for Voluntary Reduction Programs in terms of accurate assessment of emissions, monitor performance of established mitigation initiatives, identifying potential for future initiatives and exploration and initiation of the reduction measures
- Support for Regulatory Programs through recording and monitoring the compliance of entities, housing inventory data for regulatory agencies etc.
- Technical Support through extensive network of participants and advising organizations, with the flexibility of addressing continual changes in best practices and changing mitigation scenarios

- Stakeholder Reference Material in the form of data that allows stakeholders to monitor their own performance with respect to emissions and emissions reductions, update emissions profiles in their investment evaluations, and access emissions profiles to encourage positive environmental performance.
- Trading Programs would benefit from the well documented data and information provided by the registry, and registries can also act as a platform for accounting for allowance holdings, transfers, and cancellations, as well as support reconciliation of allowances or verification of emissions reporting

Most parts of the Registry's website are still under construction and NESCAUM is still in the process of reaching a consensus on the registry's functions and design criteria with the participating states. It plans on engaging stakeholders during the fall of 2005. The registry does not yet suggest if they will have an online system for registering and reporting emissions like the California Climate Action Registry. The registry can be accessed online at http://www.rggr.us/index.html.

Part 4 – The National Carbon Offset Coalition

The National Carbon Offset Coalition (NCOC) is a non-profit (501(c)(3)) organization headquartered in Butte, Montana.[55] The NCOC provides an opportunity for landowners, public and private corporations, tribal, local and state governments to participate in a market-based conservation program that can help offset the environmental impacts of greenhouse gases. The sequestration of carbon through natural resource based programs can help reverse soil, water and air degradation, while providing enhancement of wildlife and recreational opportunities. The transfer of carbon sequestration units is a potential new marketable commodity that provides landowners and communities with a new source of revenue. The Sampson Group, Inc., of Alexandria, VA provides technical consulting services. Environmental Financial Products LLC, Chicago, IL and NatSource, New York City, NY provide marketing consulting services.

The NCOC program is designed to assist landowners in planning carbon sequestration activities and documenting the resulting Carbon Sequestration Units (CSU's) in a manner that adheres to national and international standards and protocols and meets the needs of potential buyers. Those CSU's are packaged into portfolio units and offered for sale on emerging private markets. Funds realized from the sale of CSU's provide cost-sharing for participating landowners and operating funds for the NCOC (Figure 4.1). The program offers participating corporations a cost-effective way to reach the large number of landowners needed to produce enough CSU's to achieve their carbon dioxide emission reduction goals.

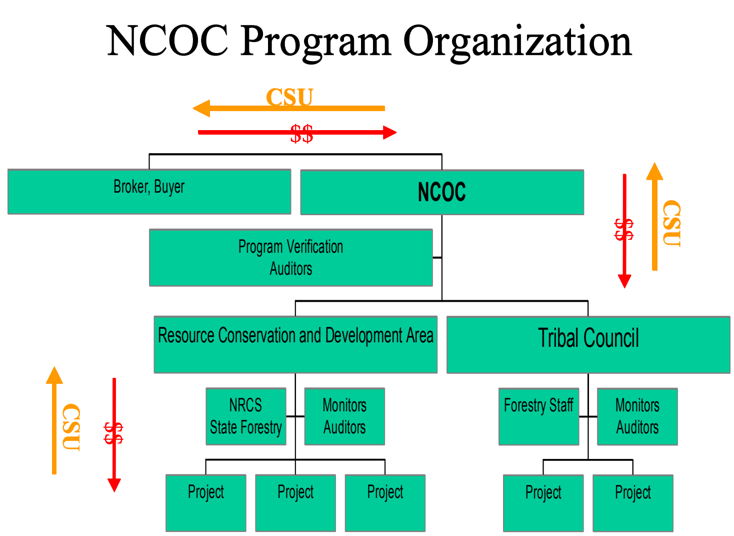


Figure 4.1. NCOC works with local organizations who sponsor carbon sequestration projects with landowners. CSU's move to market buyers; dollars move to projects.

To develop this program, the NCOC has conducted workshops and focus groups, engaged teams of experts in developing planning and measurement protocols, and completed the planning and sale of one forestry project. The NCOC is developing this handbook as well as other guidelines in the anticipation that the experimental private market in CSU's will continue to develop, providing additional economic incentive for landowners to improve the conservation and management of their soil, water, and plant resources while contributing to national and international efforts to address climate change concerns.

NCOC invites other

55 http://www.ncoc.us

private, state or nonprofit entities to become NCOC affiliate members who will serve as advisors to the Board, without full voting Board membership. There will be an annual $1,000 membership fee. The Affiliate member will receive 1 percent of all future carbon credit trades for those projects where they secure signed listing agreements and provide liaison services between the landowner and NCOC. Affiliate members will sign a confidentiality/non-disclosure agreement. This agreement will remain in effect during their membership, and for five years following termination.

Affiliate members will be expected to provide or obtain necessary technical assistance for project planning with the landowner. The cost of project planning is between the landowner and the Affiliate.

NCOC will begin a series of national workshops in 2005 targeted to natural resource consulting firms and others capable of meeting the affiliate criteria to set up the consultant network needed to bring in all forms of terrestrial sequestration projects into the NCOC portfolio.

A. The Big Sky Regional Carbon Sequestration Partnership

NCOC is one of the partners for the Big Sky Regional Carbon Sequestration partnership, supported by a Phase I grant from the U.S. Department of Energy. The Big Sky Partnership, led by Montana State University, Bozeman, MT, will:

- Identify and catalogue CO_2 sources and promising geologic and terrestrial storage sites in Idaho, Montana, and South Dakota;
- 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[56].

The partnership operates in Idaho, Montana and South Dakota, covering three major geological terrains with high geologic sequestration potential: the Snake River Plain, the Williston Basin, and the Powder River and Associated Basins[57]. The areas consist of large forest lands, cropland, rangeland and abandoned mine sites with a good potential for undertaking various carbon sequestration projects.

B. Carbon Sequestration Units (CSU's)

The term "Carbon Sequestration Unit" (CSU) is used in this handbook to represent an amount of organic carbon sequestered in wood or soil that is equivalent to the removal of one tonne of carbon dioxide (CO_2) from the atmosphere. The term tCO_2e (tonne of carbon dioxide equivalent) is used throughout this handbook, and equals 1 CSU. (See Part 8 for definitions of terms such as "tonne" and "sequestration.")

Although it is scientifically possible to measure the uptake of CO_2 through measurements of gas exchange between the atmosphere and terrestrial ecosystems, it is not feasible to do so under project conditions. Therefore, the amount of CO_2 removed

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[56] http://www.netl.doe.gov/coalpower/sequestration/partnerships/2003sel_bigsky.html
[57] http://www.netl.doe.gov/publications/factsheets/project/Proj267.pdf

from the atmosphere is indicated by the increased amount of carbon in wood and soil over a period of time. This increase reflects the net change that has resulted from a complex two-way process in which CO_2 is taken up by plants and converted into organic compounds through the process of photosynthesis, while other processes such as decomposition and oxidation are resulting in the breakdown of organic compounds and the emission of CO_2 back into the atmosphere.

The transfer of solid carbon compounds into gaseous CO_2 means that, for each unit of carbon converted into gas, 3.67 units of CO_2 are produced. (The molecular weight of C is 12 and of O is 16, so when one unit of C combines with 2 units of O, the result is 3.67 units of CO_2). This weight conversion can cause confusion if numbers are presented without clear explanation of whether they represent C or CO_2.

It is important to differentiate between the total amount of CO_2 taken up by an annual crop such as wheat or corn, and the net change in soil carbon that will result from that crop growth. In most cases, the carbon that is converted to grain or stubble leaves the field or is quickly decomposed by soil organisms, and the net change in soil carbon as a result of that crop growth is likely to be minimal. If the soil is excessively cultivated, it can lose carbon as the result of the crop production; if it is being managed under a conservation tillage system, it may show an increase. These changes due to the type of soil management employed can be measured by soil sampling conducted over a period of years.

Only these **net** changes in stable carbon pools such as wood or soil are included in the calculation of carbon sequestration credits. These changes in stable carbon pools represent the amount of atmospheric CO_2 that has been removed from the atmosphere for a period of time that can extend from a few years to, in some cases, thousands of years.

C. NCOC Requirements for Creation of CSU's

In order to create marketable CSU's in agriculture or forestry projects, NCOC requires that landowners:

- Develop a soil conservation or forest establishment and management plan with the assistance of a qualified conservation or forestry professional. This handbook sets forth the practices, activities, and issues the plan must address (see following sections).
- Enter into a legal agreement with NCOC, assigning the agreed-upon portion of the carbon credits to be produced to the NCOC. This agreement may be for any term, but will ordinarily be for 5-10 years or longer. It will contain contract provisions protecting the rights of NCOC to the CSU's produced on the site. The landowner retains ownership of the land and the trees if it is an agroforestry or forestry project, and agrees to implement the management plan. The agreement will have a buyout option under which the landowner can buy back the contract for the full contract price plus 3% interest compounded annually.
- The management plan and conservation easement or other contract will transfer with the sale of the property under the terms of the agreement, and new owners will become a party to the agreement unless they choose to invoke the buyout option.
- Implement the project management plan as agreed

- Report on activities as agreed in the monitoring section of the forest management plan
- Allow NCOC or its agent's access to the property for future monitoring, measurement, or verification of forest growth, soil carbon changes, or other aspects of plan implementation.

D. Process Outline for NCOC portfolio sale

NCOC has defined an initial process for assembling individual projects into a group of projects (portfolio) that contains the necessary amount of CSU's to meet buyer or trading system requirements. Under this process, the following steps are foreseen:

1. A landowner agrees to prepare a project plan for implementation in the event that a sale is achieved.
2. A qualified resource professional works with the landowner to develop an Initial Proposal (IP) within the guidelines of the NCOC Project Planning Handbook.
    a. The IP is reviewed for technical adequacy by NCOC Technical Adviser.
    b. The IP is accepted by NCOC as adequate
3. The landowner signs a Listing Agreement with NCOC
    a. Listing Agreement includes threshold price that seller will accept.
    b. Landowner is provided with full information about payment schedules, fees, etc., so that they know exactly how the sale will function if it goes through.
4. NCOC includes the IP within a prospective portfolio to broker.
5. Broker offers prospective portfolio to potential buyers.
6. Buyer makes buy offer through Broker.
    a. Buy offer includes price, quantity, and term for purchase.
    b. Buyer lists requirements, if other than regular, for monitoring, verification, qualifications for registry, etc.
7. NCOC accepts offer and associated conditions if consistent with listing agreement. If not, NCOC seeks landowner's approval prior to accepting offer.
8. Preliminary sale is executed
    a. Some money (1/2??) needs to be paid up front.
    b. NCOC has 6 months to firm up carbon estimates, measurements, documentation, etc. and provide buyer with solid assurance. Buyer has money-back protection during this period.
    c. Base line field measurements completed, contracts signed with landowner.
9. NCOC provides the buyer with a Certificate of Assurance containing final measurements, conditions, commitments, etc. meeting buyer demands. Buyer accepts.
10. Sale is final. Final payments made to NCOC
11. NCOC settles up with Landowners, Affiliates, Technical Providers, etc.

E. The NCOC Monitoring, Verification, and Reporting Process

The following process is the standard monitoring, verification, and reporting plan for NCOC projects. If a buyer is not satisfied with these basic approaches, they should stipulate what changes they would require.

1. NCOC sends an Annual Report form to each project landowner in early January, with a January 31 deadline for submission of the report.
    a. The report will contain:
        i. A statement that the management plan for the project is still being implemented, and is still current (does not need amendment).
            1. If amendments are done, NCOC reserves the right to approve them.
        ii. A statement that any project trees or forests are continuing to grow normally, and have not been impacted by any human or natural disturbance that threatens their continued growth and sustainability.
        iii. A statement that management practices (i.e. conservation tillage) have been maintained for the past year, and will continue to be maintained in the coming year.
        iv. Details on any change or potential change that affects the project's risks or potentials.
2. NCOC reviews Annual Reports and, if they are satisfactory, prepares a status report to be made available to buyers prior to April 1.
3. NCOC arranges for visual site inspections every 2 years. Site inspections are normally done by Point-of-Contact (POC) or Affiliate organizations that are the local contact with the landowner. These could be Conservation Districts, Agency Personnel, Consultants, NGO's, etc.
    a. NCOC provides inspection guidelines and report forms.
    b. POC technician does visual inspection, notes any problem areas, comments on general project appearance (growth, health, etc.), gives copy of report form to landowner and sends original to NCOC.
    c. NCOC reviews site inspections, notes any need for action, arranges for action if needed.
4. Results of site inspections and report on actions taken are included in the subsequent year's status report.
5. NCOC undergoes third-party program audit and verification review every 5 years unless buyers require more frequent audits.
    a. Auditors or audit firms must be ANSI/RAB qualified (e.g. SFI Program) and have demonstrated expertise in assessing carbon sequestration projects.
    b. Audit covers Program management, records, etc., reviews portfolio management, checks accuracy of calculations, etc., and field-inspects a sample of projects to provide reasonable assurance of performance as indicated. Audits use standard auditing procedure.
    c. Audit firm issues audit statement to NCOC. Audit statement is made available to buyers and the public (probably on NCOC web site).
6. For projects based on actual carbon amounts over base year measurement, a field measurement must be conducted under approved measurement techniques in the final year of the project.
    a. NCOC negotiates with landowner as to how any under- or over-production of CSU's will be handled.

        i. NCOC policy guidelines to be written.

7. NCOC negotiates project extension with landowner, recognizing new quantities from measurement, establishing a new term for the contract extension, and agreeing on new price, if there is a change. If the contract is extended, the project is retained in existing portfolio, moved to new portfolio, or split into two portfolios, depending on volumes and other details involved.

F. Services Offered to Landowners and Buyers

Learning a new form of property trading

Market trading or sales require clear ownership of the CSU's involved, so that there is no legal doubt about the rights of buyers and sellers. Sequestered carbon is a physical part of a very real asset – land or timber. It cannot be separated from the land or timber, and the ownership and control of the land and timber remains with the seller, not the buyer. As a result, CSU sales involve an assurance – a commitment on the part of the seller to produce the agreed-upon carbon sequestration, to maintain it for the agreed-upon period of time, and to provide the agreed-upon level of monitoring and auditing.

For the CSU's to obtain value, they must provide some utility to the buyer. At the current time, that utility is largely non-existent. Buyers are entering the market to develop the abilities and experience they may need in a future legal situation where their greenhouse gas emissions are regulated and they are required to reduce those emissions. Until that legal requirement is defined, however, the market will remain experimental.

The NCOC program is designed to begin operating in that experimental market phase, on the basis that future state, federal, and international rules may introduce the legal changes that create a fully operating emissions trading market. The current effort focuses on the creation and testing of the procedures and documents that landowners will be required to execute when such a market emerges.

If (most observers say 'when') legal requirements and market trading opportunities are created, landowners will only be able to participate by meeting the requirements of that market. By participating in the NCOC program at this point, landowners gain practical experience in producing CSU's for future marketing.

Clearly, this is an experiment without full assurance at this point. The rules and procedures set forth in this handbook are those seen to be most likely to be needed, based on what we know at this point. If future rules emerge that are somewhat different, NCOC will need to adhere to whatever emerges. Participating landowners and agencies will be quickly linked to those emerging opportunities and requirements by their participation in NCOC – a major advantage in an emerging and changing situation.

Managing transaction costs

Transaction costs for environmental commodities tend to be high because environmental rights are conventionally not very well defined and the markets for these commodities do not exist. Thus, even if agents are willing to engage in mutually beneficial trade of carbon offsets, they may not be able due to prohibitive transaction costs or missing institutional capabilities.

Transaction costs are incurred in the process of searching for a trading partner, negotiating deals, securing regulatory approval, monitoring and enforcing deals and insuring against risk of failure. Transactions costs of carbon offset trading projects, especially those involving small landowners, are likely to be very high, because trading partners and buyers need to meet certain requirements and standards before they can sell the CSU's in the market.

NCOC will help manage and reduce transaction costs for sellers and buyers of CSU's by providing the following services:

- Search for trading partners – Replacing the costly need for individual companies to locate farmers or landowners with which to contract, NCOC provides a platform for both buyers and sellers to match with appropriate/desired trading partners
- Negotiate deals between interested parties
- Certify qualified terrestrial carbon offsets
- Verify CSU's with an independent third party audit firm
- Monitor carbon project activities of landowners – It might be infeasible and costly for an individual buyer to monitor and verify carbon storage. NCOC can provide these services at a lower per unit cost.
- Enforce NCOC standards for Qualifying projects which also meet regulatory requirements
- Provide insurance and or self insurance against risk of failure (emissions or undelivered CSU's)

Risk reduction/ spreading

NCOC provides a well-structured platform that will help reduce risk in the market and improve the confidence of market participants in the integrity of the market. Market participants need an assurance that the commodity being traded is real and can be measured in quantitative units. This assurance will hit home only when there is an independent body like NCOC that can enforce market rules, ensure proper carbon accounting, provide independent verification, and exercise risk management. NCOC can ensure that emissions and sequestration amounts are measured using standardized transparent methodologies and that both sinks and sources are monitored in a reliable way.

NCOC will also help reduce market risk by providing market participants the confidence that property rights to tradable assets are well defined and protected.

NCOC can reduce risk by making sure that all sequestration projects are eligible to participate in the market. NCOC will help by setting up a platform where both buyers and sellers are better protected against the risks that carbon will be released sooner than the contractual period, either intentionally or by accident or neglect, and will enforce assignment of liability when this occurs.

Cost spreading

NCOC can help reduce information costs by making relevant and timely information about emerging market rules and transaction prices available to all market participants at low cost. If every participant tries to stay current with this fast-changing situation, the result would likely be more costly and less efficient.

Marketing and Advertising

In addition to all the services listed above NCOC will also help achievement of verifiable socio-economic as well as environmental benefits that strengthen community livelihoods and support sustainable development objectives for landowners.

Part 5 – Carbon Sequestration and Emission Reduction in Agriculture and Forestry

A. Basic Concepts and Processes

Carbon dioxide moves from the atmosphere into terrestrial ecosystems through the process of photosynthesis in plants. Sunlight, chlorophyll and water react in green plant cells to break the water down into oxygen and hydrogen, with the oxygen released to the atmosphere. Then the hydrogen combines with carbon dioxide to form glucose sugars, which are then transformed into the other carbon-based organic compounds in living tissue.

From their initial production in green leaves, organic compounds move throughout the plant. Some are utilized by the plant itself and re-converted into energy, water and carbon dioxide that then return to the atmosphere as respiration. Insects and animals consume plant material to gain energy, and their digestion releases carbon dioxide through respiration. Undigested carbon compounds in animal excrement or fallen leaves or branches are attacked by a variety of micro-organisms that, in turn, use some of the material for energy and release part of it as organic compounds that can be leached or mixed into the topsoil to become part of the soil's organic matter content. Although the most obvious increase in terrestrial carbon is the above-ground growth of plants, more than half of the assimilated carbon is eventually transported below ground by root growth and death, exudation of carbon compounds from growing roots, and the incorporation of litter from fallen leaves, branches, etc.

Within the soil, organic compounds provide food and energy for soil organisms. In the process, the compounds undergo a variety of chemical and physical changes. Much of the carbon is returned quickly to the atmosphere through decomposition and respiration. Some is transformed into more stable organic forms that may last in the soil for decades. A small fraction goes into very stable organic compounds that may last in the soil for thousands of years.

Illustrating (and measuring) these organic *carbon flows* within terrestrial ecosystems is facilitated by separating the ecosystem into different "pools" through which carbon flows and in which it is held for some amount of time. Those *pools* may include live woody biomass, dead woody debris (standing snags and downed logs), understory vegetation, and soil. Annual growth such as leaves, grains, etc., is not counted as a stable carbon pool because most of that carbon is re-emitted to the atmosphere in the same year as it is fixed by photosynthesis. A net increase in one of the stable terrestrial carbon pools is defined as *sequestration*.

As carbon flows in and out of any particular pool, the total amount (*stock*) of carbon in that pool will change. Thus, one method of estimating the effectiveness of an ecosystem in sequestering carbon is to measure the carbon in each stable pool at one point in time, then re-measure it again at some later date. The net change in carbon stock in the ecosystem (total of all pools) reflects total sequestration (or emission, if the stock decreased). Dividing the net change by the number of years between the two measurements provides an average annual rate of change, and dividing it by the area involved (acres, hectares) provides an average annual rate per unit area.

The goal of a carbon sequestration program is to increase the size of the soil and wood carbon pools through sequestration. Sequestration requires two steps, (1) uptake or capture of carbon and (2) storage or maintenance of the captured carbon. Increasing the flow into a carbon pool will increase the stock, while decreasing the flow out will prevent loss from the stock.

B. Conservation Practices that affect Carbon Stocks

Increasing carbon stocks on agricultural croplands requires that the carbon content in the soil be increased and maintained. This may be done in several ways that increase carbon inputs into the soil (improved cropping systems, fertilization, irrigation, animal manures, crop residue management) as well as ways that reduce the rate of carbon decomposition and loss (reduced tillage, erosion control, cover crops) (Table 5.1).

Agricultural practices on grazing lands may include improved grazing systems that encourage more vigorous and healthy plant growth (which increases root growth and carbon input into the soil), improved varieties of pasture and range plants, fertilization, or irrigation. Land use changes such as planting marginal croplands to grass or trees will result in significant soil carbon increases as well (in the case of trees) as increasing wood carbon on the site.

Agroforestry practices involve the use of trees in agricultural cropping or pasture systems. In the United States, the most common practices are windbreaks, shelterbelts, and riparian buffers. Windbreaks and shelterbelts protect homes, farm buildings, or fields from exposure to winds. In the process, they can reduce soil erosion, make homes and buildings more energy-efficient, or provide shelters for livestock or wildlife. Riparian forests or buffers planted alongside streams are valuable in filtering nutrients and protecting streams from sedimentation if soil is being eroded from adjacent farm fields or pastures.

A special case may involve mined land or waste land reclamation, which can involve planting grass or trees on bare land where *revegetation* has failed following clearing or disturbance.

Increasing carbon stocks in U.S. forests can be done in several ways, including expanding the area of forests through *afforestation* of marginal crop and pasture land, increasing the carbon density in existing forests through stocking improvement, fertilization, longer rotations, low impact harvesting, improved fire management or other practices aimed at increasing the amount of standing biomass, protecting existing forests from deforestation or land use change, and by increasing the use and longevity of wood products.

Many of the forest management techniques for improved carbon sequestration are commonly used in forest management. Periodic thinning of forests by removing small trees at various stages permits the remaining trees to grow larger, thus holding more carbon. Thinning can also reduce the “ladder fuels” that provide pathways for small non-lethal ground fires to burn into the forest canopy where they can become intense stand-replacing crown fires. On nutrient-poor soils (often associated with coniferous forests), it has been estimated that fertilization could increase forest growth and carbon storage up to rates of 0.45 tC/ha/yr. On forests managed for commercial timber products, extending the rotation length from 30 years to 45 or 50 years will add significantly to the standing biomass in the forest, plus result in larger logs that are often associated with longer-lived wood products such as structural timbers.

How forests are harvested and regenerated also has significant impact on carbon stocks. Removing all of the above-ground biomass and conducting heavy mechanical soil disturbance to prepare the soil for tree planting may, in some cases, encourage faster growth of the new crop, but at a high cost of short-term carbon emissions. Maintaining woody debris and standing trees for partial shade while minimizing soil disturbance may reduce early growth rates in the following forest, but with the benefit of retaining larger carbon stocks on site. These are trade-offs that forest managers can consider and which, if carbon sequestration gains recognized value as a public or economic asset, may be made differently in the future than was common in the past.

Table 5.1. Conservation practices in agriculture and forestry and their estimated carbon dioxide sequestration.

Practice	Carbon Yields $tCO_2e/ac/yr$[58]		Reference
	Low	High	
CROPLAND			
Conservation tillage	0.33	1.00	Lal et al. 1998
Conversion to grass	0.40	1.00	Lal et al. 1998
Improved cropping systems	0.13	0.80	Sampson et al. 2000
Fertilization	0.07	0.20	Lal et al. 1998
Irrigation	0.07	0.20	Lal et al. 1998
Conservation buffers	0.40	8.66	High is for tree plantings
Energy crops	4.33	5.00	Not counting energy offset
Windbreaks & shelterbelts	0.83	5.00	High is for tree carbon
GRAZING LANDS			
Improved pasture management	0.50	2.66	Sampson et al. 2000
Improved range management	0.00	0.40	Sampson et al. 2000
FORESTLANDS			
Afforestation	1.67	6.66	Birdsey 1996
Improved forest management	0.33	1.33	Sampson et al. 2000
Fertilization			No estimate available
Extended rotations			No estimate available
Fire management			No estimate available
Extended product life			No estimate available

58 A note about units: The scientific literature on carbon sequestration will express quantities in metric units such as kilograms or metric tonnes, and area in hectares. For familiarity in U.S. audiences, this handbook will use English units (acres or tons) for area and carbon. Quantities for carbon dioxide equivalent (CO_2e) will be expressed in metric tonnes to comply with common market practice. Conversion tables are found in Part 8E, and for those who utilize the Excel spreadsheets provided by NCOC, the conversions are made as needed.

C. Characteristics of Carbon-sequestering practices

Conservation Tillage.

This term describes a suite of practices that, in general, reduce the number of tillage operations in order to maintain crop residues on the surface of the soil year around. Practices may involve names such as no-till, mulch-till, direct seeding, strip till, etc. In general, new crops are planted directly into residues and untilled soil as a means of retaining ground cover, providing erosion protection, and improving moisture conservation.[59]

Cost: Farmers switching from conventional tillage systems to conservation tillage systems will face the costs of purchasing different equipment in many cases. Once they have the necessary equipment, conservation tillage costs are comparable or below most conventional systems.

Implementation: Switching to conservation tillage may require careful attention to local soil, climate, and crop conditions. There may be a "transition" period before weed or other problems are successfully addressed. In some years, extended rainy or cold weather may interfere with successful implementation.

Operation and Maintenance: Once established, conservation tillage systems need to be maintained if carbon stocks are to continue increasing. One year of heavy tillage may cause the accelerated decomposition and loss of the soil organic matter gained over several years of conservation tillage.

Monitoring and Verification: Fields under conservation tillage can be visually identified during the year by the amount of residue on the soil surface. Changes in soil organic matter can be measured by standard soil sampling techniques (See Part 8C) at the start of the project and at specified times thereafter. Verification is relatively straight-forward, as farmers maintain annual crop and tillage records and soil sampling methods can be replicated. Fields that have been in conservation tillage in the past may continue to sequester soil carbon for periods of 20-25 years before the soil system begins to stabilize.

Conversion to Grassland.

Converting marginal cropland to permanent grass or other perennial crops eliminates cultivation and increases root mass compared to annual crops, both of which are excellent ways to build soil organic matter. One well-known land conversion program is the Conservation Reserve Program (CRP), a federal program that pays farmers a land rental payment to convert land out of crops for 10 years or more. CRP's payments are designed to encourage land conservation and reduce crop production, but not specifically to sequester soil carbon.

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[59] For background information and data on conservation tillage, see the Conservation Technology Information Center website at http://www.ctic.purdue.edu/CTIC/CTIC.html

Cost: Establishing grass or grass-legume mixtures on former cropland is similar to establishing other crops. Land preparation, seeding, and weed control are often needed.

Implementation: Most farmers are familiar with grass establishment and have the necessary equipment. Under exceptionally dry conditions, irrigation may be required for a year or two to effectively establish a grass stand.

Operation and Maintenance: Once established, permanent vegetation may need weed control, clipping, or other care. If the land can be grazed, some economic returns may be possible. If not, as in a Conservation Reserve contract, an annual rental payment covers the cost of land taxes and maintenance.

Monitoring and Verification: Monitoring and verification are easy and straight-forward. Visual inspection easily establishes that the grass crop is or is not still intact. Standard methods of soil sampling, at the beginning of the grass establishment, at periodic intervals, and for verification audits if needed, are readily available.

3C3. Improved Cropping Systems.

There are many ways that a cropping system may be improved in increase soil carbon stocks. Generally, these are tied to practices that increase crop production (thereby increasing the amount of root growth and residue production for organic inputs) or reduce cultivation to slow organic matter decomposition. Included may be practices such as adding legume or cover crops to the rotation, reducing or eliminating summer fallow, improved fertilization management, improved water management in irrigation, or conservation practices to reduce soil erosion.

Cost: Most improved systems that sequester carbon will be linked to net profits from cropping. As a result, new practices must generally meet a cost-effectiveness test as well as improved carbon sequestration. In the event that the systems are new to the farmer, there may be a learning period during which transitional problems must be worked out, so there may be an early cost involved.

Implementation: Advice on changing crop systems is available from University and Extension specialists, Natural Resource Conservation Service conservationists, and other experts. In some cases, care will be needed to avoid secondary effects. For example, increased fertilization, if not accompanied by good soil testing and application timing, can cause increased emissions of nitrous oxide (N_2O) that will negate the effects of the additional carbon sequestration in terms of climate impact.

Operation and Maintenance: Most cropping system changes will require little, if any, change in operation and maintenance. If, however, the system is abandoned and returned to the prior cropping system, the soil carbon benefits gained will be lost as the soil system returns to its prior situation.

Monitoring and Verification: In some systems, the changes will be obvious to casual observation; in others, it may be impossible to visually tell the difference. Changes in soil organic matter may or may not be obvious under visual inspection. Measuring changes in soil carbon stocks can be done in the standard way, however, so the actual impacts of the system change can be established at periodic intervals.

Fertilization.

Maintaining appropriate levels of available plant nutrients is essential for high yields of crops, and higher yields are associated with increased plant growth and organic matter inputs into the soil. Nutrients need to be supplied in appropriate amounts and chemical formulations, in accordance with soil conditions, crop needs, and water availability, so the practice details will differ from field to field.

Cost: Fertilizers are costly, and farmers need to be concerned with establishing cost-effective application methods and rates. Over-application (or poorly timed application when plants can't utilize the added nutrients) is wasteful and costly, and can be an important contributor to environmental pollution. Both nitrogen and phosphorous (the two most widely-used fertilizer nutrients) can pollute underground and surface waters if applied in excess or allowed to be carried off the land by water or wind erosion. Nitrogen, if applied when plants cannot readily use it, can contribute to N_2O formation and emission.

Implementation: Soil testing and scientific advice for appropriate nutrient management is widely available in farm communities. In some places, farmers are required to prepare and implement nutrient management plans to document their approach to avoiding air or water pollution. Some plans may call for additional field operations, such as split applications where a portion of the needed nutrients are applied in timed applications to match crop growth cycles.

Operation and Maintenance: Most methods of proper nutrient management are known, and require little additional effort once the proper applications are made.

Monitoring and Verification: Monitoring and verification of proper nutrient timing and application are difficult, since it may be impossible to tell what happened if inspections or audits are done after the fact. Soil carbon changes over time are measured by standard sampling procedures. The impacts of additional fertilizer could affect emissions of other GHG's such as CH_4 and N_2O, but there are no field methods of measuring those impacts today.

Irrigation.

Due to its significant impact on crop yields, irrigation can be a major contributor to increased soil carbon. Irrigating desert soils (which often have 0.5% organic matter or less in the topsoil due to limited plant production) can raise topsoil organic matter levels to 4 or 5% in many cases. These higher soil carbon levels can sometimes be raised even further through improved cropping systems, fertilizer management, or conversion to hay or pasture.

Cost: Irrigation is costly, but usually profitable due to increased crop yields. Increased soil carbon levels, even if they attracted fairly attractive payments, would be marginal compared to the costs and returns associated with the production of crops or livestock.

Implementation: If dryland is to be irrigated, a source of water such as a well and an application method such as a sprinkler system must be obtained, often at high cost. On currently irrigated land, improved irrigation water management may require changes in the water conveyance or application system, as well as changes in management practices.

Operation and Maintenance: High levels of soil carbon in irrigated soils can be maintained so long as the management system remains intact. Abandoning irrigation and allowing the return of desert or dryland vegetation will result in carbon emissions until the soil carbon declines to a lower level consistent with the new conditions.

Monitoring and Verification: Irrigation can be visually monitored while it is occurring, but proper water application and timing is impossible to independently verify after the irrigation season in which it was done. Changed soil carbon levels can be monitored and verified by standard soil sampling methods.

*Windbreaks and shelterbelts***.**

These are typically linear plantings of trees and shrubs located so as to reduce wind velocities affecting fields, buildings, or roads. Around buildings, windbreaks can reduce winter heating costs and improve livestock health by protecting against cold winds. Properly located, field shelterbelts will reduce wind erosion, protect crops from wind-related damage, help conserve soil moisture, and improve crop yields. Living snow fences help deposit snowdrifts away from rural roads, reducing maintenance costs and improving highway safety.

Cost: Costs can be high, particularly in semiarid or arid areas where new plantings need special weed control, protection, or irrigation to become successfully established. Research has demonstrated that, in many situations, planting 4 to 6% of a crop field to trees may result in yield increases on the remainder that economically justify the planting, but it may take 7 to 10 years before the trees are large enough to affect yields to this extent.

Implementation: Specialized tree planting equipment and techniques may be needed, as well as protective devices to protect young seedlings from wildlife or livestock. In some areas, irrigation will be necessary in the early establishment years.

Operation and Maintenance: These plantings need to be managed to reduce weed competition and protect trees from excessive grazing and browsing, insect and disease damage, and fire. Most species may live for 50-100 years, and properly managed windbreaks can perpetuate themselves through normal succession. If that fails, decadent trees may need to be removed and replaced if the planting is to maintain its effectiveness.

Monitoring and Verification: Visual inspection will prove that a planting is in place and healthy, but quantifying carbon sequestration will require both soil testing and tree measurements. Trees growing in linear rows will exhibit different growth patterns than those in forests, so there are few existing growth and yield models upon which to predict tree growth. Current work is underway to measure the biomass in line-grown trees, and the currently available yield tables are contained in Part 8D. Measuring sample trees and expanding the sample to reflect total growth will give credible results. Verification can be done using the same sampling and measuring techniques.

Energy Crops.

Several kinds of crops can be grown to produce energy feedstocks rather than food or livestock feed, but most of these will require the development of new energy production facilities and markets before they become feasible options for landowners. Research and development is under way on a variety of these crops, including both grasses and woody crops for replacing fossil fuels in combustion-based electrical generation, feedstocks for production of ethanol for liquid fuels, and oilseed crops to produce biodiesel.

Cost: As with any new crop, costs are high in the early stages, and most landowners cannot commit to production until there are assured markets established. Since production plants can't be financed until assured feedstock supplies exist, the creation of a new crop industry involves a complex set of research, development, and coordination issues. As public interest in renewable energy supplies rises, the opportunity for addressing these complex issues may rise as well.

Implementation: Once markets exist, landowners will be able to convert to these crops with the assistance of production experts.

Operation and Maintenance: These crops will require a different set of operation and maintenance skills, depending on the crop. For long-term success, growers will need to learn and apply these skills.

Monitoring and Verification: The existence of energy crops and the amount of biomass that is sold into energy markets will be easy to document and verify from production and sale records. Increased carbon sequestration in soils can be measured by periodic soil sampling.

Afforestation.

Planting forests on land that has not been in forest for a period of time (often 20-50 years). Re-establishing forest cover on land that has been in crops or pastures is common, but the practice may also include afforesting lands that have been significantly altered or degraded by mining or other types of soil disturbance.

Cost: Costs will largely be determined by the amount of work necessary to prepare the land for planting and the difficulty in nurturing young trees until they are established.

Costs are reduced by carefully matching appropriate species to the site and by following known successful methods of seeding, planting, or transplanting.

Implementation: Successful afforestation requires establishing an adequate stand of trees, usually 300 per acre or more. Mortality can be high in the first year, particularly in drought situations or where animal damage is high. It is good practice to conduct a sampling survey after one growing season, followed by re-planting on areas where adequate survival has not been achieved.

Operation and Maintenance: Young trees may need special protection against damage by rodents, rabbits, or browsing animals such as deer, elk, or livestock. Irrigation may also be needed on semi-arid sites until tree roots are well established.

Monitoring and Verification: Visual monitoring easily confirms the presence of trees, but it may take a sampling and counting procedure to ascertain adequate stocking, and a sample and measuring procedure to estimate above-ground biomass on the site (See Part 8). Below-ground biomass in large roots is usually estimated by using established root-shoot ratio tables by species, since direct below-ground sampling is too expensive and destructive for field application. Dead and down wood, understory vegetation, and forest floor carbon are usually not significant in newly-established forests, so are seldom monitored in afforestation project areas. Soil carbon may or may not be measured, depending on the soil condition prior to planting. If it is to be measured, stratification and sample location procedures are the same as for cropland soils, although obtaining samples after roots are established may be somewhat more difficult (See Part 8). Professional environmental auditors can readily verify claimed carbon amounts.

Forest Management

Forests can be managed to provide many goods and services, such as timber, non-timber products such as mushrooms or other food crops, wildlife habitat, water conservation, biodiversity, scenic buffers, etc. In practice, many forests are managed for several of these values. Not all values may be present in all places, but a forest can be managed as a complex of species, structural conditions, and stands such that many values are present in the forest as a whole. Managing a forest for carbon sequestration is usually defined as managing so that the standing biomass (tons of carbon per acre) is increased from one amount to a greater amount. This can be done in several ways, such as thinning trees so that the remaining stand grows more rapidly and is more healthy due to reduced competition between trees, fertilizing to achieve higher growth rates, or doing supplemental tree planting to fill in a stand that is understocked for the species and site involved.

A major unknown in the treatment of forest management is the carbon accounting to be used on harvested timber. In the past, many accounting systems treated forest harvest as though all the carbon was immediately emitted. Of course, that is not the case, as much of it either goes into energy production to offset fossil fuels or is incorporated into uses ranging from paper to furniture to houses where the carbon may last in solid state for decades or centuries. Methods have been developed to estimate the fate of the carbon in harvested trees so that more accurate accounting can be done, but there have been no formal rules developed as to how the carbon should be credited. Since the wood moves off of the land, through the hands of many processors to the final user, and often, out of the final use into another form of storage such as a landfill, there are difficult questions as to how to credit the carbon to the proper owner unless the production credits are assigned to the original land where the wood was produced. Until the questions of carbon credit ownership have been answered with an accepted accounting protocol, however, most carbon transactions do not recognize harvested wood as sequestered carbon.

Cost: It will be difficult to generalize the cost of changing forest management to enhance carbon stocks, as the costs will vary greatly from one situation to another. In most cases, landowners will need to recognize the economic benefit of changing management in terms of the timber value itself, with the carbon value adding a minor margin compared to the total change in timber value.

Implementation: Forestry has changed significantly in recent years, as attention has shifted from maintaining timber harvest levels toward maintaining sustainable forest ecosystems. Additional change to enhance carbon stocks will not be a difficult technical challenge for modern forest managers.

Operation and Maintenance: All management systems must be maintained, and forest maintenance can be subjected to surprises such as an unforeseen insect or disease outbreak, a wildfire, a hurricane, or some other disturbance. Managers must continuously monitor forest conditions and adapt their management strategies to meet these situations if they are to maintain a sustainable forest.

Monitoring and Verification: Above-ground forest biomass can be measured using standard forestry techniques, so carbon stock changes between two points in time are relatively easy and low-cost to obtain. Verification is straight-forward as well. What cannot be done, however, is to disaggregate the amount of stock change in order to attribute the segments to particular management actions. In most cases, the net change in carbon stock will be the complex result of many different effects, some positive and some negative, some human-induced and some natural environmental responses. Thus, if rules require only the measurement and verification of net carbon stock changes over time, that is readily available. If, as the early Kyoto rules required, foresters must separate out the human-induced change from the natural change, that is not scientifically possible and will require some kind of politically-determined rule or formula.

Increasingly, there is a trend for larger forest managers to seek forest certification under one or more of the emerging international certification systems. Those systems require independent third-party audits of forest conditions. Such audits can readily verify claims of net forest carbon stock change, so for certified forests, it should be possible to achieve verification of CSU claims without adding to existing certification audit costs.

Part 6 – Project Planning

There are several ways to prepare a project plan, and a few of them are outlined below. Keep in mind that the project plan must not only meet NCOC's standards, but must meet the needs of the potential market or buyer where the CSU's are to be sold. Therefore, it may be necessary in some cases to construct a very complex baseline while in other cases, a fairly straight-forward measure of current carbon stocks can be used as a base year against which future quantities will be compared. Both methods are outlined below; only one will be needed in most cases. When in doubt as to the requirements of a particular project plan, consult with NCOC Portfolio Manager or Technical Staff to make sure what will be needed for the intended market. Our goal is to assist in the development of an adequate plan, without additional costs or needless requirements.

A. Integration with other conservation goals

It is widely agreed that agricultural and forest systems that have suffered depletion of carbon stocks are degraded as a result. Restoring those degraded systems represents a significant environmental improvement that will contribute to their long-term sustainability. Agreement is not so easy to achieve, however, when intensively-managed systems are used. An example is clearing native forests to make way for plantations of exotic species. The plantations might show much higher growth rates; therefore higher rates of carbon sequestration, but the negative effects on biological diversity or community impact would draw opposition.

Therefore, projects designed to increase carbon sequestration are challenged to also contribute to (or at least not detract from) other important conservation and community values. The standard established by the international negotiations requires: "That the implementation of land use, land-use change and forestry activities contributes to the conservation of biodiversity and sustainable use of natural resources."

The projects proposed by the NCOC, including agricultural soil improvement, afforestation, reforestation, agroforestry, and biomass energy, can easily be designed to enhance a broad range of conservation and biodiversity values. This will require attention to:

- Matching forest species to soils and sites so as to restore or mimic naturally-occurring systems;
- Replacing soil-depleting systems such as cultivated cropland with soil-building systems such as conservation tillage, conversion to grassland, agroforestry, forestry, or biomass production;
- Planning management or maintenance systems that help the new systems develop into stable, sustainable conditions;
- Providing guidelines and controls on management inputs such as fertilizer or pesticide that, if misused, could create other forms of greenhouse gas emissions or environmental damage; and,
- Avoiding projects or practices that, while having positive carbon contributions on the project site, might cause carbon-depletion in areas outside the project boundaries (this is called "leakage," and will be discussed in detail later.)

The conservation values of any project should be compared (as are the carbon impacts) to the conservation values that were present when the project was initiated, or that would have most likely resulted had the project not been implemented. In other words, if a project plants a forest on cropland, the conservation values of the forest should be compared to the conservation values of the cropland when it was converted or that would have otherwise developed.

B. Using existing cost-sharing and other public programs

The 2002 Farm Bill (officially known as the Farm Security and Rural Investment Act of 2002) made important additions and expansions to the agricultural conservation and forestry programs designed to influence the management of private lands. It has been called "the single most significant commitment of resources toward conservation on private lands in the Nation's history," by the Natural Resources Conservation Service. In virtually every relevant conservation program, the purposes were expanded to include carbon sequestration as an activity that would make a project eligible for federal educational, technical, and cost-sharing assistance. Table 6.1 lists most of the programs that are relevant to carbon sequestration.

The enthusiastic reception given the 2002 Farm Bill is now muted by the subsequent budget decisions that have dampened or eliminated portions of the programs. (See below)

Forestry Programs

Title VIII created a new ***Forest Land Enhancement Program*** (FLEP) to provide financial, technical, and educational assistance to non-industrial private landowners. FLEP replaced both the Stewardship Incentives Program and the Forestry Incentives Program. The new program was funded under the Commodity Credit Corporation for $100 million over the 6-year life of the program (2002-2007).

Among the expanded purposes of the program were sustainable timber management, agroforestry, carbon sequestration, wetland/riparian restoration, and hazardous fuel reduction. All of these could contribute positively to increases in soil and wood carbon stocks on forestland.

Cost-sharing at rates up to 75% were to be available to non-industrial forest landowners, including Indian tribes, NGO's, and other forms of non-industrial private ownership. The program would be administered through the State Forestry Agencies, who are charged with developing a state implementation plan in cooperation with other state, federal, local, and private agency collaboration.

In FY 2003, $20 Million in CCC funding was distributed to the State Forestry Agencies to begin implementing the program. In 2004, $40 million was taken from the FLEP account to help offset the cost of wildfire suppression. That funding was not repaid, and the President's FY 2005 budget cancelled the remaining $40 million in CCC funding for FLEP, leaving the program suspended. At the moment, the future for FLEP is uncertain. Congress has directed the Administration to re-fund the program, but until the FY 2005 Interior Appropriations Bill is enacted and programs begin to unfold, the fate of the program will not be fully known.

Soil and Water Conservation Programs

The act extends the ***Conservation Reserve Program*** (CRP) and increases the program's acreage cap from 36.4 million to 39.2 million acres at a cost of $1.517 billion over current spending. It provides equal priority for erosion control, water quality and wildlife habitat and allows for 30-year contracts for hardwood trees.

The ***Environmental Quality Incentives Program*** (EQIP) was reauthorized through 2007, with funding of $5.8 billion over the period 2002-2007. The funding comes through CCC, meaning it does not have to go through the annual appropriations process. EQIP offers producers contracts with a minimum term of one year after implementation of the last scheduled practice and a maximum term of ten years. All practices must be based on a plan developed by the producer. Farmers and ranchers may elect to use an approved 3rd party provider for technical assistance, and be reimbursed by the program for that cost. Local and state implementation committees convened by NRCS assist in setting practice and program priorities for funding.

Authorization for a new program of competitive ***Conservation Innovation Grants*** within EQIP that provide up to 50% cost-sharing to governmental and nongovernmental organizations and person to carry out projects such as "market systems for pollution reduction; and innovative conservation practices, including the storage of carbon in the soil."

Research and Extension

Section 9009 creates a new grant program to fund University research on "the flux of carbon in soils and plants (including trees); and the exchange of other greenhouse gases from agriculture." The research is to focus on:

- Developing data addressing carbon losses and gains in soils and plants (including trees) and the exchange of methane and nitrous oxide from agriculture;
- Understanding how agricultural and forestry practices affect the sequestration of carbon in soils and plants (including trees) and the exchange of other greenhouse gases, including the effects of new technologies such as bio-technology and nanotechnology;
- Developing cost-effective means of measuring and monitoring changes in carbon pools;
- Evaluating the linkage between federal conservation programs and carbon sequestration;
- Developing methods to measure the exchange of carbon and other greenhouse gases sequestered, and to evaluate leakage, performance, and permanence issues; and,
- Developing methods to account for the impact of agricultural activities (including forestry) on the exchange of greenhouse gases.

The Extension Projects are to combine measurement tools and monitoring techniques into integrated packages to monitor the carbon sequestration benefits of conservation practices and demonstrate the feasibility of measuring and monitoring the changes in carbon content and other carbon pools in soils and plants (including trees) and the exchange of other greenhouse gases.

Development of criteria and protocols

The Conference Report on the 2002 Farm Bill (p. 217) contains language encouraging the Secretary of Agriculture to take a leading role in the development of criteria and protocols for measuring carbon emissions and sequestration from land management activities. "The Managers encourage the Secretary to convene a conference of key scientific experts on carbon to evaluate tools and procedures for measuring the carbon content of soils and plants (including trees) and net emissions of other greenhouse gases from agriculture, and identify techniques and modeling approaches for measuring carbon content associated with several different levels of precision."

Table 6.1 -- USDA Programs created or expanded in the 2002 Farm Bill.

Program	Function	Administering Agency	Field Agency
Environmental Quality Incentives Program (EQIP)	Cost-sharing, technical assistance	NRCS, FSA	NRCS, FSA, 3rd Party Providers
EQIP Innovation Grants	Grants for innovative approaches (includes carbon sequestration and connection to market mechanisms)	NRCS	NRCS
Conservation Reserve Program (CRP)	Cost sharing, land rent; Acreage capped at 39.2 million.	FSA	FSA, NRCS, SFA=s
Conservation Reserve Enhancement Program (CREP)	Cost-sharing, land rental. Done in cooperation with States; program details vary state to state.	FSA	FSA, NRCS, SFA's, CD's
Forestry Land Enhancement Program (FLEP) (replaces FIP and SIP)	Financial (cost-sharing), technical, and educational assistance to private forest landowners of less than 1,000 acres.	FS	SFA=s
Wildlife Habitat Incentives Program (WHIP)	Cost-sharing, technical assistance	NRCS	NRCS
Wetlands Reserve Program	Cost-sharing, easements	NRCS	NRCS
Conservation Security Program	Cost-sharing for new or maintaining existing conservation practices	NRCS	NRCS
Sustainable Forestry Outreach Initiative (SFOI)	Education	CSREES	Extension Services

C. The NCOC Planning Process

At this stage of development in carbon markets, it is NCOC's desire to encourage the development of project plans without creating excessive costs or raising undue expectations in either landowners or project planners. Therefore, planners are encouraged to develop plans in a process that begins with an Initial Proposal, proceeds with a Project Plan if the project shows commercial promise, and concludes, as sales are completed, with Project Contracts. At each step of the planning process, the planner should consult with the NCOC Portfolio Manager to determine whether it is advisable to move to the next step, or to see if additional details or different approaches would help raise the likelihood of finding financial support for a particular project.

While the process is the same for agricultural, agroforestry, and forestry projects, many of the details will be different. To improve clarity, the following material is in four sections: 1) general process; 2) planning agricultural projects; 3) planning agroforestry projects; and 4) planning forestry projects.

The general process consists of several steps that lead from an inquiry to a final project plan, as follows:

- Step 1. Initial Inquiry

Landowner, Tribe, or Planner calls NCOC Portfolio Manager to discuss a project idea, and see if it has the potential to meet NCOC requirements. If yes, the process continues.

- Step 2. Initial Proposal

Planner works with landowner to develop an Initial Proposal (IP). The formats for the different IP's (agriculture, agro-forestry, and forestry) are found below, and Word documents are available from NCOC (www.ncoc.us) for the planner to use. The Initial Proposal contains brief, general descriptions of the project and its effects. Potential carbon sequestration is estimated, main risks and uncertainties are shown, and other environmental, economic, and social impacts are identified.

- Step 3. Technical Review

The Initial Proposal is reviewed by technical experts to assure that the carbon calculations are reasonable, and that the proposal appears to be complete. Questions are discussed with the planner, and needed changes are made. When ready, NCOC asks for a completed listing agreement.

- Step 4. The Listing Agreement

The landowner enters into an agreement with NCOC to allow NCOC to market test the CSU's in the project. In the agreement, which extends for one year, the landowner gives NCOC the exclusive right to own and market the CSU's produced if and when the project is implemented. The landowner agrees to a minimum threshold price per CSU that they are willing to accept. If NCOC obtains that (or a higher) price for the landowner in the market, the landowner is committed to completing the planning and establishing the project as planned.

- Step 5. Market Test

The Initial Proposal is included in an NCOC Portfolio (a group of projects that produce enough CSU's to interest a buyer) and submitted to the marketing broker, who tests its marketability with potential market traders or buyers. Questions may arise that will be sent back to Planners for clarification. If a potential market trader or buyer is found at or above the threshold price, the Planner is asked to prepare the:

- Step 6. Project Plan

The Project Plan is the key document in the transaction process. It amplifies the Initial Proposal, more fully describes project and baseline analyses, develops specific calculations of carbon sequestration, and addresses issues like additionality, leakage, transparency, accuracy, uncertainty, and risk management. Non-carbon issues are described and, where possible, quantified. The management plan contains a plan for monitoring and verification. The plan is submitted to NCOC, for:

- Step 7. Second Technical Review

Technical experts once again review the plan for technical accuracy and completeness. Marketing experts review it for any remaining market-related gaps, and NCOC's Portfolio Manager reviews it to assure that NCOC's portfolio management needs are met. Questions are directed to the Planner or Landowner, and adjustments, if needed, are made. When complete, the project CSU's are ready for sale. When a buy order is executed, the NCOC Portfolio Manager works with the Broker and the Seller to prepare the:

- Step 8. Final Contracts

The final step is to develop the contractual documents to convert the plan into a legal instrument. This is largely the task of the NCOC Portfolio Manager. Upon completion, the documents are signed, payments made, and CSU's transferred to the buyer.

- Step 9. Credit Registry

NCOC will assure that all projects entered into market transactions produce CSU's that qualify to be registered with appropriate registries. At this point, that will include the 1605(b) registry at the federal level and any relevant state or regional registries that are requested by the buyer. NCOC will develop and retain required landowner facts and assurances to support required reporting.

- Step 10. Monitoring and Verification

Periodically, in keeping with the schedule established in the Plan, NCOC will require reports on monitoring results and independent third-party verification to provide assurance to the buyer and appropriate authorities that carbon sequestration amounts are being produced, managed, and maintained as agreed.

D. Preparing the Initial Proposal

The purpose of the Initial Proposal is to see if a project might meet NCOC's standards for producing credible CSU's. It can be fairly informal, based on general estimates of the opportunities and potentials that exist, what the landowner wishes to achieve, the activities or practices that seem most promising, and the amount of carbon sequestration likely to occur if these activities are undertaken. Based on this general information, the NCOC Portfolio Manager can advise the planner whether or not it appears that the proposal will have enough potential to warrant moving forward with planning.

Prior to beginning work on the Initial Proposal, the planner should study the requirements for a Project Plan. The issues that will be evaluated in detail in the Project Plan are described generally in the Initial Proposal, and where data are located and organized in the Initial Proposal process, it can help make the Project Plan process more efficient.

Suggested outlines and formats for Initial Proposals are shown below. (See samples in Part 8F). The Initial Proposal serves to:

1. Establish a general project framework with the landowner, including:
    a. Proposed size and location of the project
    b. General objectives to be achieved
    c. Project activities to be carried out
    d. Time duration selected as a target for the project's lifetime. (This initial decision may need to be reconsidered later in the planning process as the

landowner considers the effect of different project durations on the marketability of a project or the price realized as a result of duration.) (Longer durations produce more CSU's in most cases).

   e. Important economic considerations, such as: how much financial incentive will the landowner need to realize in order to carry out the project?
   f. Legal considerations to be involved, such as contracts or conservation easements.

2. Estimate the changes in soil and wood carbon likely to result from the project. (See Part 8 for useful rule of thumb guidelines and methods of calculation that can be used to make quick estimates of potential carbon changes.) If important, quantify other important environmental changes likely to occur. (This step may involve different details, depending on the requirements of the marketing exchange or buyer. The NCOC Portfolio Manager should be consulted if there are questions.)
3. Provide adequate details for NCOC and buyer review. It is useful to attach a location map of the project and, if readily available, a photo or two of the existing situation. NCOC will use the Initial Proposal to test the marketability of the project. If a buyer is interested enough to warrant proceeding, NCOC will ask for development of a Project Plan.

E. Preparing the Project Plan

The Project Plan contains more detail than the Initial Proposal and is intended to provide a complete understanding of the proposed project and its impact on the environment. It should clearly highlight the assumptions that have been made and the apparent information gaps that create any uncertainty in the analysis. This includes the development and quantification of either a base year or a base and project case comparison (see below) that can be used to assess the impact of the project on carbon sequestration as well as other important aspects of the environment. The plan will be reviewed by NCOC for technical adequacy and marketability. If questions are raised, NCOC may request additional information at this stage.

The difference between the steps in the planning process is primarily one of detail and rigor, since each needs to address the full range of general issues cited above.

An example of the stepwise approach to detail might be the treatment of leakage. At the initial proposal stage, it may be adequate for the planner to say something like "There are no apparent leakage issues with the project." Once the plan moves to the planning stage, however, it will be necessary to document the results of tests for leakage that are consistent with the context, size, and details of the proposed project. Where leakage has been identified as a potential, it will need to be quantified and appropriate proposals presented to offset it.

The Project Plan is the most important document in actually describing the project and attracting financial support. Planners who submit an Initial Proposal to NCOC should do so in anticipation that, if it is accepted, they and the landowner are prepared to move to the Project Plan stage. That said, much of the information gathered in the Initial Proposal stage should be transferable, with more analysis and detail, into the Plan. The steps to follow include:

1. Prepare a technical description of the project area. (See suggested outline in Part 8H).
2. Assess current environmental conditions, including:
    a. Existing carbon content of carbon pools in soil and woody vegetation including, where appropriate, understory vegetation, dead and down wood, and litter. (In an agricultural project, or where soil carbon changes are to be reported in an agroforestry or forestry project, the monitoring plan (step 11, below) should provide a map of the soil strata to be sampled, a sampling plan (number and location of samples), and a description of the laboratory and/or methods to be used in establishing baseline soil organic matter content and bulk density.)
    b. Current levels of soil erosion, water or air pollution, or other important environmental effects under current land use and management.
3. Describe the proposed project activity, including:
    c. What activities are planned
    d. When will the activities begin, and how will they be applied
    e. What important operation or maintenance activities will be needed during the life of the project? How will these be done?
    f. What major assumptions are made, and what information gaps exist?
    g. What supporting activities will be needed?
4. Identify factors or drivers likely to affect land use and management in the project area for the foreseeable future.
5. Where a business-as-usual (BAU) baseline is required, establish a **reference case scenario** by describing the most likely future for the project land in the absence of the project, given the plans of the landowner, the relevant factors or drivers likely to influence future decisions, and the regional context that might affect the project land.
    a. Quantify the effect that the reference case scenario will have on existing carbon stocks, in 5- or 10-year time steps, for the duration of the planned project and illustrate it with tables or graphs. This is the BAU **carbon baseline**, reflecting what is likely to happen to the carbon stocks on the site in the absence of project action.
6. Create a **project scenario** that describes how the planned project activities will affect the carbon pools involved.
7. Describe and, if possible, quantify the effect that the project will have on the other important environmental, economic, social, or cultural values. Use NRCS-CPA-52 where appropriate. Where quantitative estimates are possible, create **baseline and project scenarios** (charts or graphics) for other important trends identified. For those values that are qualitative in nature (e.g. improved scenic views), provide descriptions of those changes.
8. Describe the main risks that could cause future losses from the carbon pools in the project, and the risk management activities planned to reduce or mitigate those risks.
9. Include the management plan for the project, showing important steps in installation, maintenance, and management of the project area over the duration of the project.
10. Describe the monitoring, reporting, and verification program planned for the project. This will need to be developed in consideration of NCOC, buyer, and registry requirements, as well as project and site conditions, type of project, etc.

The Project Area Description

This provides the reader with a quick but fairly complete overview of the project. Upon reading it, one should pretty much understand the physical situation, land ownership, historical land uses, and current conditions on the land. It may also be helpful to touch on any regional issues or "drivers" that are likely to come into play in analyzing the project. Think of it as an "executive summary" that outlines what the following sections will discuss.

The Project Activity Description

Again, this narrative should describe what the project is going to do, how long it will last, what general management will be done during the project life, and what kinds of outcomes are expected. It should provide the reader with a good picture of what this project seeks to achieve. It can be fairly brief, but needs to convey the project vision to someone who has never seen the land in question.

Establishing a Base Year

In projects where a base year situation is used to establish the starting point for a project, there are several methods suggested for use. In the case of emissions, where several years of record are available (such as fuel use records), the base year can be either the latest year or the average of the four previous years. In the case of soil carbon, it is suggested that the project area be stratified, sampled, and analyzed as outlined in Part 8. For forest carbon in an existing forest, a standard forest inventory (see Part 8) can be used to establish the current forest condition.

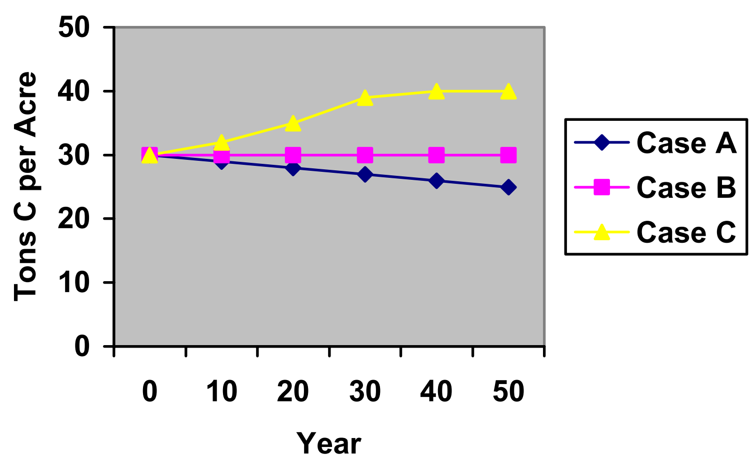

Figure 6.1. Predicted carbon baselines for three different base case situations: (A) continued carbon emissions; (B) no change in the future; or, (C) some natural infilling on the site, with increased carbon in soils or woody plants.

Creating a Business as Usual (BAU) baseline

In projects where a BAU baseline is required, the reference case scenario documents the starting point for a project and projects the most likely future for that project area if the project were not done. It begins by identifying the project boundaries and context, both for carbon and possibly for other environmental impacts.

The most important starting points for a carbon sequestration project, of course, are the carbon stock levels in the pools that are expected to change as a result of the project activities. But there are many other aspects to a reference case that should be considered. Important ancillary benefits may be part of the project's result, and they cannot be adequately evaluated unless there is some current condition against which to compare. So it is important that the reference case begin with a full description of the current situation on the project area, with as many important factors measured as possible.

It will be equally important to describe the surrounding context as well. For example, this may be a project on marginal farmland in an area where many farms are being converted to other land uses because of economic stress, and where watershed conditions are significantly affected by soil erosion from cultivated land. In any situation, what are the economic, social or environmental "drivers" that are most likely to influence land use and management on the project and surrounding areas?

The next task is to extend the description of those conditions into the future as well as possible. The extension needs to cover the commitment period of the proposed project. If the project is planned for 50 years, the reference case needs to estimate what the existing conditions are likely to become over the next 50 years. That may be a continuation of the existing condition, but it does not need to be. For example, if the project area is an eroding agricultural field, the chances are that the soil carbon levels are going to continue to decline for as long as the erosion is allowed to continue (Figure 6.1). If the base case predicts that the field will be maintained in cultivation unless the project is implemented, the soil carbon baseline should decline over that time (Case A, Figure 6.1). Estimating the amount of decline will require assumptions based on the best scientific information available.

If the area is an abandoned field, or a burned-over forest with little chance for restoration of a well-adapted forest, the base case may show a carbon increase due to natural infilling with brush and trees (Case C, Figure 6.1). Again, a science-based evaluation is needed. What conditions are most likely to develop? Figure 6.1 illustrates the different types of carbon baselines that might be encountered, depending on the reference case that seems most logical for the conditions in the project area, considering the surrounding context.

Quantifying the current level of soil carbon to establish base year conditions will require soil sampling and laboratory testing. The techniques for developing a sampling plan, taking and preparing samples, and conducting laboratory analysis have been outlined in several technical documents, and are briefly described in Part 8.

Other environmental conditions may also be able to be evaluated and quantified. For a cultivated farm field, wildlife habitat is probably pretty limited. If the field is likely to convert to brush, that will have habitat implications. If those can be quantified with sound scientific principles, do so. If dollar estimates are available, use them (Part 7). If not, describe the changes in qualitative terms.

The change from current conditions that is likely to occur over the proposed project lifetime needs to be displayed, in either table or graphic format (or both). Where projected BAU baselines are required, this will provide the baseline (or baselines) against which project changes can be measured.

For a forest management project (changing the management of an existing forest, where no change in land use is foreseen), formal procedures are not yet adopted, and the reference case may be constructed in different ways. Where a program provides CSU's for the carbon changes relative to a base year, it will be possible to inventory the existing forest and convert the current inventory to biomass and carbon estimates. Those would then provide the base year inventory from which any additions or subtractions would be calculated in the future.

Where a business as usual (forward) projection is required, there are two possible methodologies. One would be the continuation of the pre-project management plan. If that plan was specific enough to provide a sound prediction of biomass changes over time, the carbon stocks that would exist on the land from the continuation of the old plan can be predicted through the use of forest growth and yield models.

In most cases, a change in forest management practices with no change in land use will probably produce no measurable change in soil organic carbon. If it can be demonstrated that soil carbon will not decline under the new management, soil carbon measurements can be left out of these project calculations.

Another type of baseline that has been discussed, but not yet put into practice, would be to look at the average yield and forest biomass levels for the same species and sites in the region. These data are available from the Forest Service's Forest Inventory and Analysis (FIA) publications. If this regional baseline is utilized, forest management that exceeds the production of all landowners in similar situations could be credited for that difference.

In summary, the development of the reference case and associated baselines involve:

1. Identify the proposed project boundaries (in both space and time). For example, this will be a 200-acre afforestation project that will be maintained and managed for 50 years.
2. List the desired environmental objectives (carbon sequestration, erosion and sediment reduction, wildlife habitat, other) that the project will address.
3. Estimate (and quantify where possible) the current condition for each objective (See Part 8 for a case example of quantifying carbon pools).
4. Identify the key drivers that are likely to affect the land use and management of the project area (and surrounding areas) in the future. Estimate how these will affect the use and management of the project land in the absence of project action.
5. Estimate how the changes foreseen will affect carbon stocks in the carbon pools to be affected by the project, over the proposed lifetime of the project. Quantify these on the basis of available scientific data and methods. Illustrate the results in tabular or graphic format (or both) and explain any assumptions and methods used.
6. Construct similar baseline scenarios (where possible) for other environmental factors that the project will address.

Creating a Project Scenario

The project scenario begins with the same current condition as the base case scenario. It then proceeds to explain and quantify how those conditions will change under the planned project activity. The project scenario is usually created with the aid of an appropriate model. If a model was used in the creation of the base case scenario, and it is appropriate, the same model (or methodology) should be used to create the project scenario.

If trees are to be planted, there are growth and yield models that estimate how the forest will change over time. Those models usually predict merchantable timber yields by species, which can be converted to carbon yields with the methods and conversion tables contained in Part 8.

Some projects such as riparian buffers, shelterbelts, or biomass plantations may be planted to species that have little or no literature on growth and yield. Even species with forest growth and yield data may demonstrate significantly different growth characteristics if planted on a streambank or in a shelterbelt rather than in a closed forest. Each project will require the planner to search out the best scientific literature available for the species, site, and situation involved. NCOC technical support can provide assistance in many cases, and planners are encouraged to inquire about available assistance where they are facing unfamiliar situations.

Other carbon pools, such as understory vegetation or woody debris, will need to be estimated from models and technical literature if they are to be included in the estimates of carbon change.

One way to estimate the potential soil carbon increase from the project is to research information on the carbon content of the major soil groups in their native cover and condition. These may be available in published soil survey reports, or in official NRCS soil descriptions. It may be possible to find nearby areas where these soils have not been cultivated and remain under native vegetation. Soil samples taken under the native vegetation may provide insight into the native organic matter content of the soil. From the best information available, an estimate of the potential carbon levels in the soil can be made. This can be compared to the current carbon levels calculated for the baseline scenario (see above).

The challenge for the project planner is to decide how much of the difference between the current condition and the native potential will be restored during the project period. While it is possible that the native condition will be fully restored, it is probably prudent to predict a somewhat lower result. Many soil scientists believe that most of the native soil carbon can be restored over a period of 20 to 50 years. Few experiments have been done, however, to provide solid scientific evidence for these estimates. As a result, NCOC recommends that the project case be based on the restoration of 50-75% of the difference between the current condition and the native condition. These assumptions should be clearly explained in the plan, so that it will be clear to future auditors whether a difference between predicted and measured conditions is a result of faulty models or the planning assumptions that were used. If the NCOC project contract allows for it, the landowner may be able to sell additional CSU's if they exceed the projected restoration level.

For forest management projects, it is unlikely that soil carbon levels will change measurably under continued forest management, even if the forest itself is changed significantly. For forest biomass estimates into the future, the new management scheme can be evaluated with the use of forest growth models to assess the change in standing biomass likely to be achieved. For monitoring, the plan should rely on a periodic forest inventory based on fixed plots established as discussed in Part 8. In a managed forest, the change in understory vegetation and/or large woody debris may be more significant than they would be in a tree planting project, so those measures should be considered for inclusion in the carbon calculations.

Forest management projects involve one significant difference from afforestation projects, in that they represent the total impact of forest management over a variety of stands, stand ages, and conditions within the whole forest area, whereas afforestation is often one single-aged stand that grows over time in a fairly uniform manner. The challenge for achieving additionality in a forest management project will be the need to demonstrate that additional carbon has been sequestered in the measured pools across all the stands as a direct result of management activity.

Some forest management activities such as thinning are important for maintaining a healthy forest or creating more valuable timber, but may do little to increase the standing biomass in the forest itself. Most thinning will, in fact, reduce standing biomass for a few years until the regrowth in the thinned forest replaces what was removed. These effects will be averaged out over the total forest, however, and the additional impact of the management will be reflected in the periodic plot measurements.

One way to demonstrate additionality in forest management is to establish reference plots in similar stands that are left unmanaged. Where this is possible, the demonstration of additionality can rest on the difference in the change of the carbon stocks between the managed and unmanaged areas.

In summary, the development of the project case and associated trend lines consists of:

1. Illustrating how the project activity will change carbon levels in the measured carbon pools from the current levels identified in the reference case and its associated baselines, with a full explanation of any assumptions and methods used;
2. Illustrating how the project activity will affect other values to be considered, such as water quality, wildlife habitat, or regional economic activity.
3. Carrying out first-order tests for associated or offsite impacts (leakage) that might result from the project activity. Where offsite impacts are identified, it may be necessary to expand the analysis of the project's effects to a larger area in order to quantify the leakage effects. (For example, if the project will change the local market for timber, how will that affect other landowners and lands in the market area?)
4. Calculate how the project will change conditions relative to the base case scenarios on the measured values. This provides a measure of the project's additionality, or net impact over the no-project or business-as-usual scenario.

Calculating Net Carbon Change

The net carbon change predicted for the project is the difference between the project scenario and the base case scenario, as illustrated by the carbon baselines predicted for each. NCOC recommends that both the baseline and the project carbon line be estimated in time steps of 5 or 10 years, in a graphic or table format. This will give future monitors and auditors an opportunity to compare actual measurements with predicted carbon changes at these interim times. That comparison could be valuable in helping assess whether or not the project is performing consistently with the planned changes.

F. Discounting concepts and options

Some discussions have been held around the need to consider discounting CSU's on the basis that it may be some time before they are produced. Forest plantings grow according to well-established curves, and the first few years are marked by a slow buildup of wood and carbon. At this point, lacking further national or international guidance, NCOC will not discount CSU's. (Part 7 and the NCOC Financial Analysis Calculator have instructions for discounting, should that become necessary.) That may, of course, be affected if future decisions establish other required accounting techniques.

Where NCOC may utilize some form of discounting will be in cases where a project features significant uncertainties in terms of leakage or unaddressed risk. In those cases, it may be necessary to provide additional assurance by counting only a reduced portion of the calculated CSU's rather than 100 percent. For example, if NCOC determined that there was a 10% uncertainty remaining in the project, it might decide to purchase only 90% of the calculated CSU's.

It may also become necessary in the future to create a staged payment system, where CSU's are partly paid for up front, then additional payments made in stages as the CSU's are realized and measured.

These details, as they emerge, will be part of the contractual agreement between the landowner and NCOC. Since these are all private market transactions, based on a willing buyer and a willing seller, there can (and probably will) be a significant range of details that develop under different conditions. Planners should provide information so that landowners are prepared to negotiate conditions appropriate to the circumstances and consistent with their needs and desires.

G. Ancillary project opportunities, benefits, or challenges

Environmental

Most carbon sequestration projects will have many other important environmental or economic impacts that may be as important, or more important, in the landowner's plans as the value of the CSU's involved. Some of these co-benefits may make a project more marketable, as CSU buyers may also want to gain credit for promoting environmental improvement. These factors may become less important if trading markets become established to the point where CSU's no longer are identified with specific projects, but NCOC is committed to the promotion of carbon sequestration projects that feature other positive environmental effects, so it will be important to identify the full range of project impacts for NCOC projects.

These other project impacts should be detailed as well as possible in the plan. (If form NRCS-CSA-52 is used, attach a copy of the completed form as an appendix.) Many of these impacts are qualitative in nature (such as an improvement in scenic views), but others can be quantified. For the latter, it will be useful to provide as much quantitative detail as possible, particularly in the process of setting baselines. The following are general guidelines:

Soil erosion and water quality

These impacts should be quantifiable in most cases. If the land is currently in cultivation, use standard soil erosion estimating techniques to estimate the average annual soil erosion rates being experienced. An estimate of delivery percentage can be added to indicate how the current land use is contributing to the pollution of local surface waters.

If the project converts this land to well-managed grassland or forest, the rates of soil erosion, sediment delivery, and nutrient pollution of local waters should drop to zero. The plan should provide for particular care in the location and maintenance of forest roads or stream crossings, if any, since roads are often the primary source of erosion and sediment runoff from managed forests.

A project that establishes a riparian forest or buffer may remove both sediment and nutrients being transported from upslope fields or pastures.

Quantification of future soil erosion, sediment delivery, and nutrient pollution reduction offers another way to demonstrate the value of a carbon sequestration project. It also provides a basis for future monitoring and verification to test the effectiveness of project management.

Air quality

If the land to be planted is subject to wind erosion, those erosion rates can also be estimated and should diminish to zero under conservation tillage, agroforestry, or forest conditions. That may provide a basis for quantifying a local reduction in airborne dust, although this will be difficult to detect with monitoring unless a very large area is involved.

Wildlife habitat or biological diversity

Improving wildlife habitat is often a major benefit of grass or tree plantings, particularly where care is taken to design the planting plan for maximum positive effect. These effects will be highly local in nature, and will need to be evaluated in light of the site conditions and the situation in the landscape around it. Some of the potential may be quantifiable; often, however, that may prove difficult. The opportunities for habitat enhancement may include:

- Special attention to riparian zones in the project area. Planting these with local riparian species, and managing them for habitat values, can greatly improve the total habitat value of the area. The mixture of upland and riparian species, coupled with the water protection provided, will affect many species. It may be possible to demonstrate, for example, that the plan will provide habitat for aquatic species, amphibians, birds, upland mammals, and riparian and upland plant species that did not exist under pre-project conditions.
- Providing habitat structures uncommon in the area, such as closed forest or riparian forest in an area characterized by more open landscapes. The project may create a habitat type that fills an important niche for some species.
- Providing an important food or cover type for certain species or suites of species. There may be opportunities within the project area to establish food plots or other special areas.

Landscape diversity or aesthetic quality

This is highly localized in nature, and may be hard to quantify, but if changes will occur, it may be worthwhile to document them.

Economic

Economic benefits from a project may be modest, but where they exist, they should be documented. They could include:

Local community impacts; jobs; added-value products

Some possibilities include:

- Taking crop or grazing land out of production may impact local businesses or employment opportunities
- Reducing snow blowing may reduce road maintenance costs
- Providing new recreational opportunities may enhance local businesses
- New products may become available for local added-value processing

Social

These could include:

Health impacts

Reductions in airborne dust may have a positive effect on local populations.

Protection of roads from drifting snow through living snow fences may reduce accidents, save lives.

Cultural impacts

Creating a new forest situation may create new opportunities for local people to gather forest food or medicinal crops, or experience forest environments that might otherwise be unavailable to them.

H. Final Contracts

If the Project Plan is accepted by NCOC and a market is found, documents will be developed to establish the contractual agreements between the landowner and NCOC. Much of the work in developing these will fall to the NCOC Portfolio Manager and the Marketing Broker. The contracts reflect the agreement reached between NCOC, the buyer of the CSU's, and the landowner. It is based on the project plan, with any changes that have been negotiated in the final agreement. A copy will be maintained in NCOC files to serve as the basis for future verification audits.

Prior to final contracts, the detailed monitoring plan for the project will be completed, plots established in the field, and baseline measurements completed. If this is impractical due to lack of time or funding prior to the contract signing, another approach may be to sign the contract on the basis of the estimated baseline measurements so that the landowner is assured of the financial means to make the actual measurements, then provide a means in the contract for adjusting payments on the basis of the actual measurements. In either case, the contracts will reflect the measurements and assumptions against which future monitoring and verification will be conducted, so it can be technically and scientifically sound.

Part 7 – Project Economics

A. Evaluating Project Costs and Benefits

One of the most difficult challenges facing private landowners is that the costs of owning and managing land must be paid through the sale of a limited range of marketable products, since many of the land's outputs are public goods and services that bring no revenue to the owner. Thus an agricultural system that protects water and supports wildlife seldom sees any financial benefit other than the sale of crop or livestock products. Forestland is primarily supported by the sale of timber products, in spite of the fact that it may produce a regulated flow of clean water that would have a high dollar value if a market existed.

One of the major topics in conservation circles has been how to help landowners realize some economic return from the provision of those "public goods" such as clean water, wildlife habitat, scenic views, etc., that in general carry no market opportunity. One result of these concerns has been a wide array of public policies and programs designed to provide technical and financial assistance, tax breaks, or other public incentives to encourage the production of desired environmental values.

Marketable carbon sequestration units (CSU's) may offer landowners an opportunity to realize revenue from a new source. If an industry is required under national or international regulations to reduce carbon emissions, and if a trading system is allowed as one means of meeting those reductions, it will be possible for landowners to produce and market an important new environmental service. The CSU's produced from agricultural and forestry projects will need to compete in the marketplace with CSU's produced from other sources. These may include, for example, the result of technological innovation in other GHG producing sectors such as the energy sector. CSUs from other countries may also be possible, if an international GHG trading market comes into existence combined with a US decision to participate in that market.

As long as production of CSU's is competitive with other options, industry may find that purchasing CSU's as an offset for their emissions is an economical way to meet their emission reduction needs. The result can be that the landowner realizes an additional income opportunity that enhances the health and sustainability of the ecosystem, while the regulated industry can reduce or offset their carbon emissions in the most cost-effective manner. However, understanding whether the production of CSUs will be competitive will require the consideration of other environmental, ecological and social costs and benefits of the carbon sequestration project. A producer will participate in a market if the net returns from a project plus the market value of the CSUs produced exceed the net returns from their existing production practices[60].

Carbon sequestration is not the only benefit from undertaking practices and activities for capturing carbon in biomass and soil. It will be useful to determine whether and how the probable benefits of carbon sequestration in agricultural and forestland are greater than the probable costs, taking into account both the qualitative and quantitative benefits and costs. This analysis might be useful from the point of view of both the government or policy makers and the landowner. In addition, the potential buyers of CSU's will want to

[60] http://www.montana.edu/wwwpb/pubs/mt200313.html

know that the production of those CSU's did not cause negative environmental, economic, or social impacts.

Table 1 presents the potential benefits and costs associated with sequestration in agricultural land and Table 2 presents the potential benefits and costs associated with projects in forests. In addition to listing these benefit and cost items, the table includes some proposed methods of measurement based on existing literature and potential effect on the benefit or cost figure. These costs and benefits are neither exhaustive nor limited, and some may not be applicable to all sequestration projects. Each project should be evaluated individually to determine its competitiveness and merits.

Table 1. Potential costs and benefits associated with sequestration projects on agricultural land[61]

Potential Benefits	Expected Effects	Proposed Methods of Measurement
Agricultural Production	+/-	Annual dollar value of sales
Air Quality	+	Air Quality Index, Qualitative description
Water Quality[62]	+	Water Quality Index, Qualitative description
Soil Erosion	-	Avoided Cost of Erosion
Water and pesticide use	-	Dollar value of reduced irrigation water and pesticide usage
Nutrient runoff	-	Dollar value of reduced nutrient loss
Wildlife Habitat/Biodiversity[63]	+	Qualitative description
Tax credits	+/-	Dollar value of credits
Subsidy (Cost Share)	+/-	Dollar value of cost-share
Employment	+	Un-estimated
Bioenergy Use	+	Dollar value of net benefits
Fossil Fuel Use	-	Dollar value of reduction in Use
Revenue from CSUs	+	Dollar value of sales
Potential Costs	**Expected Effects**	**Proposed methods of measurement**
Opportunity Cost	+	Dollar Value
Establishment Cost	+	Dollar Value
Management Cost	+/-	Dollar Value
Transaction costs	+	Dollar Value[64]
Machinery Investment	+/-	Dollar Value
Social and economic dislocation	+/-	Un-estimated

[61] For potential C-sequestration activities on agricultural land please refer to PART 5

[62] Salinity reduction would also be a potential benefit in case of saline soils. This can be measured using a Salinity Benefit Index (http://www.dlwc.nsw.gov.au/care/synopsis_sbi.htm)

[63] Biodiversity will improve in case cropland is converted to grassland or forestland. Practices like conservation tillage are not likely to have much impact on wildlife and biodiversity, although soil fauna may change as a result.

[64] Currently the relevant data are limited, but it should be possible to estimate these costs in the future as more experience is gained in project development and formal rules are established.

Table 2. Potential costs and benefits associated with sequestration projects in forests

Potential Benefits	Expected Effects	Proposed Methods of Measurement
Biomass Production[65]	+	Dollar value of timber sales
Air Quality	+	Air Quality Index, Qualitative description
Water Quality/ Hydrological benefits	+	Avoided Cost Of Water Filtration Plants, Water Quality Index
Wildlife Habitat/Biodiversity	+	Qualitative description
Soil erosion	-	Avoided cost of erosion
Water conservation	+	Dollar value of reduced water use
Bioenergy Use	+	Dollar Value of Net Benefits
Fossil Fuel Use	-	Dollar Value of Reduced Usage
Recreational benefits	+	Contingent Valuation Method, Travel Cost Method, Qualitative description
Restoration of degraded ecosystems	+	Qualitative description
Employment	+	Un-estimated
Tax credits	+/-	Dollar Value of Tax Breaks
Subsidy (Cost Share)	+/-	Dollar Value of Cost-Share
Revenue from CSU's	+	Dollar value of sales
Potential Costs	**Expected Effects**	**Proposed methods of measurement**
Opportunity Cost	+	Dollar Value
Establishment Cost	+	Dollar Value
Management Cost	+/-	Dollar Value
Transaction costs	+	Dollar Value[66]
Machinery Investment	+/-	Dollar Value
Social and economic dislocation	+/-	Un-estimated

Quantifying Benefits

Revenue from sales: Carbon sequestration practices affect agricultural production and forest biomass, and these effects can be estimated directly to obtain dollar values from market sales.

Air Quality: In addition to reducing atmospheric greenhouse gas concentrations, sequestration activities are likely to improve air quality in general. It will not be a simple exercise to estimate the monetary value that the society places on improved air quality. One way of estimating this is to estimate the society's willingness to pay for better air quality as a result of sequestration activities using Contingent Valuation Method (CVM).

[65] Establishing forestry plantations will lead to more biomass products. (http://www.energy.ca.gov/reports/2003-04-16_500-03-025FA-IV.PDF, pp.11)
[66] Currently the relevant data are lacking, however it will be possible to estimate these costs in the future as more and more agents enter into the GHG market and formal rules are established.

CVM is used to estimate both use[67] and non-use[68] values of ecosystem and environmental services. The CVM involves directly asking people, in a survey, how much they would be willing to pay for specific environmental services or how much compensation they would be willing to accept to give up specific environmental services. It is called "contingent" valuation, because people are asked to state their willingness to pay, *contingent* on a specific hypothetical scenario and description of the environmental service[69]. The willingness to pay approach strives to identify an appropriate economic value for environmental resources to prevent their under-valuation and over utilization, even when people do not directly consume or use those resources. These methods are not feasible for individual sequestration projects, but are listed here in the event that future studies are published that can provide quantified values for use in project planning. For the moment, planners are encouraged to deal with air quality improvements as a qualitative, rather than quantitative, benefit of carbon sequestration projects.

Water Quality: Improving water quality is one of the many benefits offered by improved agricultural and forestry practices, and the conversion of cultivated land to grass or forests. Many communities, for example, depend on drinking water supplies from streams or lakes where the watershed is primarily forested. Drinking water supply catchment areas in forests filter and purify water by its passage through foliage and forest soils. Moreover, forested land is relatively free of pollutants associated with livestock rearing or industrial activity. The value of water quality protection can be monetized by calculating the avoided cost of water filtration plants. The value of U.S. watershed forests in this regard has been estimated at $3.7 billion per year (Dombeck, 1999)[70].

A recent study, 'Water Quality Co-Benefits of Greenhouse Gas Reduction Incentives in U.S. Agriculture', prepared for U.S. Environmental Protection Agency, uses the Agricultural Sector Model-Greenhouse Gas Version[71] and the National Water Pollution Control Assessment Model[72] [73] to develop a Water Quality Index. The study concludes that GHG mitigation activities in agriculture increase the national aggregate average water quality 1.38 points (about 2 percent) on a 1 to 100 scale[74]. However, this study does not provide monetary values for the benefits of water quality improvements, which

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[67] Value derived from actual use of a good or service. (http://www.ecosystemvaluation.org/contingent_valuation.htm)
[68] Values not associated with actual use, or even the option to use a good or service. (http://www.ecosystemvaluation.org/contingent_valuation.htm)
[69] http://www.ecosystemvaluation.org/contingent_valuation.htm
[70] http://www.iucn.org/themes/wani/eatlas/html/gm8.html
[71] Schneider, U.A., and B.A. McCarl. 2002. "The Potential of US Agriculture and Forestry to Mitigate Greenhouse Gas Emissions—An Agricultural Sector Analysis." Working Paper 02-WP 300, Center for Agricultural and Rural Development, Iowa State University, April 2002.
[72] RTI. 2000a. "National Water Pollution Control Assessment Model (NWPCAM) Version 1.1." Prepared for U.S. Environmental Protection Agency, Office of Policy, Economics and Innovation, Washington, DC.
[73] RTI. 2000b. "Estimation of National Surface Water Quality Benefits of Regulating Concentrated Animal Feeding Operations (CAFOs) Using the National Water Pollution Control Assessment Model (NWPCAM). Prepared for U.S. EPA Office of Water, Washington, DC. http://www.epa.gov/ost/guide/cafo/economics.html#envir.
[74] Pattanayak, S. K., B. McCarl, A. Sommer, B. Murray, T. Bondelid, and D. Gillig. 2002. "Water Quality Co-benefits of Greenhouse Gas Reduction Incentives in U.S. Agriculture. Report to EPA 2002.

will be needed before those values can be fully compared in a project's financial benefit calculations.

Soil and Water Conservation: There are studies that examine the costs of reducing soil erosion and the economic impact of soil erosion on productivity, however there aren't many studies that attempt to provide financial results. Benefits of soil erosion reduction from sequestration project activities can be estimated in terms of increase in productivity, increase or decrease in tillage costs, cost of establishment of windbreaks or other practices, and the cost (if any) of leaving crop residue on the field after harvesting. The value of water conservation as a result of agricultural and forestry sequestration activities can be obtained from the dollar value of irrigation water saved. Appropriate nutrient management of soils can reduce the need for chemical fertilizer, which may also reduce N_2O emissions. If fertilizer use can be reduced in the project, the dollar value of the avoided fertilizer use can be counted as a benefit.

Wildlife Habitat/Biodiversity: It has been proposed that benefits to wildlife habitat and biodiversity can be measured using a 'Biodiversity Benefits Index' (BBI)[75]. BBI is calculated by placing a value on the current biodiversity of a site, estimating the magnitude and direction of change in the value as a result of project activities and integrating these values into a biodiversity index. According to the biodiversity benefits index developed by the Department of Infrastructure, Planning and Natural Resources, New South Wales (NSW), Australia, the BBI will be 'estimated' using three proxy measures or indicators of biodiversity; namely vegetation condition[76], conservation significance[77] and landscape context[78]. Each of these proxies is also estimated using another set of indicators. Further details for estimating the BBI can be found on NSW government's website: http://www.forest.nsw.gov.au/env_services/ess/default.asp. At the present time, however, this appears to be more complex and subjective that would be useful in a project's economic analysis. It is therefore likely that most project planners will choose to describe changes in wildlife habitat or biodiversity if they appear to be likely, and not attempt to provide dollar values.

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[75] http://www.dlwc.nsw.gov.au/care/biodiversity_toolkit.pdf

[76] It is defined as the degree to which the current vegetation differs from a *vegetation condition benchmark* representing the average characteristics of the mature native vegetation predicted to have occupied the site before agricultural development. It describes the degree to which critical habitat components and other resources needed by indigenous plants and animals are present at the site. Predicted changes to vegetation condition due to land use change are also estimated and used to produce the BBI. (http://www.dlwc.nsw.gov.au/care/biodiversity_toolkit.pdf, pp. iii)

[77] *Conservation significance* is important for estimating the biodiversity value of a site in a regional context. Some sites may represent elements of biodiversity that are common in the landscape; others may represent elements that are now rare. Conservation significance recognises the amount of each element now in the landscape compared with a time before agricultural development, as well as the likelihood of the element persisting. (http://www.dlwc.nsw.gov.au/care/biodiversity_toolkit.pdf, pp. iii)

[78] *Landscape context* recognizes that the biodiversity value of an area of vegetation will vary depending on where the site is located in the wider landscape. Small sites surrounded by a 'sea' of agriculture will have poor landscape context compared with sites close to large semi-natural areas. (http://www.dlwc.nsw.gov.au/care/biodiversity_toolkit.pdf, pp. iv)

Tax credit benefits: Senator Sam Brownback introduced the Carbon Sequestration Investment Tax Credit (S. 765), in April 2001. This would have provided an amount equal to $2.50 per ton of carbon sequestrated during the taxable year. Although the bill was not enacted, if such a policy is ever adopted in the U.S., the dollar value of tax credits should be included as a benefit of projects that meet the requirements.

Subsidies: Cost share programs have been an integral and important part of USDA's program policy since the Agricultural Conservation Program (ACP) was created in the 1930's. More recently, the Forestry Incentives Program (FIP), the Stewardship Incentives Program (SIP), the Conservation Reserve Program (CRP), the Conservation Reserve Enhancement Program (CREP), and the Forest Legacy Program have been important conservation tools. See Part 6 for some information on integrating these programs into project plans. Although the requirements and regulations under cost-share programs are like to change in the future, it should be easy to determine their dollar values in an economic assessment of a sequestration project.

Employment: The economic impacts of job creation are likely to be negligible in the case of small projects. Labor for installing, maintaining, and monitoring projects is included as a project cost.

Biomass and Fossil Fuel Use: The use of bioenergy and bio-fuels is considered carbon-neutral in a sustainable production system since the growth and replacement of the biomass occurs at around the same time as it is consumed. Therefore, biomass fuels can be credited with mitigating carbon emissions to the extent that they replace fossil fuels. Increase in biomass energy use is likely to have many socio-economic impacts in rural areas, including increased employment and income creation. Other benefits may include regional development, rural diversification, reduced regional trade balance, enhanced competitiveness, improved infrastructure, increased investment, and support of related industries. Most these benefits may not be quantitatively traceable and can be excluded from project analysis.

Reduced fossil fuel use is likely to result from forestry activities because the production and use of wood products requires less energy than the production and use of alternate materials such as steel or concrete that provide the same service. This reduction can be estimated in terms of the dollar value of avoided costs of fossil fuel use.

Recreational Benefits: Improvement in the recreational value of land from sequestration project activities, like many other environmental services, may be hard to measure in monetary terms, unless there are local studies that have determined values such as willingness to pay [79]. Another approach that is commonly used to estimate economic use values associated with ecosystems or sites that are used for recreation is the Travel Cost Method (TCM). The method can be used to estimate the economic benefits or costs resulting from[80]:

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[79] The CVM involves directly asking people, in a survey, how much they would be willing to pay for specific environmental services or how much compensation they would be willing to accept to give up specific environmental services.

[80] http://www.ecosystemvaluation.org/travel_costs.htm

- Changes in access costs for a recreational site
- Elimination of an existing recreational site
- Addition of a new recreational site
- Changes in environmental quality at a recreational site

Quantifying Costs

Opportunity Cost: Carbon sequestration projects will be undertaken on a limited land base, which may also be used for conventional agricultural and forestry production, for other sequestration activities, or for urban development. Opportunity costs of changing land use practices are likely to be project and site-specific. The foregone revenue or opportunity cost of installing a sequestration project that changes land use (such as afforestation) is the foregone benefits realized for the former crop products. If those former production activities were marginal or unprofitable, the land use change may result in a net benefit rather than a cost. Other carbon mitigation practices such as alternative tillage and fertilization practices that are complementary to traditional production may result in little or no opportunity cost[81]. The opportunity costs of carbon sequestration projects can be estimated in terms of dollar value of net revenue forgone in the alternative use of the land.

Establishment Cost: Establishing sequestration practices or projects will usually have upfront costs that will vary due to factors such as terrain, area, existing land condition and objectives. Establishment costs can be easily quantified in terms of the dollars spent.

Management Costs: These might increase or decrease depending on the existing condition and type of land that is being considered for installing sequestration practices or projects. Changing from conventional tillage to conservation tillage will involve changes in cultivation practices, machinery operation, and other costs. Planting a windbreak may mean initial costs to provide weed control, irrigation, grazing protection, or other means of assuring that the young trees survive. Extending forest harvest rotations (combined with thinning and other cultural practices) will likely mean increased costs for holding the asset longer, but may be offset by the harvest of larger trees and higher quality wood that brings higher values per unit of volume and reduced harvesting costs per unit[82]. Treatment and annual site maintenance costs may include watering, weeding, fire control, and other tasks[83]. These costs can be estimated as direct dollar values of costs incurred or avoided.

Transaction Costs: These include the costs of search, negotiation, project approval, administration, monitoring and verification, enforcement, insurance, brokerage fees, and registering emission reductions in regional or national registries like the California Climate Action Registry or the 1605(b) national greenhouse gas registry. Estimates for these costs are not available because GHG markets are not yet formally established and data are unavailable. As more trades take place, it will be possible to get an estimate of these costs.

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[81] http://www.card.iastate.edu/publications/DBS/PDFFiles/02wp306.pdf
[82] http://oregonstate.edu/dept/econ/pdf/london2.pdf
[83] http://www.ghgprotocol.org/docs/King%20Carbon%20Trading%20article.pdf

Investment in New Machinery: New machinery may or may not be required for establishing sequestration activities or projects. For instance, new equipment may be required for changing from conventional tillage to a conservation tillage system[84]. Cost of new equipment required for installing sequestration activities can be calculated as direct dollar values.

Social and Economic Dislocation: Installation of sequestration practices could either provide or reduce social and economic opportunities, depending on the situation. While this may be a concern in very large projects, particularly in subsistence or transitional economies, it is unlikely that the impacts on social and economic conditions from small projects in U.S. communities will be large enough to be identified or measured. In the event that they appear important, however, the analysis should consider them.

Other factors to consider

Certain aspects that might be kept in mind while considering the costs and benefits of sequestration projects:

- The time span of the benefits and costs incurred for activities undertaken to mitigate climate change will most likely transcend the project's planned life span for which the cost-benefit analysis is carried out. Incorporating a discounted stream of all future benefits and costs from the project would place an appropriate value on total benefits and costs. The sequestration activities may be discontinued in the future, leading to carbon emissions. Thus, it would be appropriate to adjust for the time value of emissions offsets by estimating the net present value of GHG offsets and costs. The existence of uncertainty in returns and requirement of making a decision to enter into a long-term contract implies that the landowner places value on deferring the decision to sign a sequestration contract. This option value can be appropriately taken into consideration by estimating the net present value of a carbon sequestration scheme.
- Although taxes and subsidies are excluded from conventional cost benefit analysis because they are transfer payments within the economy that do not reflect a change in the wealth of society[85], they will affect the decisions made by an individual landowner. Hence, at the microeconomic level of an individual landowner, the change in taxes and subsidies associated with establishing a project should be incorporated in any cost benefit analysis.
- GHG trading markets face many uncertainties because formal rules are not in place. Even after a formal market is operating, some uncertainties and risks will remain. These risks can be in terms of political uncertainty, changing terms of trade, technological development, cultural or climatic change and other unpredictable risks that may be specific to some or all sequestration projects. Cost-benefit analyses should address these uncertainties whenever they can be identified.

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[84] http://www.puaf.umd.edu/faculty/papers/nelson/carbseq/pdf/1.pdf

[85] http://www.clw.csiro.au/heartlands/publications/general/hl5-01.pdf (pp.3)

Layout of Cost Benefit Analysis

NCOC has an Excel spreadsheet available for download that incorporates all of the following information and formulas. It can be downloaded from www.ncoc.us.

The preceeding has been a rather exhaustive list of the cost and benefit elements that may be present in a project. Planners should prepare a simple cost-benefit analysis that considers costs and benefits that are easily quantifiable and have direct dollar values. Comparing costs to benefits can be done in the following steps:

STEP 1: Identify Project Scope and Variables

Before conducting a cost benefit analysis it is important to identify the scope of the carbon sequestration project in terms of duration of contract, quantifiable benefits, and quantifiable costs in order to assess the economic viability of adopting practices. The first step in the analysis is to calculate the Incremental Net Benefit of a sequestration project, which is defined as the difference between net present value of an investment in a project (NPVp) and the net present value of the investment without the project (NPV), i.e:

INB = NPVp – NPV

The net present value of a project, on the other hand, is defined as the difference between present value of project benefits and costs. The present value of benefits is the sum of discounted benefits over the lifetime of the project. Similarly, the present value of costs is the sum of discounted costs over the life of the project.

Mathematically, the present value of benefits and costs (with and without the project) can be expressed as follows:

$$PVBp = \sum_{t=1}^{t=n} \frac{Bp_t}{(1+i)^t}$$

$$PVCp = \sum_{t=1}^{t=n} \frac{Cp_t}{(1+i)^t}$$

$$PVB = \sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}$$

$$PVC = \sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}$$

Where:

n = number of years being considered

t = each individual year (time)

i = the discount rate expressed as a decimal fraction

Bp_t = Benefits with Project in year ‘t’

Cp_t = Costs with project in year ‘t’

B_t = Benefits without project in year ‘t’

C_t = Costs without project in year ‘t’

$\sum_{t=1}^{t=n}$ = The sum of expressions $Bp_t or Cp_t or B_t or C_t / (1+i)^t$ for every value of t from t = 1 to t = n

As long as INB is positive, (NPVp > NPV and NPVp > 0) the landowner will be economically encouraged to go ahead and install the sequestration project.

***STEP 2: C*hoosing the discount rate**

A discount rate puts a ‘price’ on the use of money and thus reflects the opportunity cost of capital[86]. Discounting converts future values to present values by deducting the minimum acceptable return (or interest) that could be earned in an alternative investment[87]. A high interest rate would typically penalize projects with high initial expenditures and long payback periods. For carbon sequestration projects, a high discount rate might indicate that the sequestration credits are temporary rather than permanent, or it could reflect the high opportunity cost of capital in alternative uses/investment projects, or that extra income in the future (when incomes are expected to be higher) will be worth less to an individual than income at the present time. The choice of discount rate is an issue of continuing debate and will often reflect individual or current market preferences. Ideally the discount rate chosen should reflect the (real) rate of interest or rate of return on investments, though in practice it can be one of the following:

- A rate comparable to the real rate of interest that could be earned if the sum involved was put into a bank or invested in another project[88]; or
- A *social time preference rate*[89] (STP), reflecting the preference society has for present as opposed to future consumption, or the relative value it puts on the consumption of future generations; or
- An *accounting rate of interest*[90], which is the ratio of profit before interest and taxation to the percentage of capital employed at the end of a period. Variations include using profit after interest and taxation, equity capital employed, and average capital for the period.

At the moment, NCOC is not recommending the use a discount rate in project analysis. The following tables (and the Excel workbook) have discount calculations, however, in the event that future rules require that a certain discount factor be used.

[86] http://www.fao.org/Wairdocs/ILRI/x5436E/x5436e0a.htm
[87] http://www.fao.org/Wairdocs/ILRI/x5436E/x5436e0a.htm
[88] http://www.fao.org/Wairdocs/ILRI/x5436E/x5436e0a.htm
[89] http://www.fao.org/Wairdocs/ILRI/x5436E/x5436e0a.htm
[90] http://www.powerhomebiz.com/Glossary/glossary-A.htm

STEP 3: Accounting for inflation

The objective of a benefit-cost analysis is to assess the profitability or economic feasibility of an investment from today's point of view and consequently all future prices must be converted to current year (or some base year) prices. This exercise might turn out to be complicated unless professional help is used and thus it is recommended that landowners simply use present-day price levels.

STEP 4: Layout of a Cost Benefit Analysis[91]

The easiest way to organize an economic analysis is to construct a set of tables where the cost and benefit estimates can be entered by category on an annual basis. This can either be done on a per unit (i.e. per acre) basis or on a project basis. Whichever is chosen, all costs and benefits must be entered on the same basis so that the outcome is accurate. The following tables indicate some suggestions that might be used, but it will probably be more practical to download and use the NCOC Excel planning tool that incorporates all of the elements and calculations. The Excel workbook can be altered by the user if a project situation arises that is not covered, or the user can present the problem to NCOC and request that the new information be incorporated. The following tables are illustrative of those that could be used:

a) Undiscounted Benefits with Sequestration Project

Year	Agricultural / forest production	CSU's	Water Conservation	Tax credit	Cost Share	Avoided cost of soil erosion	Reduced fossil fuel use	Reduced Fertilizer/ pesticide use	Income from Bioenergy	Sum of Benefits
1										
2										
3										
n										

b) Undiscounted Costs with Sequestration Project

Year	Opportunity cost	Management cost	Establish ment cost	Transaction Costs	Machinery Investment	Sum of Costs
1						
2						
3						
n						

[91] NCOC has an Excel spreadsheet available for download (www.ncoc.us) that incorporates all of the following information and formulas.

c) Undiscounted Benefits without Sequestration Project

Year	Ag/ forest production	Tax credit	Cost Share	Sum of Benefits
1				
2				
3				
N				

d) Undiscounted Costs without Sequestration Project

Year	Opportunity cost	Management cost	Establishment cost	Sum of Costs
1				
2				
3				
N				

e) Discounted Costs and Benefits

Year	PVBp = Bp_t / $(1+t)^t$	PVCp = Cp_t / $(1+t)^t$	PVB = B_t / $(1+t)^t$	PVC = B_t / $(1+t)^t$	Incremental Benefit = (PVBp – PVCp) – (PVB – PVC)
1					
2					
3					
Total	$\sum_{t=1}^{t=n} \frac{Bp_t}{(1+i)^t}$	$\sum_{t=1}^{t=n} \frac{Cp_t}{(1+i)^t}$	$\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}$	$\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}$	$\sum_{t=1}^{t=n} \frac{(Bp_t - Cp_t) - (B_t - C_t)}{(1+i)^t}$

STEP 5: Evaluating Decision Criteria[92]

1. After the discounting has been completed, present value of project benefits (PVBp) is compared with present value of project costs (PVCp) and present value of benefits without project (PVB) is compared with present value of costs without project (PVC). For a landowner to switch to sequestration activities at a chosen interest rate, not only do we need that PVBp > PVCp, i.e. the net present value (NPVp) with project is positive, but also that (PVBp – PVCp) > (PVB – PVC), i.e. the NPV with the project is greater than the NPV without, so that the overall incremental net benefits of adopting the sequestration project are positive.
2. Another way is look at the benefit cost ratio with and without the project activities, which is obtained by dividing present value of benefits by the present value of costs:

$$Bp/Cp = \frac{\sum_{t=1}^{t=n} \frac{Bp_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{Cp_t}{(1+i)^t}}$$

$$B/C = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

For a carbon sequestration project to be acceptable, the benefit-cost ratio (Bp/Cp) should be greater than 1 and it should also be greater than the benefit cost ratio without sequestration practices, i.e., $Bp/Cp > B/C$. The benefit-cost ratio is a very useful criterion for ranking projects of different sizes, and it is relatively easy to calculate[93].

3. Internal rate of return[94] (IRR) is one more way to compare various projects. IRR is the discount rate 'i' for which PVBp = PVCp, or mathematically:

$$\sum_{t=1}^{t=n} \frac{(Bp_t - Cp_t)}{(1+i)^t} = 0$$

[92] (NCOC has an Excel spreadsheet available for download (www.ncoc.us) that incorporates all of the following information and formulas.
[93] http://www.fao.org/Wairdocs/ILRI/x5436E/x5436e0a.htm
[94] An IRR can only be calculated for those cases where costs exceed benefits in the first years of the project. These cases are by far the most common. An internal rate of return cannot be calculated if the annual incremental benefit, B_t - C_t, is always >= 0 for every year (http://www.fao.org/Wairdocs/ILRI/x5436E/x5436e0a.htm)

Also consider IRR for land use without sequestration practices, such that PVB = PVC:

$$\sum_{t=1}^{t=n} \frac{(B_t - C_t)}{(1+i)^t} = 0$$

For a carbon sequestration project to be acceptable the IRR should exceed the minimum acceptable rate or the opportunity cost of money or the rate of return on alternatives investments, 'r' but it should also be greater than the IRR for a land use without sequestration projects or practices.

STEP 6: Sensitivity Analysis

This is usually done to take into account the impact of uncertain parameters on costs and benefits. The question posed is what would happen to the project's viability if some or all of the key parameter values happen to be different from the original values[95]. The analysis uses different values for the relevant item in the calculations to illustrate how sensitive the results are to the assumptions made about the value of a particular parameter[96]. Parameters that are usually subjected to sensitivity analysis are:

- the discount rate
- length of the project planning horizon
- different timing of the project's operation
- estimate of costs
- estimate of benefits
- changes in the capital outlays
- changes in the price of market goods, and
- changes in social and environmental benefits and costs

Thus a simple sensitive analysis could look at the impact of 10% overrun in costs or a 20% shortfall in expected benefits. A sensitivity analysis helps to identify the range of parameter values within which a project can remain economically viable.

[95] http://www.unescap.org/drpad/vc/orientation/M5_lnk_7.htm#6
[96] http://www.fao.org/Wairdocs/ILRI/x5436E/x5436e0a.htm

Part 8 – Appendices

A. Rule of Thumb Estimates

In working with a landowner on an Initial Proposal for NCOC, it is often useful and necessary to make some quick estimates about carbon in soil and forest systems, and the potential for changing carbon stocks through management. It is important to be cautious in using these, so that the landowner does not get carried away with unwarranted expectations. Used properly, however, they can help with the initial estimates that will sometimes help decide if a proposed project is worth pursuing or not.

Soil Carbon

Most of the available soils data will list soil carbon in terms of percent organic matter. Since this is an estimate based on a proportion of a sample, rather than an area-weight estimate, one needs some way to quickly convert it. ***A good rule-of-thumb is that, for each 1 percent of organic matter content, there are 10 tons of carbon per acre in the top 12" (~30 cm) of soil.***[97]

If you estimate, therefore, that a change in cultural practices (such as planting trees or grass, or converting to conservation tillage) will result in a 3% increase in soil organic matter, that would lead to an estimate of a 30-ton per acre change. Keep in mind, however, that this increase won't come easily, and it won't come uniformly in the top 12". The uppermost layers will react the most rapidly, and it may take many years for the full 12" layer to increase by a significant amount.

Where you can, consult a soil scientist about the native organic matter levels for the major soils in question, and how that compares with the current situation. A conservative estimate would suggest that trees or grass may restore from one-half to two-thirds of the lost organic matter over a period of 20-50 years. If you are able to find better or more local research that provides a different estimate, use it.

More accurate estimates can be obtained if you know the bulk density of the soil in question. See Figure 8.1.

Rates of Soil Carbon Increase

These are difficult to estimate, since there are so many variables in terms of beginning soil condition, rate of plant growth (root growth and turnover, litter and debris production, etc.), temperature, moisture, and soil aeration.

Some general estimates include:

Rates of soil organic carbon increase under grass or tree cover on carbon-depleted cropland soils range from 0.2 – 0.5 tons of carbon per acre per year, with an average somewhere around 1/3 of a ton of carbon per acre per year. Those rates of increase

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97 *To arrive at the 10 tons per acre, we used a bulk density estimate of 1.3. Therefore:*
An acre-foot of soil would weigh 1 (foot deep) x 43560 (square feet per acre) x 62.4 (lbs. per cubic foot of water) x 1.3 (bulk density) = 3.5 million pounds or around 1,767 tons. Thus, each 1 % of OM content would equal about 18 tons of organic matter, which is 58% carbon, so 18 x 0.58 =~ 10 tons.

should occur over a 20-30 year period, or until the soil carbon level begins to approach native levels.

Rates of soil organic carbon increase under conservation tillage range from 0.1 to 0.25 tons of carbon per acre per year, with an average of around 0.2. These rates should continue for 10 years, or until the soil reaches a new equilibrium. It should be noted, however, that the rate of loss of this soil carbon can be quite rapid if conventional tillage is again carried out.

These estimates should be used with caution, particularly until the current condition of the soil relative to its native state can be determined. The potential for increasing soil carbon lies mainly in the restoration and maintenance of near-native levels of organic matter in projects involving conversion to grass or trees, so while the annual rate of carbon sequestration may be about the same regardless of the soil condition, the degree of depletion in the current condition controls the total amount likely to be restored under the new land use.

Tree Carbon

Most of the estimates one encounters for the amount of wood in a tree, or an acre of forest, will be given as volume estimates. Most of the carbon conversion tables in the U.S. will use cubic feet as the standard volume estimate. So, if possible, estimate the average annual forest growth in terms of cubic feet of merchantable wood per acre per year. (See the conversion tables (8.1 and 8.2) for ways to convert many common volume estimates such as board-feet to cubic feet.)

A reasonable rule-of-thumb is that, ***for every cubic foot of merchantable wood grown in a forest, the forest will contain about 30 pounds of carbon***. Thus, a forest that is growing at the estimated rate of 70 cubic feet of merchantable wood per acre per year is increasing its woody carbon stock by around 2100 pounds, or about1 ton of C per acre per year.

This estimate is obtained as follows:

Different species of wood will vary in their weight per cubic foot (See table 8.2). If we assume a dry weight bulk density of 0.50, each cubic foot of wood would have a dry weight of 31.2 pounds. (Weight of a cubic foot of water times 0.5). Since the merchantable wood is usually only about ½ of the total tree wood (including branches, stump, large roots, etc.), each cubic foot of merchantable wood represents around 62 pounds of total tree weight. Since wood is about ½ carbon by weight, there are around 31 pounds of carbon per cubic foot of merchantable wood.

This estimate can be improved by using species-specific factors from the conversion tables, but for a fast "back of the envelope" estimate derived from an average annual wood production figure, 30 pounds per cubic foot of merchantable wood per acre is reasonable.

A more accurate estimate may be derived if you know the tree species involved in the project. See Figure 8.2 and Table 8.2.

Conversion Graphs

The following graphs provide one additional means of making rapid estimates of soil and forest carbon contents. To use Figure 8.1, find the soil's bulk density on the X axis, then go to the graph line and find the associated amount of carbon on the Y axis. The amount of carbon is the tons of carbon per acre-inch for each 1 percent of organic matter contained in the soil. So, for example, if the soil laboratory returns a bulk density of 1.35 and an OM of 4% for the surface soil horizon, which is 2” thick, the chart would indicate that the horizon contains about 0.89 tons of organic carbon for each percentage point and each inch of thickness. The 2” thick horizon with 4% OM would contain about 7.1 tons of organic carbon per acre. Increasing the organic matter in this horizon to 7% as a result of a project would result in a total of around 12.46 tons of carbon per acre, representing the sequestration of about 5.3 tons of soil carbon per acre. Use this graph for each separate soil horizon to get an estimate for the total soil carbon sequestration likely to result from the project. (Keep in mind that the deeper the soil horizon, the less rapidly it is likely to respond to changes in soil or crop management.)

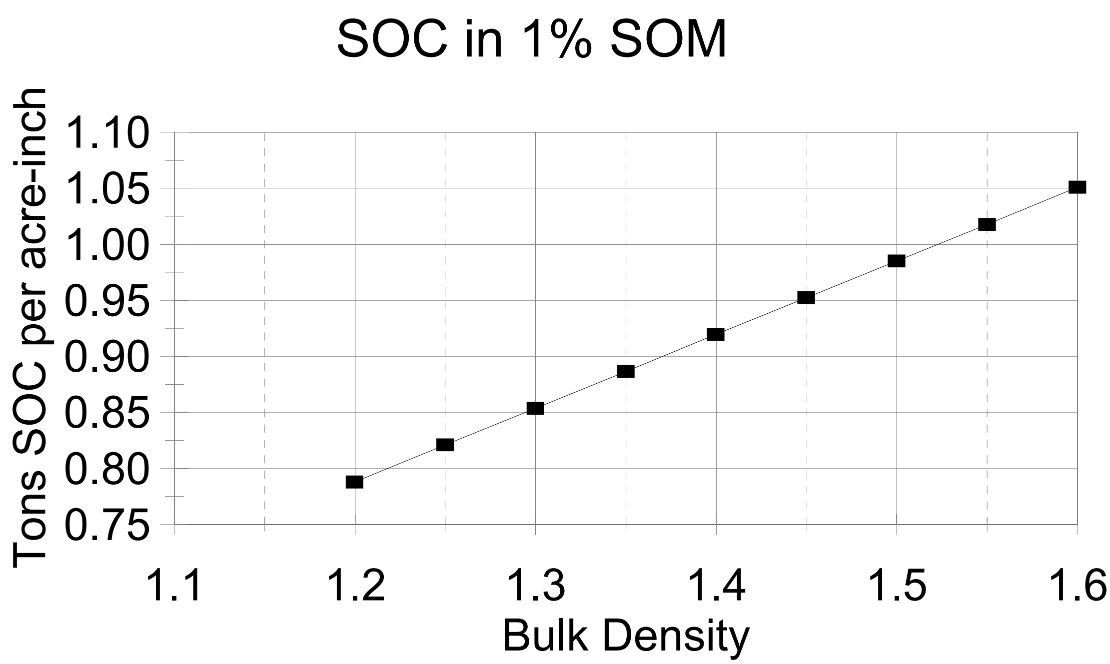

Figure 8.1. Soil organic carbon (SOC) per acre-inch of soil for a range of bulk densities.

Figure 8.2 allows an estimate of total tree (above and below-ground) carbon in a forest on the basis of the primary species involved and the estimated mean annual increment (MAI) of merchantable timber (a common means of expressing forest growth potential). If the MAI is not provided, get an estimate of the total merchantable wood predicted for the end of the project period, and divide by the length of the project in years. This gives the average annual growth of the forest through the project period. If the MAI estimate is in some unit other than cubic feet, see Table 8.1 (below) for factors that can be used to convert to cubic feet. (Note that Table 8.1 converts to *thousand cubic feet*, so be careful to use matching units such as thousand board feet (MBF).)

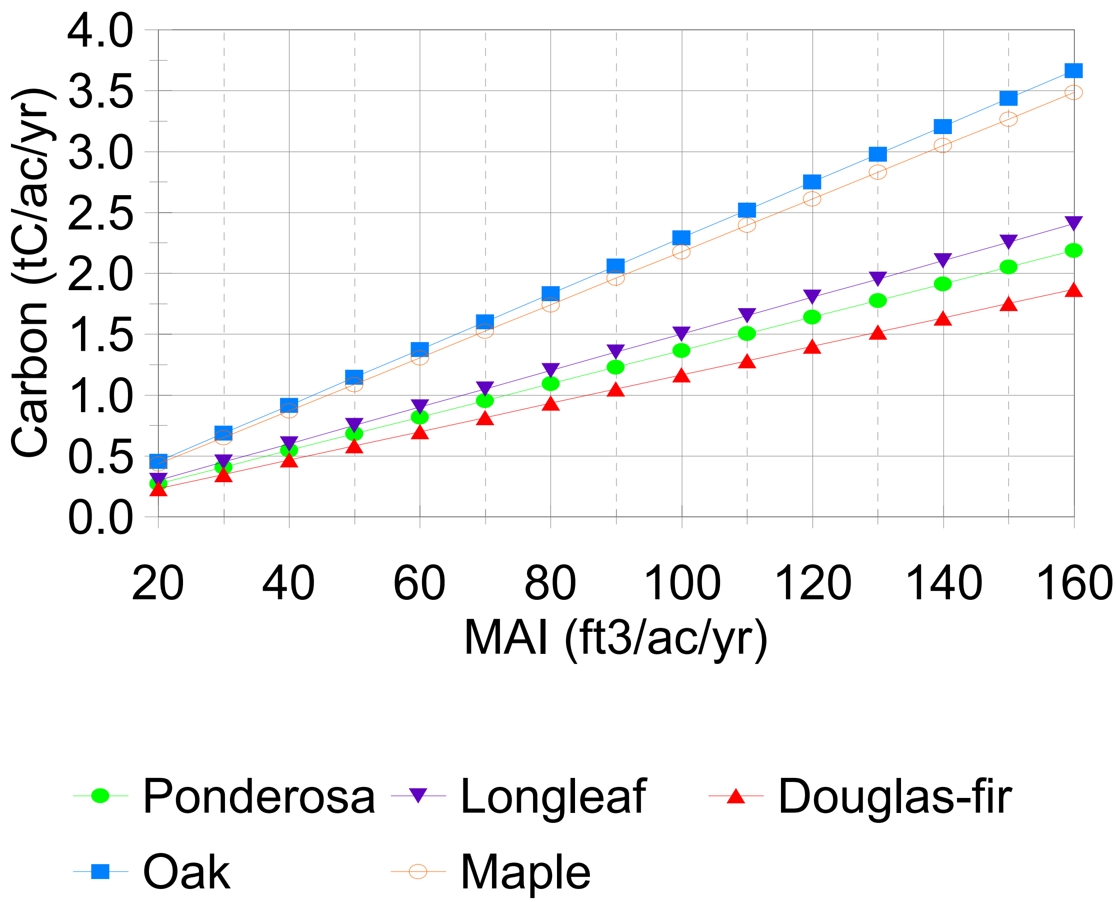

Figure 8.2. Conversion chart for estimating the amount of carbon (in tons per acre per year) created by different annual growth rates (MAI) in common U.S. species.

Once the MAI has been expressed in cubic feet per acre per year, Figure 8.2 can be used to convert to the average annual increase in carbon per acre, according to the species involved. If the species involved in the project is not listed, it may be acceptable to use the nearest species (softwood or hardwood), but the uncertainty around the estimate will increase, and should be explained.

For example, a ponderosa pine plantation that is calculated to produce a merchantable MAI of 70 cubic feet per acre per year over the life of the project will sequester about 1 ton of carbon per acre per year as a result. This would be about the same as an oak plantation producing about 40 cubic feet of merchantable wood per acre per year.

B. Look-up Tables and Modeling Methods

USDA has developed a computer-based tool that enables project planners to interface with the Century soil carbon model.[98] The tool, CarbOn Management Evaluation Tool (COMET), estimates annual rates of soil carbon fluxes based on simple inputs that characterize the project area and agricultural practices that are applied. COMET is available on the USDA website at (to be determined).

Underlying COMET are multiple runs of the Century model based on user inputs and a background survey conducted by USDA to assess regional patterns in agricultural land use. Soil carbon rates of change are estimated for each of 20 Land Resource Regions (LRR) in the conterminous United States and are based on data for climate, soils, and past and current land management practices for each specific region.

COMET also produces an uncertainty analysis (based on advanced statistical methods) of the soil carbon sequestration rates, reflecting the precision of the values. Results from more than 50 long-term agricultural experiments were used for the comparison between modeled estimates and field data, with differences statistically analyzed using linear-mixed effect models. Uncertainty was applied to the model output based on predictions from the statistical models and the estimates varied by management system and LRR. This application accounted for both bias and random error.

Detailed guidance on using COMET will be available on-line, which also provides supplemental documentation of COMET's development. This methodology uses some site-specific inputs, but is still based on regional level factors. In some situations, site-specific factors may be similar to research locations where model inputs were derived. In those cases, estimates may have a low level of uncertainty. In other instances, soil, tillage practices and crop rotations may differ drastically from experimental locations and the uncertainty is high. The model output includes both an estimate for average amount of change in soil carbon stocks and estimates of uncertainty associated with those estimates.

The simplest approach to estimating carbon stock inventories in forest biomass is to use look-up tables that represent average forest conditions for a region, ownership class, forest type, and productivity class. Before using the look-up tables, it is necessary to determine the area of land to be included in the estimate, and characterize that area (i.e., stratify the land area) in a way that is compatible with the estimates in the look-up tables. The average values presented in the look-up tables can then be multiplied by the area estimate to obtain the carbon stock estimate. Although this approach is simple and inexpensive to use, the uncertainty for individual activities or projects may be high relative to other approaches that may be more applicable to the specific circumstances of the activity or project.

A variety of look-up tables, based on inventories conducted across all U.S. forestlands, are provided below, and more tables are available at www.fs.us. GET EXACT WEB SITE WHEN IT IS AVAILABLE. Because these tables represent average conditions over large areas, the actual carbon flows for a specific activity or project may be different than the estimate developed by using the default carbon factors in the look-up tables. If it is determined that the conditions for an activity or project are not represented

[98] This portion is excerpted from Parts H and I, 1605(b) Guidelines. See those guidelines for more detail.

by any of the pre-compiled look-up tables, project planners may choose to generate custom look-up tables or use a different estimation method (models or measurement).

A web-based tool is also available for interfacing with forest inventory data to provide customized estimates of forest carbon for user-selected areas of the conterminous United States. The user interface is known as Carbon Online Estimation (COLE) and can be accessed at web site http://ncasi.eml.edu/COLE/. The program allows the user to designate an area of interest, and currently provides area, growing-stock volume, and carbon pool estimates for States east of the Great Plains. By designating areas that are similar to the area in the project, the carbon pool estimates will match the specific conditions of the project lands better than using the pre-compiled look-up tables.

Growth and yield models are available for many different forest conditions and activities. In some cases models may be more accurate than look-up tables for specific activities, but may require more effort and possibly a higher cost to apply. Models useful for estimating quantities of forest carbon may be based on traditional empirical forestry models developed to predict timber production, which can be modified to predict carbon stocks or flows. More recently, models that include representation of key ecosystem processes such as photosynthesis and respiration are becoming available. Such models may be applied to conditions and treatments beyond those represented in the data used to develop the models, although this should be done cautiously with appropriate verification to ensure the accuracy of estimates.

Before using a model it is necessary to determine the area of land to be included in the estimate, and characterize that area in a way that is compatible with estimates from the model. To achieve the best results, the selected model should be parameterized for the specific conditions of the land area to which the model is applied. Partitioning of the land area into relatively uniform strata may help in matching and parameterizing a model for a specific application.

If a modeling approach is used to estimate carbon stocks, periodic validation of model estimates with field data is strongly recommended. Models may also be used to update inventories of carbon stocks for annual reporting in the years between measurements if the primary approach to estimation is a measurement system (discussed in the next section).

Models should be evaluated (validated) to be sure they are appropriate for each application. The basic elements of model evaluation are: (1) scientific peer review, (2) quantitative comparison of model results to field observations, and (3) sensitivity analyses.

C. Measuring and Monitoring Methods

While rule-of-thumb methods and models are appropriate in the early planning stages, when landowners need a general idea of the potential carbon sequestration in a contemplated project, such methods are generally agreed to be inadequate when it is necessary to provide actual documentation of carbon stock changes to a potential buyer on a trading market. At that point, the changes in carbon will need to be measured by a credible scientific method that can be reviewed and, if audited, replicated in the field. Acceptable methods have been described by USDA scientists as part of the revised guidelines for the 1605(b) federal registry. The following material is consistent with those guidelines, as most of it has been extracted from draft materials. When the final materials are published, we may need to update, or expand these sections. In many situations, reporters may wish to consult a specialist in forest inventory and monitoring to assist in applying the direct measurement approach.

The use of permanent sample plots is generally regarded as a statistically superior means of evaluating changes in forest and soil conditions. The plots are usually located through a stratified random sampling design. Stratified design means dividing the project area up into non-overlapping subdivisions representing similar soil, site, species, and growth conditions. This can be done with soils maps, aerial photos, topographic maps, etc.

The number of sample plots and their allocation between the different sub-units or strata can be determined for a desired level of precision through standard statistical methods. As a general rule, somewhere between 20 and 30 plots per strata should be established and measured to test for statistical results. Unless other rules or requirements are imposed, the standard NCOC target for precision will be 90%. It is prudent to install a few extra plots initially, in case some get lost or damaged later. The National Institute of Standard's website contains a calculator for estimating sample size, located at www.itl.nist.gov/div898/handbook/prc/section2/prc243.htm.

The procedure for plot establishment within each strata can either be random or on a systematic grid. Once plots are located, they should be marked on a well-annotated map or aerial photo. This can be easily done on a GIS system or, if that is not available, on an aerial photo. Permanent markers should be used to establish plot center points in the field, unless they would interfere with cultivation or other field operations. GPS coordinates for each plot center should be recorded.

Once the plots are located in the field, and the GPS coordinates established, the baseline samples need to be taken. For an afforestation or reforestation project, the land will normally be bare, so soil samples will be all that are needed. It is usually desirable to take a number of soil samples (4-6) per fixed plot. Samples should be taken with soil corers or from hand-dug pits to depths of 30 cm (12"). Take a core or a slice from the side of each pit and place it on a plastic tarp. Remove any coarse fragments using a screen. Mix the samples from the plot thoroughly to a uniform color and consistency, then extract a sample of appropriate size and place it in a clearly labeled sample bag for transport to the laboratory. The size, preparation, and shipment of the sample should be discussed with the laboratory before sampling to assure that their needs are met, and these methods should be documented to assure consistent treatment in follow-up measurements.

To convert organic matter concentrations into total quantities, the bulk density of the soil should be determined. Bulk density is considered to have relatively low spatial variability, so four samples should be adequate for each strata or soil group. Use a standard sampling procedure as outlined in NRCS guidelines and instructions from the laboratory (Information on approved soil laboratories is available from the Land Grant University).

When the laboratory results are available, convert organic matter concentrations into tons per acre total C, which will represent the baseline datum for each of the project's strata. Unless more specific information is available, soil organic carbon can be estimated as 58% of soil organic matter content. An Excel workbook is available from NCOC to assist in this calculation at www.ncoc.us.

Soil carbon pools are normally separated into soil organic carbon, soil inorganic carbon, and inert carbon compounds such as charcoal. Where a project is designed to effect changes in soil carbon pools, it is common to limit the calculation of those changes to the soil organic carbon pool. Little is known about the dynamics of change in soil inorganic carbon, but it is generally considered to change too slowly to be measured in the short time frames of carbon sequestration projects. The formation of charcoal is largely related to the frequency, intensity, and severity of wildland fires, so is seldom a factor in agricultural or managed forest projects.

Above-ground biomass is measured by standard forestry mensuration techniques that consist of establishing fixed sample plots within a forested area (see above), measuring the diameter at breast height (dbh) and total height of all trees in the plot area, and utilizing standard forestry charts to convert those measurements into an estimate of either merchantable timber or total tree biomass on the plot. Plot data are then expanded to estimate the total volume on the sampled area. It should be acceptable to use the same fixed plots for the forest measurements as were established for the soil sampling.

Measured amounts of merchantable timber can be converted to total biomass through the use of tables that have been developed for each species. Normally, these tables will contain expansion factors that include not only the non-merchantable aboveground biomass, but also the large roots below ground. In that case, the above- and below-ground biomass carbon pools are reported as one pool. This does not, of course, include soil carbon.

Carbon content varies slightly between tree species, and the appropriate factor must be taken from the table to convert the estimate of total biomass into its carbon component. If the species involved are not listed in available tables, use a factor of 0.50 to convert total biomass to estimated carbon content. Belowground biomass refers to large live and dead roots that are not included in soil organic matter. Normally, this will be estimated as a function of the live aboveground biomass (see above).

Litter and woody debris is measured by sampling the volume and dry weight of all snags, down woody debris, and forest litter included in the sample plots established within the area to be sampled. For an afforestation or reforestation project on bare land, these baselines will be zero and should be noted as such in the initial baseline document. Site photographs strengthen this documentation.

Wood Products represent another long-term storage of forest-derived carbon, and the general decomposition rates of different wood products (paper, structural wood, manufactured wood products, furniture, etc.) are available. It is not yet clear, however, how or if wood products will be accounted under future state or national guidelines. Until those decisions are made, wood products will be left out of NCOC project calculations.

For most projects, follow-up measures should be scheduled at 10 years, at which time the trees will be large enough for measurement with standard forestry methods (see above), and soil changes may have begun to be measurable. Periodic measurements of biomass should follow on a 5-year interval, with follow-up measures of soil carbon every 10 years. All records of measurements, including plot data, photographs, and other backup material, will be filed in the project files maintained by the NCOC-approved monitoring organization and with NCOC. These files are critical in providing the basis for future verification.

Above-ground biomass measurement in windbreaks, shelterbelts, or conservation buffers can be done by measuring samples of each species (diameter and height), counting the number (or estimating the area) occupied by each species, and expanding the sample values to represent the full number of plants (or area). Since line-grown trees generally exhibit different growth forms than those of the same species grown in closed stands, the use of agroforestry tables is recommended unless well-documented local growth tables are available.

All soil and biomass carbon sequestration should be reported as Carbon Sequestration Units (CSU's) in tonnes of carbon dioxide equivalent (tCO_2e). The basic conversion formula is:

$tCO_2e = tC * 3.67$ (where tC is metric tonnes or 2204 lbs C).

The direct measurement approaches described above allow project planners and monitors to develop an estimate of carbon stocks and flows with known, quantified accuracy, assuming that the guidance in the 1605(b) guidelines is followed. A suggested target for an inventory of soil or tree carbon stocks is to obtain an estimate that is within 10 percent of the true value, with 95 percent confidence that the estimate lies within those bounds. Such an estimate would receive a rating of "A" in the federal 1605(b) guidelines, and should provide adequate precision for most market-based transactions.

D. Charts and Tables

Table 8.1. Volume multipliers for converting timber and chip units to Thousand Cubic Feet (MCF)

Unit	Factor
Bone Dry Tons	0.0713
Bone Dry Units	0.0825
Cords	0.0750
Cubic Meters	0.0353
Cunits-Chips (CCF)	0.1000
Cunits-Roundwood	0.1000
Cunits-Whole tree chip	0.1260
Green Tons	0.0315
MBF-Doyle	0.2220
MBF-International 1/4"	0.1460
MBF-Scribner ("C" or "Small")	0.1650
MBF-Scribner ("Large" or "Long")	0.1450
MCF-Thousand Cubic Feet	1.0000
Oven Dried Tonnes	0.0758

Source: American Forest & Paper Association, Sustainable Forestry Initiative Program Annual Progress Reporting Form

Table 8.2. Basic Factors (to be used unless better local research-based figures are available) for converting merchantable wood yield to carbon yield, by species. The basic formula is (merchantable timber volume (ft^3)) * (Multiplier) = (Total wood volume above and below ground). (Total wood volume) * (lbs. C per cubic foot of wood) = (lbs C in total wood volume).

Region	Forest Type	a. Specific Gravity	b. Lbs. per cu. foot (a*62.4)	c. Multiply from timber to Total biomass	d. Percent Carbon	e. Lbs C per cubic foot (b * d)
SE	Loblolly Pine	0.47	29.33	1.682	0.531	15.57
	Longleaf Pine	0.54	33.70	1.682	0.531	17.89
	Oak-Hickory (SI = 79)	0.61	38.06	2.233	0.479	18.23
NE &	Pines	0.41	25.58	2.193	0.521	13.33
MA	Spruce-fir	0.37	23.09	2.193	0.521	12.03
	Oak-hickory (all)	0.61	38.06	2.140	0.498	18.96
	Maple-beech-birch	0.61	38.06	2.140	0.498	18.96
NC	Pines	0.41	25.58	2.514	0.521	13.33
	Spruce-fir	0.37	23.09	2.514	0.521	12.03
	Oak-hickory	0.61	38.06	2.418	0.498	18.96
	Maple-beech	0.58	36.19	2.418	0.498	18.02
	Aspen-birch	0.46	28.70	2.418	0.498	14.29
West	Douglas-fir	0.45	28.08	1.675	0.512	14.38
	Ponderosa pine	0.38	23.71	2.254	0.512	12.14
	Fir-spruce	0.35	21.84	2.254	0.512	11.18
	Hemlock-Sitka sp.	0.43	26.83	1.675	0.512	13.74
	Lodgepole pine	0.42	26.21	2.254	0.512	13.42
	Redwoods	0.42	26.21	1.675	0.512	13.42
	Hardwoods	0.38	23.71	2.214	0.496	11.76

Source: Birdsey 1996 (See also Appendices 2 & 3, Sampson and Hair 1996)

E. Conversion Units

In working with carbon sequestration projects, it is common to encounter a variety of metric units of measure. These often will need to be converted to English units when working with U.S. land managers, and the reverse is true, as well. U.S. units will need to be converted to metric units when working with international situations. The following conversion units can be found in any good scientific reference source, but they are reproduced here for convenience in using the handbook.

1 acre (ac) = 0.4047 hectare (ha)
1 hectare (ha) = 2.471 acres (ac)

1 inch (in) = 2.54 centimeters (cm)
1 centimeter (cm) = 0.394 inch (in)
1 foot (ft) = 30.5 centimeters (cm)
1 cubic foot (ft^3) = 0.02832 cubic meters (m^3)
1 meter (m) = 1.094 yards (yd)

1 pound (lb) = 454 grams (g)
1 kilogram (kg) = 2.205 pounds (lb)
1 ton (t) = 0.907 tonne (t)
1 tonne (t) = 2204 pounds (lb)

1 ton per acre (t/ac) = 2.242 tonnes per hectare (t/ha)
14.3 cubic feet per acre (ft^3/ac) = 1 cubic meter per hectare (m^3/ha)

1 unit (lb, t, etc) of carbon (C) = 3.67 units (lb, t, etc) of carbon dioxide (CO_2)

NOTE: The unit "t" is commonly used in both English and metric situations to indicate ton or tonne, and unless otherwise specified, it is necessary to judge which it represents by the context in which it appears.

Large metric units are also encountered, particularly in the presentation of data concerning large-area carbon or carbon dioxide quantities. The metric units commonly encountered include:
1 kilogram (kg) = 1,000 grams (g)
1 tonne = 1,000 kilograms (kg)
1 gigagram (Gg) = 1,000 tonnes = 1 kilotonne (Kt)
1 teragram (Tg) = 1,000,000 tonnes = 1 megatonne (Mt)
1 petagram (Pg) = 1,000,000,000 tonnes = 1 gigatonne (Gt)

F. Samples of Initial Proposals

The following samples may be amended to meet the needs of different buyers or market exchanges. For example, the first sample relates to the Chicago Climate Exchange and its current requirements. Other markets (or changes in CCX rules) will necessitate appropriate changes. Be aware of all relevant requirements before using these samples as guides. NCOC will maintain an array of sample IP's in Word files that can be downloaded from www.ncoc.us.

INITIAL PROPOSAL
NATIONAL CARBON OFFSET COALITION

SMALL FOREST PROJECT – CHICAGO CLIMATE EXCHANGE

Project Name: ________________________ Date of Proposal: _____________

Background and Purpose: *This form is a guide to an initial proposal for a carbon sequestration project designed to qualify for consideration by the Chicago Climate Exchange (CCX). The data and attestation requirements are those set by the CCX in 2003 for small forestry projects, and could be changed by CCX in the future. The National Carbon Offset Coalition (NCOC) offers no assurance that this project will be accepted by CCX or that further information and/or CCX qualifications may not be required in the future. Neither NCOC nor CCX makes any warranty as to the marketability or market value of the carbon offsets represented in this Initial Proposal.*

At the current time, the CCX uses two methods to calculate additionality. The first method, required of large projects that produce over 12,000 tonnes of carbon dioxide equivalent (tCO_2e) per year, is a base year calculation. In this calculation, field sampling methods establish the carbon content of the forest in the base year, then subsequent sampling establishes the amount of change. Small projects (less than 12,000 tCO_2e/yr) can use either the base year method or a default table that CCX has published. This Initial Proposal has tables for either method, and project developers for small projects can choose the most acceptable.

If more space is needed in any item in the following form, please attach a separate sheet numbered to correspond with the form. The form is also available as a Word document that can be downloaded from the NCOC web site at www.ncoc.us.

1. Project Owner:

2. Brief description of the project:

3. Project Location: *(Please attach a site map with GPS points indicated if possible)*

4. Project size (acres):

5. Date(s) of Planned Project Initiation:

6. Planned Project duration (years):

7. What are the primary purposes of the project: (Check all that apply)
Carbon Sequestration ___ Soil and Water Protection ___ Wildlife Habitat ___
Timber Production ___ Other (list)__________________________

9. General technical description of the site (climate, soils, aspect, current vegetation, current and previous land use, etc.): *(Note: for CCX forestation projects, indicate the land cover or land use as of December 31, 1989.)*

10. What forest management practices, if any, are planned during the duration of this project? *(Thinning, fertilization, pruning, selective harvest, etc.)*

11. What legal protections exist to assure that the forest parcels included in this project will remain in forest cover?

12. What evidence exists to assure that the forests owned by this landowner outside the project area are, and will remain, in sustainable forest management?

13. Carbon Sequestration Calculations. *Please indicate what method will be used to claim carbon stock increases for the duration of this project. If only the CCX Default Tables are used (Table 13C, below), note reasons for departure, if any, from table values. If direct measurement methods are used, note models and methods used, and be prepared to provided documentation for review. See CCX rules for guidance.*

Table 13A. Forest Characteristics (Direct Measurement Method)

				Inventory as of ____________(date)			
Parcel/Stand	Acres	Year Est.	Major Species	Stocking (trees/ac)	Basal Area	Site Index (Age 50)	Carbon (tonnes/ac)
TOTAL							

Table 13B. Forest Growth Projections (From Inventory Above)

			Annual Accumulation of Carbon Stocks (in tonnes CO^2 equivalent)				
Parcel/Stand	Acres	Year Est.	Major Species	2003	2004	2005	2006
TOTAL							

Table 13C. Forest Growth Projections (From CCX Carbon Accumulation Table)

			Annual Accumulation of Carbon Stocks (in tonnes CO^2 equivalent)*				
Parcel/Stand	Acres	Year Est.	Major Species	2003	2004	2005	2006
TOTAL							

* See CCX default values below

14. Description of other (non-carbon) impacts of the project *(NRCS-CPA-52 can be helpful in identifying issues, which can be described briefly below.)*

14a. Environmental Impacts

14b. Social and cultural impacts

14c. Economic impacts

15. How does the project support other local, state, tribal, or federal programs, policies, or priorities?

16. Other information

17. Contact Person: (Name, address, phone, fax, email):

CCX Default Table.

The current CCX default table only lists ponderosa pine for the Rocky Mountains. In developing the Initial Proposal for this first round, use the following figures as the default yield values. Later, we may get more focused information. For other species, or other regions, consult the CCX Handbook or inquire with Neil Sampson at rneilsampson@cs.com.

Years since Establishment	Tons CO_2e per acre per year
0 to 5	1.40
6 to 10	1.40
11 to 15	1.51
16 to 20	2.33

INITIAL PROPOSAL
NATIONAL CARBON OFFSET COALITION

CONSERVATION TILLAGE PROJECT

Project Name:___________________________ Date of Proposal:___________________

Background and Purpose: *This form is a guide to an initial proposal for a conservation tillage project on agricultural soils designed for consideration as a carbon sequestration project by the National Carbon Offset Coalition (NCOC). The data and attestation requirements on this form are those required at this time, and could be changed in the future. The National Carbon Offset Coalition (NCOC) offers no assurance that this project will be accepted for registration or purchase by any segment of the regulatory framework or market at this time, or that further information and/or qualifications may not be required in the future. Neither NCOC nor any other organization makes any warranty as to the marketability or market value of the carbon offsets represented in this Initial Proposal.*

Two methods of determining additionality are provided on this form. Direct measurement of base year soil carbon, achieved through a well-designed and properly conducted soil sampling and laboratory analysis, is the most accurate, and is acceptable at this time in most registries. The use of regional default tables is far less accurate, but is a quick and easy way to estimate soil carbon changes if allowed.

If more space is needed in any item in the following form, please attach a separate sheet numbered to correspond with the form. The form is also available as a Word document that can be downloaded from www.ncoc.us.

1. Project Owner:

2. Brief description of the project:

3. Project Location: *(Please attach a site map with GPS points indicated if possible. If the project will be carried out on several fields that are not physically adjacent, a site map showing the outer boundary of all the involved lands is appropriate.)*

4. Project size (acres):

5. Date(s) of Planned Project Initiation:

6. Planned Project duration (years):

7. What are the primary purposes of the project: (Check all that apply)
Carbon Sequestration ___ Soil and Water Protection ___ Wildlife Habitat ___
Crop Production ___ Other(list)___________________________

8. General technical description of the site (climate, soils, aspect, current and previous land use, etc.

9. Cropping and Tillage History. For each field involved, list the crop on the land during the current and 4 prior growing seasons, and the tillage method used. If abbreviations are used, explain them. (e.g. WW/Conv to indicate winter wheat with conventional tillage.)

Field	Acres	Current Year	Year ______	Year ______	Year _____	Year ____

10. What cultivation practices are planned during the duration of this project?

11. Are all the farm's fields involved in this project? Yes ___ No ____. If no, what protections exist to assure that the remainder of the cropland included in this ownership will be managed in accordance with an appropriate conservation plan?

12. Carbon Sequestration Calculations. *Please indicate what method (e.g. direct measurements, default tables) will be used to claim soil carbon increases for this project. For this Initial Proposal, it is sufficient to estimate acres, organic matter percentages, and carbon amounts for both base year and future years. If the project is approved, field sampling and laboratory results will be used to arrive at actual base year and future carbon stocks.*

Table 12A. Current (Base Year) Soil Carbon (Direct Measurement Method)

Sampling Strata (Soil Type)*	Acres	Organic Matter Percentage	Soil Horizon or Sample Depth	Estimated Bulk Density	Carbon (tonnes)**
TOTAL					

* Sampling strata should be identified and mapped using standard soil survey or other methods to group similar soils together for estimation and measurement. Add rows to the table if additional strata are needed. See NCOC Handbook (Part 8) for guidelines on establishing sampling plan. If possible, attach a soils map showing selected sampling strata and fields in the project.
** An Excel spreadsheet can be downloaded from www.ncoc.us that can be used to convert estimates of acreage, organic matter percentage, soil horizon thickness, and bulk density into metric tonnes of carbon. For general estimates, use 10 tonnes of carbon per acre for each 1 percent organic matter in the top 12" (30 cm) of soil.

Table 12B. Future Soil Carbon Projections at Year ____ (Direct Measurement Method)

Sampling Strata (Soil Type)*	Acres	Organic Matter Percentage	Soil Horizon or Sample Depth	Estimated Bulk Density	Carbon (tonnes)**
TOTAL					

* See above; ** See above

Table 12C. Soil Carbon Projections (From Default Table, below)

Sampling Strata (Soil Type)*	Acres	Current Soil Carbon (t/acre)	Soil Carbon at Year _____	Estimated Change (tonnes/acre/year)	Total Carbon Gain (tonnes)
TOTAL					

14. Description of other (non-carbon) impacts of the project *(NRCS-CPA-52 can be helpful in identifying issues, which can be described briefly below.)*

14a. Environmental Impacts

14b. Social and cultural impacts

14c. Economic impacts

15. How does the project support other local, state, tribal, or federal programs, policies, or priorities?

16. Other information

17. Contact Person: (Name, address, phone, fax, email):

Default Values for use in Table 12C.

The average annual soil carbon increase will be affected by soil type, initial soil condition, cropping system used, conservation tillage methods, and regional climate factors. The following table has been reproduced from NRCS guidelines and can be used for general estimates. It is recognized that the use of these factors has a high level of uncertainty, since individual field conditions may differ greatly from regional averages.

[TABLE TO BE ADDED]

INITIAL PROPOSAL
NATIONAL CARBON OFFSET COALITION

AGROFORESTRY PROJECT

Project Name: ___________________________ Proposal Date:_________________

<u>Background and Purpose:</u> *This form is a guide to an initial proposal for a carbon sequestration project designed to qualify for consideration by the National Carbon Offset Coalition (NCOC). The data and attestation requirements on this form are those required at this time, and could be changed in the future. The National Carbon Offset Coalition (NCOC) offers no assurance that this project will be accepted for registration or purchase by any segment of the regulatory framework or market at this time, or that further information and/or qualifications may not be required in the future. Neither NCOC nor any other organization makes any warranty as to the marketability or market value of the carbon offsets represented in this Initial Proposal.*

There are no standards for the calculation of baselines and additionality for agroforestry projects at this time, so this proposal is limited to base year calculation. Soil sampling prior to tree planting will establish the base year carbon amount, and soil sampling plus tree measurements will establish the end-of-project amount.

If more space is needed in any item in the following form, please attach a separate sheet numbered to correspond with the form. The form is also available as a Word document that can be downloaded from www.ncoc.us.

1. Project Owner:

2. Project Type: Windbreak ___; Shelterbelt ___; Riparian buffer ___
Other (list)________________________

3. Brief description of the project:

4. Project Location: *(Please attach a site map with GPS points indicated if possible)*

5. Project size: Length of planting _____ft. Width of planting _____ ft. Acres: _____

6. Date(s) of Project Initiation:

7. Planned Project duration (years):

8. What are the primary purposes of the project: (Check all that apply)
Carbon Sequestration ___ Soil and Water Protection ___ Wildlife Habitat ___
Fuelwood Production ___ Other(list)__________________________

9. General technical description of the site (climate, soils, aspect, current vegetation, current and previous land use, etc.): *(Note: for agroforestry projects, indicate the land cover or land use on the adjacent agricultural fields.)*

10. What management practices, if any, are planned during the duration of this project? *(Weed control, irrigation, fertilization, pruning, etc.)*

11. What protections will be used to assure that the trees in this project will be adequately protected from grazing or wildlife damage during establishment?

12. Carbon Sequestration Calculations. *Initial measurements are only soil organic matter estimate where trees don't yet exist. Future measurements will include both soil and trees.*

Table 12A. Current (Base Year) Soil Carbon (Direct Measurement Method)

Sampling Strata (Soil Type)*	Acres	Organic Matter Percentage	Soil Horizon or Sample Depth	Estimated Bulk Density	Carbon (tonnes)**
TOTAL					

* Sampling strata should be identified and mapped using standard soil survey or other methods to group similar soils together for estimation and measurement. See NCOC Handbook (Part 8) for guidelines on establishing sampling plan. If possible, attach a soils map showing selected sampling strata and adjacent farm fields in the project area.
** An Excel spreadsheet can be downloaded from www.ncoc.us that can be used to convert estimates of acreage, organic matter percentage, soil horizon thickness, and bulk density into metric tonnes of carbon. For general estimates, use 10 tonnes of carbon per acre for each 1 percent organic matter in the top 12" (30 cm) of soil.

Table 12B. Future Carbon Projections at Year ____ (Direct Measurement Method)

Sampling Strata (Soil Type)*	Acres	Organic Matter Percentage	Soil Horizon or Sample Depth	Estimated Bulk Density	Carbon (tonnes)**
TOTAL SOIL C					
Species	Number	Average Diameter	Average Height	Lbs. C/Tree	Carbon (tonnes)***
TOTAL TREE C					
TOTAL CARBON					

* See above; ** See above; *** See table below for estimated tree carbon by selected species. If the species to be used are not included, please call NCOC for guidance.

14. Description of other (non-carbon) impacts of the project *(NRCS-CPA-52 can be helpful in identifying issues, which can be described briefly below.)*
14a. Environmental Impacts

14b. Social and cultural impacts

14c. Economic impacts

15. How does the project support other local, state, tribal, or federal programs, policies, or priorities?

16. Other information

17. Contact Person: (Name, address, phone, fax, email):

NCOC Agroforestry Species Table.

[TO BE ADDED]

G. Suggested Outline For Plan[99]

The following suggested outline focuses primarily on a forestry project, but should be equally useful for a project involving conservation tillage or agroforestry practices. Planners are encouraged to add, delete or adapt sections as appropriate.

1. Overview

(A 3-4 paragraph explanation that gives the size, location, and general goals of the project, lists the participating landowners and organizations, and provides enough information that the reader has a good general idea what the project is about, and what it will accomplish).

2. Project area description

A. Geographic location (Give legal description, latitude & longitude, or other official means of locating. A location map showing the location within the U.S. is helpful when foreign buyers are involved.)
B. Size of area
C. Land ownership and tenure
D. Physical description of the project site
    a. Soils, topography, geology, site index if known. A soils map if possible, with explanation of major soil types or characteristics.)
    b. Climate (Irrigated?)
    c. Native vegetation (if known)
    d. Provide a map, preferably on a USGS quad sheet, aerial photo, or other base, showing the proposed project boundary.
E. Past and present land use and management on the project site
    a. Include the reason why the site is not currently forested, and the basis for judging the site to be suitable for trees now.
F. Local or regional conditions or trends that are likely to be important "drivers" of future land use and management that could affect the project area. (An example might be a general decline in agricultural markets or infrastructure that seems likely to drive up the cost of agricultural production and make other land uses more attractive by comparison.)

3. Project activity description

A. Type of project (afforestation, reforestation, forest management, conservation tillage, grass planting, windbreak, etc.)
B. Length of planned project
C. What activities are planned? (tree planting, change in management, etc.)
D. When will the activities begin, and how will they be applied?
    a. If tree or grass planting, what species will be used, what planting methods, who will do the planting, when? Will other species (shrubs, etc.) be involved?
E. What types of management will be done over the length of the project? Who will be responsible for management oversight and activity? (Attach a copy of the land management plan as an appendix if appropriate)
    a. Include important management needs, such as:
        i. Thinning, competition control
        ii. Weed control

[99] The contractual parts of the final plan are not included in this handbook. Current samples should be obtained from the NCOC Portfolio Manager.

iii. Insect & disease control
iv. Grazing management (or elimination if needed for success)
v. Fire protection

F. Other types of supporting activity that will be needed. (Special planting stock, contractors, drip irrigation for establishment, etc.)
G. Carbon pools to be affected (and measured) as a result of project activity. (e.g. above- and below-ground biomass, litter and debris, understory vegetation, soil carbon, forest products). For each of these pools, provide the scientific assumptions that were used to decide whether or not to include them in project accounting. (e.g. "Carbon change in the litter and debris pool will not be measured because this will be a young forest that will not develop much litter and debris within the life of the project. What develops will add slightly to carbon stocks, but not enough to warrant the cost of measurement.")

4. *Estimating greenhouse gas mitigation effects*

A. Establishing the Base Year or Reference Case
  a. There are two basic methods in current use to establish a "base" or "starting point" for a project. The method to be used will be established by buyers or future rules governing market transactions. Contact the NCOC Portfolio Manager if there are questions as to which method should be used.
  b. If the project is to be measured on the basis of the carbon stock changes that occur after the project is initiated, it is important to establish base year conditions. That requires carbon stock measurements (either in soil or trees or both) as of the start of the project. See Part 8 for suggested methods.)
  c. If the project is to be measured on the basis of carbon change in comparison to a "business as usual" (BAU) estimate, it is necessary to describe how the land use or management would most probably continue if the project were not done.
    i. What is the likelihood of such a future? On what basis can these assumptions be made? Are there other futures that might be nearly as likely? Are there activities on adjacent or similar lands that provide some idea what might happen?
    ii. Describe how the carbon pools would be affected under the base case, giving the reasons and assumptions behind those estimates. (e.g. "If the land continues in cultivation, there will be no woody biomass pools created. Soil carbon will continue to decline at the rate of about ___ .")

B. The Project Case
  a. Describe how the affected carbon pools will change under the project. Show with tables, formulas, or other explanations how each pool was calculated. Indicate the source of all growth and yield estimates, soil carbon estimates, etc., and show how they were used in the calculations.
    i. Show by tables or graphs how the increase in carbon is anticipated through the life of the project. (This can be done with average annual growth (mean annual increment or MAI) estimates, 5-year increments, or 10-year increments, as appropriate. The idea is to provide some kind of interim estimates against which monitoring and verification can be compared to see how well the projections are being achieved.) Indicate the degree of uncertainty that may be associated with those estimates.

C. Project Additionality
  a. The additional carbon due to project activity is calculated as the difference between the project case and the reference case or base year. (This figure may need to be adjusted for leakage or uncertainty, as described below)

D. Leakage
    a. Leakage occurs when project activities cause actions or effects outside the project boundary that result in changing carbon emission or sequestration rates on those other lands. (See Part I for further background on addressing potential leakage). If leakage is thought to exist, the extent needs to be calculated and the project adjusted accordingly.

E. Uncertainty
    a. Where there is significant uncertainty in either the additionality or leakage calculations, it may be wise to discount the estimated project gains to protect against future shortfalls. If the uncertainty works both ways (the estimates could as likely be under- as over-estimated), does the preliminary plan foresee contract provisions that protect both landowner and buyer in the final plan?

5. Other Project Impacts

(In this section, briefly describe the non-carbon benefits (or negative impacts) that are anticipated as the result of project activities. Form NRCS-CPA-52 may prove useful in making these assessments.)

A. Environmental Impacts
    a. Soil conservation, erosion control
    b. Effect on water quality and quantity (surface, sub-surface), both on the site and downstream
    c. Effect on wildlife habitat in the area, conservation of biological diversity, food or cover species planted, etc.
    d. Impact on recreational use of these lands, if any.
    e. Visual impacts, other esthetic values
    f. Impact on regional environment or landscape quality, if known.
    g. Air quality (wind, dust, snow control, other non-CO_2 benefits)

B. Economic Impacts
    a. Effect on economic flows from the project land*
        i. Maintenance, monitoring costs
        ii. Protection costs
        iii. Reduced grazing values, if present
        iv. If cropland, change in annual net income from the land (crop income could be negative in recent years in some cases)
    b. Effect on economic activity in the local community*
        i. Jobs associated with the project land
        ii. Products flowing to local markets
        iii. Value-added processing materials from the project land (more, less, any impact?)

C. Social Impacts
    a. Are the proposed land uses or management activities familiar and well accepted in the local community, or will there need to be some effort to familiarize people with them to gain acceptance?
        i. If additional education or communication is needed locally to gain acceptance, how will it be done?

6. Risk Management

A. What has been done to assure that the planned activities are technically appropriate for the site, and are installed correctly? If the project is a grass or tree planting, how will quality planting and survival be assured? What will be done in case of a planting failure?

B. What provisions have been made to assure that the sequestered carbon will remain the property of the buyer for the project period (e.g. contract assurance, conservation easement, etc.)
C. What provisions have been made to protect and maintain a healthy forest that has a chance to be resilient in terms of insects, diseases, or wildfires?
D. What provisions have been made that provides some protection for both landowner and buyer of carbon credits in the event of a disaster that overwhelms management and protection efforts? (wildfire, hurricane, etc.)

7. Monitoring, Reporting, and Verification

A. What types of baseline measurements will be made before the project is established? Where will those records be filed?
B. What types of regular (annual) inspections of the project will be made and reported? Who will make the inspections, and where will the reports go? Where will the records be kept?
C. What types of periodic monitoring (measurements) will be done to provide actual carbon sequestration data that can be compared to the baseline data and to the model projections used in predicting forest growth and response? Who will do the monitoring? Where will the reports be sent? Where will the records be kept?
D. When and how often is third-party auditing and verification planned?
E. What will assure access to the project area for future monitoring and verification activities?
F. Any other types of monitoring planned, such as periodic low-altitude photography or videography, or satellite image inspection?

H. Sources of Additional Information

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I. Glossary of Terms

Additionality – Carbon sequestration projects are expected to bring about additional, real, measurable, and verifiable increases in selected carbon pools that would not have occurred without intentional action. There are no formal rules for determining additionality at this time, but the issues and techniques in current use are discussed in this handbook. One of the most common approaches is to calculate how carbon pools would change in the absence of the project (reference case) and compare that to how they will change under the project (project case). The difference represents the additional carbon produced by the project.

Afforestation – Afforestation is the direct conversion of land that has not been forested for a period of time (often described as at least 50 years) through planting, seeding, and/or the human-induced promotion of natural seed sources. (See also deforestation and reforestation).

Base (or Reference) Case and Carbon Baseline – As one method of demonstrating additionality, project planners may be required to calculate how carbon stocks in affected pools would have changed in the absence of project action. The situation that would have occurred, called the base or reference case, is almost always a counterfactual situation. In other words, it will not happen, and cannot therefore be subjected to scientific measurement. So the base case must be supported by an argument based on logic and probability. That argument says, in effect: "this is what would most likely happen in the future if this project were not done." The carbon baseline is then calculated from that base or reference case using accepted scientific methods.

Carbon Dioxide (CO_2) – A common gaseous carbon compound found in the atmosphere. The atomic weight of carbon is 12; oxygen is 16. So one atom of carbon combines with 2 atoms of oxygen to create carbon dioxide, which has a molecular weight of 44. Thus, one ton of carbon, when it is emitted to the atmosphere in gaseous form, creates 3.67 tons of carbon dioxide.

Carbon Pool – A system that has the capacity to accumulate or release carbon, such as:

- Forest biomass (aboveground and belowground live biomass, dead wood and litter, understory vegetation)
- Wood products
- Soils
- Oceans
- Atmosphere

Carbon Stock -- The absolute quantity of carbon (C) held within a carbon pool at a specific time. Measured as mass (e.g. tC) or mass per unit area (e.g. tC/ac).

Carbon Flux or Flow – Transfer of carbon from one carbon pool to another. Measured in units of mass per unit area and time (e.g. tC/acre/year)

Chicago Climate Exchange (CCX) – A self-regulatory exchange that administers a voluntary, legally-binding pilot program for reducing and trading GHG emissions in North America. The CCX program began live on-line trading of GHG emission allowances in 2003.

CSU – Carbon Sequestration Unit– the equivalent of one tonne of carbon dioxide (CO_2) sequestered in agricultural soils or forests that meets international standards for credit against emissions or emission reduction targets.

Commitment Period – The length of time (duration) a carbon sequestration project will be maintained under the terms of the management plan, as set forth in the legal agreement signed between the landowner and NCOC.

COP – The "Conference of Parties," made up of the signers of the United Nations Framework Convention on Climate Change (UNFCCC). The COP holds periodic meetings to develop and refine rules and techniques for meeting the goals of the UNFCCC.

Deforestation – The direct human-induced conversion of forested land to non-forested land.

Emissions Trading – A market-based mechanism to promote cost-effective emissions reductions such as the U.S. sulfur dioxide trading program under the Clean Air Act. Under such a system, industries facing emission reduction requirements may find it economically advantageous to purchase mitigation credits from projects that enhance carbon sequestration in agricultural soils or forests. Although there is no national program that establishes emission reduction targets or emissions trading rules for CO_2 and other greenhouse gases in the United States at this time, it is possible that such a program will be enacted in the future. The current activity in emissions mitigation and trading is experimental, carried out by companies, organizations, and landowners wishing to test and develop feasible operating methods prior to any future decisions on state, national or international rules and regulations.

Forest Certification – A process where forest managers develop a plan for sustainable forest management under the guidelines of a forest certification organization, then have that plan and the associated field activities audited by an approved, independent auditing firm on a schedule established by the certification organization. There are several certification programs emerging across the world. Under most of them, timber or other products sent to market from a certified forest may carry, under tightly controlled conditions, a seal or mark indicating their certified status. Forests managed for CSU's under the NCOC program, which establish and maintain certification under recognized programs, and which include carbon pool audits in their regular certification audits, will meet the requirements of NCOC for verification (see below).

Forest Management – is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner. (Official definition for implementing the Kyoto Protocol)

Global Warming Potential (GWP) – is a calculation designed to equate the different global warming effects of various greenhouse gases. In terms of their ability to reflect heat back toward earth, the IPCC has calculated that methane (CH_4) is 21 times more effective than CO_2, and nitrous oxide (N_2O) is 320 times as reflective. This means that, in order to offset one ton of CH_4 emissions, it would take 21 tons of CO_2 sequestered in stable carbon pools. The net effect is that any project that sequesters CO_2, but in the process increases emissions of either CH_4 or N_2O, may easily wind up being a net loser in terms of climate change impact.

Greenhouse Gas (GHG) – A term given to those gas compounds in the atmosphere that reflect heat back toward earth rather than letting it escape freely into space. Several gases are involved, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone, water vapor and some of the chlorofluorocarbons. Different gases have different reflective capacity, called Global Warming Potential (see above). In terms of the current atmospheric situation, it is estimated that CO_2 is by far the most important contributor to climate change, causing some 80 percent of the impact according to the IPCC.

IPCC – Intergovernmental Panel on Climate Change – a scientific body created by the United Nations Environment Program (UNEP) and World Meteorological Organization (WMO) in 1988 to assess available information on the science of climate change. It also provides, on request, scientific, technical, and socioeconomic advice to the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). The IPCC has produced a series of assessments and reports that have become the standard works of reference on topics related to climate change.

Kyoto Protocol – The agreement reached in 1997 at the third meeting of the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). The Protocol established binding greenhouse gas emissions limits for industrial nations. It was controversial in the United States before it was adopted, with the U.S. Senate passing a resolution saying that the U.S. would never ratify it without "meaningful participation" of developing countries and an analysis of the costs for the U.S. economy. After it was adopted at Kyoto, there have been a continuing series of COP meetings to reach decisions on the rules for implementing the Protocol. Those meetings reached agreement on many aspects relating to land use, land use change, and forestry at the final session of the 6^{th} COP meeting in Bonn, Germany in 2001. At that meeting, the United States indicated that it would not sign the agreement, and removed itself from the ongoing Kyoto process. The U.S. remains, however, a participant to the UNFCCC and, as such, is committed to the goals of the Convention. Whether it will seek to achieve those goals through a process similar to, parallel with, or as a replacement to the Kyoto Protocol remains unknown at this time.

Leakage – This refers to situations where emission reductions or carbon sequestration activities within a project results in changes in emissions or sequestration outside the project boundaries. There are no formal rules for assessing or accounting for leakage at this time, but the issues and techniques in current use are discussed in a following section.

Methane (CH_4) – A gaseous carbon compound produced primarily by decomposition of organic compounds under anaerobic (no oxygen) conditions. It is an important greenhouse gas, with a global warming potential roughly 21 times that of carbon dioxide. It is produced primarily in the gut of ruminant animals and in the anaerobic conditions created by saturated soils (wetlands), sealed landfills, or covered manure lagoons. Healthy forests, in the absence of supplemental fertilization, have been shown to be an important methane sink, removing methane from the air through the action of soil organisms. The scientific basis for quantifying these methane effects is poorly known at this time, however, and NCOC forestry projects will not, at this time, consider forest effects on methane sources and sinks in project accounting.

MMTCE – (Million metric tonnes of carbon equivalent) – is a term encountered in the climate change literature. It results from converting all greenhouse gas emissions to the equivalent amount of carbon emissions through the use of the GWP factors (see above).

Monitoring – Periodic measurements at planned intervals to assess changes in the carbon pools affected by project activities. Methods of measurement must be consistent with accepted scientific practice, and comparable between monitoring cycles to allow comparison of results. Monitoring methods and intervals will be contained in the monitoring section of the final project management plan.

NGO (Non-governmental organization) – a term often used to describe the private conservation, environmental, industry, and other organizations that have been active in the climate change debate.

Nitrous Oxide (N_2O) -- An important greenhouse gas, with a global warming potential of 320 times as much as carbon dioxide, according to the IPCC. The primary source of N_2O emissions under current conditions are estimated to come from agricultural soils that have high nitrogen levels due to the application of fertilizers at times or in amounts that exceed the ability of vegetation to absorb the nitrogen into plant metabolism. The conversion of cropland to grass or forest, accompanied by a significant reduction in the use of commercial fertilizers, may be an important contributor to reducing emissions of N_2O from that land, but scientific methods of estimating that impact are not well developed. Therefore, NCOC will not attempt to calculate the impact of projects on N_2O emissions at this time.

Reforestation – the conversion of non-forested land to forest through planting, seeding, or the intentional promotion of natural seed sources on land that was forested but that has been converted to non-forested land. (The distinction between afforestation and reforestation is the 50-year time for non-forested condition. The effects of both practices are the same. For purposes of Kyoto accounting in the first commitment period, and qualification under the current CCX rulebook, only reforestation on land that was non-forest on 31 December, 1989 can be counted.)

Sequestration – The process of increasing the carbon stock (content) of a carbon pool other than the atmosphere. The goal of a carbon sequestration project is to increase the stock of stable carbon pools such as wood or soil, and maintain that increase for a planned number of years.

Soil Organic Matter (SOM) (e.g. **humus**) –SOM consists of a wide variety of organic compounds that form the most chemically and biologically active component of the soil. Many of the compounds are short-lived in the soil, being consumed or transformed by soil biota with the carbon released through respiration. Some of the compounds are gradually transformed into longer-lived forms, however, and the most stable soil organic compounds have been radiocarbon dated to ages of thousands of years. SOM does not include soil biomass (roots, bulbs, etc.) or soil fauna (insects, worms, other animals). Soil organic matter is a key component affecting water intake rates, water holding capacity, soil fertility, and the stability of soil structures. Thus, SOM is directly correlated with soil quality and productivity, and maintaining healthy SOM levels is a basic goal for soil and water conservation as well as sustainable agriculture or forestry.

In standard soil survey practice, SOM is often calculated as a percentage of the total soil material less than 2 mm in diameter. In order to convert these percentages to weight per unit area (e.g. tons per acre-foot), the specific gravity of the soil must be known. The specific gravity is then multiplied times 62.4 (the weight in pounds of a cubic foot of water) to get the total weight of a cubic foot of soil. The percent SOM is then multiplied by the total weight to arrive at the weight of SOM per cubic foot of soil, and multiplied by 43,560 to arrive at the weight in pounds of SOM per acre-foot.

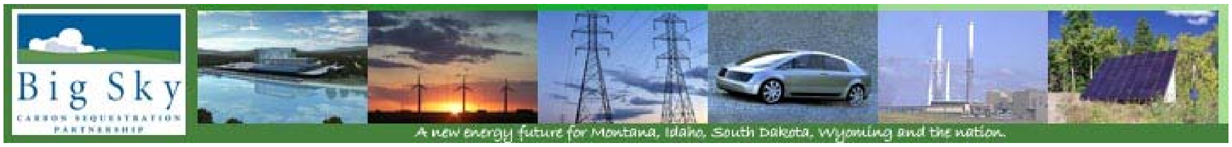
SOC – Soil organic carbon – the carbon content of SOM (usually estimated as about 58% of SOM). The estimate of SOC (calculated as 0.58 times the weight of SOM per acre) is usually presented as the amount of the soil carbon pool, and changes over time in this pool are reported in tons per acre as sources (emissions) or sinks (sequestration) of soil carbon as a result of management activities.

SIC – Soil inorganic carbon (e.g. lime ($CaCO_3$), charcoal**).** Changes in SIC from management activities are not well understood, and SIC is normally excluded from calculations of soil carbon pools as a result. It is generally thought that SIC pools change very slowly in soils and would not likely be relevant in accounting for soil carbon changes over periods of a few years or decades.

Ton or Tonne – The two spellings are used in this handbook to differentiate between the English (or short) ton consisting of 2000 pounds, which is commonly used in the United States, and the metric tonne consisting of 2204 pounds, which is commonly used in international literature and computations.

UNFCCC – The United Nations Framework Convention on Climate Change, adopted at the 1992 “Earth Summit” in Rio de Janeiro. The UNFCCC launched a continuing process through which the participating countries are working to meet the goal of reducing human-induced climate change.

Verification **–**A periodic third-party audit that provides quality assurance and credibility as to the reported amount of CSU's produced and maintained, as well as the achievement of other management goals. Verification audits, to be officially recognized, must be done by qualified professionals under the protocols established by the American National Standards Association's Registration Advisory Board.



Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 14:
Report on the Feasibility of Mineralization Trapping in the Snake River Plain Basin

Attachment A –
"Advanced Concepts for Geologic Sequestration of CO_2: Assessing Mineralization Trapping Potential for Mafic Rocks"

July 2005

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Advanced Concepts for Geologic Sequestration of CO_2: Assessing Mineralization Trapping Potential of Mafic Rocks

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July 28, 2005

Introduction

Carbon sequestration is one approach to stabilize or reduce the levels of greenhouse gases in the Earth's atmosphere. Geologic sequestration is the storage or entombment of carbon dioxide (CO_2) in subsurface geologic formations. Potential geologic formations in our region that may be conducive to sequestration include: deep saline reservoirs, depleted oil/natural gas reservoirs, deep unmineable coal beds, and mafic/ultramafic rocks. Because many of these natural reservoirs are known to have stored fossil fuels and other fluids over geologic time frames, they can be expected to have high potential for the long-term sequestration of CO_2.

Geologic sequestration occurs via three interrelated processes. The first is hydrodynamic trapping where CO_2 is physically isolated by trapping beneath impermeable geological barriers, such as a shale bed. This is the primary sequestering process in the short-term and is largely a function of the storage capacity of the deep system and its degree of isolation from the Earth's surface. The second process is solubility trapping in which CO_2 dissolves in subsurface fluids such as brines or petroleum. Solubility trapping is slower than hydrodynamic trapping and depends on the CO_2 dissolution rate in the fluid of interest. The third process is trapping due to mineralization in which CO_2 is entombed by increased weathering of the geochemically reactive base cations (primarily Ca^{2+}, Mg^{2+}, and Fe^{2+}) in subsurface minerals. The weathering reactions result in the conversion of CO_2 into carbonate alkalinity and ultimately carbonate minerals. Because existing groundwaters are often saturated with carbonate phases, carbonate minerals formed from anthropogenic CO_2 will be permanently entombed in the subsurface. The time frame for mineralization trapping is primarily a function of the weathering rate and is much slower than the other two trapping processes. Mineral trapping will be most pronounced in rocks that have high concentration of base cations and rapid reactions rates such as mafic volcanic rock. The permanence of sequestration by the three trapping processes is the inverse of their trapping time scale. Mineralization trapping offers the most permanent sequestration, hydrodynamic trapping the least. In an ideal sequestration site, CO_2 would be permanently stored through the presence of multiple trapping processes.

The Big Sky Carbon Sequestration Partnership is one of the U.S. Department of Energy's seven regional partnerships. 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 plays an important role.

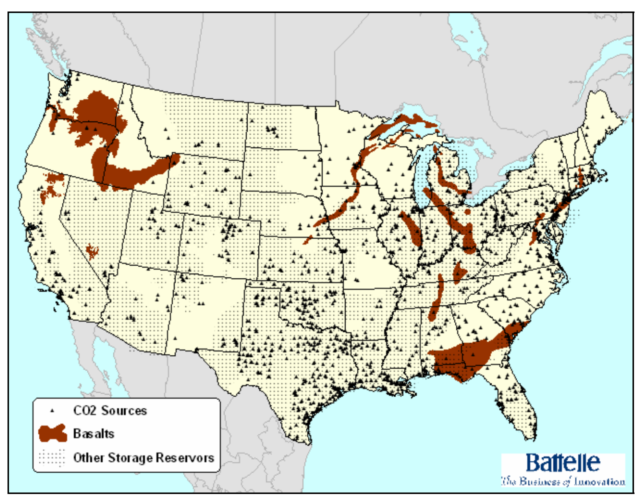

Figure 1. Map of U.S. Basalts, large CO_2 sources, and other candidate storage reservoirs.

The Big Sky Partnership has evaluated the geologic sequestration potential of the 64,700 km^2 basalt bearing Snake River Plain volcanic basins in Idaho and will, in Phase II, evaluate the potential for similar rock types of the 163,700 km^2 Columbia River Basalt Group in western Idaho and eastern Oregon and Washington. In addition to the formations located in the Partnership's region and as shown in Figure 1, other mafic rock provinces exist within large parts of the United States. Specifically considered in this report, and an example of the potential of mafic volcanic rocks, is an evaluation of sequestration in a mixed volcanic sedimentary section in southern Idaho. Given that the types of deep subsurface characterization data that is widely available for sedimentary basins containing energy resources are not available for the volcanic basins of Idaho, a preliminary evaluation of sequestration potential that relies solely upon average characteristics and literature results is considered here.

Assessment Approach

Geologic sequestration involves the injection of CO_2 captured from point sources into geologic formations as a supercritical fluid. The amount of CO_2 injected will exceed (in the short term) its solubility in the formation fluids (e.g., water) and will form a separate fluid-phase. Over time, the CO_2 will dissolve forming carbonic acid (H_2CO_3) that will be neutralized by weathering or corroding subsurface minerals to produce carbonate and bicarbonate ions (alkalinity) and/or mineral carbonates. Of particular importance are weathering reactions of silicate minerals rich in Ca, Mg and Fe. For example, the weathering of the calcic component of plagioclase feldspar (a common rock forming mineral) to calcite and a clay mineral can be written as:

$$\text{Plagioclase}(CaAl_2Si_2O_8) + 2H_2O + CO_2 \rightarrow \text{Calcite}(CaCO_3) + \text{Clay}(Al_2Si_2O_5(OH)_4) \quad (1)$$

Consideration of the thermodynamics of this reaction indicates that for any CO_2 pressure important for sequestration, the reaction will proceed as written, entombing the introduced CO_2 as solid calcium carbonate. Mineralization potential will be highest in rocks with abundant Ca-, Mg-, and Fe-silicates (e.g., basalt) and lowest in rocks poor in these phases (e.g., sandstone). The time frame and extent of mineralization for a given subsurface environment is a function of the silicate weathering rate and the abundance of appropriate silicate phases. The quantitative assessment of reaction (1) requires an understanding of the reaction rates and the abundance of the reactive phases. To address reaction rates, a generalized kinetic expression for mineral dissolution reactions that accounts for changes in pH was developed from results presented by Lasaga et al. (1994) and Drever (1997)

$$R = k_+ \cdot A \cdot \left(a_{H^+}^{0.5} + 10^{-3} + 10^{-5} \cdot a_{H^+}^{-0.25}\right)\left[1 - \frac{Q}{K}\right] \quad (2)$$

R	=	Reaction Rate
k_+	=	Forward Rate Constant
A	=	Reactive Surface Area
a_{H+}	=	Aqueous hydrogen ion activity (pH)
Q	=	Ion Activity Quotient
K	=	Equilibrium Constant

Published kinetic information that can be used to derive k_+ is available for a limited set of minerals (e.g., Lasaga et al. 1994). Reactive surface area required in equation (2) can be estimated from geometric considerations or surface areas measured for whole rocks. The effects of pH on the relative value of R are shown in Figure 2. As may be seen, at lower pH values, reaction rates are more rapid than at higher pH values. The ion activity quotient can be calculated from water compositions. Equilibrium constants for a large number of minerals are available in published data bases (e.g., Bethke 2002).

In our assessment approach, mineral precipitation reactions and reactions occurring in the water-rich fluid phase are assumed to be rapid when compared to dissolution reactions and are treated using equilibrium considerations. Reactions with the CO_2-rich fluid phase are ignored. The Geochemist's Workbench (v 4.03), a commercially available, mixed equilibrium-kinetics geochemical computer code (Bethke 2002), is used to model the weathering reactions that transform CO_2 to solid phase carbonate minerals.

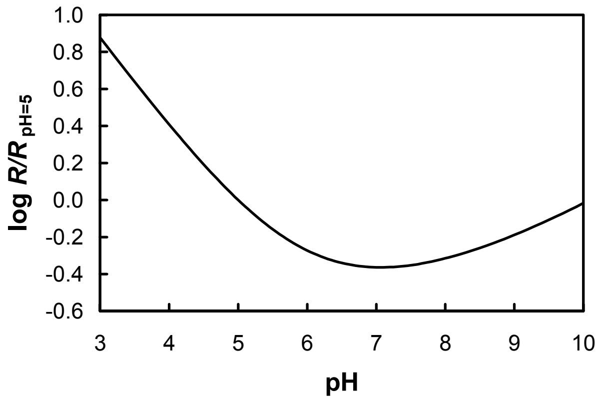

Figure 2. Relative reaction rate as estimated from Equation 2.

Subsurface geologic formations are composed of a multitude of site (or rock type) specific minerals. Because kinetic data are available for only a limited subset of the possible minerals, an approach that transforms actual rock mineralogy to an idealized set of minerals that can be modeled is required. The approach used here relies upon bulk whole rock chemical analyses for formation geomedia to calculate normative mineralogies (Lowenstern 2000). This approach provides a small, common-set of minerals that are independent of the site or formation being considered. For geochemical modeling, the normative mineralogy is simplified by removal of titanium and phosphorous containing phases. The use of normative mineralogies and geochemical modeling allows a uniform assessment of carbon sequestration potential for a variety of rock types. Although this approach does not accurately predict the capability for a given formation to sequester CO_2, site-specific kinetic data is not required, making it ideally suited for a regional survey of sequestration *potential* that includes a variety of rock types. The design of a sequestration system at a specific location should be guided by site specific models and mineralogoies.

Application of Assessment Methodology to Volcanic Rocks of the Snake River Plain, Idaho

The carbon sequestration potential of hypothetical hydrocarbon plays in the Idaho-Snake River Downwarp Province (USGS 1995) is part of the Partnership's regional assessment and evaluation. The direct injection of CO_2 into mafic-volcanic rocks is the scenario considered for this paper. This scenario has applicability to three of the four Idaho-Snake River Downwarp plays that contain or are bounded by volcanic rocks.

Geology

The Idaho-Snake River Downwarp plays considered include the Pliocene Lake Idaho sediments and Columbia River Basalts, Miocene Lake Bruneau sediments and basalts, and Pre-Miocene sedimentary and volcanic formations (Figure 3). Maximum thickness for the different plays range from 2,100 to 3,000 meters. These plays are located within the eastern and western provinces of the Snake River Plain (SRP) in southern Idaho. The Eastern Snake River Plain (ESRP) and the Western Snake River Plain (WSRP) have been differentiated based on their geologic history and their hydraulic attributes. Structural evolution leading to the development of the ESRP and the WSRP began ~17 million years ago as the North American Plate moved southwesterly over the Yellowstone Hotspot, resulting in a volcanic province that becomes thinner and younger to the northeast (Barrash and Venkatakrishnan 1982). The ESRP is generally younger than the WRSP and is composed of volcanic rock (primarily basalt with lesser amounts of rhyolite) and relatively thin layers or lenses of sedimentary material that tend to thin towards the center of the basin. The ESRP is host to an extremely productive aquifer that flows through the fractured basalts in a southwesterly direction. The

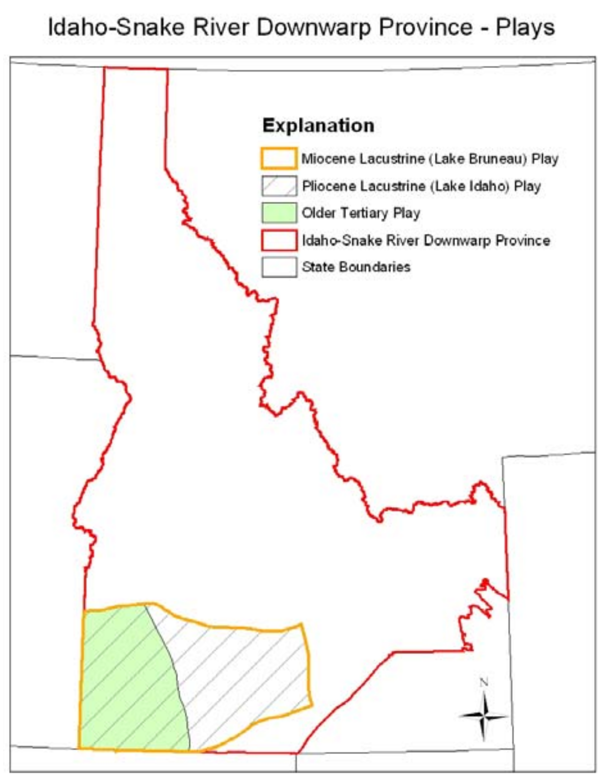

Figure 3. Map of Idaho showing locations of three plays (USGS 1995) with potential as carbon sequestration locations.

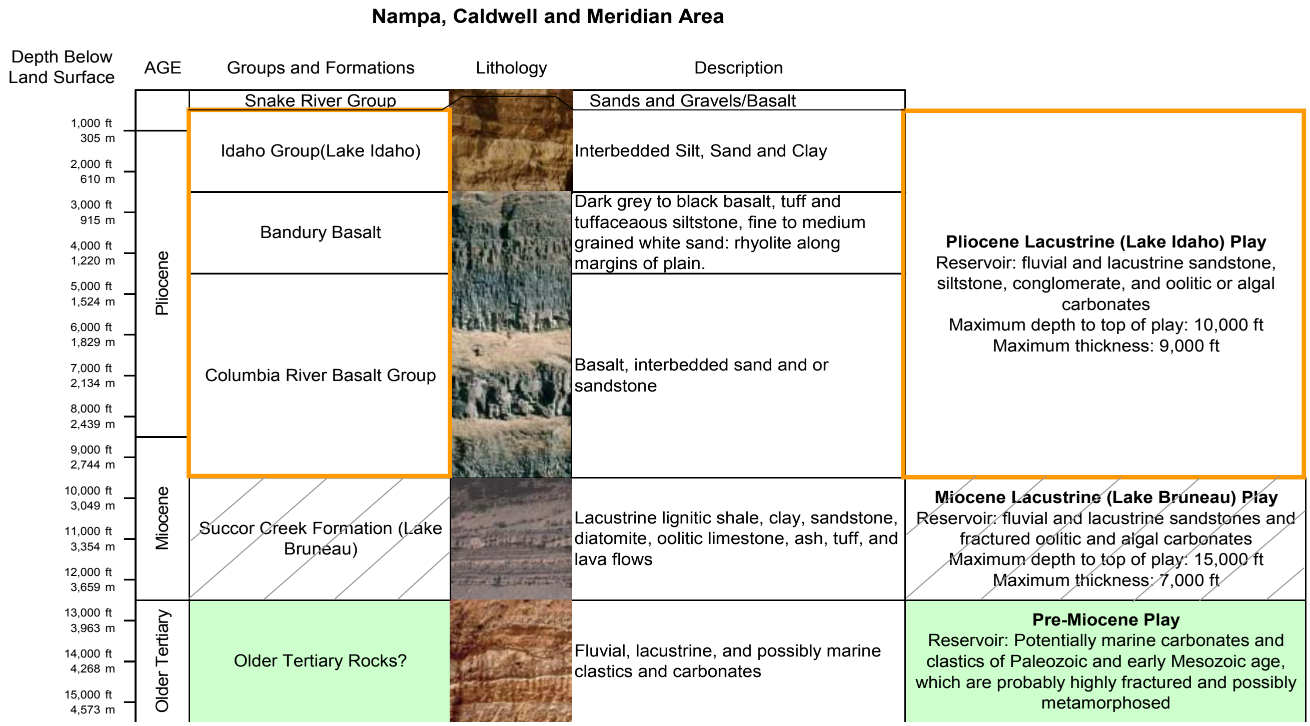

Figure 4. Generalized stratigraphic sections of Idaho plays with carbon sequestration potential.

WSRP is a structural downwarp that is believed to have been formed by crustal extension, beginning as early as 17 million years ago (Malde, 1991). Over these 17 million years, this structural depression has been filled with basalt flows separated by thick lacustrine sequences (Figure 4).

Basalts of the Snake River Plain are dominantly olivine tholeiites consisting of approximately 50-60 percent labradorite, 40 percent augite, less than 10 percent olivine, and 5 percent glass (Kuntz et al. 1992). Iron-titanium oxides (mostly magnetite) and minor apatite also occur. Of this assemblage, the most reactive phases are mafic glass followed by silicic glass, olivine, pyroxene, oxides, and labradorite (Morse and McCurry 2002). Reactive minerals in the sedimentary interbeds include K-spar, clays, calcite, dolomite, quartz, and volcanic glass (Rightmire and Lewis 1987).

Normative Media Properties

Average whole rock chemical composition for Snake River Plain basalts and the calculated normative mineralogy are given in Table 1. The normative mineralogy, comprised of end-member phases, are recast into solid solutions for the geochemical calculations. The required thermodynamic data for the new phases are estimated as a linear combination of the end-members and are included in the modeling database. Specific surface areas for basalt phases are also given in Table 1, are estimated from a total surface area calculated for the basalt, and are distributed among the normative mineral phases based on their volumetric abundances. The specific surface areas of the basalt is derived from geometric consideration with 1/3 of the porosity being attributed to one mm parallel fractures and 2/3 of the porosity attributed to intergranular porosity (assumed to be bundled capillary tubes with radius of 10.4 µm). A total porosity of 12.5 percent and median pore size of 10.4 µm is estimated from the averages of high pressure mercury injection tests conducted on 15 basalt samples.

Table 1. Average compositions of Snake River Plain Basalts (Kuntz et al. 1992), calculated normative mineralogy and specific surface areas.

Oxides	Wt %	Normalized Mineralogy	Wt %	Ti, P Free	Wt %	Surface Area $cm^2\ g^{-1}$
SiO_2	46.10					
TiO_2	2.60					
Al_2O_3	14.51	Orthoclase (Or)	5.51	K-Feldspar $KAlSi_3O_8$	5.51	123
Fe_2O_3	2.62	Albite (Ab)	20.89	Plagioclase $NaCaAl_3Si_5O_{16}$	46.66	115
FeO	10.57	Anorthite (An)	25.77			
MnO	0.20	Diopside (Di)	17.09	Clionpyroxene $Ca_3Mg_2FeSi_6O_{18}$	17.07	87
MgO	8.49	Hypersthene (Hy)	3.31	Orthopyroxene $Mg_2FeSi_3O_9$	3.31	87
CaO	10.34	Olivine (Ol)	16.64	Olivine $Mg_4Fe_2Si_3O_{12}$	16.64	84
Na_2O	2.47	Magnetite (Mt)	3.80	Magnetite Fe_3O_4	3.80	115
K_2O	0.93	Ilmenite (Il)	4.93			
P_2O_5	0.70	Apatite (Ap)	1.63			
Total	99.53	Total	99.55	Total	92.98	

Geochemical Modeling

The Geochemist's Workbench computer code is used to model the reaction of the normalized 'rock' from Table 1 and a representative Snake River Plain groundwater. The geochemical model is 'calibrated' by adjusting the surface area to yield an estimated basalt reaction rate of 150 mg L^{-1} yr^{-1} (Roback et al. 2001). Estimated specific surface areas are uniformly reduced by a factor of 100 to achieve calibration.

Using the calibrated model, a 500 year simulation for 200 bars CO_2 pressure and 40°C is conducted. In this simulation, 50 percent of the porosity is instantaneously flooded with supercritical liquid (SCL) CO_2 (with a density of 821 kg m^{-3}) to simulate the rapid injection phase. Under these P-T conditions a total of 15.4 kg m^{-3} of carbon is sequestered with hydrodynamic trapping accounting for approximately 14 kg m^{-3} of carbon and solubility trapping accounting for the remaining 1.4 kg m^{-3} of carbon. Because the simulation considered is for a single injection of CO_2, the total carbon sequestered is a constant 15.4 kg m^{-3} with time.

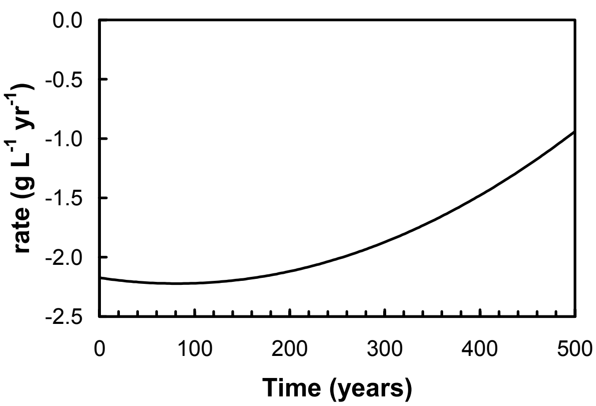

Figure 5. Dissolution Rate of primary basalt mineral as a function of time normalized to one liter of the aqueous phase.

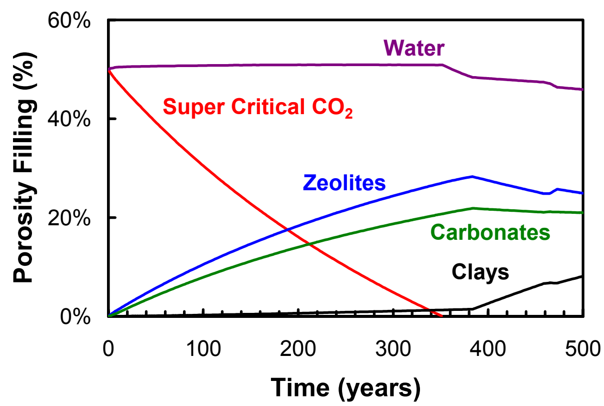

Figure 6. Relative filling of porosity (orignal porosity plus new porosity created by dissolution of primary minerals) as a function of time.

As a result of mineralization reactions, sequestered CO_2 dissolves the original minerals in the basalts (Figure 5) and precipitates secondary minerals (Figure 6). Within 350 years the SCL CO_2 phase disappears, ending the period in which hydrodynamic trapping contributes to sequestration. Initially, as may be seen in Figure 5, the rate[1] of dissolution is greater than 2 g L^{-1} yr^{-1}. Over time, the rate decreases reflecting the loss of the SCL CO_2 and an associated increase in pH. Figure 6 shows that during the period that SCL CO_2 is present (first 350 years), formed secondary minerals include zeolites and Ca, Fe, and mixed Ca-Mg carbonates. Following the loss of the SCL CO_2, dissolved aqueous CO_2 continues to react with the basalt for another 30 years. At approximately 380 years all the CO_2 is consumed, zeolites begin to dissolve, and clay minerals are formed.

Figure 7 shows that alteration reactions result in a steady decrease in porosity from 12.5 percent to 8.5 percent during the first 380 years. Following this period, the porosity remains essentially constant for the remainder of the simulation. Because the simulation considers only chemical interactions and does not include multiphase fluid flow, the full implications of porosity reduction on sequestration is not be evaluated. However, it is interesting to note that significant clay mineral formation does not occur until after the SCL CO_2 completely reacts. In addition, during early times (e.g. during injections) there is minimal porosity reductions suggesting that mineralization reactions are not important during the operation lifetime of an injection well. At later times, mineralization reactions with their associated reduction in porosity may serve to seal and isolate formation fluids. Figure 8 shows the relative importance of hydrodynamic, solubility, and mineral trapping over time of 1 m^3 of basalt geomedia. During early times, this potential is dominated by hydrodynamic (14 kg m^{-3} of carbon) and solubility (1.4 kg m^{-3} of carbon) trapping. Solubility trapping potential remains relatively constant as long as the SCL CO_2 fixed the activity of aqueous CO_2. With the loss of the SCL CO_2 phase at 350 years, solubility trapping decreases as aqueous CO_2 reacts with basalt silicates. Mineral trapping exceedes solubility trapping in about 160 years and accounts for 90 percent and 99 percent of the total carbon sequestered by 340 and 380 years, respectively.

Conclusions

The evaluations of potential geologic sequences for carbon sequestration need to consider the relative contributions of hydrodynamic, solubility, and mineralization trapping. The relative contribution to sequestration of these three processes will vary with rock type and time. In sequences that include basalts, such as those located in southern Idaho, all three processes contribute to sequestration, with hydrodynamic trapping important early and mineralization trapping dominating later. The specific potential of the Snake River Plain Basin is not determined in this report, but an preliminary assessment incidate that the Basin should be further studied.

[1] The reaction rates as presented here are negative (the mass of primary minerals is decreasing) and are normalized to the volume of water in the system.

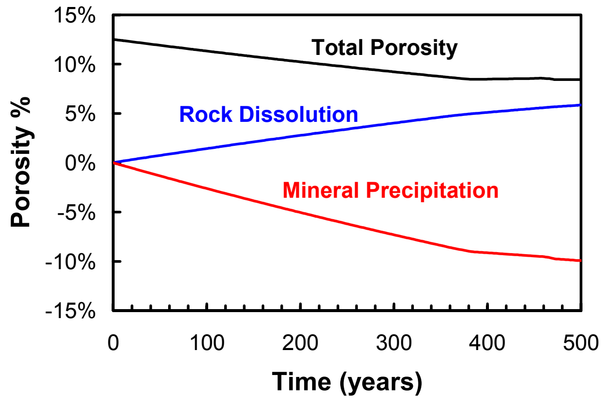

Figure 7. Changes in porosity as a function of time.

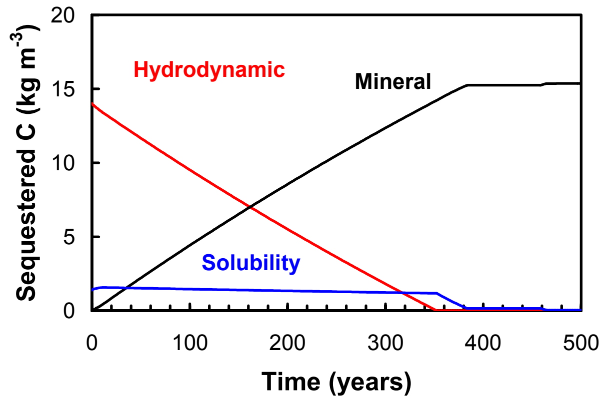

Figure 8. Caron sequestration potential of basalt by different mechanism as a function of time. The nature of the simulation fixed the total carbon sequestered at 15.4 kg m^{-3} (see text).

Acknowledgement

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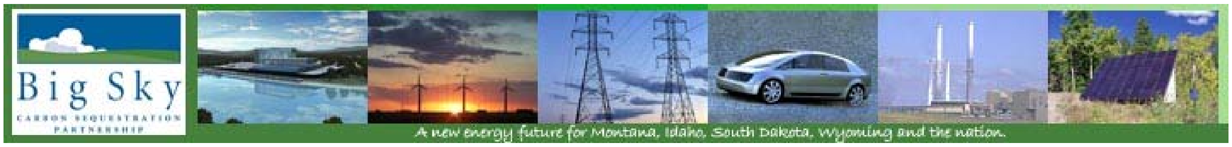

Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 15: Report on Results of Best Production Practice for Soil C Sequestration

Soil Carbon Sequestration and Best Production Practices: Some Preliminary Results for Montana

(Note: Analysis jointly supported by USDA/CASGMS and DOE Phase I efforts)

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I. Farm Management Practices Can Affect Greenhouse Gases

The greenhouse effect is caused by heat from the sun that is trapped in the atmosphere by gases, much like the glass of a greenhouse traps the sun's warmth. Trapping the sun's heat allows fairly hospitable global temperatures and is essential to life. Without this natural greenhouse effect, Earth's average temperature would be below freezing and most life would be impossible.

But if the greenhouse effect becomes too intense, temperatures rise and have important environmental consequences. This is popularly known as "global warming," which scientists have stated is a leading global concern. Global warming is an increase in the earth's temperature caused by increased greenhouse gas concentrations in the atmosphere. As these gases increase, the 'greenhouse effect' intensifies, trapping more of the sun's heat.

Which Greenhouse Gases are Important to Agriculture? The primary greenhouse gases: water vapor, carbon dioxide, methane, and nitrous oxide, with water vapor being the most common. Carbon dioxide, methane, and nitrous oxide result mainly from human activities. Carbon dioxide is released mainly due to combustion of fossil fuels such as coal, gasoline, diesel, and natural gas, and is also produced when solid wastes, wood, and wood products are burned. Carbon dioxide concentrations have increased from 270 parts per million in the mid-1800s to 370 parts per million in 2004. These increases have been implicated in a gradual increase in the earth's temperature.

All atmospheric gases contribute to global warming, but some gases like nitrous oxide and methane are more powerful than carbon dioxide due to their long duration in the atmosphere and strong absorption of long-wave radiation. Scientists sometimes use the term global warming potential to compare the heat-trapping ability of other greenhouse gases to carbon dioxide. Carbon dioxide is used as the baseline greenhouse gas and assigned a value of 1. Methane has 21 times and nitrous oxide 310 times the global warming potential of carbon dioxide. Thus, every ton of methane has the global warming potential of 21 tons of carbon dioxide and every ton of nitrous oxide warms as much as 310 tons carbon dioxide. These values are referred to as carbon equivalents.

How can Agriculture Affect Climate Change? Agricultural activities serve as both sources and sinks for greenhouse gases, so specific agricultural practices could slow the pace of global warming. Methane dynamics are linked closely to livestock production practices and wetland agriculture, such as rice production. We focus on crop management in Great Plains agriculture in this note and so will ignore methane here. Carbon dioxide dynamics are related to energy use cycles on farms and more importantly, to soil management. Nitrous oxide dynamics are related to soil nitrogen management, including fertilizer nitrogen.

What is Soil Carbon Sequestration? Carbon sequestration refers to the removal of carbon dioxide from the atmosphere into a long-lived stable form that does not affect atmospheric chemistry. Currently, the only viable way to trap atmospheric carbon dioxide is via photosynthesis, where carbon dioxide is absorbed by plants and turned into carbon compounds for plant growth. Carbon is considered sequestered if it ends up in a stable form, such as wood or soil organic matter. Soil carbon sequestration is an important and immediate sink for removing atmospheric carbon dioxide and slowing global warming.

II. Management Practices that Sequester Soil Carbon

Practically, there are three areas of farm management that can affect soil carbon sequestration in the Great Plains: tillage, cropping intensity and fertilization.

Tillage and soil carbon are negatively related. The greater the tillage, the less soil carbon. No-till systems build soil organic matter, which is about 58 percent carbon. No reliable data exist in Montana regarding soil carbon accumulation rates due to no-till, but extensive research in nearby southwestern Saskatchewan shows that soils depleted of organic matter typically accumulate soil carbon at a rate of 0.1 tonne/ha/yr (~0.045 tons/ac/yr), but may vary from 0 to 0.2 t/ha/yr depending on soil type, soil management, local weather patterns and specific no-till systems.

Different no-till systems result in varying soil disturbance, but any system that reduces tillage substantially can increase soil carbon. Montana field research completed in 2001 showed carbon storage rate from no-till adoption similar to that in southwestern Saskatchewan, but with considerable farm-to-farm variability. That variability needs to be understood.

Cropping intensity and soil carbon are positively related. The more frequent the cropping and greater the biomass inputs, the more soil carbon. Summer fallow reduces cropping intensity. Reducing fallow typically increases soil carbon through greater annualized biomass inputs, but may be economically difficult. No Montana data exist on carbon storage rates due to cropping intensity, but data from southwestern Saskatchewan show average carbon storage rates of about 0.2 tonne/ha/yr (0.09 ton/ac/yr) when converting from 50:50 crop-fallow to continuous cropping. Field research began in 2003 in north central Montana to compare soil carbon accumulation due to no-till adoption and continuous cropping. We expect this research to provide important information about greenhouse gas emissions in the short term, and may serve as long term benchmark sites to support future carbon credit trading.

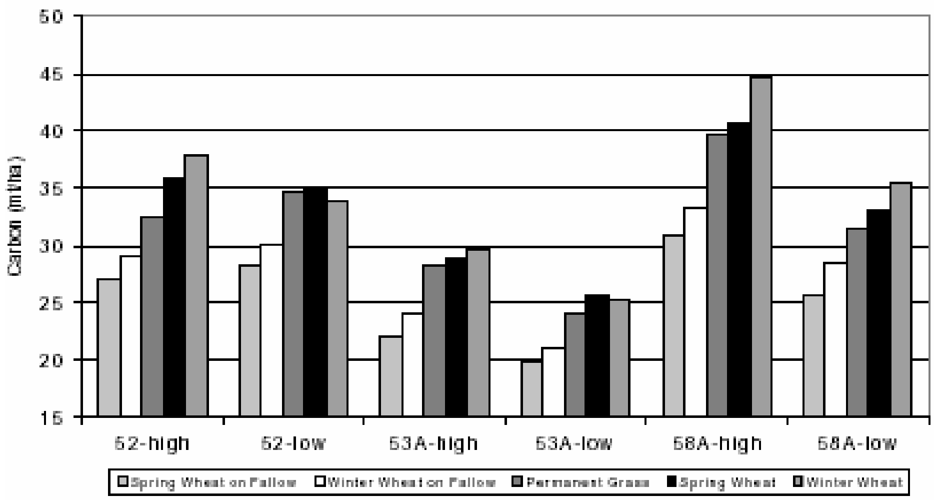
Fertilization affects soil carbon mainly through crop biomass. However the carbon:nitrogen ratio of soil organic matter results in stable organic matter typically within a range of about 8-10:1. If insufficient nitrogen is present to permit stable formation of soil organic matter via soil microbial degradation of crop residues, then little carbon may be sequestered.

<u>How are Soil Carbon and Nitrogen Related?</u> This 8-10:1 carbon:nitrogen ratio means that for every 8-10 lb of carbon sequestered in soil organic matter, 1 lb of nitrogen must accompany it. This tie-up of nitrogen reduces nitrogen for crops. For example, if a farmer adopted no-till that resulted in an increase of soil carbon of 0.45 ton/ac over 10 years, 0.045 t/ac (90 lb) of applied nitrogen would have been tied up in soil organic matter and would not have been available to his crops. Legume crops such as alfalfa, peas, lentils and chickpea could serve as alternative sources for nitrogen. Economic considerations of changing crop rotations should be considered carefully.

<u>Is Nitrous Oxide an Important GHG?</u> Nitrous oxide can be emitted from the soil during both nitrogen mineralization and immobilization processes and is linked to fertilizer nitrogen. The Intergovernmental Panel on Climate Change uses a default value of 1.25 percent of fertilizer nitrogen inputs are lost as nitrous oxide. Since nitrous oxide has a global warming potential equivalent 310 times that of carbon dioxide, a loss of even one pound of nitrous oxide has a large impact, potentially canceling out carbon credits due to carbon dioxide removal. Marked differences in such losses likely exist in different climates, and research is underway to measure such loss in semiarid cropping systems. Indications are that the 1.25 percent used by the IPC carbon is too large for semi-arid environments and may over-estimate nitrous oxide emissions from fertilizer applications in our region. Wet soils favor nitrous oxide losses. More intensive cropping by lowering fallow frequency, which reduces periods of high soil moisture, may minimize nitrous oxide emissions from soils.

III. Some Empirical Results on Changes in Soil Carbon Due to Changes in Management Practices in Montana.

IIIA Century Model results. The crop ecosystem model known as Century is utilized to represent the processes controlling crop growth, water, nutrient, and organic matter dynamics that determine the productivity of agricultural ecosystems (Parton et al 1994.; Paustian, Elliott, and Hahn 1999). Century is a generalized-biogeochemical ecosystem model which simulates C (i.e., biomass), nitrogen and other nutrient dynamics. It includes submodels for soil biogeochemistry, growth and yield submodels for crop, grass, forest and savanna vegetation and simple water and heat balance. For use in agricultural and grassland ecosystems, the model incorporates a large suite of management options including crop type and rotation, fertilization, tillage, irrigation, drainage, manuring, grazing, and burning. The model employs a monthly time step and the main input requirements (in addition to management variables) include monthly precipitation and temperature, soil physical properties (e.g., texture, soil depth) and atmospheric nitrogen. For the current application, soils and climate data for each of the sub-MLRAs are used as Century model inputs in addition to management variables such as crop type and rotation, fertilization and tillage practices. The Parameter-elevation Regressions on Independent Slopes Model (PRISM) data set was used to determine weather-related data. Information on current management systems is from the 1995 survey of Montana producers, augmented with the USDA National Agricultural Statistics Service (NASS) database, the National Resources Inventory (NRI) database, and county-level databases of the National Association of Conservation Districts (NACD). Soil characteristics are determined using the Advanced Very High Resolution Radiometer (AVHRR) database (USGS-Earth Resources Observation System (EROS) Data Center), the State Soil Geographic Database (STATSGO) and the NRI database. Baseline projections of soil C are made using historical climate and land-use records. These projections are compared to NASS records of county-level crop yields and changes in soil C derived from the Century database of native and cultivated soils. The initial land-use allocation from the 1995 Montana survey was used to calculate base C levels for each sub-MLRA. The variability in the levels of soil C predicted by the Century model across the six major crop producing sub-MLRAs and production systems in Montana is shown in Figure 1. Simulations of the crop-fallow, continuous cropping, and permanent grass production systems with the Century model show that the equilibrium levels of soil C under a crop-fallow rotation range from 3–7 MT per hectare less than continuous grass over a twenty year horizon, and that soil C levels under permanent grass range from 1–5 MT per hectare less than under continuous cropping depending upon sub-MLRA. In sub-MLRA 52-low, soil C levels under permanent grass compare favorably with soil C levels under a continuous cropping system. The variability across sub-MLRAs reflects the heterogeneity in biophysical and climatic conditions, which translates into different equilibrium levels of soil C for the production systems.



Note: Soil C levels for barley are the same as for spring wheat.

Figure 1. Soil C levels predicted by Century model for cropping systems in Montana

IIIB Field scale studies. To provide additional information about C sequestration rates in Montana cropland three studies were initiated. The first study, completed in 2003, used a predictive model (Century) to estimate historic gains in soil carbon 6 to 10 yr following conversion to no-till management at six farm fields in north central Montana. When field-specific soil textures were used the model predicted soil C gains within 10% of measured values with soil C sequestration rates ranging from 0.07 to 0.38 tons/acre/yr among the field sites. The second study, initiated in 2002, contrasts the effects of tillage system and cropping intensity on C sequestration in six farm fields in north central Montana. Scientific controls are more rigorous than the first study through the use of a common baseline, a single operator managing all cropping practices, and the field treatments are sufficiently large to be observed with remote sensing. Also, costs, returns and net GHG emissions are being closely monitored for each treatment and augmented with data collected from a survey instrument developed for this study. The third study was initiated in 2002, and compares C sequestration in 9 cropping systems within a replicated experimental plot design. The second and third studies are planned to run 10 years.

The objectives are to:

- Estimate direct and indirect changes in soil organic C and N_2O emissions as result of changes in tillage and cropping intensity.
- Compare alternative tillage systems and cropping intensity for full GHG accounting (energy-related and soil-sequestered C and N_2O) in dryland farm field settings.
- Estimate the potential for C sequestration as a result of adopting windbreaks and riparian plantings using different tree species in locations across the state.

Six paired farm fields in north central Montana were selected to compare conventional with no-till wheat cropping systems (Figure 2). Site selection was constrained by management history, soil characteristics and current crop growth, to enable valid inferential comparisons of these fields based on tillage management. Experimental design involved a randomized 30-m grid sampling approach (Nelson and Buol, 1990) of both tillage systems of adjacent fields within the soil type. Soil sampling was a stratified (depth varied systematically from 50 to 100 cm) protocol using a georeferenced 2x5 m grid approach (B. McConkey, K. Paustian, pers. comm., 2000). Fields were compared for soil organic C differences and sampling intensity was compared for cost efficiency. Measurements were compared with Century model predictions.

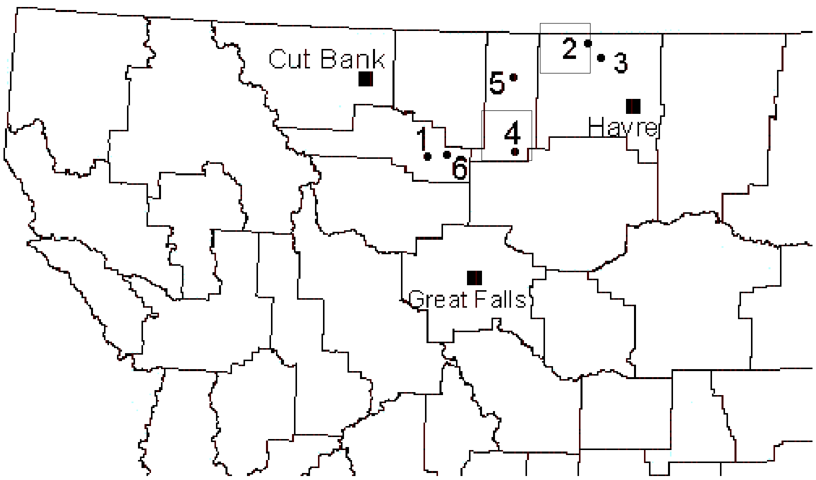


Figure 2. Locations of six farms in north central Montana for the On-farm Tillage Systems Comparison.

The use of agricultural best management practices, most notably the adoption of no-till systems, has become a potential technique to sequester (store) carbon in soils and help mitigate the effects of global warming. Efficient sampling designs and the use of process-based soil organic carbon (SOC) dynamics models are potential methods of monitoring and verifying soil carbon change. This research combined field-scale soil sampling and the use of the Century model to explore field-scale SOC variability and the effects of soil texture input data sources (STATSGO and SSURGO databases) on predicted SOC dynamics in north central Montana. Using soil-landscape associations for field stratification and sampling of microsites for paired management comparisons was an efficient design for measuring SOC (CV = 8-13%). An optimal sampling design of 4 microsites by 2 cores or 3 microsites by 3 cores provided reliable detection of a tillage effect on SOC, given the magnitude of differences (1.3 to 5.1 t C ha^{-1}) and degree of variability measured. Including the effects of soil clay content as a covariant may provide unbiased estimations of the effects of tillage on SOC among sites, particularly for coarse scale comparisons. The Century model accurately predicted SOC content at five sites using site-specific soils data (10% deviation from measured values). Neither the STATSGO (1:250,000 scale) nor SSURGO (1:24,000 scale) soil databases adequately predicted soil textures, nor supplied adequate soil textural information for use in the Century model and so introduced error to field-specific predictions. Century proved to be sensitive to the effects of clay content when predicting the amount of SOC in a particular field; however the model was insensitive to the effects of soil texture on C sequestration as a result of no-till management. The methods used to measure SOC and the Century model proved to be useful tools for determining carbon stored due to no-till management. Additional research is needed to determine if a consistent relationship exists between soil texture and the effect of tillage on SOC and thus determine if adjustments are needed to the Century model's treatment of soil texture.

These results support future measurement, prediction, and general understanding of soil organic carbon sequestration in semiarid dryland agricultural systems. Reliable measurement of soil organic carbon change associated with a shift in tillage management can be difficult, for SOC varies spatially and the degree of variability can be substantial. Confounding variables such as climate, topographic position, erosion potential, and soil texture also vary spatially and can greatly influence SOC change across small distances. A soil-landscape association method of field stratification addressed these confounding variables effectively and reduced SOC measurement variability; however, due to natural variation in soil texture, differences in soil texture still occurred between tillage treatments at some sites. Differences in soil textures may confound determination of the tillage effect, particularly at regional and larger areas. A measure of soil texture (i.e., % clay) was added as a covariant in statistical analyses. Including percent clay as a covariant provided estimates of SOC under no-till and tilled management adjusted for differences in clay content, and reliable determination of tillage effects.

The effect of soil textural variation at field-, 1:24,000 (SSURGO), and 1:250,000 (STATSGO) scales on the predictive capability of the Century model was explored. Both the SSURGO and STATSGO databases were limited in their accuracy of predicting soil textures at the sampled fields. Ranges in clay percentage reported by SSURGO included the measured values for three of 10 fields and STATSGO included five of 10. Due to the differences in scale, the width of the STATSGO ranges in clay % were two to seven times as wide as the SSURGO ranges. The shortcomings of these soils databases had a large effect on the accuracy of Century model predictions. Using field-scale soil textures and site-specific management data, Century accurately predicted soil organic carbon at five sites in north central Montana to within an average of 10% (range of -1 to +28%) of measured values.

Soil organic carbon estimates from Century for the management systems in this study were sensitive to the effect of clay content based on the range of modeled soil organic carbon values. Estimated SOC for the upper limit of reported clay content was 2.3 to 2.7 times greater than SOC estimates for the lower clay limit at the five sites modeled using STATSGO database ranges in clay content. Conversely, Century was largely insensitive to the effects of soil texture on the potential soil carbon change in response to the adoption of no-till. Century did not predict the amount of implied carbon change in response to the adoption of no-till at the five sites modeled in this study over a wide range in clay percentages. Model results for the five sites in Montana showed little difference in the amount of carbon stored in coarse-textured soils (5% clay) compared to fine-textured soils (35-40% clay), with the exception of the Ft. Benton site. The insensitivity of Century to a soil textural effect on C storage under no-till management assumes that a strong relationship exists between soil texture and the effect of tillage on soil organic carbon. This relationship is currently not well understood.

Additional analysis of the Century model's sensitivity to soil textural input variables is needed to determine if adjustments to the model would be necessary. This research was not an exhaustive look at the effects of soil texture on Century's predictive capabilities. Largely, it was shortcomings of the SSURGO and STATSGO soils databases that limited the effectiveness of Century. The model was sensitive to the effects of soil texture when predicting the amount of SOC in fields managed with and without tillage; however the model was not sensitive to the effects of soil texture on the ability of a particular soil texture to accumulate SOC over a 6-to-10-year period of no-till management. From a modeling standpoint, neither the SSURGO nor the STATSGO databases provided adequate soil textural information for use in the Century model, thus site-specific soil information is recommended for use with the Century model.

IV. Some empirical results for other parts of the Great Plains

In order to provide some additional information on how the best practices for sequestering soil carbon are spatially dependent, we report some preliminary results for grain and corn production in Nebraska, and compare no-till and reduced tillage practices to conventional tillage. The Century model provided estimates of carbon rate changes and crop yield changes.
Tillage options included conventional tillage (C), reduced tillage (R), and no-till (N). We also considered a CRP option within the tillage simulation scenario. Conventional tillage change to

CRP sequesters highest amount of carbon followed by reduced tillage to CRP and no-till to CRP for all dryland crop rotations. For irrigated crops, conventional to no-till change sequesters highest amount of carbon. Table 1 gives the carbon change estimates for selected rotations and selected tillage options.

Soil carbon change by MLRAs indicates that there is virtually no spatial variation for switching from conventional tillage practice to no-till. However, switching to CRP from conventional or no-till yields to higher rates of soil carbon in MLRA 75 and MLRA 106 compared to MLRA 73. This variability reflects the spatial heterogeneity in the biophysical and climate conditions across the survey transect.

Since switching to CRP sequesters 3 to 4 times as much carbon as opposed to switching to no-till, the economic simulation model is expected to yield higher degree of land use changes toward CRP for a given carbon price and CRP payment.

Table 1. Soil carbon change for consolidated rotations and tillage switch

Rotations	***Carbon change due to tillage change (mt/acre/year)***		
	C to N	***C to CRP***	***N to CRP***
Dryland Crops:			
Corn-soybean-sorghum	***0.12***	***0.48***	***0.36***
Wheat-corn-fallow	***0.10***	***0.54***	***0.44***
Fallow-wheat	***0.07***	***0.59***	***0.52***
Continuous wheat	***0.08***	***0.49***	***0.41***
MLRA 73			
Corn-soybean-sorghum	***0.13***	***0.43***	***0.31***
Wheat-corn-fallow	***0.10***	***0.49***	***0.39***
Fallow-wheat	***0.06***	***0.54***	***0.48***
Continuous wheat	***0.08***	***0.44***	***0.37***
MLRA 75			
Corn-soybean-sorghum	***0.12***	***0.49***	***0.37***
Wheat-corn-fallow	***0.10***	***0.56***	***0.46***
Fallow-wheat	***0.07***	***0.61***	***0.54***
Continuous wheat	***0.08***	***0.51***	***0.43***
MLRA 106			
Corn-soybean-sorghum	***0.12***	***0.50***	***0.38***
Wheat-corn-fallow	***0.10***	***0.57***	***0.47***
Fallow-wheat	***0.07***	***0.62***	***0.55***
Continuous wheat	***0.08***	***0.51***	***0.43***
Irrigated Crops:			
Corn-soybean	***0.19***	***-***	***-***
MLRA 73			
Corn-soybean	***0.19***	***-***	***-***
MLRA 75			
Corn-soybean	***0.19***	***-***	***-***

C = Conventional till; N = No-till; CRP = Conservation Reserve Program

Given the land use changes within each MLRA based on maximizing expected returns, the levels of soil carbon sequestered are calculated using the equilibrium average soil carbon rates for each field obtained from the Century model. The Century model preliminary results indicate that reduced tillage changes for the selected dryland crop-rotations enhance soil carbon levels. The average amount of carbon sequestered under these tillage scenarios for each MLRA and the total carbon sequestered over all three MLRAs are presented in Table 2.

Table 2. Average and total carbon sequestration by MLRAs

	Soil carbon (000 mt) over 20 years			
	C to N	***C to CRP***	***N to CRP***	***All Changes***
Average MLRA 73	***0.6***	***43.4***	***19.4***	***63.4***
Average MLRA 75	***3.7***	***16.5***	***5.6***	***25.9***
Average MLRA 106	***3.0***	***4.6***	***1.7***	***9.3***
Total for MLRAs in survey transect	***73.8***	***645.0***	***266.9***	***985.7***
Total for MLRAs in Nebraska State	***25,991.1***	***274,595.8***	***117,269.3***	***417,856.2***

Assuming identical crop productivity and soil carbon rates for the entire MLRA areas within the state of Nebraska, the model simulation is extrapolated for and entire MLRA areas and the total amount of soil carbon that could be sequestered for the entire MLRA areas is presented in the last row of Table 2. The total amount of carbon sequestered for the entire Nebraska MLRA areas range between 26 million metric ton for CN scenario and 275 million metric tons for the CCRP scenario over the 20 year period.

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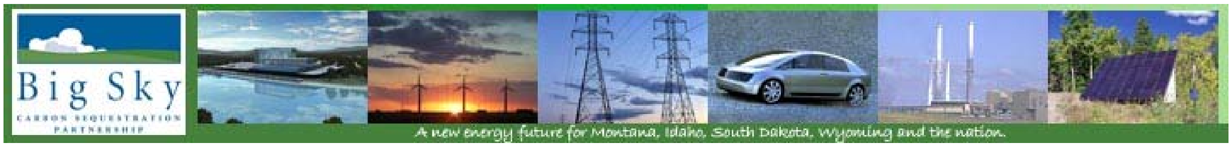

Big Sky Carbon Sequestration Partnership – Phase I

Deliverable 18:
Action Plan for Outreach and Education

June 2005

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Big Sky
Carbon Sequestration Partnership

Education and Outreach Plan

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1 I. BACKGROUND

On August 16, 2003, the U.S. Department of Energy (DOE) named seven regional partnerships of state agencies, universities and private companies to form the core of a nationwide network to determine the best approaches for capturing and permanently storing greenhouse gases (GHGs) in their regions. DOE has designated Montana State University (MSU) in Bozeman to lead one of the partnerships. Called the Big Sky Carbon Sequestration Partnership ("Partnership"), the group consists of 14 public and private organizations including two Indian tribes. Funded with a $1.6-million DOE grant matched by $400,000 of state and regional dollars, the Partnership will identify the most suitable ways of sequestering GHGs in Montana, Idaho and South Dakota.

PARTNERSHIP TEAM	
Partner Name	Location
Montana State University	Bozeman, MT
South Dakota School of Mines and Technology	Rapid City, SD
University of Idaho	Moscow, ID
Boise State University	Boise, ID
Los Alamos National Lab	Los Alamos, NM
Idaho National Engineering and Environment Lab	Idaho Falls, ID
National Carbon Offset Coalition	Butte, MT
Montana Governor's Carbon Sequestration Working Group	Bozeman, MT
Texas A&M University	College Station, TX
EnTech Strategies, LLC	Washington, DC
The Sampson Group	Arlington, VA
Environmental Financial Products	Chicago, IL
The Confederated Salish and Kootenai Tribes	Pablo, MT
Nez Perce Tribe	Lapwai, ID

The Partnership will also develop a framework to validate and potentially deploy carbon sequestration technologies, study regional regulations, safety and environmental concerns and explore public acceptance issues. At the end of the first, two-year phase, the Partnership will recommend technologies for small-scale validation testing in a Phase II competition expected to begin in 2005.

This document outlines the Partnership's education and outreach goals, key constituents and activities. It is intended to serve as a guide for implementing outreach activities under Phase I, commencing October 1, 2003 through June 2005.

2 II. EDUCATION AND OUTREACH GOALS

The primary goal of the Education and Outreach Plan is to increase awareness, understanding and public acceptance of carbon sequestration and build support for the Partnership; however, each constituent group also has targeted outreach goals. The Partnership's eight key constituencies include: scientific and research community; the university community; environmental non-governmental organizations (NGOs); industry; farmers, ranchers and land owners; Native American Tribal Nations; state legislative and regulatory officials; Stakeholders and the general public. Targeted goals for these constituencies are:

University Community: Encourage new and future research scientists and collaborations and design a competition for carbon sequestration research papers in collaboration with the American Society of Mechanical Engineers (ASME).

Environmental NGO Organizations and Professional Societies: Define and facilitate opportunities for technical and public outreach collaborations.

Industry: Secure sponsorship for carbon sequestration research paper contest and other outreach activities, and facilitate partnerships for participation in voluntary carbon trading pilot programs.

Farmers, Ranchers and Landowners: Facilitate partnerships for participation in voluntary carbon trading pilot programs and collaborate on education and outreach activities.

Native American Tribal Nations: Facilitate partnerships for participation in voluntary carbon trading pilot programs and collaborate on education and outreach activities.

State and Regulatory Officials: Determine the legislative and regulatory barriers and pathways to implementing carbon sequestration projects and explore economic development opportunities that may emerge from the development and commercialization of carbon and GHG measurement technologies.

General Public: Broaden understanding of carbon sequestration and stimulate informed public discussion.

3 III. MAIN ACTIVITIES

The main education and outreach activities designed to help achieve the above goals include:

Education and Outreach Plan: The plan outlines the Partnership's education and outreach goals, constituencies, activities and timeline and serves as a guide for implementing Phase I outreach activities.

Partnership Listserv: A Partnership Listserv is an electronic "mailing list" that will enable members to send messages or announcements to everyone in the Partnership at once. The Partnership will establish both an internal Listserv for Partnership business issues and an external Listserv open to all interested parties. Messages sent or posted to the external mailing list will be saved in a list archive and posted on the Partnership website.

Partnership Brochure: The brochure will provide background information on carbon sequestration, DOE's carbon sequestration program and the Partnership. It will be written in non-technical language and address the most frequently asked questions of policymakers, the media, and the general public.

Partnership Poster and Display: A partnership poster and display will be developed for general distribution and used in conference poster sessions and public outreach events.

Website: A website designed to share information about the Partnership and carbon sequestration will be developed. Content will include: Partnership introduction; key issues; DOE program overview; Partnership news and publications; events and a community bulletin board.

Community Roundtable Discussions: A series of community roundtables or small seminars to discuss the Partnership activities and carbon sequestration approaches will be held. Seminars will be conducted at high schools, universities, state legislatures and other public venues.

Strategic Workshops: The Partnership will hold three workshops – one in Montana, Idaho and South Dakota -- to engage community leaders who will be key to implementing carbon sequestration projects. Groups may include: elected and regulatory officials; state sequestration advisory committee members; tribal leaders; journalists; environmental NGOs; labor organizations; entrepreneurs; industry; landowners and academia.
Workshops will be held to introduce carbon sequestration and determine barriers and implementation strategies for carbon sequestration projects in each state. The information exchanged at these workshops will provide the basis for the potential development of a public outreach plan for deployment during Phase II.

Washington Seminar on Carbon Sequestration: Corresponding to the date of the DOE National Energy Technology Laboratory's (NETL) Carbon Sequestration Conference in 2005, the Partnership will sponsor a seminar in Washington, D.C. for interested stakeholders that includes an award ceremony and reception for the research paper competition co-sponsored with ASME. The seminar will provide an opportunity for the Partnership to directly interface with its Stakeholders, introduce Partnership activities and outline possible carbon sequestration approaches for the region. A photographer will cover the seminar and news stories will be developed for various local news outlets.

Carbon Sequestration Research Paper Competition: In collaboration with ASME, the Partnership will design a carbon sequestration research paper competition for undergraduate and graduate students in MT, ID and SD that includes a discussion on the issues of implementing a Phase II project. ASME will review the papers and one or more awards will be given to a student in each state. The prize will be a trip to Washington, DC, attendance at the 2005 NETL Carbon Sequestration Conference and the Washington Seminar on Carbon Sequestration. An awards ceremony and reception that is covered by press will be held following the seminar. (The number of prizes awarded will be contingent on the Partnership's ability to raise funds from industry sponsors.)

4 IV. TASKS AND TENTATIVE TIME LINE

TASK	TIMELINE
Education and Outreach Plan	October 15, 2003
Listserv	November 15, 2003
Website (Content)	February 27, 2004
Website Launch	March 15, 2004
Website Maintenance	March 15, 2004 – ongoing
Brochure	March 31, 2004
Poster and Display	March 31, 2004
Community Roundtable Discussions	April 1, 2004 – ongoing
Strategic Workshops	April 1, 2004 – ongoing
Washington Seminar on Carbon Sequestration	To correspond with NETL Carbon Sequestration Conferences in 2005
Sequestration Research Paper Competition	February 2004 call for papers
Carbon Sequestration Research Paper Competition Awards Ceremony	To correspond with 2005 Washington Seminar on Carbon Sequestration and NETL Carbon Sequestration Conference