Big Sky Carbon Sequestration Regional Partnership

www.bigskyco2.org

Annual Program Review Meeting
November 16-17, 2004

Overview

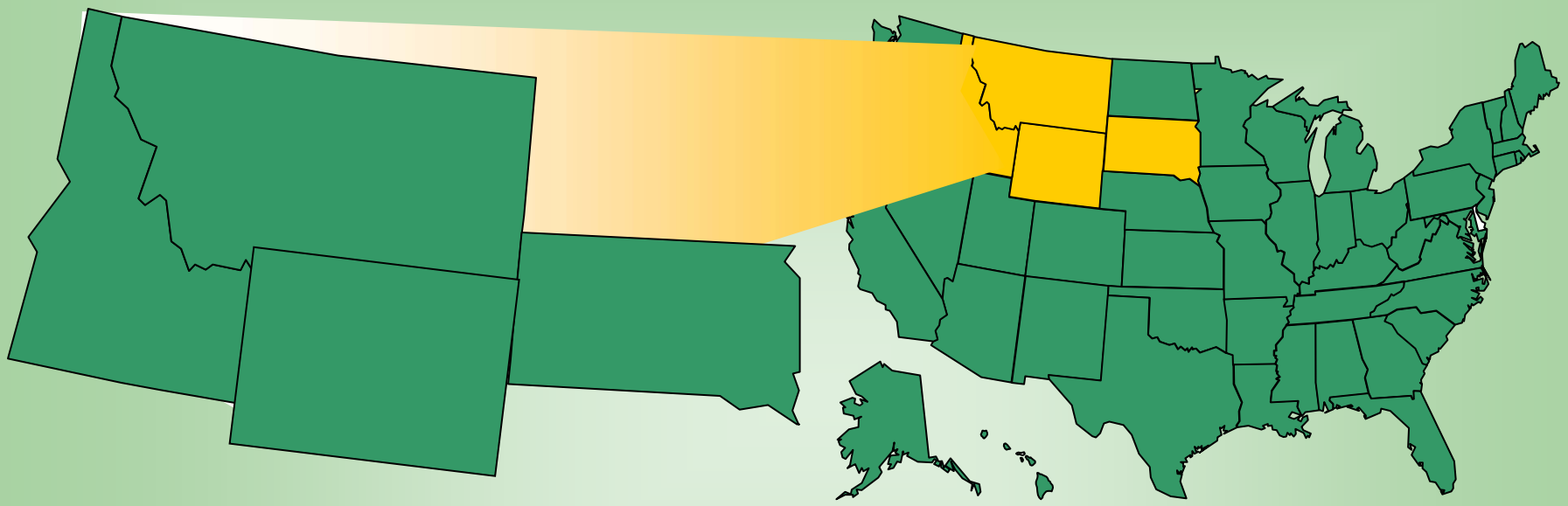
Updates: Susan Capalbo, MSU

GIS: Paul Rich, LANL

Geological Sequestration: Bob Smith, U Idaho

Terrestrial Sequestration: Susan Capalbo

Education and Outreach: Pamela Tomski, EnTech Strategies



<u>Focal States</u>: Idaho, Montana, South Dakota, Wyoming

Initial Partners:

Montana State University-Bozeman
University of Idaho
Boise State University
South Dakota School of Mines and Technology
Texas A&M University
Idaho National Engineering and Environmental Laboratory
Los Alamos National Laboratory
EnTech Strategies and New Directions
National Carbon Offset Coalition
Inland Northwest Regional Alliance
States of Montana, Governor's Office
Nez Perce Tribe
The Confederated Salish and Kootenai Tribes

New Coverage:

Wyoming

New Partners (confirmed):

Montana Bureau of Mines and Technology

University of Wyoming/
WY Carbon Sequestration Advisory Committee

ID Carbon Sequestration Advisory Committee/
ID Soil Conservation Service

Montana Department of Environmental Quality

Western Governors' Association

New Partners (not yet confirmed)

Puget Sound Energy

Colstrip “Big Four”

Ducks Unlimited, US

WY Department of Environmental Quality

Jackson Hole Center for Global Affairs

Sempra (CA, ID)

Plasma, INC (MT)

Mt Rural Electric Cooperatives

Eastern Montana Economic Coalition

MRED

Yellowstone Business Partners

Collaborations

USDA and CASMGS

Canada -- BIOCAP CA

China –Shanxi Province

IOGCC

Norway

Budget

Primary:

- authorized: $1,198,279 (excluding labs, matching, etc.)
- spent: $416,344
- balance: $781,934

Matching:

- authorized: $399,610
- spent: $148,563
- balance: $251,046

LANL and INEEL:

- authorized: $400,000

- **Oct 2003** Outreach - action plan for carbon sequestration implementation
- **Nov 2003** Outreach - web site (to Jun 2005)
- **Nov 2003** Outreach - proceedings from innovation sessions/workshop (ongoing to Mar 2005)
- **Mar 2004** Advanced Concepts - planning standards, protocols and contracting options ready to implement within the region in Phase II (ongoing to Mar 05)
- **Sep 2004** Terrestrial Sequestration - data collection summaries for rangeland
- **Nov 2004** Advanced Concepts - contracting and project implementation handbook
- **Nov 2004** Terrestrial Sequestration - literature review and data collection report (changed from Mar 04 to include Wyoming)
- **Dec 2004** Advanced Concepts - measurement, monitoring and verification technology assessment report

- **Jan 2005** Geological Sequestration, GHG source and infrastructure characterization - report on infrastructure data compilation and analysis (changed from July 04 to include Wyoming)
- **Jan 2005** Geological Sequestration - report and action plan on the evaluation of geologic sinks and pilot project deployment (changed from July 04 to include Wyoming)
- **Jan 2005** Terrestrial Sequestration - action plan report and infrastructure needs for enhancing terrestrial sequestration sinks (changed from Jul 04 to include Wyoming)
- **Mar 2005** Geological Sequestration - report on technology needs (changed from Nov 2004 to include Wyoming)
- **Mar 2005** Terrestrial Sequestration - manuscript on carbon budget and analyses/GIS database (changed from Sept 04 to include Wyoming)
- **Mar 2005** Terrestrial Sequestration - report on the interface between C-lock and producer decision support framework
- **Mar 2005** Terrestrial Sequestration - volume table development

- **Mar 2005** Advanced Concepts – report on results of best production practice for soil C sequestration
- **Jun 2005** Terrestrial Sequestration - report on evaluation of terrestrial sinks (to include Wyoming – same time frame)
- **Jun 2005** Advanced Concepts – report on the feasibility of mineralization trapping in the Snake River Plain Basin.
- **Jun 2005** Advanced Concepts – report on common methodology for assessing tradeoffs among carbon sinks.
- **Jun 2005** Advanced Concepts – overall assessment and evaluation report and workshop proceedings on advanced concepts for geological and terrestrial sequestration.
- **Jun 2005** Outreach – a summary of public comments.

GIS

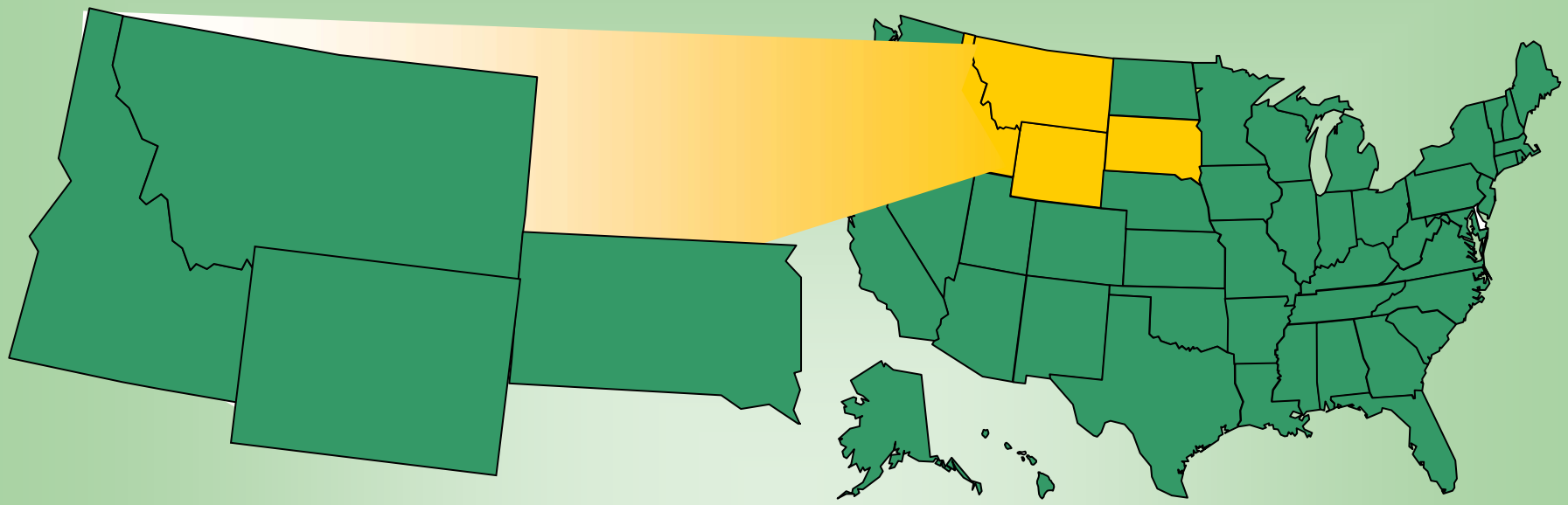
Paul Rich
Los Alamos National Laboratory

Randy Lee
Idaho National Engineering and Environmental Laboratory

Karen Updegraff, Maribeth Price, and Rick Clawges
South Dakota School of Mines and Technology

Richard Aspinall and Leslie Jones
Montana State University

Big Sky GIS



<u>Focal States</u>: Idaho, Montana, South Dakota, Wyoming

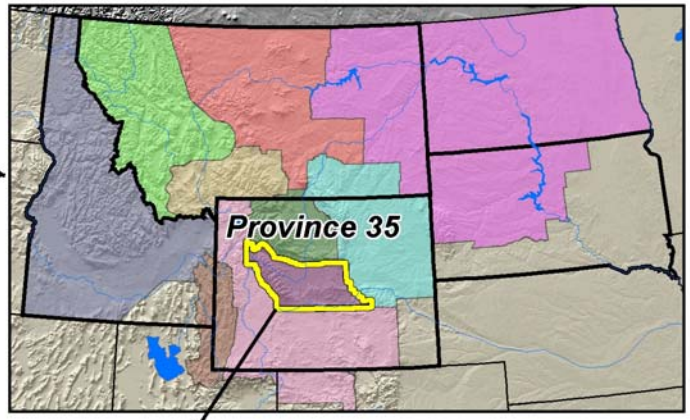
Task	Description
3	Incorporate Geologic, Infrastructure, and GHG Source Data into GIS

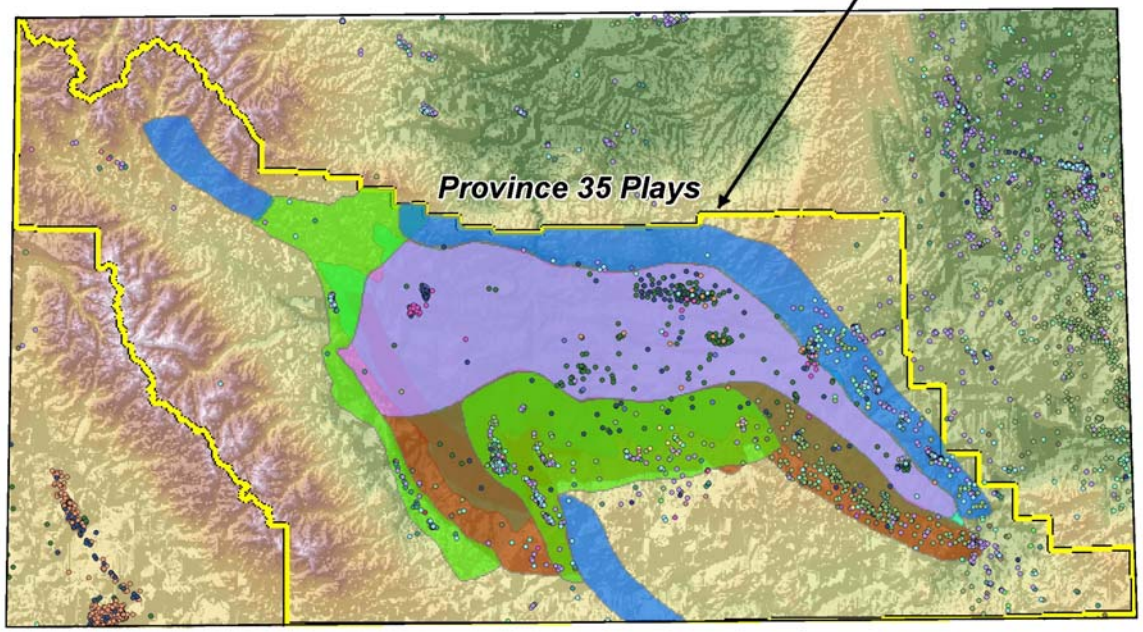
Big Sky Geological GIS

INEEL Lead

- **<u>Focal States</u>:** Idaho, Montana, South Dakota, Wyoming
- **<u>Goal</u>:** assess geologic sequestration potential of sedimentary and volcanic basins (deep saline aquifers, depleted oil/gas reservoirs, deep unminable coal beds, mafic/rock hosted fresh aquifers)
- **<u>First Year</u>:** develop GIS database structure; identify sources of data; begin populating database
- **<u>Second Year</u>:** complete populating database; deliver data for placement on server; use data to determine geological sequestration potential

Big Sky Partnership Geologic GIS Data Holdings

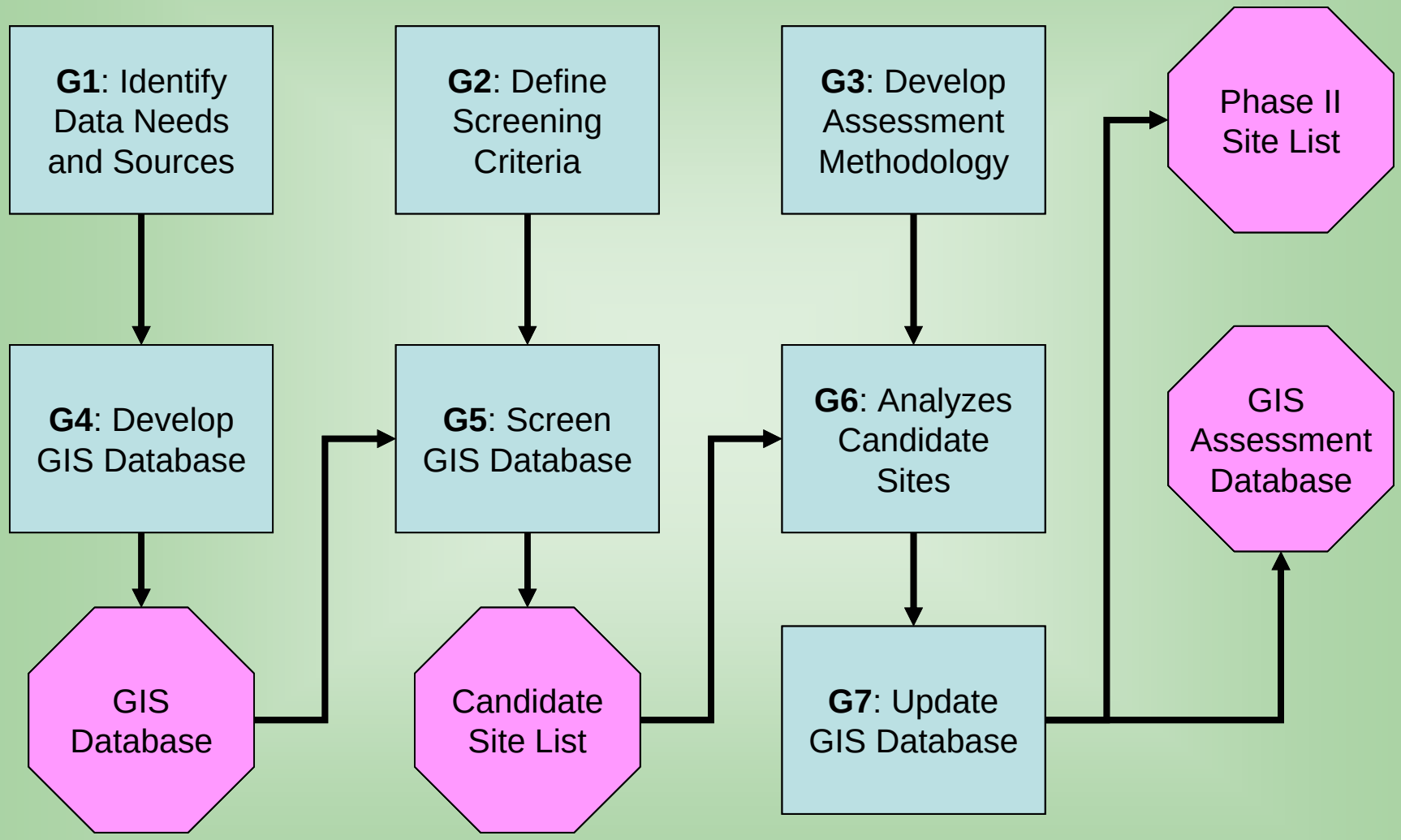




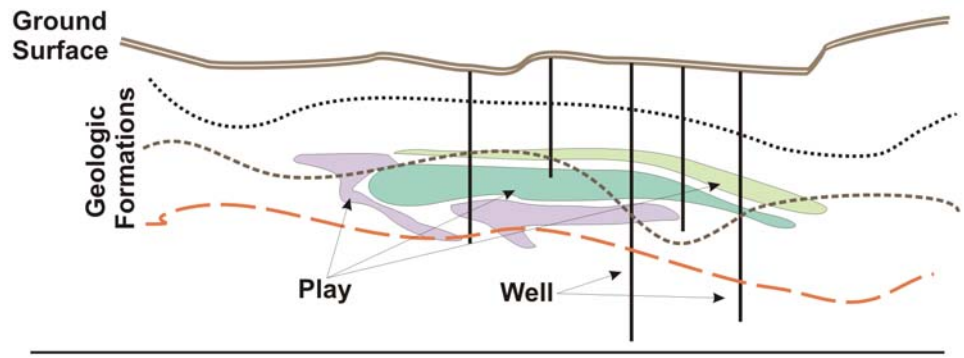
Wells by Formation

- CLOVERLY
- CODY
- CROW MOUNTAIIN
- DAKOTA
- FORT UNION
- FRONITER
- JELM
- LAKOTA
- LANCE
- MADISON
- MEETEETSE
- MESAVERDE
- MORRISON
- MUDDY
- NUGGET
- PHOSPHORIA
- SUNDANCE
- TENSLEEP
- WIND RIVER

Process to Organize Data and Model Sequestration Potential



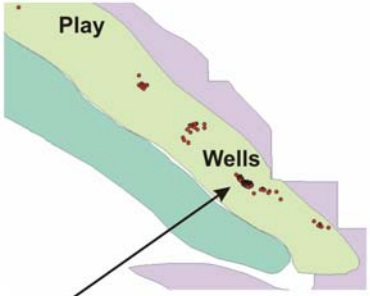
Carbon Sequestration GIS Database Design



Well Information Table

	LONGITUDE	LATITUDE	API_NUMBER	TOW	RAN	SEC	SUR	QTR_QTR	ALIQUOT	WELL
1	-105.986670	41.444200	49-001-05148	17N	77W	13	W	NE SE	635 FNL 250 FEL	FREDERICK G HOLST 15
2	-105.976550	41.439660	49-001-20113	17N	78W	18	W	SE SW	200 FSL 1800 FWL	WILSON 12
3	-107.859050	44.246010	49-003-05217	49N	92W	1	W	NW SW	1980 FSL 660 FWL	FEDERAL 5
4	-107.931910	44.267420	49-003-05245	50N	92W	32	W	NE NE	660 FNL 660 FEL	MANDERSON UNIT F-41-32-P
5	-108.533350	44.794197	49-003-06209	56N	97W	33	W	NW NE	2040 FNL 660 FEL	CROSS GAS 7
6	-108.462440	44.782860	49-003-06268	56N	97W	25	W	SE SW	220 FNL 1542 FEL	STATE 3
7	-108.575470	44.800320	49-003-06278	56N	97W	30	W	NE SE	1580 FSL 1000 FEL	KINNEY COASTAL 14
8	-108.507420	44.825870	49-003-06418	56N	97W	14	W	SW SW	325 FSL 440 FEL	HOSKINS A 4
9	-107.977820	44.380300	49-003-06605	51N	93W	24	W	SW NE	1850 FNL 2300 FEL	TLMTU 24
10	-107.981170	44.405670	49-003-20178	51N	93W	12	W	NE NW	2121 FSL 2121 FWL	ANTICLINE UNIT 12
11	-108.544960	44.794140	49-003-20188	56N	97W	33	W	NE NW	200 FNL 1077 FEL	GEORGE EASTON 8
12	-108.550580	44.797310	49-003-20198	56N	97W	28	W	SW SW	400 FSL 425 FEL	P O SESSIONS 4
13	-108.535210	44.783780	49-003-20286	56N	97W	33	W	SE SE	535 FNL 925 FEL	VERNON SMITH 13
14	-108.543830	44.794630	49-003-20790	56N	97W	28	W	SW SW	513 FNL 1897 FWL	GEORGE EASTON 12
15	-108.534860	44.791070	49-003-20792	56N	97W	33	W	SE NE	625 FNL 659 FWL	YATES 5
16	-108.545940	44.795780	49-003-20842	56N	97W	33	W	NE NW	2653 FSL 1374 FWL	CROSS GAS 13
17	-108.577380	44.809520	49-003-20924	56N	97W	19	W	SW SE	361 FSL 1500 FEL	KINNEY COASTAL 100
18	-108.583230	44.808627	49-003-20925	56N	97W	30	W	NE NW	813 FNL 2171 FWL	KINNEY COASTAL 99
19	-108.577910	44.803460	49-003-20931	56N	97W	30	W	SW NE	1848 FNL 1638 FEL	UTAH SOUTHERN 72
20	-108.533320	44.869450	49-003-20973	56N	97W	4	W	NW NE	94 FNL 577 FEL	WELCH 4
21	-108.551820	44.794310	49-003-20977	56N	97W	32	W	NE NE	863 FNL 169 FEL	UTAH SOUTHERN 73
22	-108.536150	44.780230	49-003-20979	56N	97W	33	W	SE SE	1401 FNL 1387 FEL	VERNON SMITH 17
23	-108.536250	44.780230	49-003-20980	56N	97W	33	W	SE SE	1401 FNL 1412 FEL	VERNON SMITH 16
24	-107.953880	44.291560	49-003-20989	50N	92W	19	W	SW NE	1876 FNL 1511 FEL	MANDERSON UNIT 32-19I
25	-107.955040	44.284150	49-003-20995	50N	92W	19	W	SW SE	687 FSL 1794 FEL	MANDERSON UNIT 34-19P
26	-108.609440	44.943050	49-003-21008	57N	97W	7	W	NW NE	330 FNL 2310 FEL	SAGE CREEK UNIT 22
27	-108.582301	44.797230	49-003-21025	56N	97W	29	W	SE SW	456 FSL 2437 FWL	UTAH SOUTHERN 71
28	-108.526000	44.829230	49-003-21044	56N	97W	15	W	NE SW	1590 FSL 1494 FWL	HOSKINS B 6
29	-108.526000	44.829230	49-003-21044	56N	97W	15	W	NE SW	1590 FSL 1494 FWL	HOSKINS B 6

X Y coordinates from table used to build Well Map



Formation Table

API_NUMBER	TD	WELL_CLASS	TD_FORM	STATUS	COMPLETED	APPROVED	SYMBOL	TOP1	DEPTH_TOP1	TOP2	DEPTH_TOP2
49-001-05148	DAKOTA	OIL	5511	PR	6/25/2000	3/1/1948	11	TENSLEEP	5372		
49-001-20113	TENSLEEP	OIL	5555	PS	6/28/2002	12/13/2001	11	TENSLEEP	5318		
49-003-05217	TENSLEEP	OIL	6840	FL	7/7/1999	4/7/1960	11	TENSLEEP	5830	AMSDEN	5946
49-003-05245	PHOSPHORIA	OIL	7396	PA	3/2/1953	12/22/1952	61	TENSLEEP	5042	LEWIS	5262
49-003-06209	MADISON	GAS	4395	FL	7/1/1999	2/23/1950	12	TENSLEEP	3112	MADISON	3382
49-003-06268	EMBAR	OIL	5489	DR	12/15/1946	9/27/1946	41	TENSLEEP	6790	AMSDEN	7082
49-003-06278	MADISON	OIL	4877	PR	4/6/1946	12/12/1945	11	TENSLEEP	4121	MADISON	4420
49-003-06418	TENSLEEP	INJECTOR	5758	AI	2/7/2003	8/28/1958	11	TENSLEEP	5138	AMSDEN	5395
49-003-06605	PT	OIL	3680	PR	7/21/2000	4/17/1968	11	TENSLEEP	3080		
49-003-20178	MADISON	OIL	4394	PR	6/22/1970	4/29/1970	11	TENSLEEP	3606	MADISON	3802
49-003-20188	MADISON	GAS	4590	FL	7/1/1998	8/25/1970	12	TENSLEEP	3120	MADISON - A	3520
49-003-20198	MADISON	OIL	4535	FL	12/0/1998	8/5/1971	11	TENSLEEP	3242	AMADEN	3343
49-003-20286	MADISON	OIL	4540	FL	2/1/1974	10/30/1973	11	TENSLEEP	3454	AMSDEN	3604
49-003-20790	MADISON	OIL	4560	SI	8/14/1998	3/18/1987	21	TENSLEEP	3106	AMSDEN	3388
49-003-20792	DAKOTA	GAS	4505	SI	5/11/1998	7/16/1987	22	TENSLEEP	3180	DARWIN	3424
49-003-20842	MADISON	OIL	4560	DR	12/27/1989	10/20/1989	41	TENSLEEP	3200	AMSDEN	3325
49-003-20924	EMBAR	OIL	4755	PR	8/31/1997	12/13/1995	11	TENSLEEP	4202	AMSDEN	4307

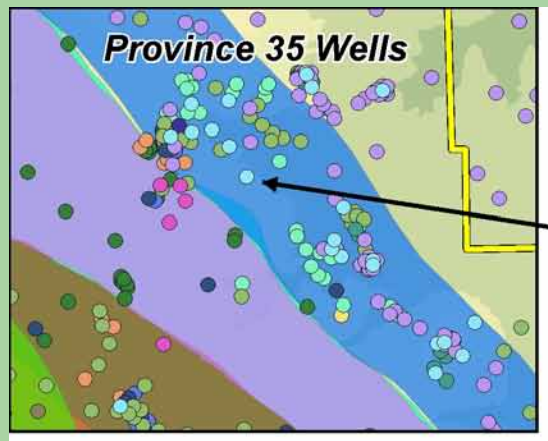
Water Chemistry

API	Top	Base	Temp	RW	Pres	Formation
049-007-20220	5062	5140	130	0	1584	Cloverly
049-013-21202	3960	4050	130	2	1800	Dakota
049-013-20113	5172	5220	132	0	1870	Dakota
049-013-20783	4903	4923	0	5	2265	Dakota
049-025-21678	4525	4620	148	0.6	2082	Dakota
049-025-21039	7366	7417	174	4.5	2796	Dakota
049-025-21221	7210	7250	159	0	2226	Dakota
049-025-20501	6375	6387	152	0	604	Dakota
049-025-20006	7285	7314	0	0	0	Dakota
049-009-21828	6830	6866	136	5	1086	Dakota
049-009-20695	5880	5992	167	2.2	2552	Dakota
049-009-20078	6341	6395	130	3.2	1985	Dakota
049-009-21927	4720	4774	88	0	0	Dakota
049-009-22231	5001	5021	112	42	1448	Dakota
049-009-27895	5110	5148	114	1.7	2207	Dakota
049-007-05575	1285	1298	88	0	478	Dakota
049-007-21458	6402	6436	0	2.8	161	Dakota
049-001-20059	6331	6368	144	2	2327	Dakota
049-001-20005	5890	5902	134	0	1803	Dakota

Pressure Table

Api Number	SODIUM	POTASIM	LITHIUM	CALCIUM	MAGNESIUM	IRON	SULFATE	CHLORIDE	CARBONATE	BICARBONATE	HYDROXIDE	HYD SULFIDE	Dialy Solids	pH	Formation
049-025-05408	823.19	7	0.32	14	2.2	0.05	80	1250	0	0	0	0	2176.76	7.9	Cloverly
049-035-22239	1190	88.7	0	1700	3.18	0.09	93	3300	0	609	0	0	12100	7.89	Lance
049-035-22233	1590	33.1	0	34.9	0.38	4.83	60	1340	0	1430	0	0	4960	7.55	Lance
049-035-22288	761	0	0	489	0	0	194	1950	0	780	0	0	5120	8.96	Lance
049-035-21543	1380	88.7	0	2940	3.83	0	18	7000	0	462	0	0	12000	8.97	Lance
049-035-21546	1080	0	0	1.74	1.45	0	30.5	1220	0	1310	0	0	4130	8.24	Lance
049-035-21667	1100	78.8	0.74	5.34	0.93	8.08	77.3	1780	0	1770	0	0	4880	7.44	Lance
049-035-21942	950	0	0	0.65	0.39	0	220	913	0	1200	0	0	3670	7.44	Lance
049-035-21764	1220	0	0	6.7	0.77	0	100	1020	0	1580	0	0	4720	7.28	Lance
049-035-22241	1620	171	0	1540	17.2	0	126	4000	0	800	0	0	9540	7.38	Lance
049-035-21556	991	0	0	5.63	0.72	0	260	945	0	609	0	0	2870	8.07	Lance
049-035-21591	844	0	0	108	3.57	0	30.5	4570	0	447	0	0	2600	7.91	Lance
049-035-21595	215	0	0	0	0.15	0	9.88	103	347	0	0	0	1260	7.04	Lance
049-035-21918	264	0	0	3.45	0.56	0	196	362	0	651	0	0	1290	6.93	Lance
049-035-21958	258	9.71	0	897	0.32	0	4	2000	0	171	0	0	3500	7.19	Lance
049-035-21960	902	0	0	90.2	4.06	0	88.1	1570	0	467	0	0	3300	7.34	Lance
049-035-22065	3200	0	0	154	31.7	0	41.2	6000	0	839	0	0	15500	6.95	Lance

Big Sky Carbon Sequestration Partnership
A new energy future for Montana, Idaho, South Dakota, Wyoming and the nation.



Well Attribute Table

Attributes of wy_well_pts point

API_NUMBER	LATITUDE	LONGITUDE	ELEVATION	TOP1	DEPTH1	TOP2	DEPTH2
49-025-20691	42.66351	-106.61611	5334	SUNDANCE	7800	CROW MOUNTAIN	8076
49-025-20692	43.16717	-106.23308	5645	DAKOTA	7038	FUSON,FM (INYAN KARA GP)	7090
49-025-20692	43.16717	-106.23308	5645	FRONITER	5746	MOWRY,MBR (SH)	6668
49-025-20692	43.16717	-106.23308	5645	MUDDY	6902	SKULL CREEK,SH	6913
49-025-20693	43.3879	-106.31106	4965	MORRISON	2595	SUNDANCE,FM	2762
49-025-20693	43.3879	-106.31106	4965	SUNDANCE	2762	TENSLEEP,FM	3932
49-025-20694	43.40808	-106.29842	4898	SUNDANCE	2747	TENSLEEP,FM	3941
49-025-20695	42.79793	-107.23684	6791	FRONITER	1173	FRONTIER 1ST	1280
49-025-20695	42.79793	-107.23684	6791	FRONITER	1280	FRONTIER 2ND	1533
49-025-20695	42.79793	-107.23684	6791	FRONITER	1533	FRONTIER 3RD	1627
49-025-20695	42.79793	-107.23684	6791	FRONITER	1627	MOWRY	2188

Record: 0 Show: All Selected Records (1 out of 60027 Selected.) Options

Water Chemistry Linked by API Number

Water Chemistry Data Table

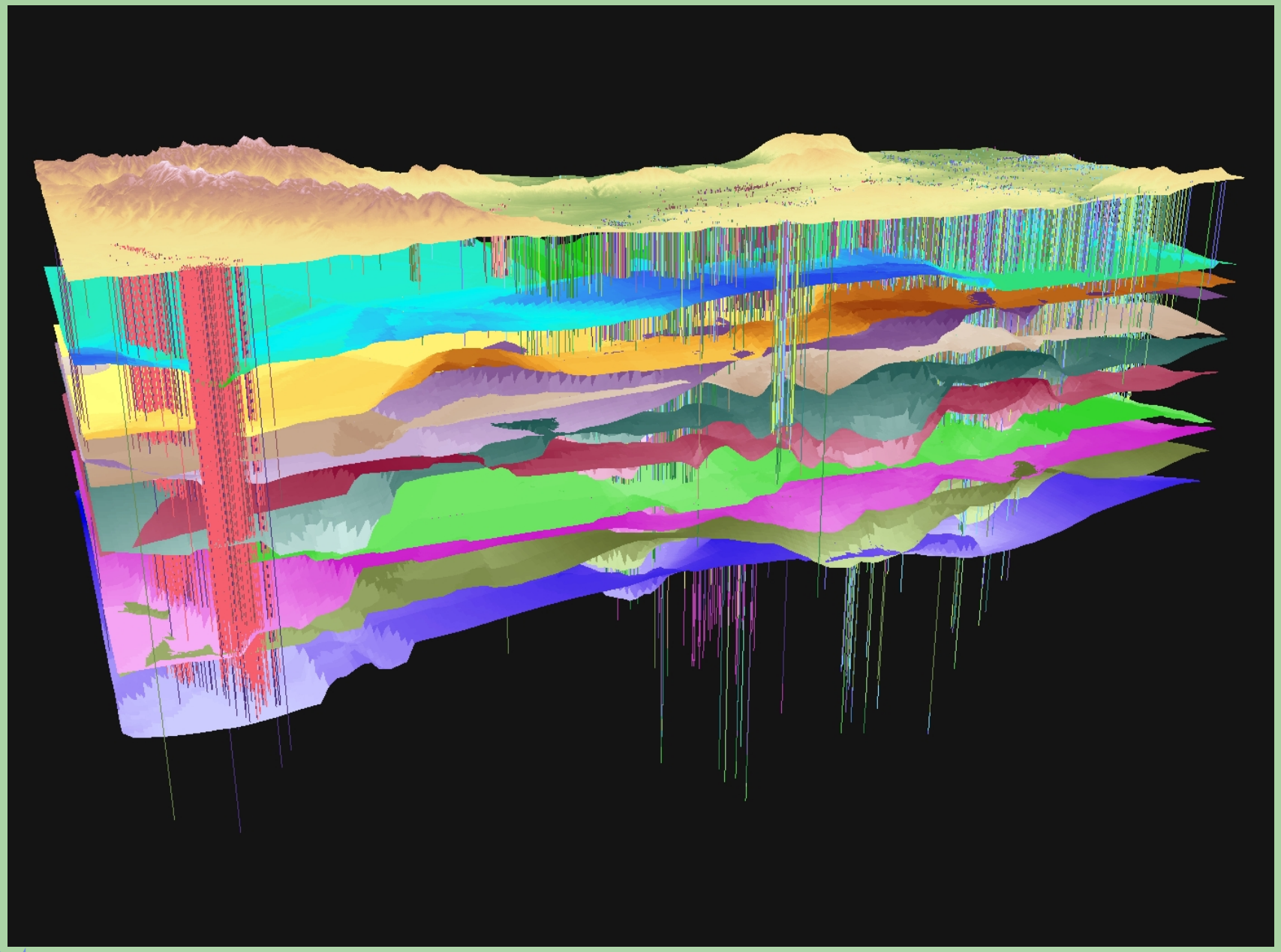
Microsoft Access - [Wyoming_Water : Table]

File Edit View Insert Format Records Tools Window Help

Api Number	Formation	Date	SODIUM	POTAS	LITHIU	CALCI	MAGNES	IRON	SULFATE	CHLORIDE	CARBONATE	BICARBONATE	HYDROXI	HYDROGEN SL	Total dissolved solids	Observed pH
049-025-20269	KMD	19690630	1223	19	0	13	3	0	186	150	84	2147	0	0	3035	8.4
049-025-20606	TENSLEEP	19860222	476	38	0	330	49	0	1040	621	0	122	0	0	2614	7.4
049-025-20692	DAKOTA	19901217	2970	0	0	25	8.9	0	226	3770	0	1240	0	0	8239.9	7.76
049-025-20692	DAKOTA	19910111	2950	0	0	25	10	0	215	3700	0	1270	0	0	8170	7.87
049-025-20758	DAKOTA	19910420	0	0	0	0	0	0	0	633	0	0	0	0	0	7.53
049-025-20790	DAKOTA	19901217	2360	0	0	25	10	0	198	3700	0	1380	0	0	6543	7.9
049-025-20803	MUDDY	19851126	0	0	0	0	0	0	0	338	0	0	0	0	1744	7.9
049-025-21207	FRONTIER	19851226	10690	714	0	554	34	0	0	18560	0	244	0	0	30132	6.1
049-025-21219	JM	19850220	13737	465	0	810	68	0	1340	21900	0	610	0	0	38620	7.7
049-025-21331	DAKOTA	19850121	614	0	0	176	16	4	230	800	0	600	0	0	0	6.9
049-025-21332	DAKOTA	19810909	7161	0	0	300	120	50	9000	5000	0	1230	0	0	22811	7.1
049-025-21334	JM	19830406	14241	583	0	770	62	0	1520	22500	0	720	0	0	40030	6.5
049-025-21335	DAKOTA	19901217	1501.99	0	0	9.8	6.4	0	885	1700	0	0	0	0	4103.19	7.37
049-025-21335	DAKOTA	19910111	2340	0	0	15	11	0	881	1710	0	1610	0	0	6567	7.72
049-025-21413	JM	19850221	13642	470	0	780	69	0	1280	21800	0	529	0	0	38301	7.7
049-025-21449	2ND W C	19820429	1868.77	31	0	18.45	3.89	0	95	1480	60	2293.6	0	0	5851	8.27

Record: 2102 of 3268

Datasheet View NUM



Big Sky Terrestrial GIS

SDSMT Lead

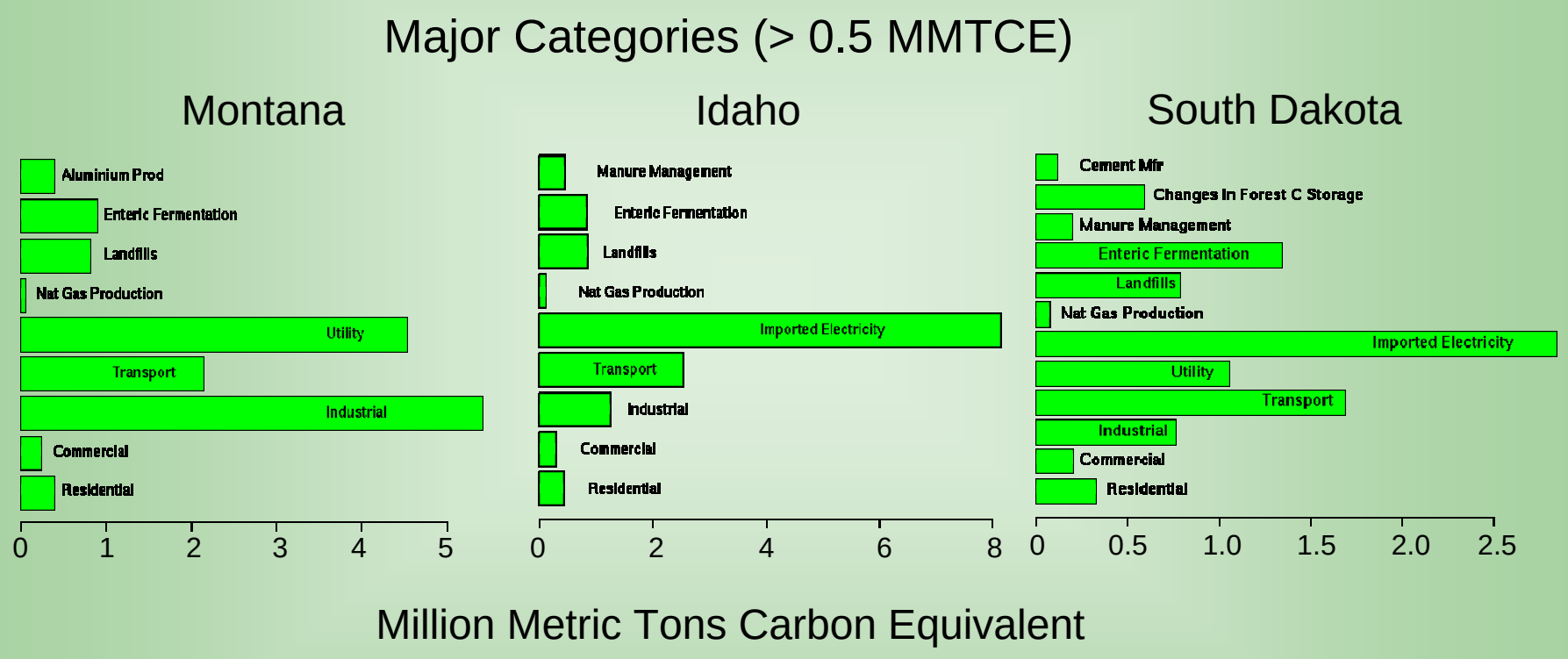
- **<u>Goal</u>:** assess terrestrial sequestration potential, based on evaluation of sources and sinks
- **<u>First Year</u>:** develop GIS database structure; identify sources of data; begin populating database
- **<u>Second Year</u>:** complete populating database; deliver data for placement on server; use data to determine terrestrial sequestration potential

Terrestrial Base Data

- Political: states, counties, cities, townships
- Demographic: population density, urban areas, metropolitan statistical areas
- Environmental: fire perimeters 2000 and 2003 (MT)
- Hydrologic: rivers, streams, lakes, wetlands, dams
- Land management: Land ownership, national forests, Indian reservations, National Wildlife Refuges, National Forests
- Transportation: roads, railroads

Sources

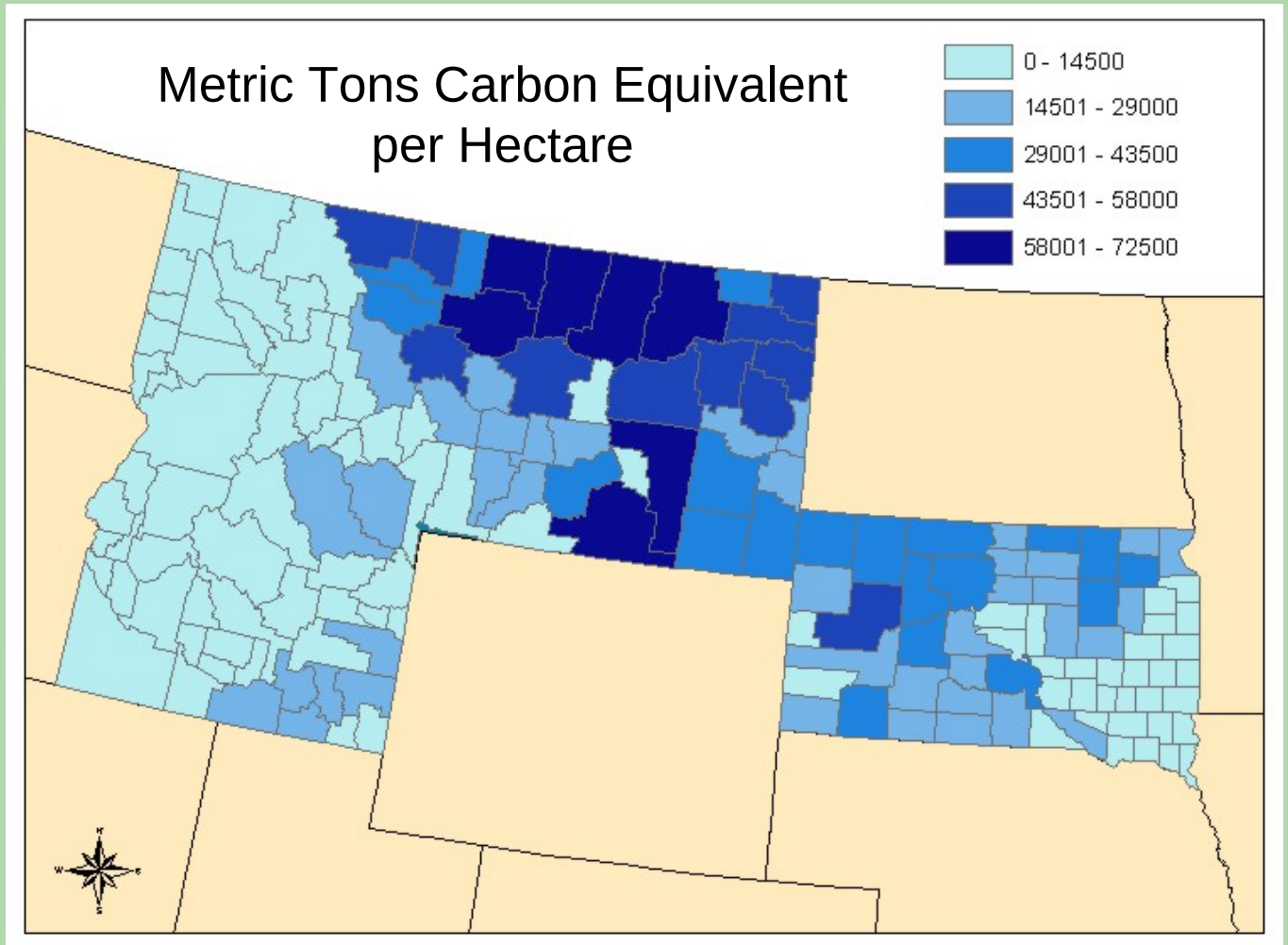
- Point locations for major utility and industrial emitters (SD complete, MT, ID, and WY in progress)



Terrestrial Sinks

- Climate
  - Climate divisions (polygons)
  - Cooperative weather stations (points)
  - Summary for cooperative weather stations 1895-2003
- Tillage (CTIC)
  - by acre by county for 1989 and 2000 (includes CRP and method)
- Soils
  - STATSGO soil polygons (state level)
  - SSURGO soil grids (county level)
    30m grids; Sand, silt, clay percents and bulk density; not all counties
- Forests
  - Forest C stocks/fluxes, 1997
- Land Cover (National Land Cover Data)
  - Categorical data
  - 30m grids
  - Estimates made of land cover percentages in each county

Terrestrial Carbon Baseline

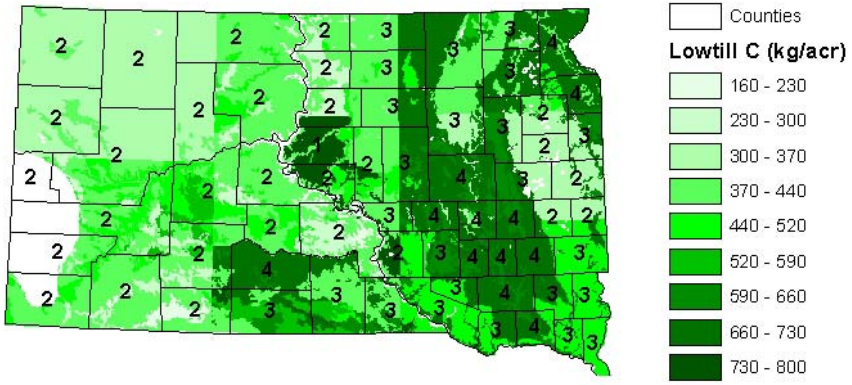


Terrestrial Carbon Sequestration

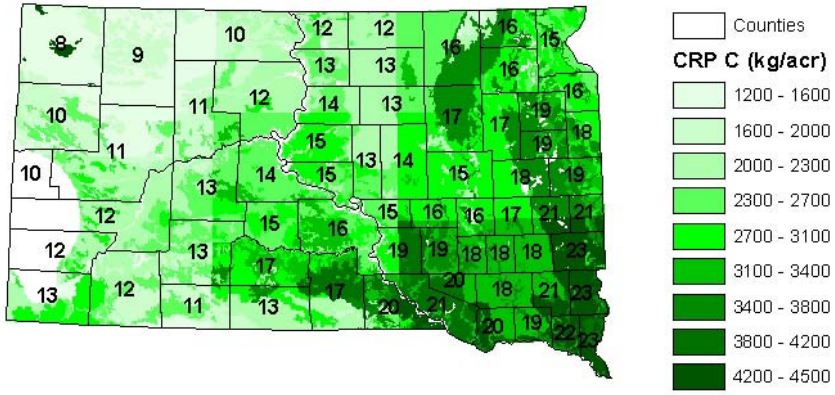
Projected Average Yearly Income

Assuming a price of $15/ton of CO2

Average yearly income for LowTill land at $15/ton in dollars



Average Yearly Income for CRP land at $15/ton in dollars

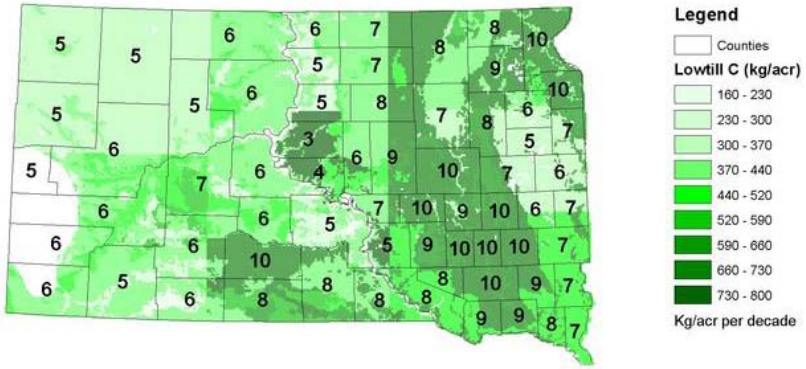


Terrestrial Carbon Sequestration

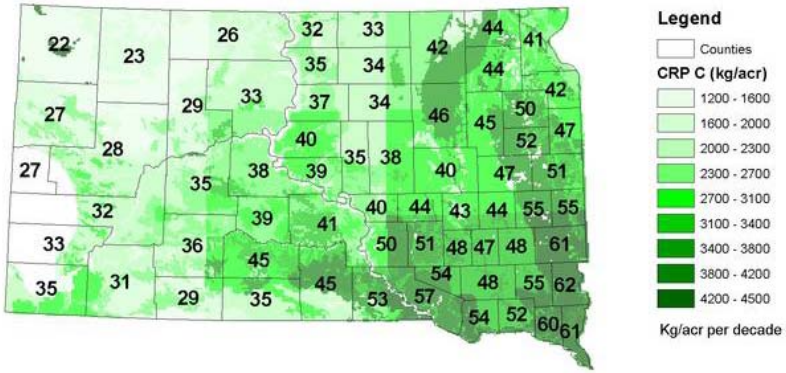
Estimated Average Yearly Income

Assuming a price of $40/ton of CO2

Average yearly income for LowTill land at $40/ton in dollars per acre



Average Yearly Income for CRP land at $40/ton

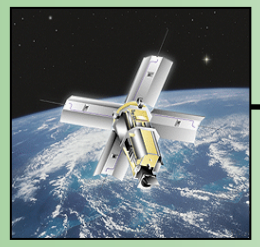


Carbon Cyberinfrastructure

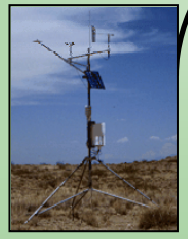
***Enterprise GIS** as the "glue"*
sensor/data/model/analysis integration

Field Worker

Analyst



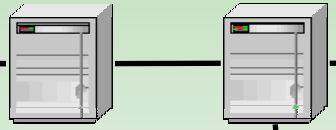
Remote Sensing



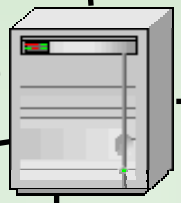
Sensor Network

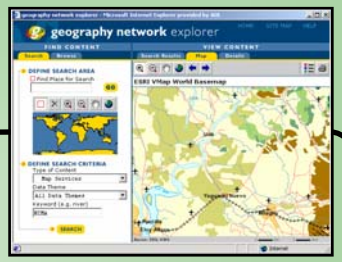
Web Server

Map Server



Spatial Data Engine





Public

NATCARB portal
Partnerships servers

Decision Maker

Knowledge Base

Data Warehouse

Model Warehouse

System Dynamics Models

Operations Models

Process Models

Field Measurement

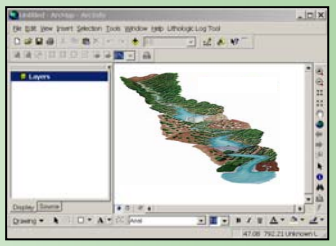
Knowledge Base

"Digital Library", "Faithful Scribe", "Universal Translator", "Friendly Traffic Controller"

Measurement, Monitoring, & Verification (MMV)

- Remote sensing
- Sensor arrays / networks
- Ground truth

Access and Decision Support



- Data Access (NATCARB)
- Data/model integration
- Map-based analysis and visualization

Knowledge Base

Data Warehouse

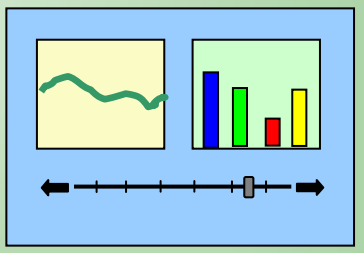
Model Warehouse

- National Carbon Atlas
- MMV library
- Model component archive (inputs, parameters…)
- Scenario library

Process Models

- Physical models
- Operations models
- Scenario analysis

System Dynamics



- Integrated system behavior
- Quick analysis

Big Sky GIS Perspective

- Geologic and Terrestrial Data
- Coordination Between Partnerships
- Links with NATCARB
- National Carbon Cyberinfrastructure

Geologic Sequestration

Robert W. Smith and Nathan P. Erickson
University of Idaho

Travis L. McLing
Idaho National Engineering and Environmental Laboratory

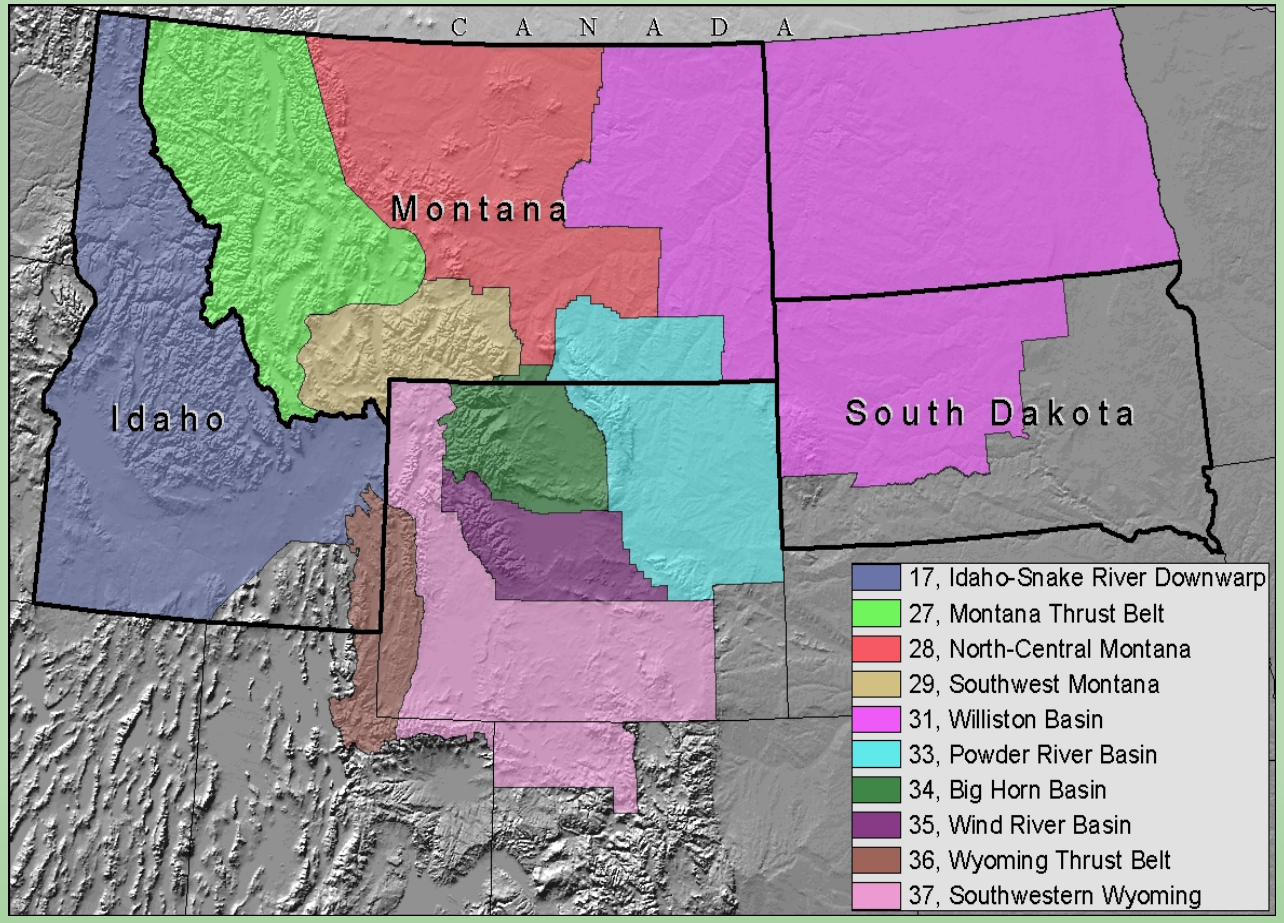
Warren Barrash and William P. Clement
Boise State University

John P. Kaszuba
Los Alamos National Laboratory

Geologic Sequestration Objectives

- Evaluate geologic sequestration potential of sedimentary and unconventional mafic volcanic basins in Northern Rockies and Great Plains Region
  - Favorable and worthy of further consideration
  - Unfavorable
  - Insufficient information to classify
- Identify potential pilot-scale sequestration site(s)

USGS 1995
National Oil and Gas Assessment



Available Information

- Wyoming Oil and Gas Conservation Commission
  - Lithology and Location of wells
  - Pressure and Temperature
  - Cores: Porosity, Permeability, and Saturation
  - Water Chemistry
- Montana Geological Society
  - Data by oil field
- Montana Board of Oil and Gas Conservation
  - Lithology and Location of wells
- Idaho – no single data source
  - USGS Reports, Technical and Geologic Papers, INEEL, and Geothermal Exploration Reports

Organization of Database

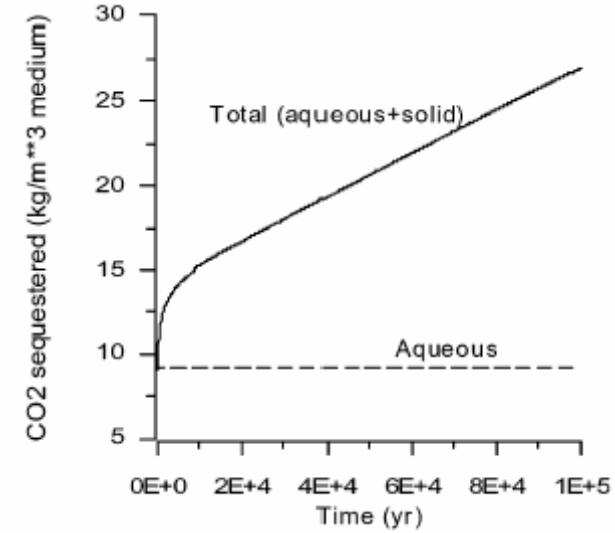
- Access Database
- Converted to a Geodatabase in GIS
  - Files contained in GDB
    - Well Location and Lithology
    - Water Analysis
    - Pressure and Temperature
    - Cores: Porosity, Permeability, and Saturation

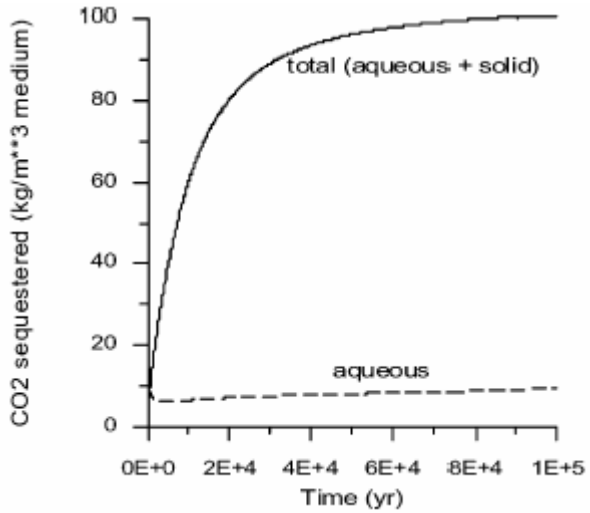
Geologic Sequestration

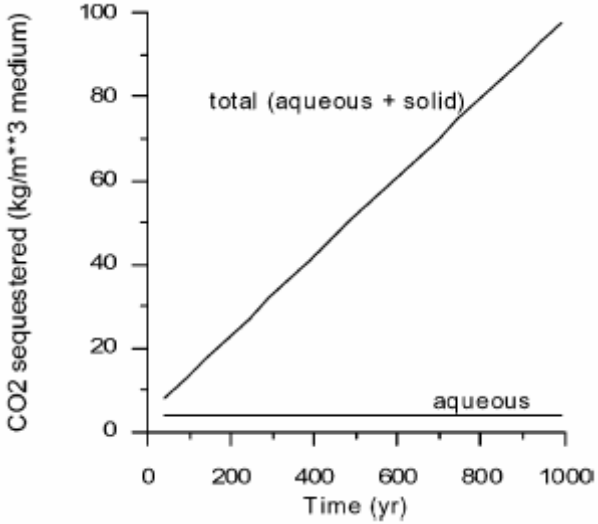
- Disposal of CO_2 in deep geologic formations
  - Depleted oil and gas reservoirs
  - Saline aquifers
  - Deep coal beds
  - ***Mafic rocks***
- Sequestration Processes
  - Hydrodynamic trapping → Seal and Phase
  - Solubility trapping
  - ***Mineral trapping***

Mineral Trapping
Xu, Apps and Pruess (2004)

Fixed CO_2 pressure of 260 bars







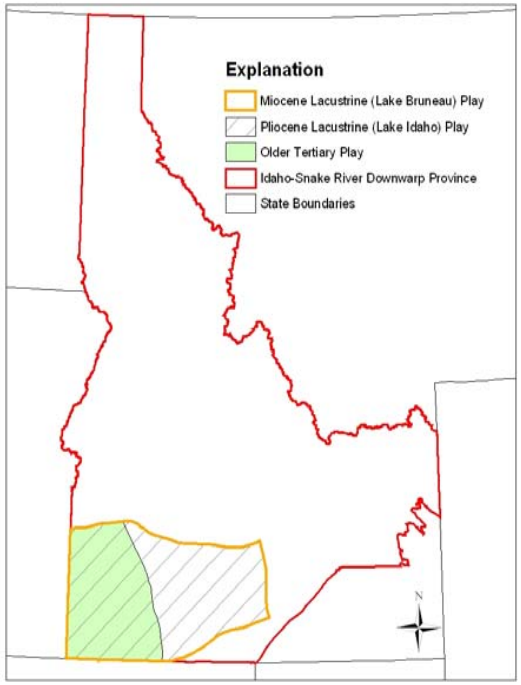
Glauconitic sandstone
~0.2 g yr^{-1} m^{-3}

Gulf Coast sediments
~3 g yr^{-1} m^{-3}

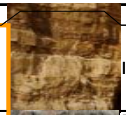
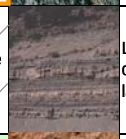
Dunite
~100 g yr^{-1} m^{-3}

Southwest Idaho
Mafic Rock Example

Idaho-Snake River Downwarp Province - Plays



Nampa, Caldwell and Meridian Area

Depth Below Land Surface	AGE	Groups and Formations	Lithology	Description	
		Snake River Group		Sands and Gravels/Basalt	
1,000 ft 305 m – 2,000 ft 610 m	Pliocene	Idaho Group(Lake Idaho)		Interbedded Silt, Sand and Clay	**Pliocene Lacustrine (Lake Idaho) Play** Reservoir: fluvial and lacustrine sandstone, siltstone, conglomerate, and oolitic or algal carbonates Maximum depth to top of play: 10,000 ft Maximum thickness: 9,000 ft
3,000 ft 915 m – 4,000 ft 1,220 m	Pliocene	Bandury Basalt		Dark grey to black basalt, tuff and tuffaceaous siltstone, fine to medium grained white sand: rhyolite along margins of plain.	
5,000 ft 1,524 m – 6,000 ft 1,829 m – 7,000 ft 2,134 m – 8,000 ft 2,439 m – 9,000 ft 2,744 m	Pliocene	Columbia River Basalt Group		Basalt, interbedded sand and or sandstone	
10,000 ft 3,049 m – 11,000 ft 3,354 m – 12,000 ft 3,659 m	Miocene	Succor Creek Formation (Lake Bruneau)		Lacustrine lignitic shale, clay, sandstone, diatomite, oolitic limestone, ash, tuff, and lava flows	**Miocene Lacustrine (Lake Bruneau) Play** Reservoir: fluvial and lacustrine sandstones and fractured oolitic and algal carbonates Maximum depth to top of play: 15,000 ft Maximum thickness: 7,000 ft
13,000 ft 3,963 m – 14,000 ft 4,268 m – 15,000 ft 4,573 m	Older Tertiary	Older Tertiary Rocks?		Fluvial, lacustrine, and possibly marine clastics and carbonates	**Pre-Miocene Play** Reservoir: Potentially marine carbonates and clastics of Paleozoic and early Mesozoic age, which are probably highly fractured and possibly metamorphosed

Normalized Mineralogy

Snake River Plain Basalt

Oxides	Wt %
SiO_2	46.10
TiO_2	2.60
Al_2O_3	14.51
Fe_2O_3	2.62
FeO	10.57
MnO	0.20
MgO	8.49
CaO	10.34
Na_2O	2.47
K_2O	0.93
P_2O_5	0.70
Total	99.53

Normalized Mineralogy	Wt %
Orthoclase (Or)	5.51
Albite (Ab)	20.89
Anorthite (An)	25.77
Diopside (Di)	17.09
Hypersthene (Hy)	3.31
Olivine (Ol)	16.64
Magnetite (Mt)	3.80
Ilmenite (Il)	4.93
Apatite (Ap)	1.63
Total	99.55

Ti, P Free	Wt %	Surface Area $cm^2\ g^{-1}$
K-Feldspar $KAlSi_3O_8$	5.51	123
Plagioclase $NaCaAl_3Si_5O_{16}$	46.66	115
Clionpyroxene $Ca_3Mg_2FeSi_6O_{18}$	17.07	87
Orthopyroxene $Mg_2FeSi_3O_9$	3.31	87
Olivine $Mg_4Fe_2Si_3O_{12}$	16.64	84
Magnetite Fe_3O_4	3.80	115
Total	92.98	

Model Conditions

- Porosity → 12.5 %
  - 6.25% supercritical CO_2
  - 6.25% groundwater
- Pressure → 200 bars (2 km hydrostatic load)
- Temperature → 40 ^{o}C
- Super critical CO_2 density → 821 kg m^{-3}
- Relative reactions rates from “literature” rate law
- Calibrated to estimated basalt reaction rate of 150 mg L^{-1} yr^{-1} (Roback et al. 2001)

Reaction Rate Model

$$R = k_{+} \cdot A \cdot \left(a_{H^{+}}^{0.5} + 10^{-3} + 10^{-5} \cdot a_{H^{+}}^{-0.25} \right) \left[1 - \frac{Q}{K} \right]$$

k_{+} Forward Rate Constant

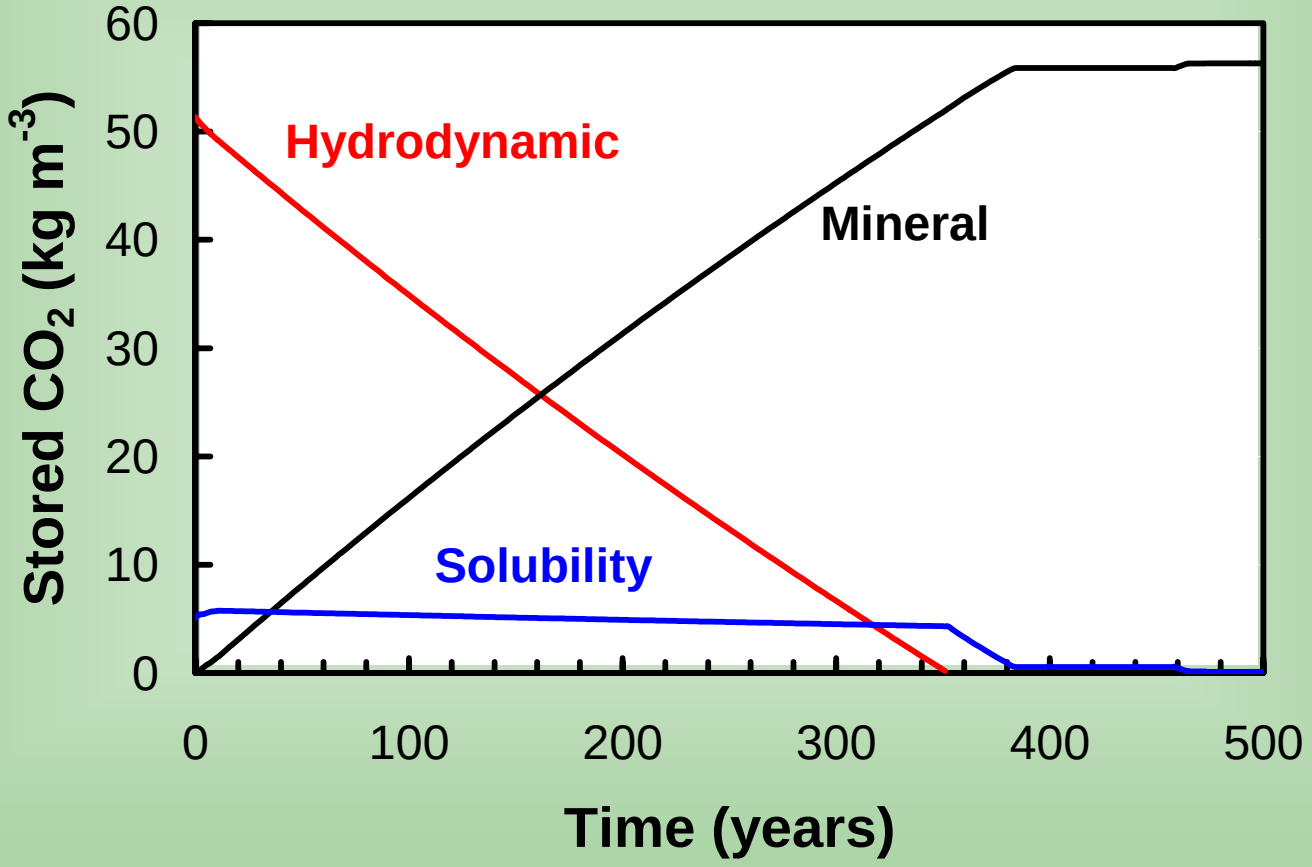
A Surface Area

a_{H+} Hydrogen ion activity (pH)

Q Ion Activity Quotient

K Equilibrium Constant

Hydrodynamic, Solubility, & Mineral Trapping Mafic Volcanic Rocks



Summary

- Hydrodynamic, solubility and mineral trapping contribute to long-term storage of CO_2
- Relative importance of mineral trapping is a function of rock type
- For mafic rocks, mineral trapping is dominate mechanism after ~150 years
- Mineral trapping eliminates risk of leakage

Monitoring Issues

1. Geophysical Method
   - Property measured
2. Acquisition Geometry
   - Information about subsurface
   - Interpretation
3. Physical Properties
   - Sensitivity to parameters of interest

Geophysical Monitoring

Time-lapse imaging

- Acquire data over time
  - -Pre-injection
  - -Post-injection
- Compare to baseline image
- Very sensitive

Methods

Seismic

- Wave type
  - P-waves
  - S-waves
- Geometry
  - Surface reflection
  - VSP
  - Crosshole tomography

Electromagnetic (EM)

- Electrical Resistivity Tomography (ERT) – zero frequency EM
- Electromagnetic imaging – low frequency EM

Terrestrial Sequestration

Susan Capalbo, John Antle, Perry Miller
Montana State University

Pat Zimmerman
South Dakota School of Mines &Tech

Jerry Stuth
Texas A&M

Dick Benson
LANL

Ted Dodge
National Carbon Offset Coalition

Terrestrial Sequestration Component

- Bridge to Geological sequestration
- Technical potential
- Economic potential
  - finding those elusive supply curves for soil carbon
- Regional, aggregate analysis in support of policies for GHG reductions
- Producer decision-support framework(s)
- Pilot studies for carbon trading
- MMV technologies
- Collaboration with USDA, EPA
- International transferability
- Risk assessment framework in conjunction with advanced concepts

Progress

Task 4: database and literature review – completed at county scale for technical potential (rangeland, cropland, reclaimed mine lands, forestry)

- Baseline carbon levels
- Maximum carbon levels

Task 5: input in GIS data base format – near completion by Jan 05

In Progress

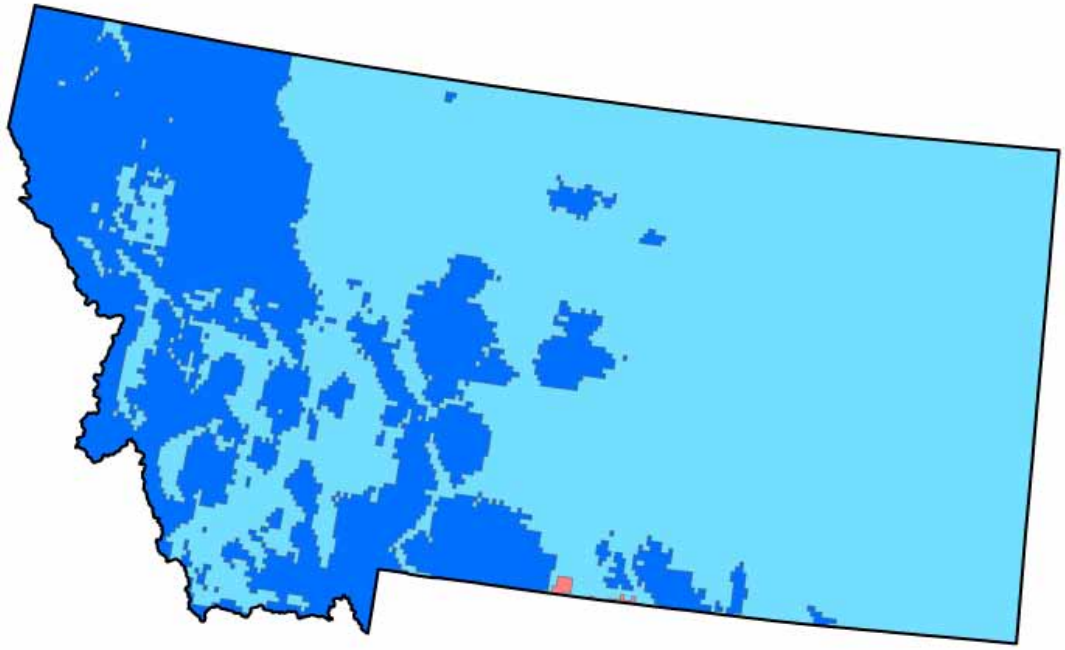
Task 6: overlay technical potential with economic potential

Task 7: modeling and policy potentials

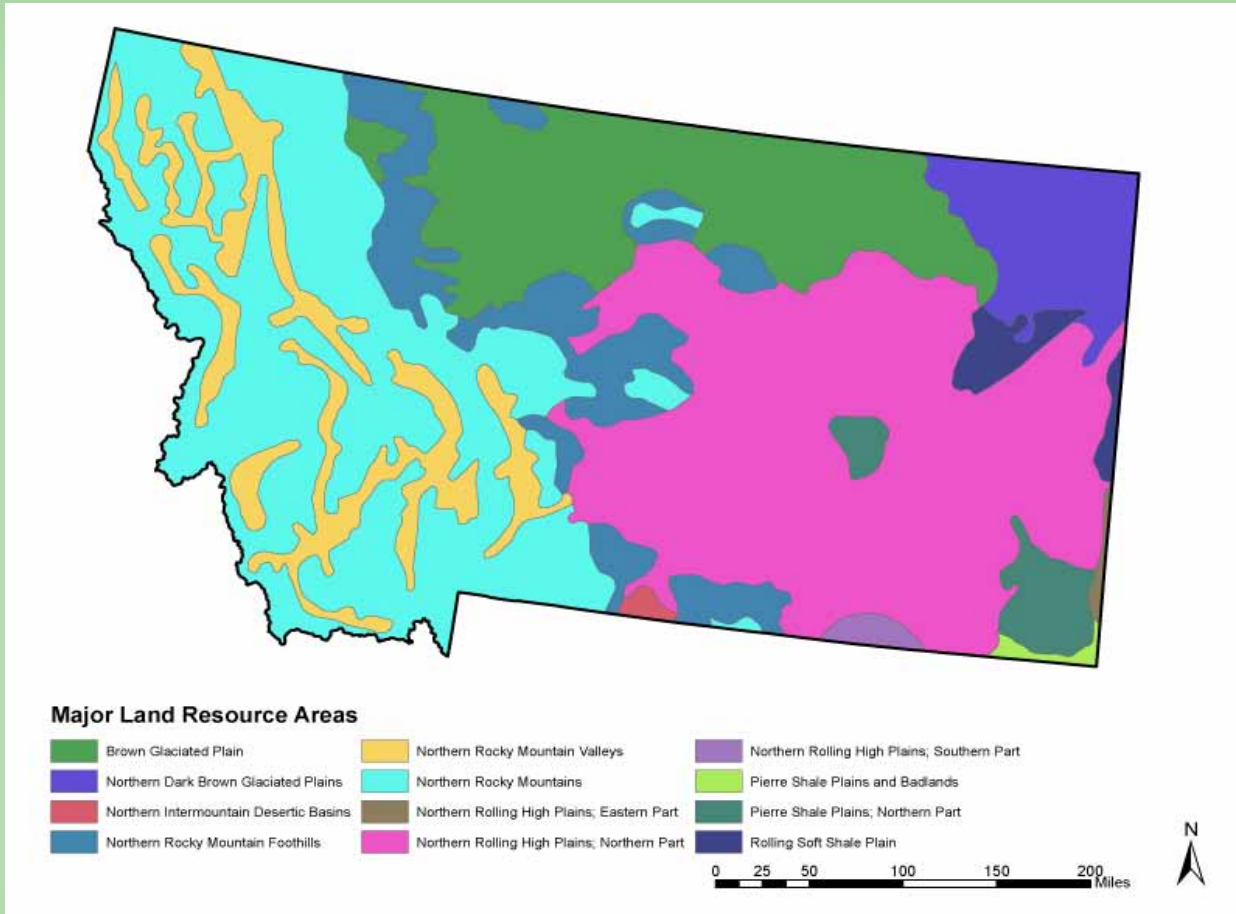
Highlights

<u>Rangeland project</u>:

- MT, ID, SD
- 31.5 million hectares (state, private, reservations)
- classification: moderate potential -- 21 million hectares
  high potential – 10 million hectares
- potentials based on precipitation, MLRA, land tenure, cover type
- assessed in conjunction with USDA/NRCS (Joel Brown)

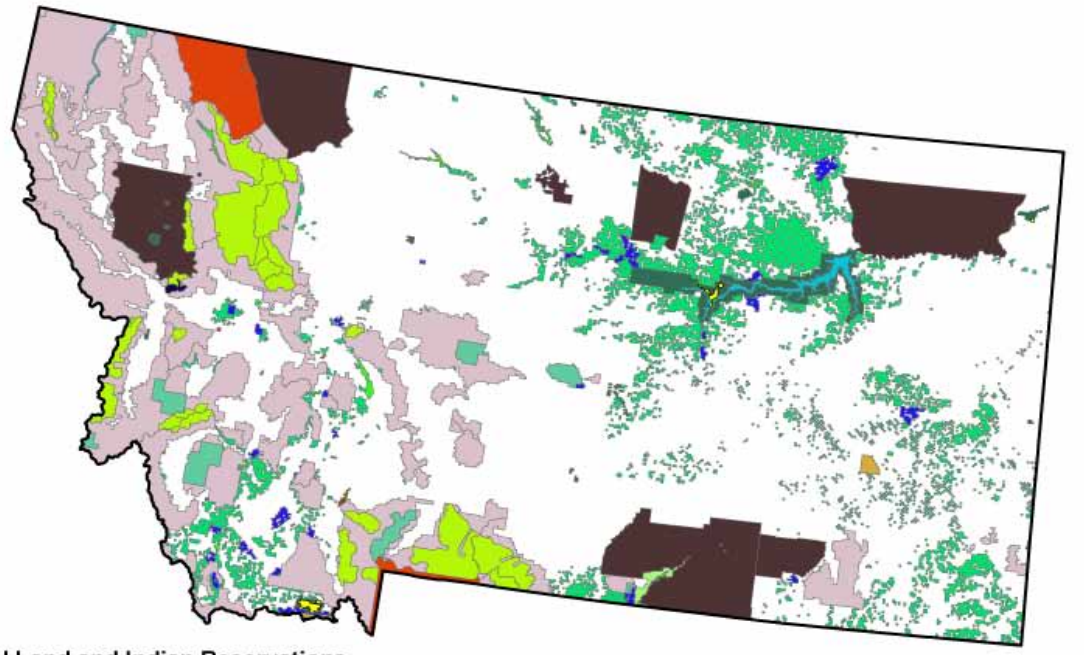

Rainfall Potential
High Potential
Moderate Potential
Low Potential
0 25 50 100 150 200 Miles
N

Big Sky
CARBON SEQUESTRATION
PARTNERSHIP
A new energy future for Montana, Idaho, South Dakota, Wyoming and the nation.


Major Land Resource Areas
Brown Glaciated Plain
Northern Dark Brown Glaciated Plains
Northern Intermountain Desertic Basins
Northern Rocky Mountain Foothills
Northern Rocky Mountain Valleys
Northern Rocky Mountains
Northern Rolling High Plains; Eastern Part
Northern Rolling High Plains; Northern Part
Northern Rolling High Plains; Southern Part
Pierre Shale Plains and Badlands
Pierre Shale Plains; Northern Part
Rolling Soft Shale Plain
0 25 50 100 150 200 Miles
N

Big Sky
CARBON SEQUESTRATION PARTNERSHIP

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

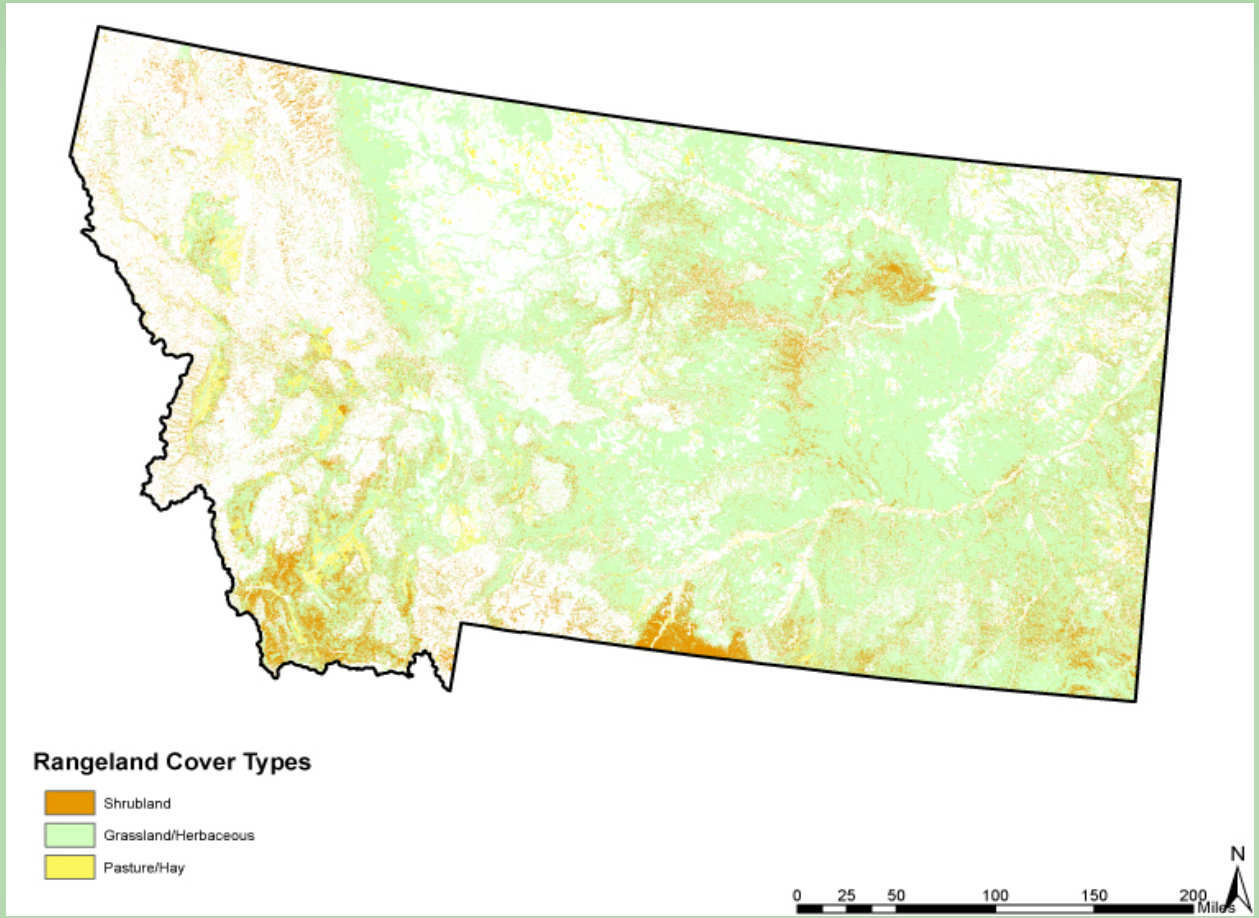


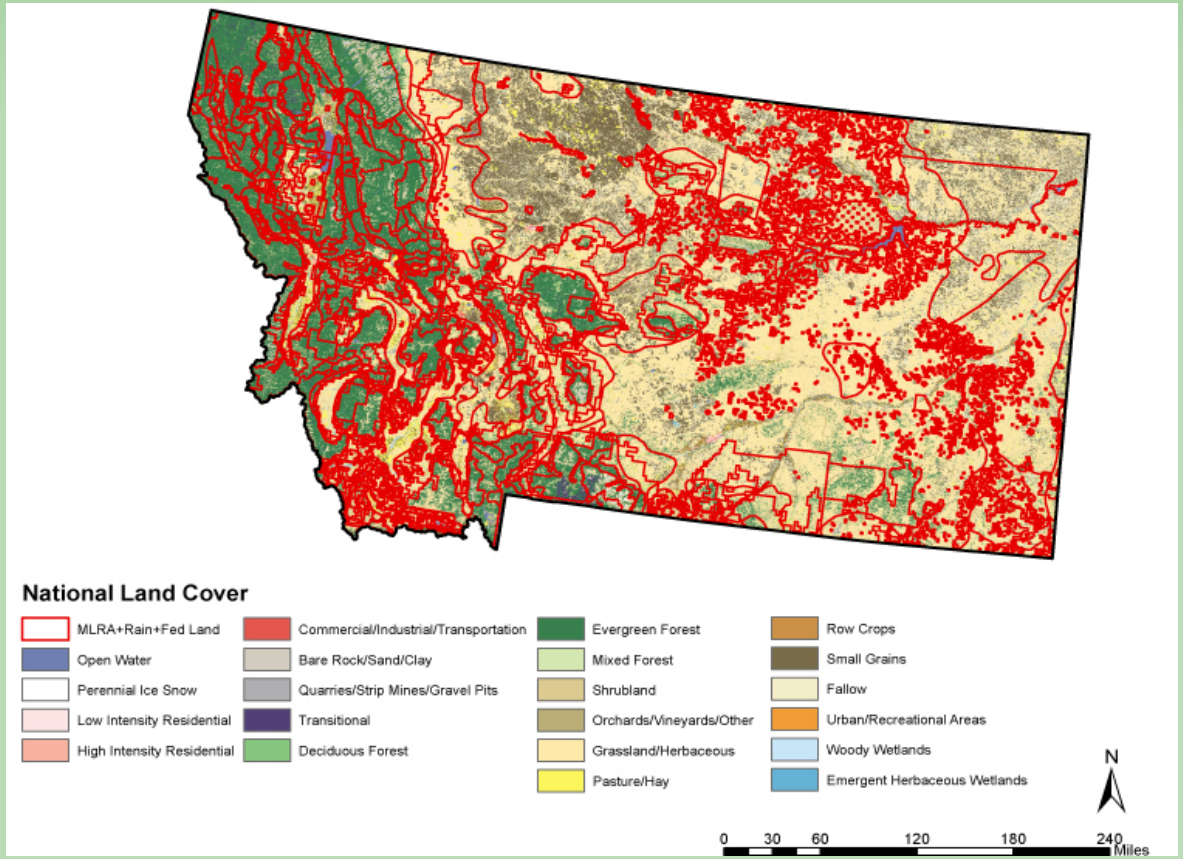
Federal Land and Indian Reservations

- Agricultural Research Service ARS
- Air Force DOD
- Army Corps of Engineers DOD
- Army DOD
- Bureau of Reclamation BOR
- Indian Reservations BIA
- National Battlefield NPS
- National Forest FS
- National Historic Site NPS
- National Monument NPS
- National Park NPS
- National Recreation Area FS
- National Recreation Area NPS
- National Wildlife Refuge FWS
- Public Domain Land BLM
- Wilderness BLM
- Wilderness FS
- Wilderness FWS
- Wilderness Study Area BLM
- Wilderness Study Area FS

0 25 50 100 150 200 Miles

N


Rangeland Cover Types
Shrubland
Grassland/Herbaceous
Pasture/Hay
N
0 25 50 100 150 200
Miles



Sampling units (red lines) used in spatial cross tabulation for Montana. Sampling units represent intersection of MLRA, climatic potential, land tenure, and land cover.

Montana AND Big Sky Region Totals (hectares)

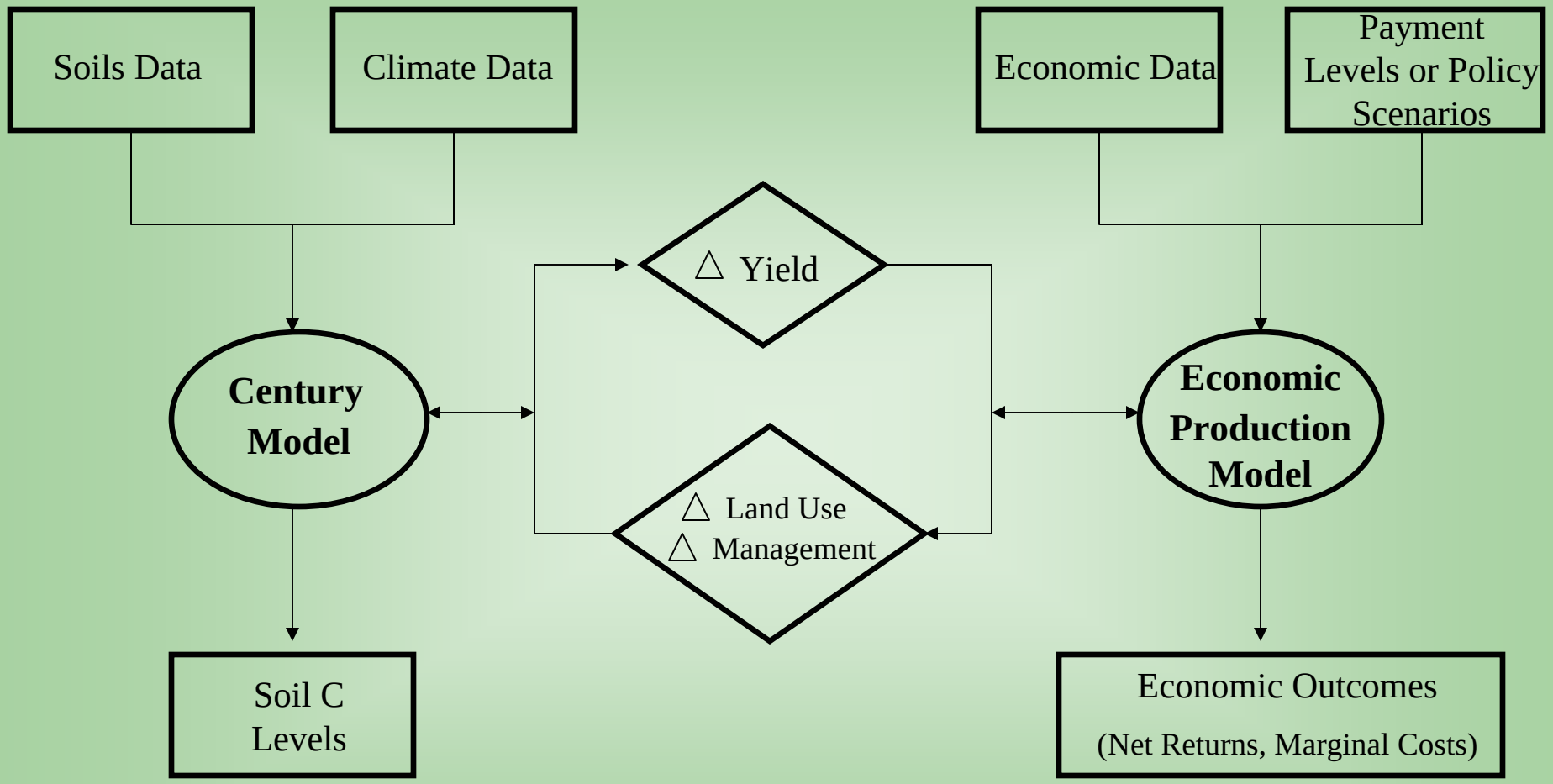
<u>High Climatic Potential</u>		
• Indian Reservations	476,300	1,932,096
• Private or Other Non-Federal	1,629,173	8,347,725
<u>Moderate Climatic Potential</u>		
• Indian Reservations	1,518,059	3,098,461
• Private or Other Non-Federal	12,847,170	18,155,895
<u>Low Climatic Potential</u>		
• Indian Reservations	77	77
• Private or Other Non-Federal	82,745	94,380
Totals	16,470,702	31,534,178

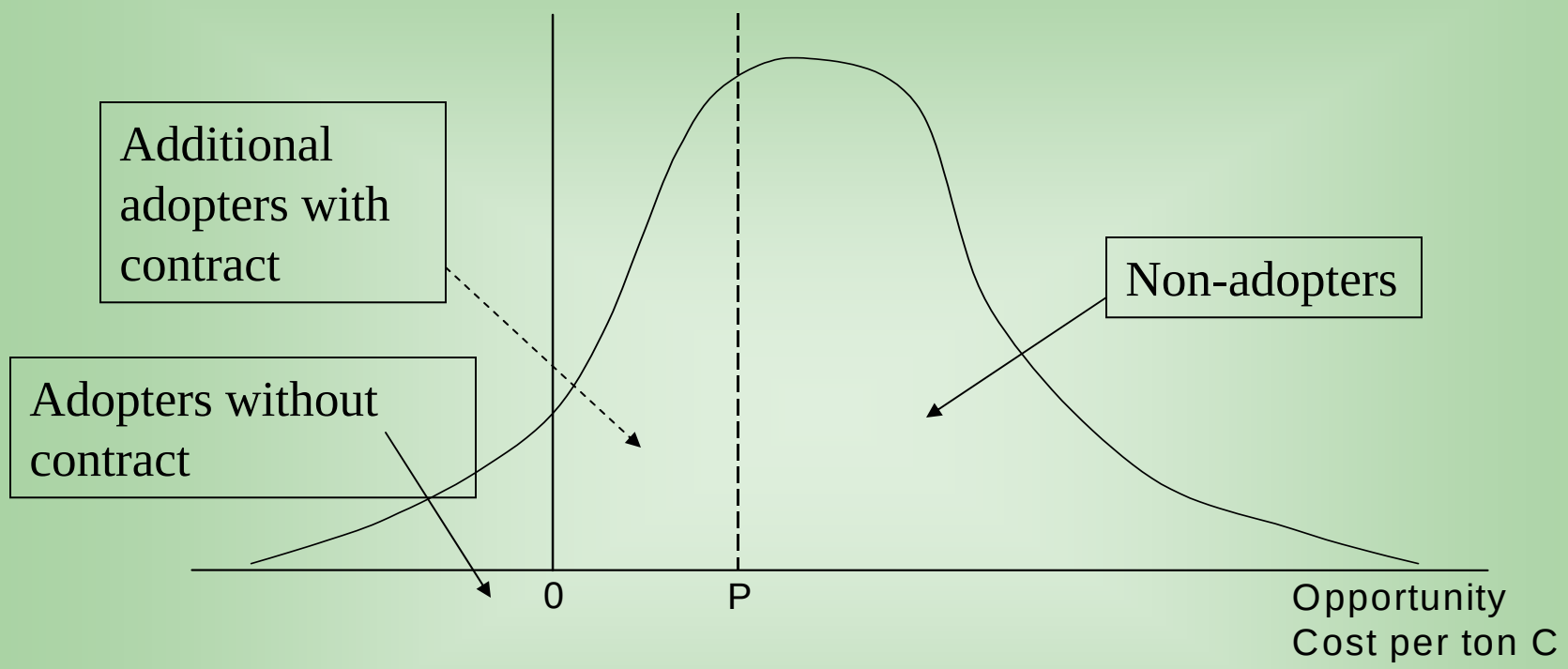
Use this information in economic analysis of cost of sequestering a ton of carbon

Economic Project or Projects

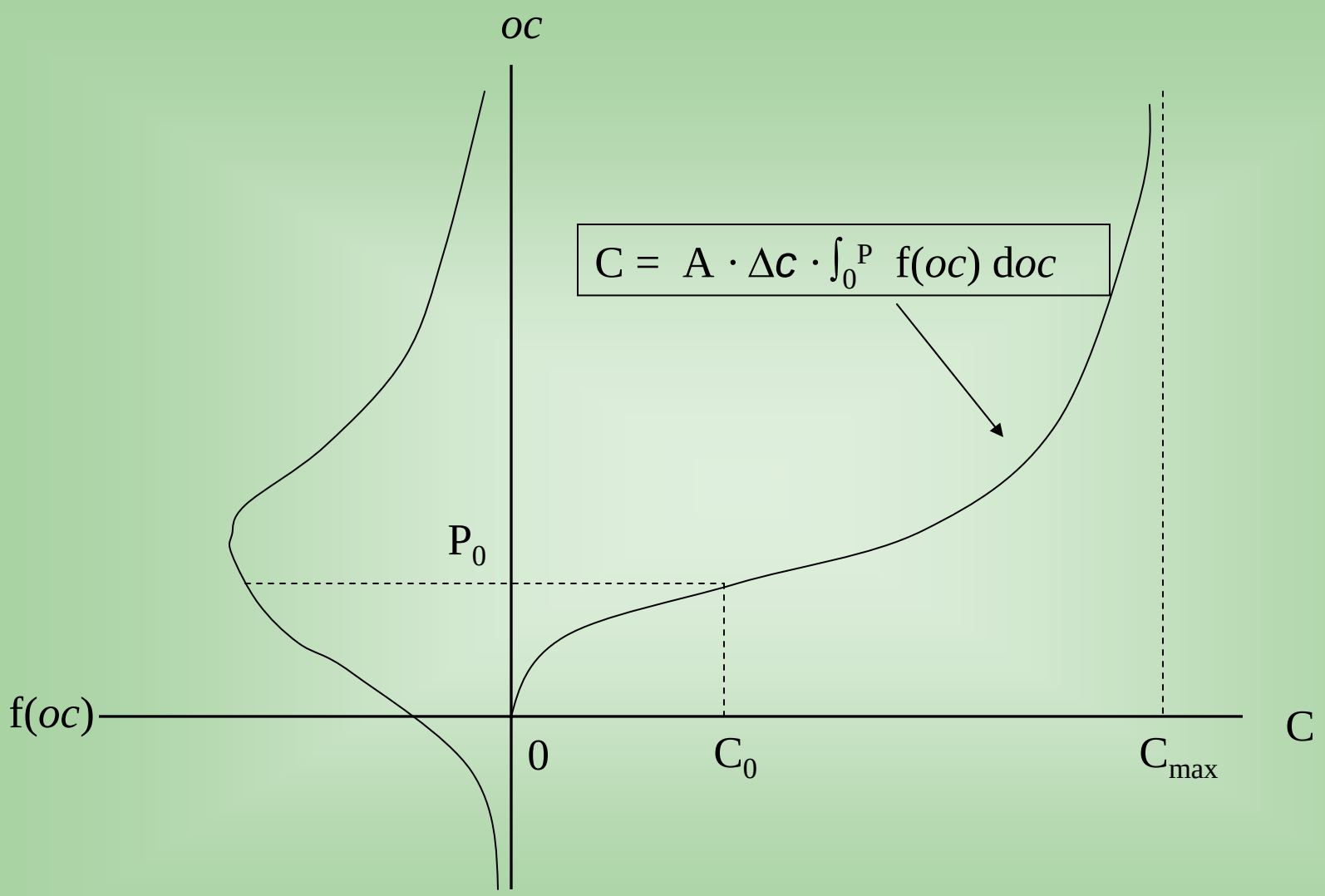
- Leverage with funding from USDA/CASMGS and USAID
- Key Factors in Ag Soil C Sequestration: Spatial Heterogeneity
  - Carbon rates vary due to bio-physical conditions (soils, climate)
  - Opportunity costs vary spatially due to factors affecting productivity and
  - profitability
  - soils & climate
  - production practices
  - farm-specific management factors (experience, education, attitudes, etc.)
  - prices (location)

Big Sky
CARBON SEQUESTRATION PARTNERSHIP
A new energy future for Montana, Idaho, South Dakota, Wyoming and the nation.


Soils Data
Climate Data
Economic Data
Payment Levels or Policy Scenarios
△ Yield
Century Model
Economic Production Model
△ Land Use
△ Management
Soil C Levels
Economic Outcomes
(Net Returns, Marginal Costs)



Carbon supply curve derived from area between 0 and P under density function

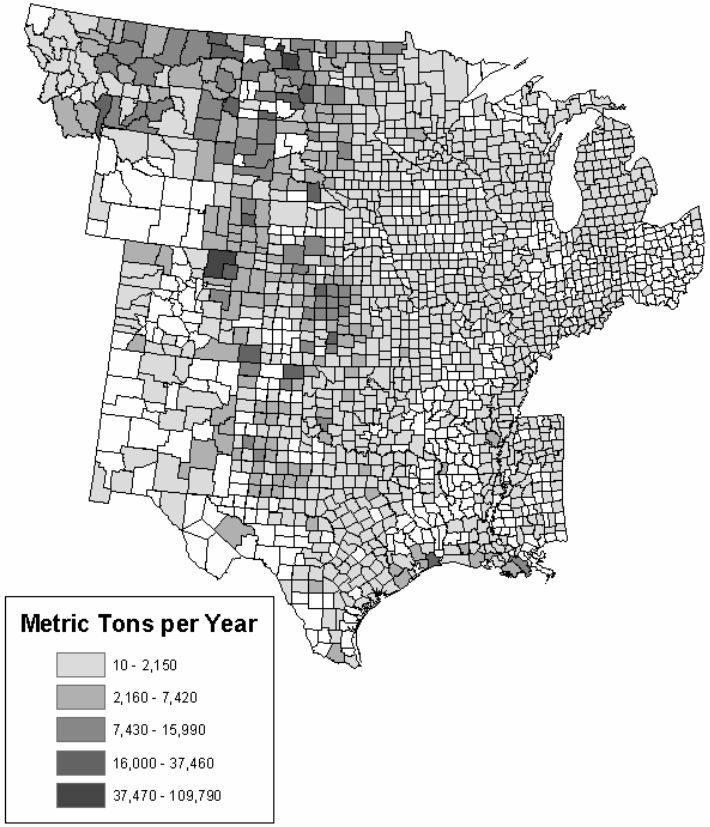


Spatial Distribution of Opportunity Cost and Carbon Supply Curve

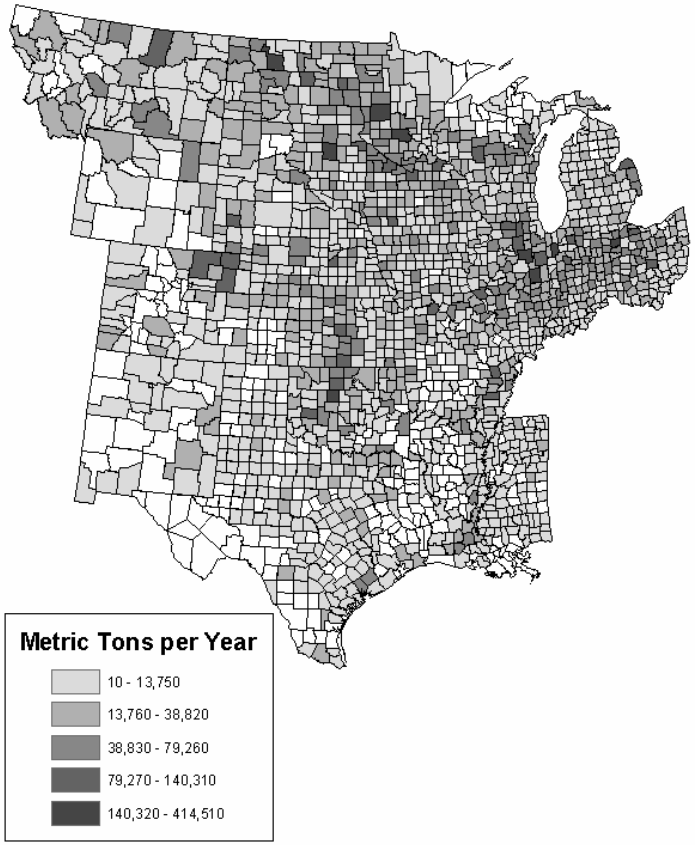
Suite of Models

- Central US analysis
- Montana MLRA scale
- Field/farm scale

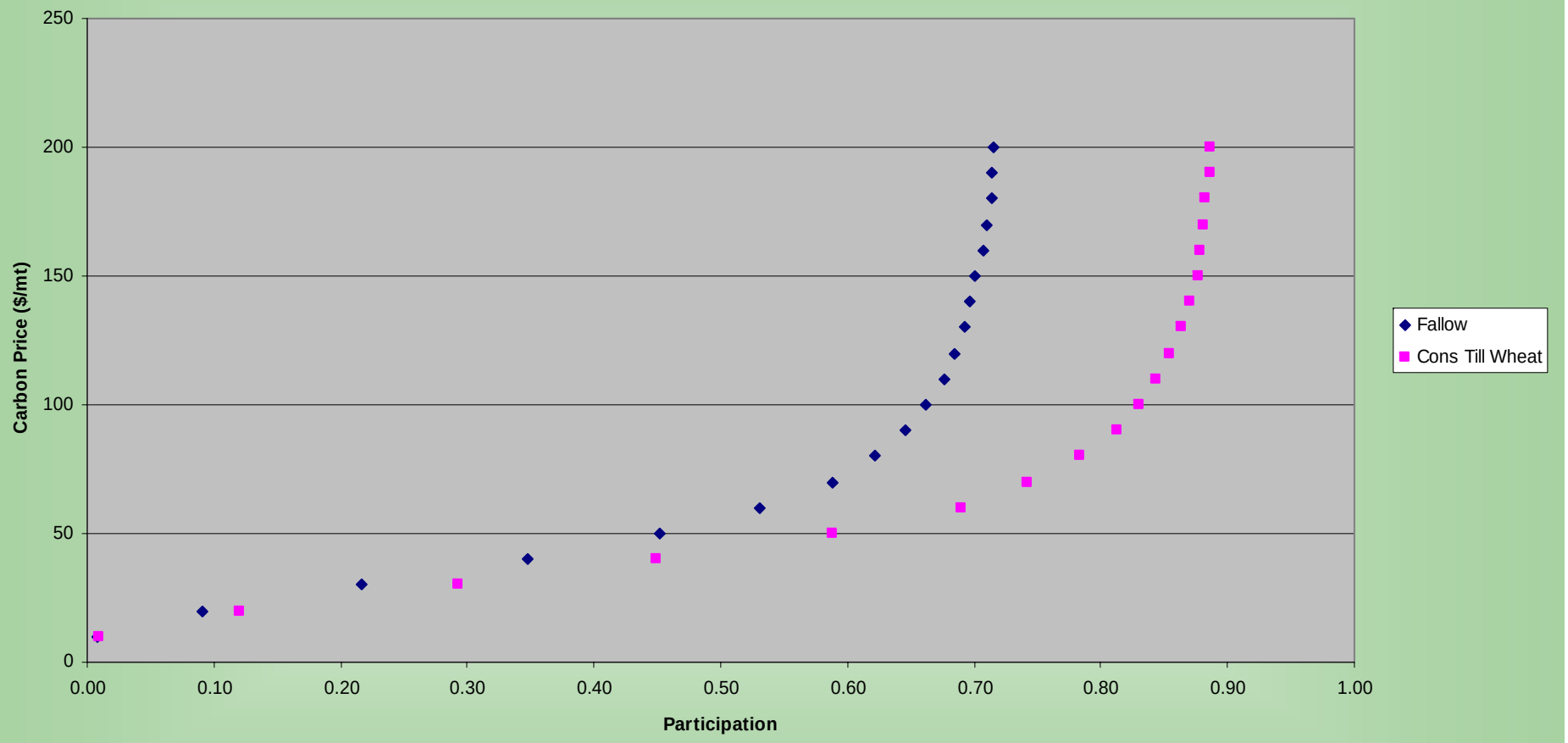
Simulated Soil Carbon Sequestration from Fallow Reduction with a $50 per metric ton Carbon Price



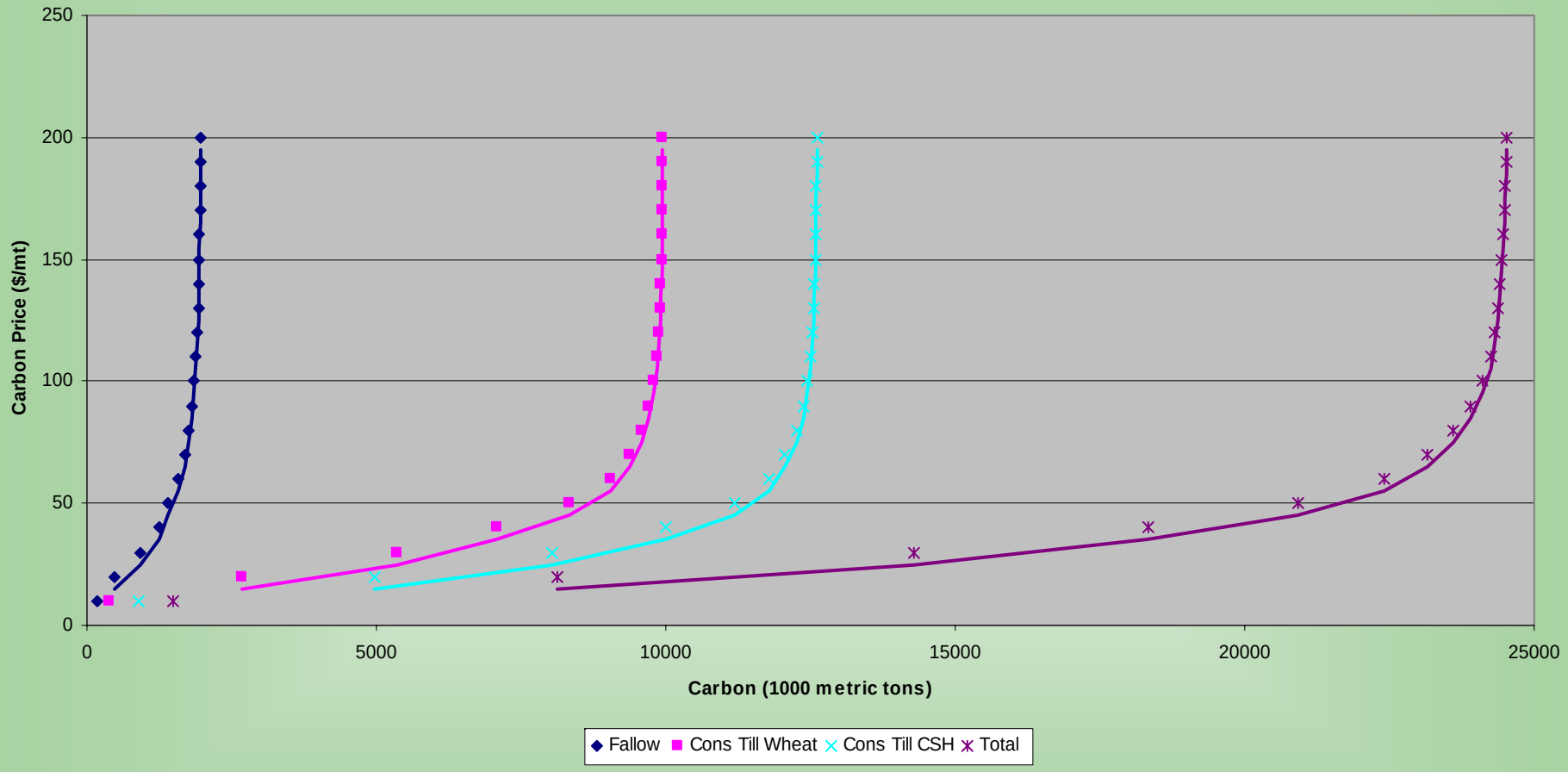
Simulated Soil Carbon Sequestration from Conservation Tillage with a $50 per metric ton Carbon Price



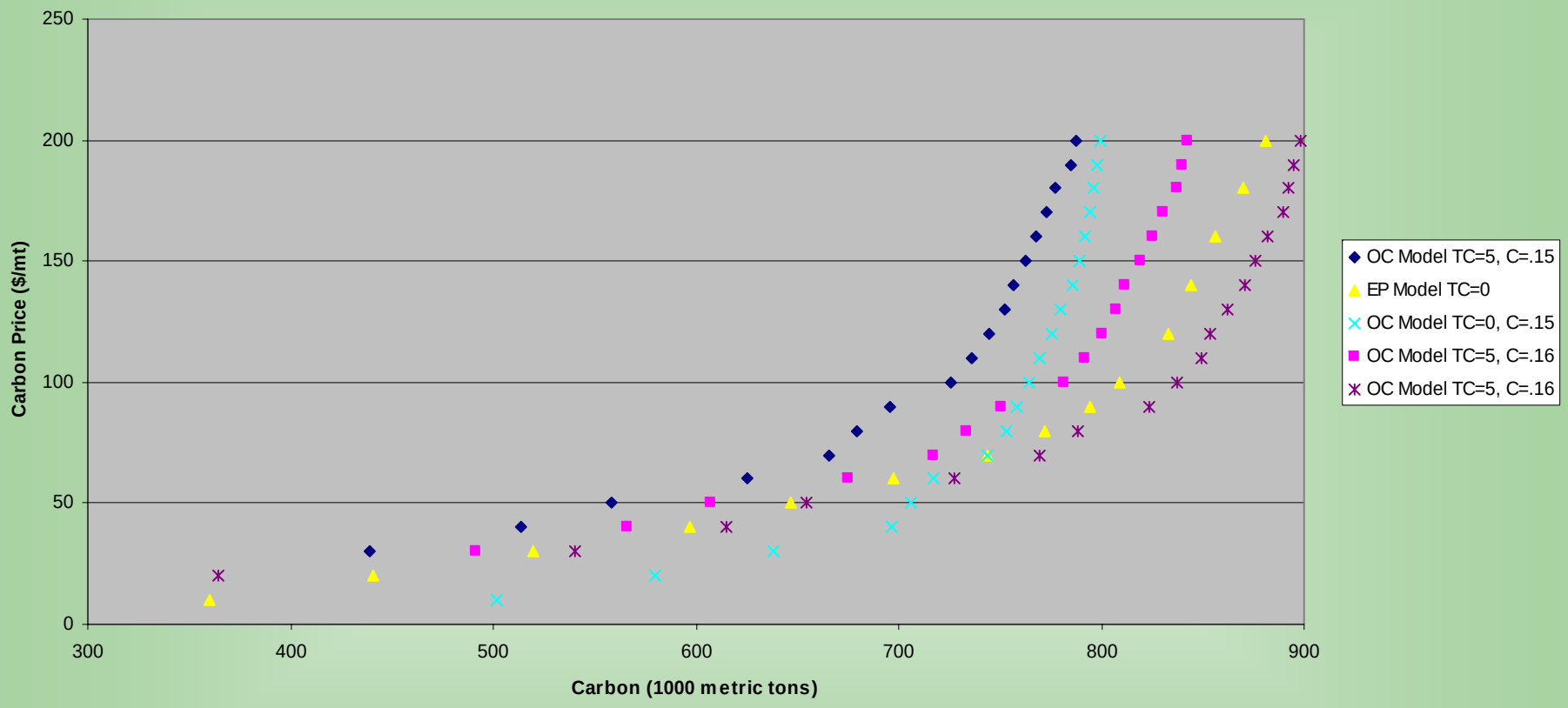
Fallow and Conservation Tillage Contract Participation, Central U.S. Wheat



Fallow and Conservation Tillage Carbon Supply Curves, Central U.S.



Montana Fallow Carbon Supply Curves for Econometric-Process and Opportunity Cost Models



Preliminary Results for Central U.S.

- Preliminary estimates for Central U.S. region indicate that supply is elastic at low C prices, approaches maximum at $100/ton

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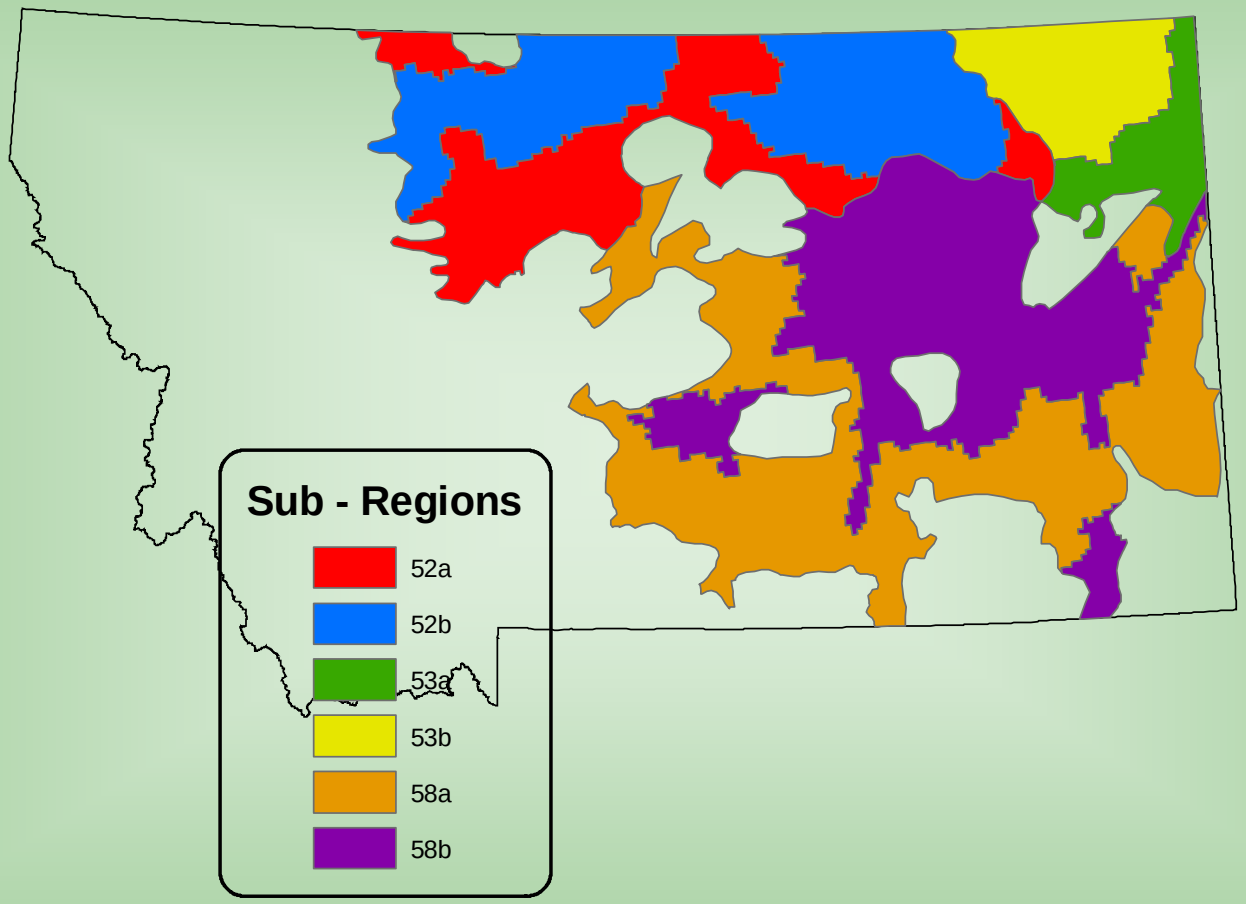
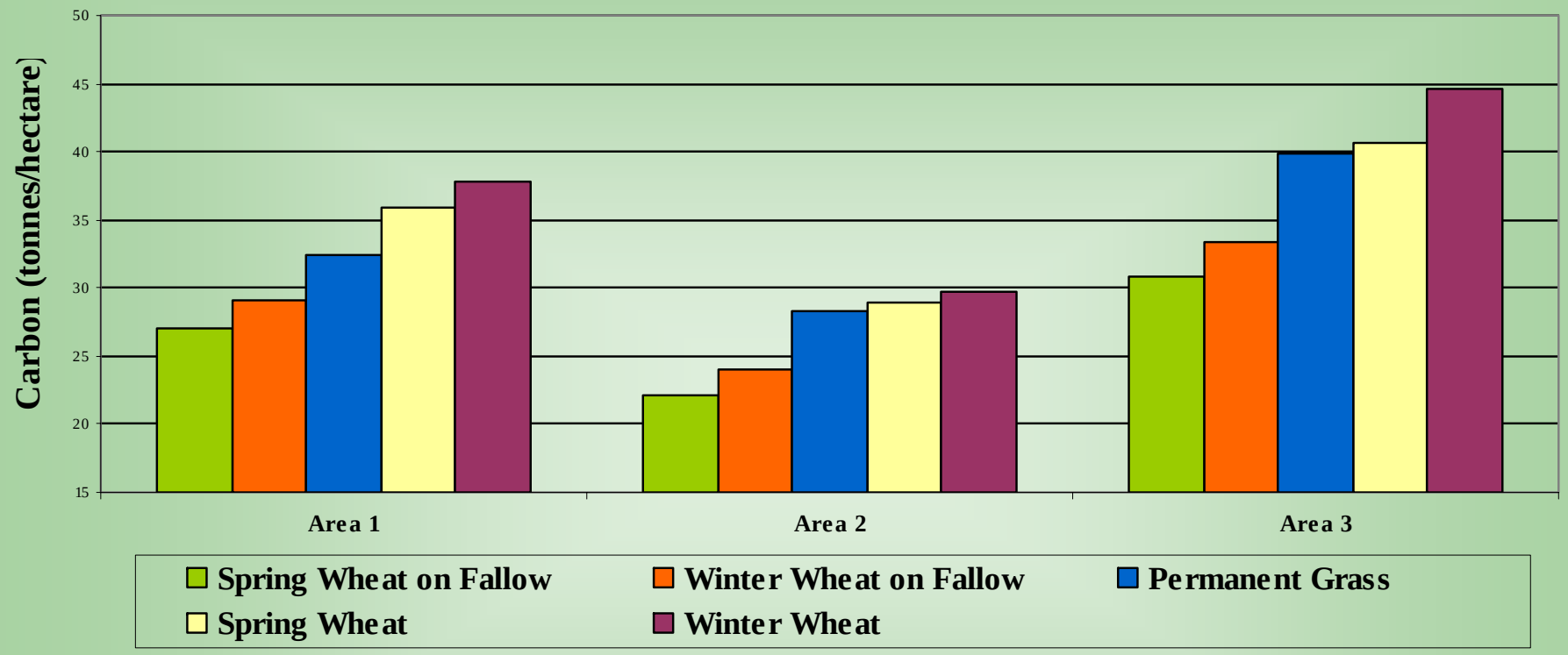
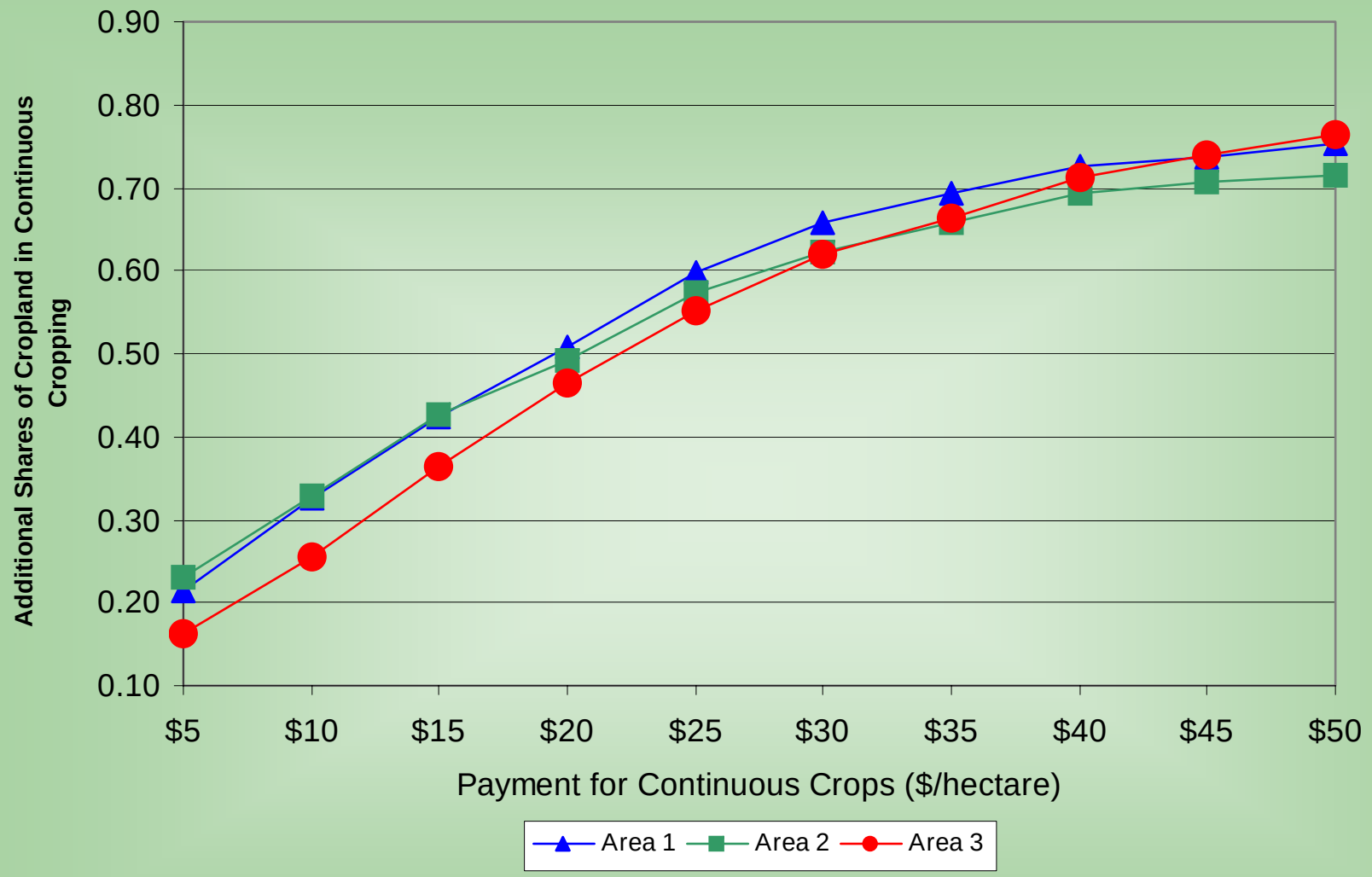

Sub - Regions
52a
52b
53a
53b
58a
58b



Soil Levels Predicted by the Century Model
for Cropping Systems in Montana



Additions to Share of Cropland in Continuous Cropping by Area: Base Scenario

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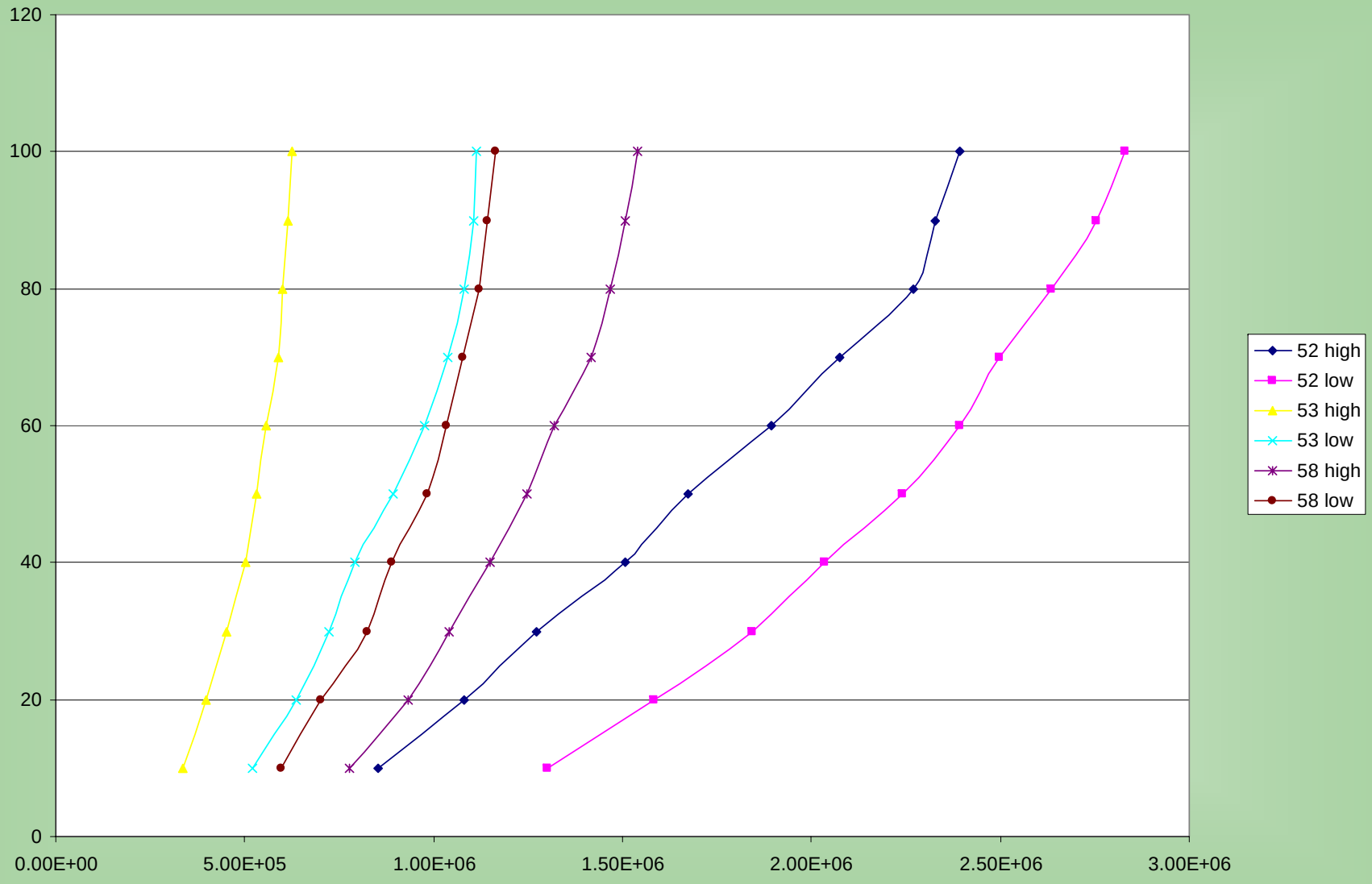
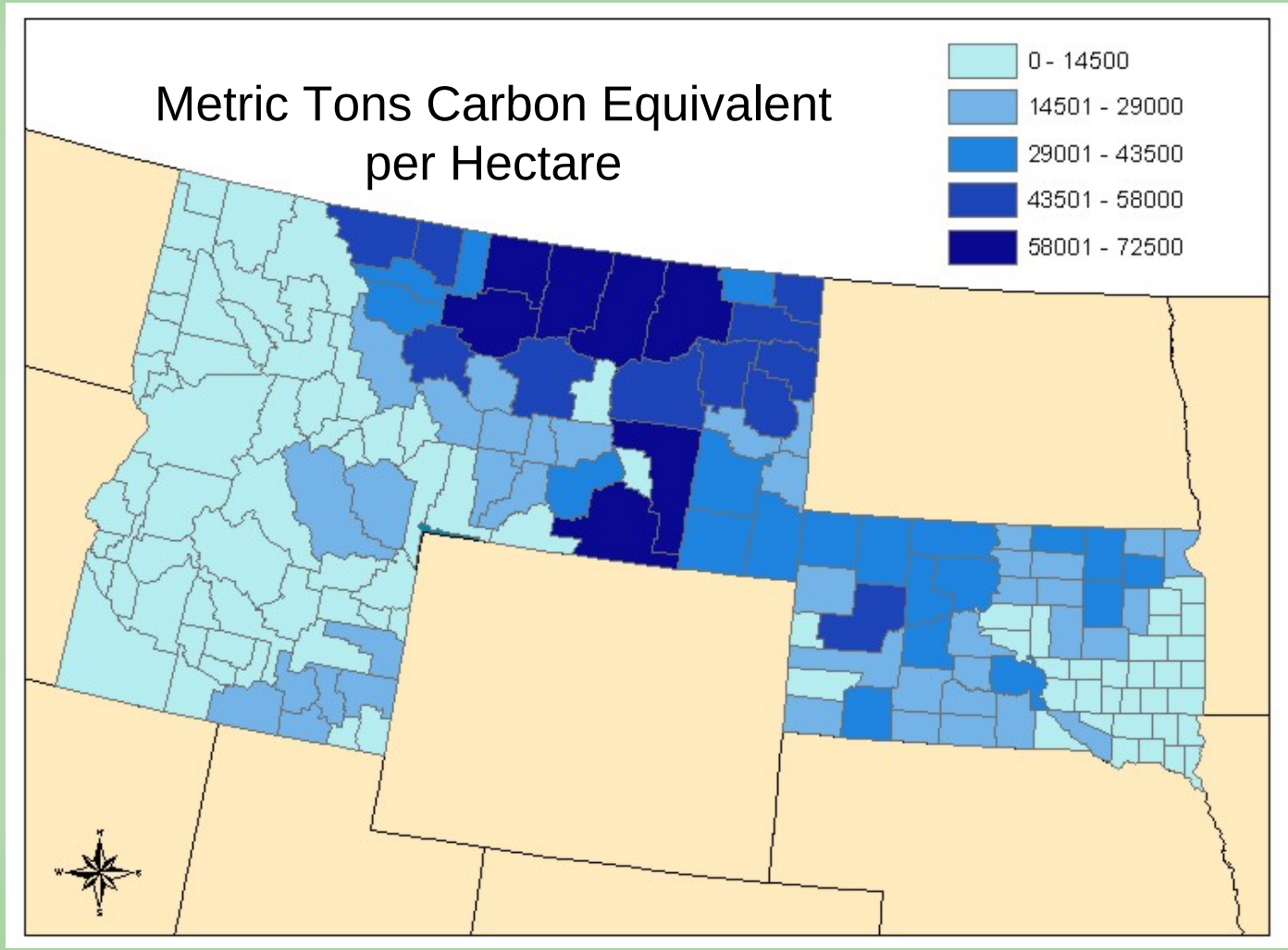

120
100
80
60
40
20
0
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
52 high
52 low
53 high
53 low
58 high
58 low

Terrestrial Carbon Baseline



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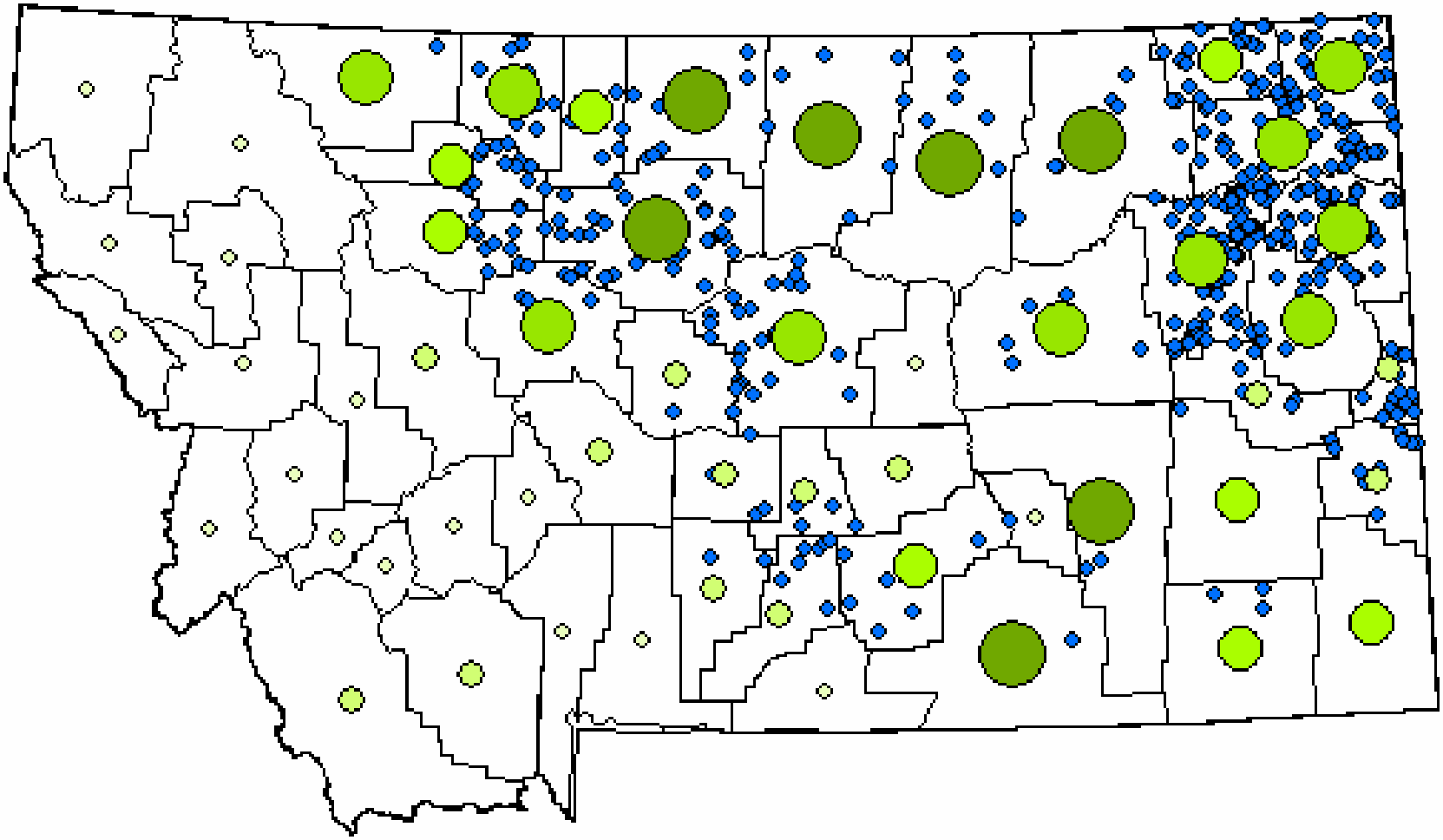
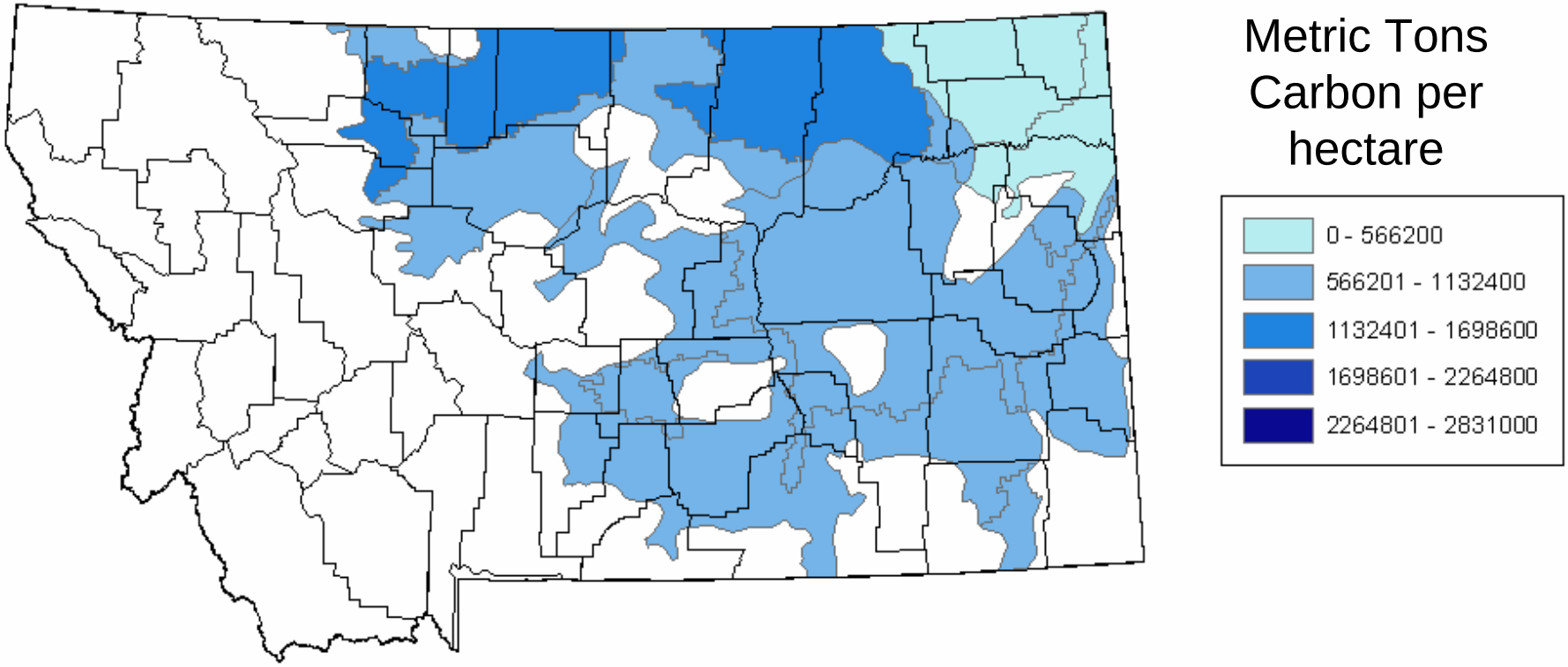
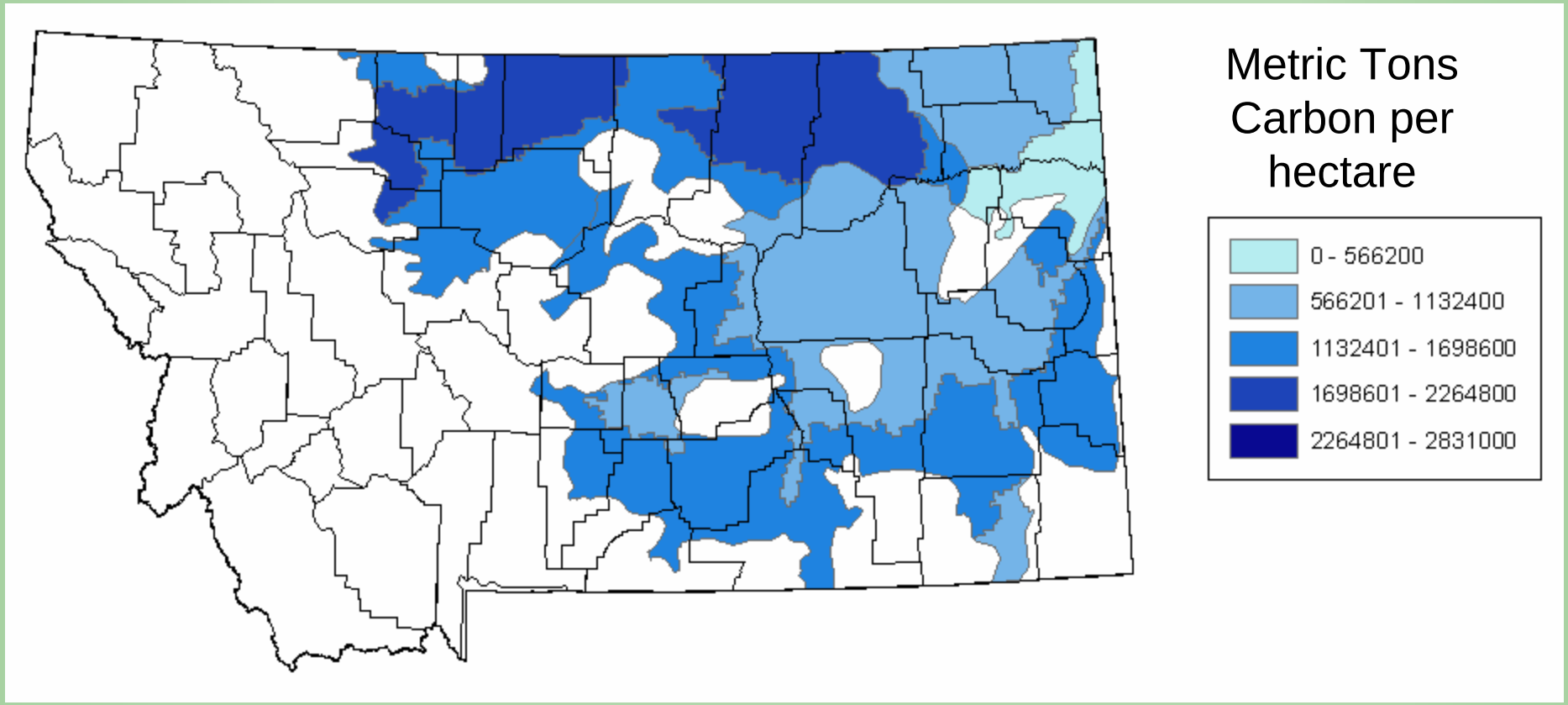


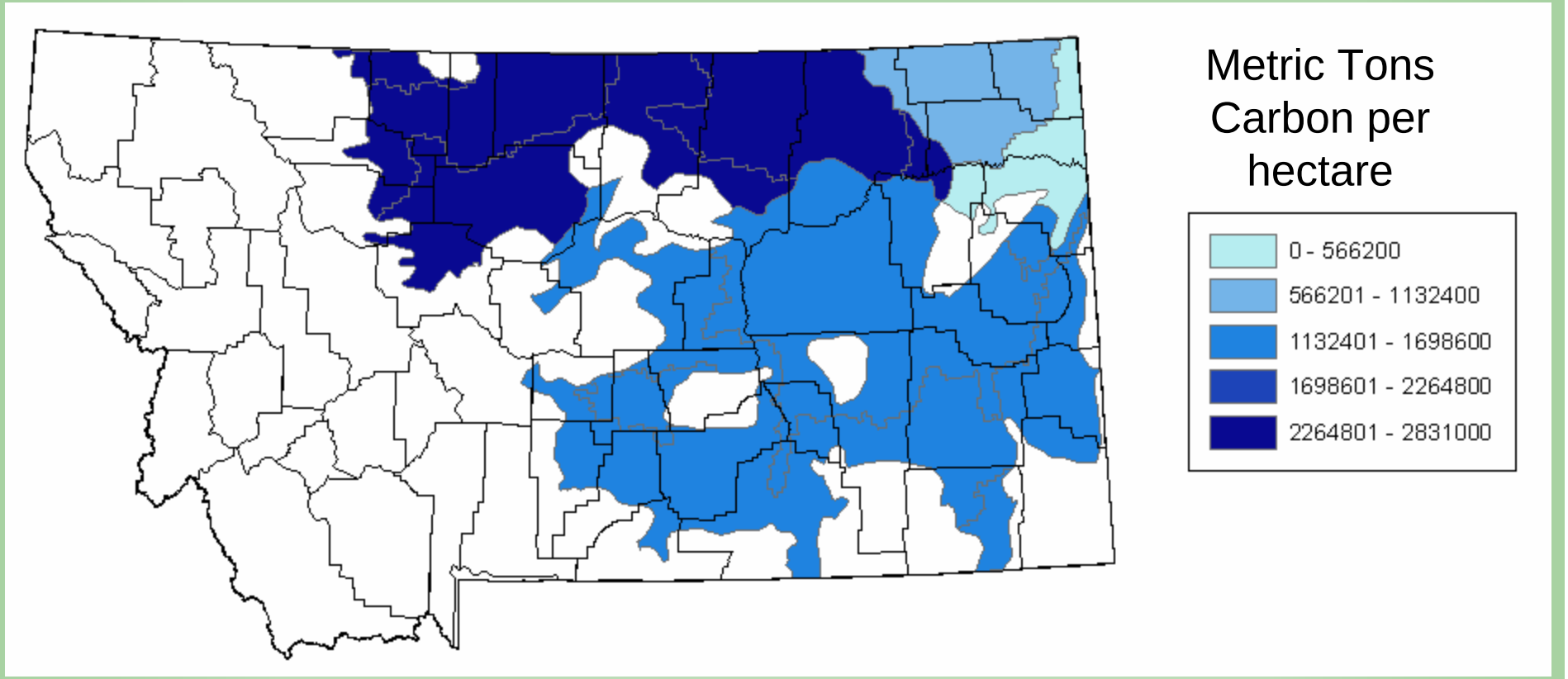
$10 per Ton of C



$50 per Ton of C



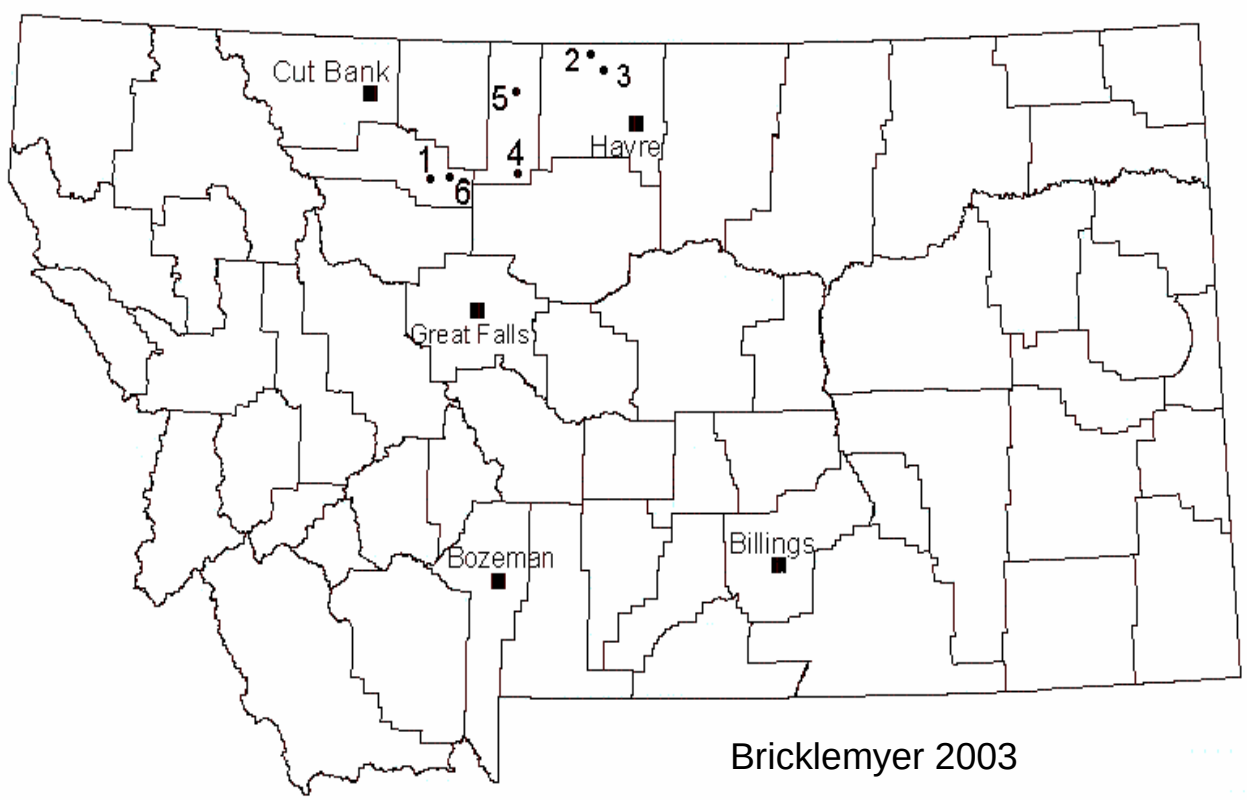
$100 per Ton of C



Pilot studies: Golden Triangle of MT

Perry Miller, Ross Brickelmeyer

Rick Engel, Montana State University



Bricklemyer 2003

Methods

- Field studies – measure change in SOC as change from conventional tillage to no till
- Work with actual producers
- Bottom line:

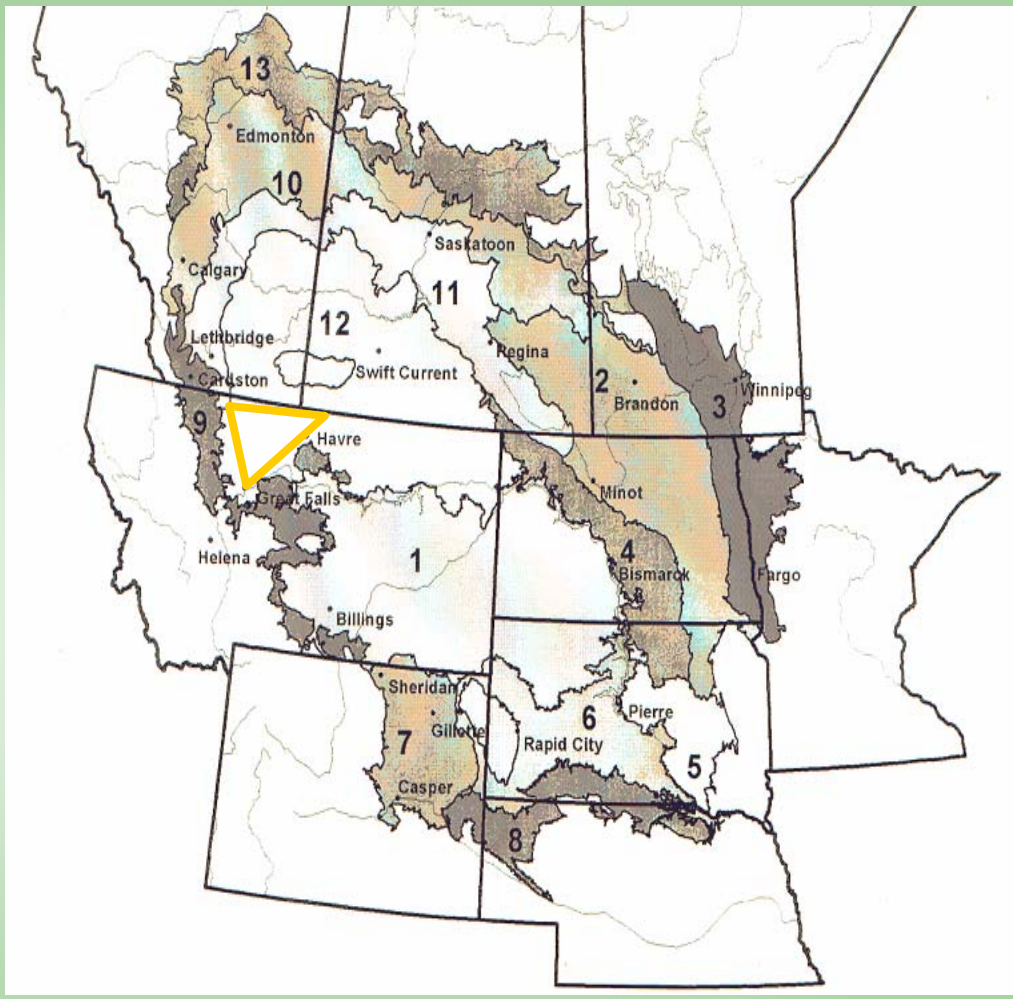
0.13 - 0.4 t C/ha/yr

Carbon Sequestration Potential in North Central Montana

1.3 M ha cropland in yellow triangle
Estimated: .4MMTC/yr

Q: How compare with Modeling Amounts?

A: Within 10% (high side)



C-Lock: producer-decision support framework

- Provides interface among science, policy, producers, and buyers
- Designed to maximize income to producers and to minimize risk to purchasers in scientifically-defensible, reproducible way
- Example of privatizing services – clean air, clean water, decreased sedimentation that can be provided by producers in addition to commodities

C-Lock

- Web-based system
- Allows landowners to register land parcels for which carbon emission reduction credits (CERCs)
- CERCs estimated and certified based on client-specified management changes
- Individual producers optimize potential income because each parcel estimated using site-specific parameters
- uses publicly-available spatial and climate databases and CENTURY to estimate soil carbon stocks
- field-specific modeling approach helps ensure project additionality, or that sequestered carbon is in excess of that which would occur under business-as-usual (BAU) management

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Field Information for Joe Smith - Microsoft Internet Explorer

Field Information for Joe Smith

To quantify and certify Carbon Emission Reduction Credits that can be generated and sold by individual producers in South Dakota.

C-Lock Home | Log-in/My Info | What's New

* Indicates required data

Each field must contain only one type of crop (or grass) at the present time. This field must be managed all in the same manner (cultivation, fertilizer, irrigation, etc.); otherwise, it must be divided into sub-fields for the purpose of calculating carbon credits.

*Field Name: Joe Smith

*County Name: Buffalo

Field Identification:

State Code	Farm Number	Tract ID	Field ID Information	Sub-division
46	219	2	5	C

* What is your role for this field?

- (•) I own and manage this land
- ( ) I own but do not manage this land
- ( ) I manage but do not own this land
- ( ) I rent and manage this land

*Area of this field in acres 10000

*Percentage of this field that is tillable most years 50 %

Please enter the average soil texture values for this field, if known. If you are not sure leave them blank, and we will estimate them from soil maps. Use percentages, eg. 40% sand, 40% silt, 20% clay. (The total percentage must equal 100%.)

Fraction sand 10 % Fraction silt 20 % Fraction clay 70 %

Enter Field Location

Click here to locate your field.

Save and Close | Cancel

Start | Eud... | Micr... | Macr... | Clim... | Scali... | User... | Fiel... | 9:16 AM

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Overview for Joe Smith - Microsoft Internet Explorer

Overview for Joe Smith

To quantify and certify Carbon Emission Reduction Credits that can be generated and sold by individual producers in South Dakota.

C-Lock Home | Log-in/My Info | What's New

State Legislator

To add information about the history of this field use the [Edit] links. Upon completion of all required data, a [View] link will appear. From the [View] page you will have the ability to print your data for review. You may edit your data until you choose to calculate your credits.

Field Information

Field Name: Joe Smith [Edit] [View]
Field Location: [Edit]

General History

1900 **to** 1989 [Edit]

Detailed History

1990 [Edit]

1991 [Edit]

1992 [Edit]

1993 [Edit]

1994 [Edit]

1995 [Edit]

1996 [Edit]

1997 [Edit]

1998 [Edit]

1999 [Edit]

2000 [Edit]

2001 [Edit]

2002 [Edit]

2003 [Edit]

Start | Eud... | Micr... | Macr... | Clim... | Scali... | User... | Ove... | 9:19 AM

1990 Detailed History for Joe Smith - Microsoft Internet Explorer

1990 Detailed History for Joe Smith

To quantify and certify Carbon Emission Reduction Credits that can be generated and sold by individual producers in South Dakota.

C-Lock Home | Log-in/My Info | What's New

Crop Type: Corn

Cultivation [Edit Values]

Type	Month
Disc	March
Disc	April
Planter	May
Row-Cultivator	June
Row-Cultivator	July
Moldboard Plow	October

Fertilizer [Edit Values]

Amount (Lbs/acre)				Type	Month
N	P	K	S		
30	20	0	0	Dry	May

Organic Matter Additions [Edit Values]

Month	Type	Amount (Tons/acre)

Irrigation [Edit Values]

Month	Type	Amount (Inches)

Start | Eu... | Mic... | Ma... | Cli... | Sc... | Us... | 19... | 9:21 AM

The South Dakota Carbon Sequestration Project

To quantify and certify Carbon Emission Reduction Credits that can be generated and sold by individual producers in South Dakota.

C-Lock Home | Log-in/My Info | What's New | Log-out

CERC Report for John Doe	Thursday, May 9, 2002

Producer: John Doe
Producer ID: 999-999

Field ID: 46-115-52-200859
Number of acres: 160

Decade Ending:	Maximum potential CERCs generated since 1990	Certified CERCs generated since 1990	Reserve CERCs generated since 1990
2000	820	767	53
2010	2544	2461	82
2020	3688	3593	94

Producer-committed credits--Carbon Pool maintenance	1259 accrued + 2334 committed

Send Comments to C-Lock

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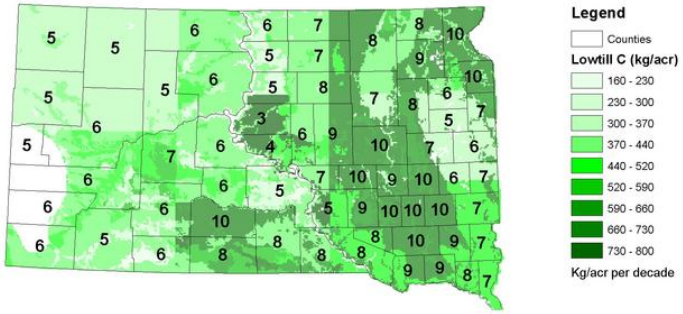
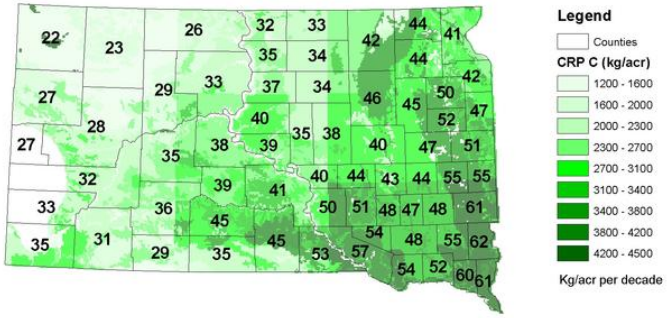
Estimated Average Yearly Income

Assuming a price of $40/ton of CO2

Average yearly income for LowTill land at $40/ton in dollars per acre



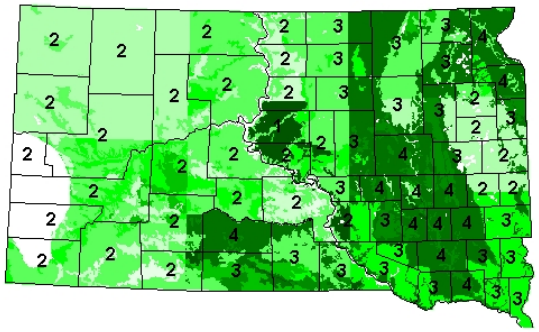
Average Yearly Income for CRP land at $40/ton



Projected Average Yearly Income

Assuming a price of $15/ton of CO2

Average yearly income for LowTill land at $15/ton in dollars



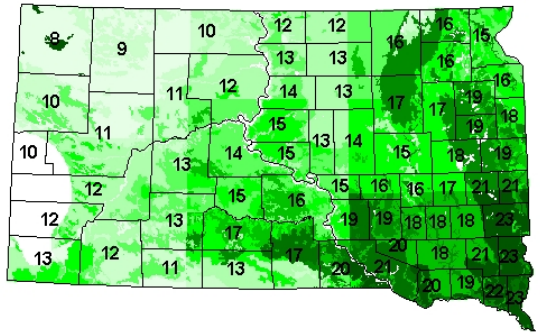
Legend

Counties

Lowtill C (kg/acr)

- 160 - 230
- 230 - 300
- 300 - 370
- 370 - 440
- 440 - 520
- 520 - 590
- 590 - 660
- 660 - 730
- 730 - 800

Average Yearly Income for CRP land at $15/ton in dollars



Legend

Counties

CRP C (kg/acr)

- 1200 - 1600
- 1600 - 2000
- 2000 - 2300
- 2300 - 2700
- 2700 - 3100
- 3100 - 3400
- 3400 - 3800
- 3800 - 4200
- 4200 - 4500

Extensions of C-Lock (phase I, yr 2 and Phase II)

- Add economic component
- Extension to MT, WY (possibly Eastern WA and OR)
- Leverage with USDA funding for pilot on Cheyenne River Sioux Tribe – 400 producers, 1 million acres of tribal lands

(funded as part of USDA conservation program)

Education & Outreach

Pamela Tomski
EnTech Strategies, LLC

Montana State University

Task Deliverables

- Action Plan
- Web Site
- Poster
- Fact Sheet
- Workshops, Symposia, Roundtables
- CO2 Networks

What We Have Learned

- Climate change is 800 lb gorilla
- Sequestration associated with terrestrial
- General interest in concept; no overt hostility
- Questions about permanence/safety
- Economic development matters a lot

Approach: Year 1

- Materials Development
  - Action Plan
  - Web Site (*www.bigskyco2.org*)
  - Poster
  - Fact Sheets

- Discussions with Key Decision Makers, State and Community Leaders
  - State Carbon Sequestration Advisory Committees
  - Environmental NGOs
  - Tribal Council Leaders
  - Economic Development Groups
  - Departments of Environmental Quality and EPA
- Establish Network to Disseminate Information
  - Access to about 800 people

Approach: Year 2

- Establish CO2 Networks
- Workshops/Symposia
- Web Site Enhancements
  - Expand Links to Site
  - Bulletin Board
  - Incorporate GIS
- Student Research Paper Contest
- Utilize Listserv Network to Report on Progress
- Broaden News Coverage
- International

Keeping Score: Year 1

- Presentations: 27
- Poster Sessions: 3
- External Meetings: 22
- Workshops/Symposia: 1
- News Articles: 6

Upcoming Scheduled Events

- Idaho Carbon Sequestration Advisory Committee: Dec 9
- Tribal Carbon Sequestration Forestry Workshop: Jan 11-12
- Tribal Ag Sequestration Workshop: Jan 13-14
- 5th North West Harvesting Energy Conference: Jan 20-21
- E. Montana Economic Development Coalition:

  Jan 20
- Electric Utilities Environmental Conference:

  Jan 24-26
- Montanans for Responsible Energy Development:

  April 2005

The National Carbon Offset Coalition

- 8 non-profit resource conservation organizations
- Technical/financial support from federal (EPA, NRCS), state (conservation districts, forestry agencies) and tribal organizations
- Goal: create an administrative framework to encourage private and tribal landowners to participate in a future carbon credit market.

Institutional Approach

- Working through local organizations to reach landowners and facilitate carbon sink projects
- Assisting with marketing carbon sequestration units (CSU's) resulting from projects
  - Developing a Portfolio
    - Benefit of large numbers
- Providing credibility and stability
- Managing long term obligations

Planning Handbook

- Audience – Technical staff who work with landowners. Experienced in planning; but not in carbon project requirements
- Goal – Improve the quantity, quality, consistency, and credibility of NCOC carbon sequestration projects

Handbook Organization

- Part 1 – Background and Context
  - Build awareness of international and U.S. policy issues and general planning considerations in carbon sequestration projects
- Part 2 – Carbon Trading and Marketing
  - Background on existing experience in markets
- Part 3 – Registering Carbon Credits
  - The emergence of national, regional, and state registries (1605(b), California, RGGI, etc.)

Handbook Organization

- Part 4 – The National Carbon Offset Coalition
  - NCOC requirements, processes, and services
- Part 5 – Carbon Sequestration and Emission Reduction in Agriculture and Forestry
  - Background on conservation and management practices that affect carbon stocks in soil and wood
- Part 6 – Project Planning
  - Integration with other programs; NCOC process

Handbook Organization

- Part 7 – Project Economics
  - Guidelines for estimating costs and benefits
- Part 8 – Appendices
  - Rule of Thumb estimating, Models, Measurements
  - Tables and Charts, Conversion Units
- Handbook Supplements
  - EXCEL Carbon Calculator for Soil and Wood
  - EXCEL Project Economic Calculator

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