Greenhouse Gas Inventory from Agriculture, Forestry and Other Land Uses for Boulder County, Colorado Parks and Open Space

Mark Easter[1], Amy Swan, and Stephen Williams
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523-1499

and

The Brendle Group
212 W. Mulberry St
Fort Collins, CO 80521

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[1] Corresponding Author: (970) 491-1098, Mark.Easter@Colostate.edu

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Executive Summary

This study was done for the Boulder County, Colorado Department of Parks and Open Space, in response to IRFQ I502-13, *Greenhouse Gas Inventory and Forecast of Land Management Practices*. There were six key tasks to accomplish:

- Quantify a baseline of GHG based on existing vegetation, use, and condition on BCPOS lands.
- Identify and quantify the inputs and outputs of GHG on BCPOS lands based on existing agricultural production on cropland, pasture and rangeland including livestock.
- Identify and quantify the inputs and outputs of GHG on BCPOS grassland restoration.
- Identify and quantify the inputs and outputs of GHG on BCPOS forestry land based on forest type and management (e.g. thinning and prescribed fire).
- Provide a forecast of carbon emissions for a 10 year period.
- Make recommendations about best management practices to reduce GHG emissions and increase carbon sinks on BCPOS lands.

We worked closely with BCPOS staff to collect GIS layers and identify land management details which affect soil and biomass carbon and greenhouse gas emissions on BCPOS lands. We utilized a combination of IPCC Tier 1, 2 and 3 methods (Eggleston *et al*. 2006) as follows:

- For agricultural cropland, pasture and grazing land, we used the DayCent model to predict soil carbon stocks and greenhouse gas cycling in response to land management (Parton *et al.*1998).
- For soil carbon stocks on non-agricultural lands, we used the USDA NRCS SSURGO soil database (NRCS 2014).
- For biomass carbon stocks on BCPOS non-agricultural forest, shrub, and range lands, we used a combination of local, regional and IPCC default biomass carbon stock measurements in combination with BCPOS vegetation maps.
- On BCPOS agricultural conservation easements, we used a combination of statistical models to predict soil and biomass carbon stocks (Eggleston *et al.*2006).
- For livestock, we used IPCC Tier 2 empirical models to predict annual greenhouse gas emissions (Eggleston *et al.*2006).

Results of the analysis are as follows:

- Carbon Stocks: At the end of 2013, BCPOS lands and conservation easements held a total of 6.6 million metric tonnes of sequestered soil organic carbon in the top layers of the soil and biomass carbon, including the following:
    - Agricultural lands held 1.46 million Mg (metric tonnes) CO_2e of organic soil carbon 20cm depth at the end of 2013.
    - Non-agricultural lands held 1.36 million Mg (metric tonnes) CO_2e of organic soil carbon to 30cm.
    - Agricultural conservation easements held 1.3 million Mg (metric tonnes) CO_2e of organic soil carbon to 30cm.
    - Non-agricultural forest and shrub lands held 2.47 million Mg (metric tonnes) CO_2e of biomass carbon at the end of 2013.
- At least 40% or 2.6 million metric tonnes of the protected carbon sequestered in these lands is vulnerable to rapid decomposition and hence becoming atmospheric CO_2 if the forests, rangeland and cropland that holds these carbon stocks were developed. The calculated 2012 transportation emissions from user visits to these lands is about 0.4%, or one-250th of the total carbon stocks.
- BCPOS could offset annual visitor recreation travel emissions by changing tillage intensity on agricultural lands to no-till or reduced till systems and replacing synthetic fertilizers with compost or manure. This is based on the 2012 transportation emissions.
- Net Greenhouse Gas Emissions: BCPOS agricultural lands had a net emission of 5,621 Mg CO_2e/year for the period 2004-2013. Emissions are likely to drop to 3,261 Mg CO_2e/year in 2014-2023 as growers are expected to reduce tillage and more compost/manure is used in place of synthetic fertilizers as more BCPOS lands move into organic management. Soil organic carbon stocks on non-agricultural lands are unlikely to change in the next decade in the absence of major changes in land use and land management. The net greenhouse gas balance on agricultural conservation easements could not be calculated. The current unpredictable nature of wildfire makes it difficult to predict how biomass carbon stock will change on BCPOS lands in the next decade; however forest restoration efforts have a net greenhouse gas offset value of about 0.6 Mg CO2e per dry metric tonne (Mg) of biomass utilized at boilers.

Energy Use in BCPOS Buildings and Operations: Energy use in BCPOS buildings and operations averaged 808 Mg CO_2e/year between 2008 and 2012. Emissions peaked at 849 Mg CO2e in 2009 and declined at an average rate of 2.2%/year to 794 Mg CO_2e in 2012. Net emission for recreational travel by visitors to BCPOS lands was 9,858 Mg CO_2e in 2012.

BCPOS has already done a great deal to reduce its net emissions from energy use and transportation. Further progress can be made to reduce net emissions through the following practices:

- Energy Use:
    - Increase use of biomass fuels for heating.
    - Manage IT plug loads.
    - Source electricity from renewable sources.
    - Increase use of biodiesel as a replacement for conventional diesel fuel when possible.
- Cropland:
    - Replace synthetic fertilizer with manure and/or compost to meet crop nutrient needs.
    - When using synthetic fertilizers, use slow-release products and nitrification inhibitors, and inject or bury fertilizers when they are applied to fields.
    - Reduce tillage intensity and events where possible.
    - Expand use of cover crops where possible.
    - Intensify crop production on non-irrigated crops by adding dryland corn and millet to rotations.
    - Consider growing biofuel crops such as switchgrass when a regional market develops for the product.
- Pasture, Rangeland and Livestock: Continue to manage pastures and rangeland for optimum vegetative cover, and graze at moderate levels to maintain the current greenhouse gas balance.
- Forestland: Continue with forestland restoration work where possible, and divert harvested biomass to burn in biomass boilers where possible.
- Roadside Corridors: Manage unmowed corridor sections to grow and maintain woody shrubs where the presence of these plants does not reduce visibility or otherwise create a safety issue.

Introduction and Objectives

This report summarizes greenhouse gas (GHG) emissions from Agriculture, Forestry and Other Land Uses for The Boulder County, Colorado Department of Parks and Open Space (BCPOS), from 2004 through 2013, with projections to 2023 in land use categories where predictions were possible.

There were 5 major objectives to this study, as identified in the project RFQ:

a) To quantify a baseline of GHG based on existing vegetation, use, and condition on BCPOS lands
b) To identify the inputs and outputs of GHG on BCPOS lands based on existing agricultural production on cropland, pasture and rangeland including livestock
c) To identify and quantify the inputs and outputs of GHG on BCPOS grassland restoration
d) To identify and quantify the inputs and outputs of GHG on BCPOS forestry land based on forest type and management (e.g. thinning and prescribed fire)
e) To provide a forecast of carbon emissions for a 10 year period

The major greenhouse gases analyzed are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and carbon monoxide (CO). Life cycle (embodied) emissions are included for land management processes where those data were available.

We modeled the following GHG source categories, which include both biogenic emissions and sequestration from the management of soils and vegetation, as well as anthropogenic emissions from the burning of fossil fuels:

- Soil Organic Carbon (SOC)
- Soil Nitrous Oxide
- Biomass Carbon
- Enteric Methane
- Manure Methane
- Manure Nitrous Oxide
- Non-CO2 Trace Gas Emissions from Biomass Burning
- Carbon Dioxide, Nitrous Oxide and Methane from Fossil Fuel Combustion

There are three driving emissions types that underlie this assessment of the GHG balance of BCPOS land use and management:

Ecosystem Carbon Change: Ecosystem carbon resides in a state of dynamic equilibrium until land use or management change, forcing either a release of carbon into the atmosphere or an uptake of carbon into soil or biomass. For example, Ponderosa pine woodlands and forests on BCPOS non-agricultural lands are considered to be in a state of dynamic equilibrium, storing as biomass carbon an average 100-140 Megagrams (Mg) of carbon dioxide equivalents (CO_2e) per hectare (ha) in roots, trunks, branches and leaves. These ecosystems also store on average 58 Mg of CO_2e of soil organic carbon in the top 30 cm of soil (depending on the soil type, stand age, and stand condition). If a ponderosa pine forest in the county were cleared for some other land use, the majority of the carbon in those trees would be lost to the atmosphere and over time the tree and soil biomass in the new land use system would reach a different equilibrium state, generally much lower than that in the native forest. The difference between the equilibrium states is calculated as the net carbon emission. The change occurs over a period of 20 or more years depending on the carbon source or sink and the type of land use or management change that occurred.

GHG Emissions from Annual Land Management Activities: Land use and management conducted on an annual basis such as tilling, planting and fertilizing cropland, restoring forests, and grazing livestock releases ecosystem carbon and nitrogen as greenhouse gases into the atmosphere in the form of carbon dioxide, methane and carbon monoxide or other GHG gasses such as nitrous oxide.

Embodied Emissions: Many land use practices use equipment, energy, fuel, or soil amendments. These incur some net emission of greenhouse gases to the atmosphere when they were produced, manufactured, or distributed to the user. These life cycle *embodied* emissions are generally specific to that particular item or process. They can be large in some cases, and knowledge of these emissions can aid decision makers in making informed decisions for land use and management practices. For example, synthetic nitrogen and phosphorus fertilizers require large amounts of energy during manufacturing. Fossil fuels are generally required to create the energy needed in these processes, or as the raw material for the chemicals involved. Storing and transporting the materials to the user requires additional energy as well. The sum of these upstream emissions contributes to the total embodied emissions for the product or item being used.

The sum total of land management activities often involve a combination of emissions into the atmosphere of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and carbon monoxide (CO) as well as sequestration of carbon into plant biomass and soils via the uptake of carbon dioxide in photosynthesis. We refer to the sum of these emissions and sequestration as the

greenhouse gas balance of the process. All amounts are reported in Megagrams (Mg, also known as *metric tonnes*) of carbon dioxide equivalents (CO_2e). We apply the IPCC Fourth Assessment figures 100 year time horizon estimates for global warming potentials of these gases (IPCC 2006), which are 1 for carbon dioxide, 25 for methane, 298 for nitrous oxide, and 1.8 for carbon monoxide. Areas are in hectares. A positive number indicates an emission into the atmosphere, and a negative number indicates a net sequestration of carbon in soil or biomass.

We diverge somewhat from convention by presenting carbon stocks in the units of Megagrams of carbon dioxide equivalents (Mg CO_2e) rather than Megagrams of carbon (Mg C). We did this to make comparisons between emissions and stock values more straightforward for BCPOS staff. To convert carbon dioxide equivalents to carbon, divide by (44/12) or 3.67.

Methods

We utilized a combination of Tier 3, 2, and 1 approaches as classified by the Intergovernmental Panel on Climate Change (IPCC) (Eggleston *et al.* 2006), as follows

- For energy use, we used emission factors published by U.S. EPA's EGrid database, Xcel Energy's gas quality database, and The Climate Registry, where applicable (IPCC Tier 3).
- For croplands, rangelands, and roadside corridors, we utilized DayCent Ecosystem Model (Parton *et al.* 1998) in our analysis of soil carbon and nitrogen flux (IPCC Tier 3).
- For livestock emissions, we utilized the IPCC Fourth Assessment, "Enhanced Characterization" methods with emission factors specific to the United States (IPCC Tier 2).
- For forest and shrubland biomass we utilized U.S. Department of Agriculture (USDA) Forest Vegetation Simulator (FVS) model results (USDA FVS 2014) provided by BCPOS staff, information from peer-reviewed studies from our region (where available), and IPCC default biomass stock values specific to Temperate North America when other data sources were not available (IPCC Tier 3).
- For forest and shrubland soil carbon we utilized the Natural Resource Conservation Service (NRCS) SSURGO database (NRCS 2014) (IPCC Tier 2).
- For biomass burning, we utilized IPCC Tier 2 methods (Eggleston *et al.* 2006).

The availability of data was the primary factor determining the method. A Tier 1 analysis uses the IPCC default equations and default factor values. A Tier 2 analysis uses improved calculation techniques and region- or country-specific emission factor values in the calculations, and a Tier 3 approach utilizes region-specific dynamic or empirical models, such as our use of the DayCent model.

For all of the above analyses, we utilized the excellent spatial data provided by BCPOS staff.

Spatial Analysis

The location of a number of land use and management activities as well as climate and soil types for BCPOS lands were determined using spatial data and GIS methods. Using parcel boundary data provided by BCPOS, lands were divided into three categories for analysis (Figure 1): non-agricultural lands (parks, open space and other non-agricultural lands), agriculture (defined by BCPOS agriculture fields data), and agricultural conservation easements and other lands (lands with little to no direct management by Boulder County).

Agricultural fields owned by Boulder County were defined in a spatial dataset provided by the county. All remaining parcels were then classified into land cover categories using Boulder County vegetation mapping data and any gaps were filled with Southwest Regional Gap Analysis Project (SWReGAP) data (USGS National Gap Analysis Program 2004). If lands were classified as "Agricultural Vegetation" according to SWReGAP data, they were categorized as "agricultural conservation easements and other lands." In general, spatial overlay methods were used to create unique intersections of land use and management, climate and soil types. The climate data source used for all lands was the North American Regional Reanalysis (NARR) grid data (NOAA 2004). Soil types were derived for all lands from the Soil Survey Geographic database (SSURGO) (NRCS 2014). Other data sources that were used for each category in addition to boundary, climate and soil data are listed below.

- Non-agricultural lands: vegetation alliances (BCPOS), SWReGAP land cover (USGS National Gap Analysis Program 2004**),** past wildfire areas (BC), past and future prescribed burning (BCPOS), and other forest restoration activities (BCPOS).
- Agriculture: Cropland Data Layer (CDL) (USDA-NASS 2008-2012)
- Agricultural conservation easements and other Lands: Cropland Data Layer (CDL) (USDA-NASS 2008-2012)

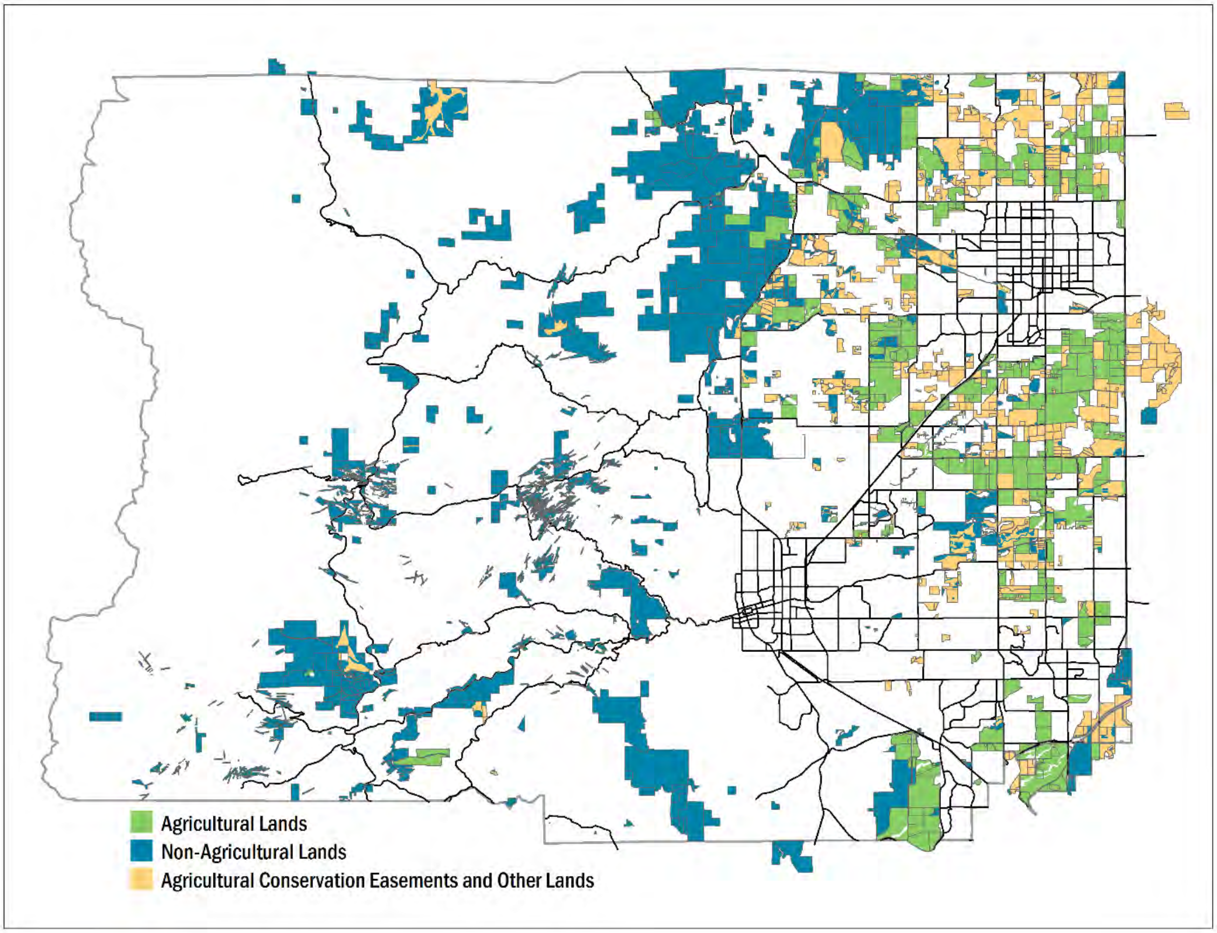

FIGURE 1. BOULDER COUNTY LANDS CATEGORIZED INTO ANALYSIS GROUPS: BCPOS AGRICULTURAL LANDS, NON-AGRICULTURAL LANDS, AGRICULTURAL CONSERVATION EASEMENTS AND OTHER LANDS.

Energy Use

A combination of resources and methods were used to assess the greenhouse gas balance of various energy uses, as follows:

Electricity

Total annual electricity consumption data was provided by Boulder County Parks & Open Space for the Parks Administration, Parks Shop, and Biomass buildings. Electricity consumption data were provided for each year between 2007 and 2012, and the unit of electricity provided for each building was kilowatt hours (kWh). Annual GHG emissions from electricity use in all buildings were calculated by multiplying total electricity use by the appropriate emissions factors for carbon dioxide, methane, and nitrous oxide for grid-connected electricity in the Rocky Mountain Region of the United States. Specifically, the emissions factor for carbon dioxide used is from Xcel Energy for electricity consumed in Colorado. Emissions factors for methane and nitrous oxide are from the U.S. Environmental Protection Agency's eGRID 2012 report.

Note: Only half of the electricity consumption in the Biomass building was included in this analysis because Boulder County Parks & Open Space only occupies half of the building. The Boulder County Transportation Department occupies the other half.

Natural Gas

Total annual natural gas consumption data were provided by Boulder County Parks & Open Space for the Biomass building, which is the only building for which natural gas data were available. Natural gas consumption data were provided for each year between 2007 and 2012, and the unit of consumption provided was therms. Annual GHG emissions from natural gas use in the building were calculated by multiplying total natural gas use by the appropriate emissions factors for carbon dioxide, methane, and nitrous oxide. Specifically, the carbon dioxide emissions factor used was provided by Xcel Energy for natural gas supplied to the Denver region in 2013. Methane and nitrous oxide emissions factors used are from The Climate Registry's General Reporting Protocol, Table 12.9.

Note: Only half of the natural gas consumption in the Biomass building was included in this analysis because Boulder County Parks & Open Space only occupies half of the building. The Boulder County Transportation Department occupies the other half.

Biomass Boiler

Total annual biomass consumption data were provided by Boulder County Parks & Open Space for the Biomass building, which is only building that uses biomass fuels for heating. Biomass consumption data were provided for each year between 2007 and 2012, and the unit of consumption provided for the building was short tons. Biomass, in the form of wood chips, is combusted in a boiler to produce heat for the Biomass building. Annual GHG emissions from the biomass boiler were calculated using two steps.

First, the amount of energy produced in the boiler was calculated by multiplying the amount of wood chips combusted by the energy content of wood and the efficiency of the boiler. There were no specific efficiency ratings provided, so it is assumed the efficiency of the boiler is 72%. Next, the total energy produced is multiplied by the carbon dioxide, methane, and nitrous oxide emissions factors for wood boilers. The factors come from The Climate Registry's General Reporting Protocol Tables 12.1 and 12.7.

Note: The carbon dioxide emissions from wood are considered carbon neutral. Also, only half of the biomass consumption in the Biomass building was included in this analysis because Boulder County Parks & Open Space only occupies half of the building. The Boulder County Transportation Department occupies the other half.

Fleet Fuel

Total annual fleet fuel consumption data were provided by Boulder County Parks & Open Space for each year between 2008 and 2012, and the unit of consumption provided was gallons. Three types of fuel were used each year: diesel, gasoline, and biodiesel. Annual GHG emissions from fleet vehicles were calculated by multiplying total consumption of each fuel by the appropriate emissions factors for carbon dioxide, methane, and nitrous oxide. All emissions factors for each fuel come from The Climate Registry's General Reporting Protocol Tables 13.1 and 13.4.

Note: The biodiesel consumed was B20, which means only 20% of the fuel was biodiesel and the rest diesel. So, only 20% of the biodiesel blend is a biofuel, and therefore carbon neutral. The remaining 80% was added to other diesel usage.

Roadside Corridors

Total annual fuel consumption data for machines used for roadside maintenance were provided by Boulder County Parks & Open Space for only 2012, and the unit of consumption was gallons. The type of fuel is diesel. Annual GHG emissions from roadside corridor maintenance were calculated by multiplying total diesel fuel consumption by the appropriate emissions factors for carbon dioxide, methane, and nitrous oxide. All emissions factors come from The Climate Registry's General Reporting Protocol Tables 13.1 and 13.4.

Recreation Travel

Recreation travel consists of travel by people to Boulder County Parks & Open Space managed areas. Boulder County Parks & Open Space provided estimates of the number of visitor trips each year to all managed areas and the percentage of those trips by vehicle. In addition, the percentages of those visitor trips that originated in five different regions were also provided. Those regions are: from within Boulder County (31%), from Longmont (17%), from Denver (6%), from neighboring counties (37%), and from other parts of Colorado (9%).

Multiple steps are necessary to estimate the GHG emissions from these vehicle-based visitor trips, which is based on the total vehicle fuel used by visitors to reach the managed areas. The first step was to determine the miles driven from each of the five regions to managed areas. This is accomplished slightly differently for each region, which is detailed below:

- Trips originating from Boulder County (minus Longmont):
  Averaged the estimated distance between the cities of Boulder, Lafayette, Louisville, and Erie, and the center of Boulder County. The average distance is 12.88 miles.
- Trips originating from Longmont:
  Estimated the distance between the cities of Longmont and the center of Boulder County, which is 13.96 miles.
- Trips originating from Denver:
  Estimated the distance between the city of Denver (using the Capitol Building as the point of reference) and the center of Boulder County, which is 31.03 miles.
- Trips originating from neighboring counties:
  Averaged the estimated distance between the center of Boulder County and 1) Denver County (using the Capitol Building as the point of reference), and 2) the population center of Colorado, which is estimated to be in Jefferson County between the towns of Kassler and Conifer. The average distance is 35.79 miles.
- Trips originating from other parts of Colorado:
  Estimated the distance between the population center of Colorado, which is estimated to be in Jefferson County between the Towns of Kassler and Conifer. The distance is 40.54 miles.

The second step is to determine the number of vehicle-based visitor trips originating from each region. The estimates provided by Boulder County Parks & Open Space assumed 80% of all visitor trips were by vehicles, which is 800,000 vehicle trips. Multiplying 800,000 by the percentage of vehicle trips originating from each region provides the total number of trips from each region.

The third step is to estimate the total number of miles recreationalists drove to reach managed areas. This is done by multiplying the total number of miles driven from each region by the estimated distance between each region and the center of Boulder County.

The fourth step is to determine the number of miles driven by gasoline vehicles and diesel vehicles. For this calculation, it is assumed that 80% of miles driven are in 4-door sedans with gasoline engines, and 20% of miles driven are in diesel-powered light trucks or sport utility vehicles.

The fifth step is to determine the total amount of fuel consumed during vehicle visitor trips. This is accomplished by dividing the total miles driven by diesel and gasoline vehicles by the fuel economy for each representative vehicle. Mid-sized vehicles have an assumed fuel economy of 19.4 gallons per miles, while light duty diesel trucks have a fuel economy of 16.7.

The final step is to calculate the GHG emissions resulting from the total fuel consumption. This is done by multiplying total consumption of each fuel by the appropriate emissions factors for carbon dioxide, methane, and nitrous oxide. All emissions factors come from The Climate Registry's General Reporting Protocol Tables 13.1 and 13.4.

Irrigation Emissions Factor

This is based off of the required energy to lift one acre foot of water one foot. The calculation follows:

325,851	gallons = 1 acre foot of water
8.345	lbs. per gallon of water
2,719,227	lbs. of water / acre foot
1	one foot of lift
2,719,227	foot pounds (energy to lift one acre foot of water one foot)
0.0013558	foot pounds to kilojoules conversion
0.000278	kilojoules to kWh conversion
1.02	kWh to lift one acre foot of water one foot
12	feet of vertical lift
12.30	kWh to lift one acre foot of water 12 feet
1,000	kWh to MWh conversion
0.0123	MWh to lift one acre foot of water 12 feet
1678	lbs. CO2 / MWh - emissions factor for Xcel Energy electricity in Colorado
22	lbs. CO2 to lift one acre foot of water 12 feet
0.000453	lbs. to metric tons conversion
0.0093	**metric tons of CO2 to lift one acre foot of water 12 feet**

Soil C & N Modeling

Simulation of Current Practices on Agricultural Lands

We employed the DAYCENT Agroecosystem Model to perform simulations of the agricultural systems on BCPOS lands. DAYCENT simulates fluxes of carbon and nitrogen among the atmosphere, vegetation, and soil (Del Grosso et al., 2001; Parton et al., 1998). Agricultural parcels were defined by BCPOS as irrigated, sub-irrigated, non-irrigated, or farm operations. Recent crops (2008 – 2012) reported in CDL as grown on these parcels were used to develop appropriate representative cropping or grazing systems for the different land use categories. Parcels categorized as farm operations were not modeled.

After discussions with BCPOS staff, we determined that the current non-irrigated agricultural systems could be adequately modeled as conventionally tilled fallow-winter wheat systems (non-irrigated crops) or as grazing lands (agricultural rangeland). Conventional tillage included chisel plow, rodweeder, small grain planter, and mechanical cultivations such as disking during the fallow period. The wheat system was modeled as assigned to parcels so that wheat was harvested from one half of the non-irrigated cropping parcels each year of the simulation. Current non-irrigated grazing systems were defined as rotational with moderate offtake occurring twice a year (late spring and late summer) resulting in 45-50% removal of aboveground annual production. Rangeland was not fertilized (BCPOS personal communication 2013).

It was determined that the current irrigated agricultural systems could be modeled either as a grain-root crop-legume hay rotation, a mixed grass/legume hay system, or as irrigated pasture. The ten year rotation modeled was a conventionally tilled corn silage corn-winter wheat-sugar beet-barley-alfalfa (6 years) rotation. Conventional tillage included moldboard plowing, soil finishing implements, planters, and growing season cultivations in the non-alfalfa years. Different entry points into the rotation were assigned to irrigated parcels based on recent crops found in the CDL. This was done to assure that each crop was present for each year of the simulations.

Parcels simulated as irrigated mixed grass/legume hay were fertilized and had two harvests per year (July, September) and grazing in the fall (October, November). The systems were assumed to be no-till and reseeded every ten years.

Parcels simulated as irrigated pasture were set up as grasslands with occasional fertilizer input. As with non-irrigated grazing systems these were defined as rotational with moderate offtake occurring twice a year (late spring and late summer) resulting in 45-50% removal of aboveground annual production.

The few parcels categorized as sub-irrigated fell into the hay or pasture categories according to the data found in the CDL. The current uses for these parcels then were simulated in the same manner as the irrigated hay lands and pastures.

Simulation of Possible Future Scenarios

To examine the potential effects on soil organic carbon and greenhouse gas emissions, different scenarios of changes in management were simulated for a ten year period. The changes to management simulated included tillage reduction, fertilizer reduction, reduced fallow frequency, manure/compost additions as a substitute for synthetic fertilizer nitrogen, cover crops, organic cropping, change to biofuel crops, and cessation of grazing. The non-irrigated systems simulated are summarized in Tables 1 and 2. Irrigated systems simulated are presented in Tables 3, 4 and 5.

TABLE 1. NON-IRRIGATED CROPPING SYSTEMS SIMULATED IN DAYCENT.

	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Rotation	F-W	F-W	F-W	F-W	F-W
Tillage	CT	RT	NT	CT	RT
Fertilizer (rotation average lbs./acre/year)	17.5	17.5	17.5	0	0
Manure/Compost (rotation average tons/acre/year)	0	0	0	2.7	2.7
	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Rotation	F-W	F-W-C	F-W-C	F-W-C-M	F-W-C-M
Tillage	NT	NT	NT	NT	NT
Fertilizer (rotation average lbs/acre/year)	0	32.7	0	33.3	0
Manure/Compost (rotation average tons/acre/year)	2.7	0	4.7	0	5.3
	Scenario 9	Scenario 10	Scenario 11	Scenario 12	
Rotation	F-W-C-M	SG	SG	Grassland restoration	
Tillage	NT	NT	NT	NT	
Fertilizer (rotation average lbs/acre/year)	0	35	0	0	
Manure/Compost (rotation average tons/acre/year)	5.3	0	5.2	0	

BAU: current practice (business as usual); F-W: fallow-wheat; F-W-C: fallow-wheat-corn; F-W-C-M: fallow-wheat-corn-millet; SG: continuous switchgrass; CT: conventional tillage; RT: reduced tillage; NT: no-till

TABLE 2. NON-IRRIGATED GRAZING SYSTEMS SIMULATED IN DAYCENT. BAU REFERS TO "BUSINESS AS USUAL".

	BAU	Scenario 1	Scenario 2
System	grassland	Grassland	Post-prairie dog restoration
Grazing	moderate	No grazing	No grazing first 5 years then moderate
Fertilizer N	0	0	0
Additional manure/compost input	0	0	0

TABLE 3. IRRIGATED CROPPING SYSTEMS SIMULATED IN DAYCENT.

	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Rotation	C-W-S-B-A(6)	C-W-S-B-A(6)	C-W-S-B-A(6)	C-W-S-B-A(6)	C-W-S-B-A(6)
Tillage	CT	RT	NT	CT	RT
Fertilizer (rotation average lbs/acre/year)	37[1]	37[1]	37[1]	0	0
Manure/Compost (rotation average tons/acre/year)	0	0	0	5[3]	5[3]
	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Rotation	C-W-S-B-A(6)	C-W-C-B-A(6)	C-Wcc-Scc-B-A(6)	SG	SG
Tillage	NT	CT	NT	NT	NT
Fertilizer (rotation average lbs./acre/year)	0	36[2]	37[1]	35	0
Manure/Compost (rotation average tons/acre/year)	5[3]	0	0	0	5.2[3]

BAU: current practice (business as usual); C-W-S-B-A(6): 10 year rotation of corn-wheat-sugar beets-barley-alfalfa (6 years); C-W-C-B-A(6): 10 year rotation of corn-wheat-corn-barley-alfalfa (6 years);); C-Wcc-Scc-B-A(6): 10 year rotation of corn-wheat/cover crop-sugar beets/cover crop-barley-alfalfa (6 years); SG: continuous switchgrass; CT: conventional tillage; RT: reduced tillage; NT: no-till

[1]Fertilizer N inputs average 92.5 lbs./acre/year for non-alfalfa crops. No fertilizer added to alfalfa.

[2] Fertilizer N inputs average 90.0 lbs./acre/year for non-alfalfa crops. No fertilizer added to alfalfa.

[3]Manure/Compost inputs average 12.5 tons/acre/year for the non-alfalfa crops. No manure/compost was added to alfalfa.

TABLE 4. IRRIGATED MIXED GRASS/LEGUME HAYLANDS SIMULATED IN DAYCENT.

	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Rotation	Grass/legume mix	Grass/legume mix lower N	Grass/legume mix manure/compost input	Switch grass	Switch grass
Harvests/year	2	2	2	2	2
Fall grazing	yes	yes	yes	no	No
Fertilizer N (average lbs./acre/year)	35	25	0	35	0
Manure/Compost (average tons /acre/year)	0	0	5.2	0	5.2

BAU: current practice (business as usual).

TABLE 5. IRRIGATED GRAZING SYSTEMS SIMULATED IN DAYCENT.

	BAU	Scenario
System	grassland	grassland
Grazing	moderate	No grazing
Fertilizer N (average lbs./acre/year)	14[1]	0
Additional manure/compost (average tons/acre/year)	2.8[2]	0

BAU: current practice (business as usual).

[1]Irrigated pastures are assumed to be fertilized at 35 lb. N/acre only in 2 out of 5 years.

[2] Manure/Compost added at 7 tons/acre in 2 out of 5 years.

Fertilizer rates for the crops simulated are derived in consultation with BCPOS as well as additional sources. Nitrogen fertilizer rates for non-irrigated winter wheat are averages for Colorado from the 2009 Agricultural Resource Management Survey (ARMS) for wheat (ERS 2013). Non-irrigated corn fertilizer rates come from the 2010 ARMS. Non-irrigated millet is assumed to be fertilized at a rate comparable to non-irrigated winter wheat. Fertilizer rates for irrigated corn, winter wheat, sugar beets and barley are from the crop budgets provided by the Colorado State University Extension Agriculture and Business Management Economists (CSU

2013). The fertilizer rate for corn following alfalfa is reduced from suggested rates due to the preceding legume crop (Davis and Westfall 2009). In the irrigated scenario involving cover crops an N credit is applied to the following crop. Fertilizer rates by crop are summarized in Table 6.

TABLE 6. CROP FERTILIZER RATES AND RATES OF MANURE/COMPOST ADDITION NECESSARY TO REPLACE FERTILIZER N.

Crop	System	Fertilizer N (lbs./acre)	Replacement Manure/Compost* (tons/acre)	Manure/Compost (tons/acre) adjusted for previous manure/compost additions in rotation
winter wheat, non-irrigated	F-W, F-W-C-M	35	7	5
corn, non-irrigated	F-W-C-M	63	13	11
millet, non-irrigated	F-W-C-M	35	7	3
corn, irrigated	C-W-S-B-A(6), C-W-C-B-A(6)	110	22	15
winter wheat, irrigated	C-W-S-B-A(6)	75	15	8
sugar beets, irrigated	C-W-S-B-A(6)	120	24	17
alfalfa, irrigated	C-W-S-B-A(6)	0	0	0
switchgrass	SG	35	7	5.2

*First year of manure/compost application.

Manure/Compost composition is highly variable (Cornell University 2005, Leikman and Lamond 2003, Davis and Westfall 2009). Manure/Compost additions used in the simulations are assumed to contain 20 lbs./ton nitrogen and to provide 5 lbs./ton of available nitrogen (25%) in the year of application. Manure/Compost N credits in the year following the application year are assumed to be 12% of the original N content. Manure/Compost N credits in the second year following the application year are assumed to be 5% of the original N content. No manure/compost N credits are given for additional years after application. Carbon input from manure/compost additions are simulated based on a manure/compost C:N ratio of 12. Manure/Compost rates by crop used in the simulations are summarized in Table 6.

Rangeland Restoration

BCPOS staff advised us that two rangeland restoration scenarios are most frequently practiced in the county: Restoring degraded rangeland overgrazed by a prairie dog colony, and retiring non-productive and/or erosive non-irrigated cropland parcels and restoring them to rangeland. After conversations with BCPOS staff, we determined it was problematic to model each actual restoration projects that have occurred in the last 10 years or which might occur in the next 10 years. Therefore we took a more general approach to determine the average net GHG balance of restoration work on BCPOS lands county-wide. We modeled the following restoration scenario on all rangeland and non-irrigated cropland BCPOS parcels, and calculated the area-weighted average net GHG balance of the restoration work separately for the rangeland and non-irrigated classes: land was tilled, sprayed with herbicide, and then planted with winter wheat. Native grasses were seeded into the stubble the following fall or spring after winter wheat was harvested, and then were re-seeded the following year. The parcels took 4 years to achieve full vegetative cover.

Soil Organic Carbon Cycling on Forestland and Shrubland

We modeled soil organic carbon under forestland and shrubland systems utilizing the NRCS SSURGO model for Boulder County. We first identified land cover polygons identified as forestland and shrubland in the alliance descriptions of the BCPOS vegetation map and the Southwest Regional Gap Analysis Project (Shrupp *et al.* 2014) where alliance descriptions were absent from the BCPOS map. We then overlaid these forestland and shrubland polygons with the NRCS SSURGO map for Boulder County, and calculated the representative soil organic carbon to depth, and also the top 30 cm for relative comparison with cropland soil organic carbon.

Soil organic carbon values were calculated by multiplying the SSURGO representative organic matter fraction for each soil layer by the associated soil bulk density and the carbon fraction of soil organic matter (0.5), subtracting out the estimated proportion of rock fragments, and then expanding the soil c fraction to depth.

Woody Biomass in Forests and Shrublands

Forests, woodlands, and shrublands in Boulder County can hold significant quantities of biomass carbon, consisting of carbon stored in trunks, branches and leaves aboveground as well as roots belowground. Examples in Boulder County include low elevation mountain mahogany shrublands, low-to-mid elevation ponderosa pine – Douglas fir woodlands, mid elevation lodgepole pine and aspen forests, and high elevation spruce-fir forests (BCPOS vegetation database, 2014). We integrated data on aboveground biomass carbon from multiple sources for BCPOS-owned lands as well as conservation easements (BCPOS Personal Communication 2013, Eggleston *et al*. 2006, Tinker and Knight 2000, Ryan and Waring 1993, Fahnstock and Agee 1983) and then assigned representative biomass carbon stocks to the vegetation alliances and SW Gap vegetation classes. Table 7 shows representative values for the biomass C stocks.

TABLE 7. REPRESENTATIVE BIOMASS CARBON STOCK VALUES FOR BOULDER COUNTY, CO.

Vegetation Alliance	C Stock (Mg CO_2e/ha)
alderleaf – mountain mahogany	24
Rocky Mountain juniper woodland	40
quaking aspen forest	74
ponderosa pine forest	140
lodgepole pine forest	348
Engelmann spruce forest	471

Belowground carbon in woody systems was assigned a biomass fraction of 29% of aboveground for forestland systems (Jenkins *et al.* 2004), 40% for shrubland systems (Eggleston *et al.* 2006), and up to 400% for grassland and herbaceous systems (Eggleston *et al.* 2006). The total biomass carbon stocks assigned to each SW Gap vegetation class or BCPOS vegetation alliance are shown in *Appendix 1: Woody Species Biomass Carbon Stock*.

Biomass and soil organic carbon stocks on these lands are shown in Table 16.

Biomass Burning

Burning biomass produces CO_2 as well as the trace gases methane, nitrous oxide, carbon monoxide and various nitrogen oxides. The CO_2 emissions are generally not included as GHG emissions since they are from biogenic sources and they may readily be taken up by growing vegetation (Eggleston *et al.* 2006). Non-CO_2 trace gases are treated as a GHG source, and are therefore counted as an emission.

We utilized the IPCC method for calculating these trace gas emissions, with U.S. emissions factors for each trace gas category. The method therefore qualifies as Tier 2.

Embodied Emissions

In every GHG Source Category analyzed in this study, we attempted to include the upstream life cycle (embodied) emissions associated with the land use practices. Embodied emissions are often also called the “Embodied Energy” of a product, and they include the energy and associated GHG emissions made in the manufacturing, marketing, and distributing a product.

In the case of synthetic and metal materials, they also include the emissions required to mine and refine the raw materials.

The two most significant classes of embodied emissions in this study are those dependent upon fossil fuels, and those associated with agricultural amendments such as fertilizers, herbicides, and pesticides. The rules of thumb applied in this study are as follows:

- Petroleum fuels have an embodied emission rate of 21.7%, meaning for every gallon of fuel burned, an estimated equivalent of 0.217 gallons of fuel were burned in the mining, refining, marketing and distribution of that fuel to the location where it was burned.
- Synthetic nitrogen fertilizer has a representative embodied emission rate of 6.9 kg CO_2e for every kg of nitrogen in urea-ammonium nitrate and similar fertilizers (Johnson *et al.* in press). This amount can vary depending on the actual type of fertilizer applied, ranging from 3.8 for anhydrous ammonia to over 9 for a variety of other types.
- Synthetic phosphorus fertilizer has a representative embodied emission rate of 6.4 kg CO_2e for every kg of anhydrous phosphoric acid (P_2O_5) applied to soils. This amount can vary depending on the actual type of phosphorus fertilizer applied and whether it is combined with N (e.g. MAN or DAN).
- Herbicides, pesticides, and fungicides have a wide range of embodied emissions, ranging from 6 to 31 kg CO_2e for every kg of amendment applied (Table 8). Glyphosate represents the majority of the chemicals applied, therefore an average value of 30 kg CO_2e kg^{-1} of total agricultural chemicals applied is used in this analysis.
- The embodied emission rate for natural gas (largely composed of methane) has not been firmly established at this time, as it varies between regions and is highly dependent on leakage during drilling and production of natural gas (Howarth *et al.* 2012). In their review, Howarth *et* al. proposed 2.5% as a representative leakage rate (range of 0.7-10%, noting an industry-wide lack of comprehensive measurements. A 2.5% leakage rate implies an embodied emission rate of 60% of emissions from burning natural gas, due to the high global warming potential of methane (methane GWP = 25). BCPOS should use caution in applying embodied emissions to systems or processes dependent on natural gas until leakage rates are confirmed, after which embodied emissions should be calculated at a rate of 25% CO_2e for every 1% of leakage.

TABLE 8. EMBODIED EMISSIONS FOR THREE AGRICULTURAL CHEMICALS COMMONLY USED ON THE COLORADO FRONT RANGE.

Chemical Applied	Embodied Emissions (kg CO_2e per kg applied)
2,4,D	6
Atrazine	13
Glyphosate	32

The embodied emissions associated with the manufacture of farm, forestry, and other equipment used by BCPOS staff and its contractors, and for buildings used by BCPOS staff and its contractors were not included in this study due to the difficulty in collecting information on such emissions and the accounting problems posed by unknowns regarding the origin and life span of buildings and equipment.

Agricultural Conservation Easements and Other Lands

Limited management and activity data were available for agricultural conservation easements and other lands, therefore IPCC Tier 1 and Tier 2 methods were used to determine GHG flux from land use (Eggleston *et al.* 2006). Land use on these lands was determined using the Cropland Data Layer (CDL) for 2008-2012. Parcels with cropland cover were classified as irrigated or non-irrigated cropland, based on the crop types present according to CDL. The specific crop rotations and general management were based on predominant systems in Boulder County, which were determined in cooperation with Boulder County staff (Table 9). Lands classified as “Hay or Pasture” or “Rangeland” according to CDL were classified as grasslands and it was assumed that no nitrogen amendments were applied. While these lands are likely hayed or grazed, there wasn’t sufficient information to apply these management activities to the analysis. The majority of land area in this analysis was cropland or grassland, though some miscellaneous land uses, such as woody wetlands, forests and shrublands were also present.

TABLE 9. CROPPING SYSTEMS FOR AGRICULTURAL CONSERVATION EASEMENTS IN BOULDER COUNTY.

Cropping System	Crop Rotation	Tillage	N Fertilizer (rotation average lbs./acre/year)
Irrigated Annual Cropland	corn-winter wheat-soybean-barley-alfalfa (6 y)	Conventional	30.7
Non-irrigated Annual Cropland	winter wheat-fallow	Conventional	17.6

Soil organic carbon stocks on all land uses were determined using IPCC Tier 2 methods, using local reference soil organic carbon stocks and regionally specific emission factors. Soil organic carbon stock changes during the reporting period (2004-2013, 2014-2023) could not be determined because land use and management changes over the reporting time period could not be discerned from the available data. Direct and indirect soil N_2O emissions were assessed on croplands and grasslands using IPCC Tier 1 methods. Nitrogen inputs from N fertilizer and plant residues were used to calculate direct N_2O emissions and indirect N_2O emissions from leaching. Emissions from leaching were only estimated on irrigated croplands as minimal leaching is expected on non-irrigated lands in this climate. Indirect N_2O emissions were estimated from volatilization of N fertilizer on croplands. Biomass C was estimated for forests, woody wetlands and shrublands using the same methods applied in the preceding methods section titled “Woody Biomass”. Biomass C stock changes could not be calculated due to limited data. Embodied emissions were not estimated from management activities because management was applied very generically across agricultural conservation easements and other lands.

Livestock

Three major livestock greenhouse gas source categories apply to BCPOS lands. We applied the IPCC Tier 2 “Enhanced Characterization” method for livestock on BCPOS lands, using emission factors specific to North America for the source categories of enteric methane, manure nitrous oxide, and manure methane. Livestock on BCPOS lands are fed on rangeland and/or pasture, and the IPCC method for livestock fed in such ways advises that manure nitrous oxide be included in the analysis of soil nitrous oxide from those parcels where livestock are reared. Therefore, we have modeled these emissions in the soil organic carbon and nitrogen modeling on rangelands and pasture, using the DayCent model.

BCPOS staff provided an animal unit census for livestock populations, indicating all livestock are Angus beef cattle managed as a cow-calf operation. Based on that census we calculated there were on average 1,116 cattle grazing on BCPOS range and pasture lands each year during the study period. We applied data specific to Colorado from Extension resources to estimate livestock weights, sex ratios, weaning dates and other applicable information required for the method (CSU Extension 2014). From this we evaluated a typical total herd of 669 mature and/or replacement females, 417 calves, and 30 mature bulls.

The following information was used in the analysis:

- Pregnancy rate: 88%

- % of females lactating: 88%
- Ash content of manure: 20%
- Average daily weight gain: 0 for mature animals, 1.1 kg/head/day for calves
- Average live weight: 455 kg for mature/replacement females, 680 kg for bulls.
- Daily milk production for lactating cows: 5 kg/head/day at 2.7% milk fat content.
- Digestible energy from pasture/rangeland grasses: 55%.

Results

Energy Use in Buildings, Operations and Recreational Visits to BCPOS Lands

Energy use data were available from BCPOS records for electricity, natural gas, biomass boilers, and fleet fuels from 2008 through 2012. Fuel use in maintaining roadside corridors was available for 2012, and was considered by BCPOS staff to represent fuel use in the previous 4 years. Table 10 and Figure 2 summarize the GHG balance of this energy use.

TABLE 10. BCPOS DIRECT EMISSIONS (MG CO_2E) FROM ENERGY USE IN BUILDINGS, OPERATIONS, AND RECREATIONAL VISITS TO BCPOS LANDS, 2008 TO 2012.

Category	2008	2009	2010	2011	2012
Recreational Travel	9,858	9,858	9,858	9,858	9,858
Electricity	283	276	295	298	316
Natural Gas	138	144	70	93	89
Biomass Boilers	9	5	11	10	3
Fleet Fuel	313	405	429	390	367
Roadside Corridors	19	19	19	19	19
Total	10,619	10,707	10,682	10,667	10,651

Emissions from Recreational Travel to BCPOS Lands

Fuel use from recreational travel to BCPOS lands accounted for 93% of the total emissions in this category. The Climate Registry (2014) estimates 25% of recreational travel emissions were from diesel vehicles, the balance were from gasoline vehicles, according to the most current vehicle use and efficiency surveys.

Electricity Use

Electricity use increased by 12% over the period of record, from 277 Mg CO_2e in 2008 to 316 Mg CO_2e in 2012. This represents the electricity use by BCPOS staff, which occupy ½ of the building shared with the Boulder County Transportation Department.

Natural Gas and Biomass Boilers

Natural gas emissions dropped 35% from a high of 144 Mg CO_2e in 2010 to 89 Mg CO_2e in 2012. Emissions from biomass boilers varied in a corresponding fashion over the same period, peaking at 11 Mg CO_2e in 2010 and dropping to 3 Mg CO_2e in 2012, with an average value of 7.6 Mg CO_2e.

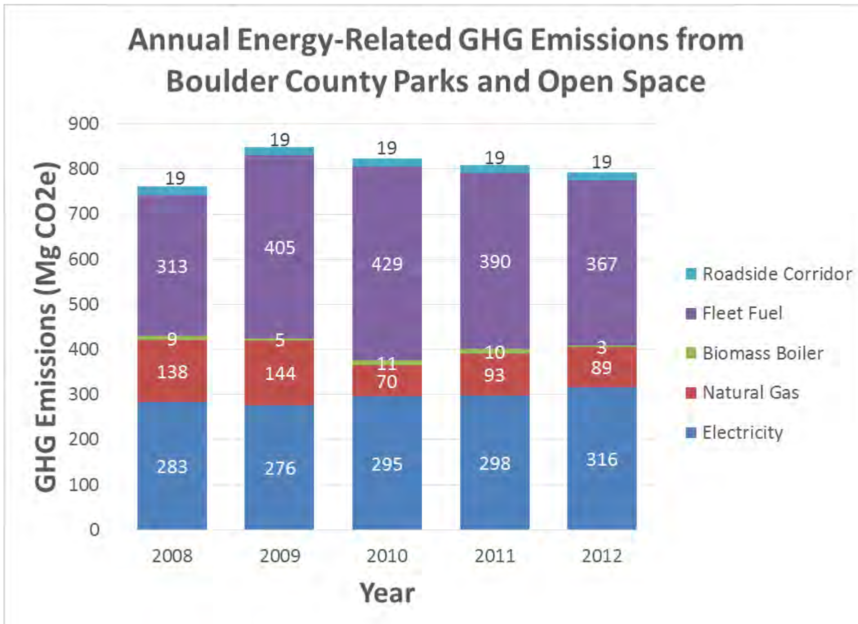

FIGURE 2. SUMMARY OF GHG EMISSIONS FROM BCPOS ENERGY USE IN BUILDINGS, OPERATIONS AND ROADSIDE MAINTENANCE.

All Emissions from the Biomass Boiler are methane and nitrous oxide from burning biomass. These trace gases are a portion of the unburnt hydrocarbons emitted from the burning process. Carbon dioxide emissions from this process are considered to be carbon neutral, since they were sourced from vegetation removed in forest restoration work on BCPOS lands.

Through the use of the biomass boilers, BCPOS avoided natural gas emissions averaging 208 Mg CO_2e per year from 2008 to 2012 (Table 11).

TABLE 11. AVOIDED EMISSIONS FROM BIOMASS BOILER USE.

Year	MMBTU Natural Gas	Avoided Emissions (Mg CO_2e)
2008	4,579	249
2009	3,519	137
2010	5,653	308
2011	5,127	279
2012	1,240	68

Fleet Fuel

Fuel use for vehicles rose from 34,093 gallons in 2008 to peak in 2010 at 48,990 gallons, and then dropped to 42,345 gallons in 2012. Biodiesel use was a blend of 80% conventional fuel mixed with 20% biodiesel derived from used vegetable oil (BCPOS Staff personal communication 2014). Greenhouse gas emissions during that time peaked at 429 Mg CO_2e in 2010, with an average of 381 Mg CO_2e per year during that time (The Climate Registry 2014). Emissions shown for biodiesel represent those from the conventional fuel portion of the blend, as emissions from biodiesel are considered to be net zero as the fuel is derived from waste material from plant and/or animal-based sources.

TABLE 12. BCPOS FLEET FUEL USE (GALLONS) AND GHG EMISSIONS (MG CO_2E FROM 2008 TO 2012.

Year	Conventional Diesel	Gasoline	Biodiesel	Total	Direct Emissions	Embodied Emissions	Total Emissions
2008	8,787	25,275	31	34,093	313	66	379
2009	11,005	33,200	2,750	46,995	405	85	490
2010	13,370	33,100	2,520	48,990	429	90	519
2011	14,120	27,800	2,500	44,420	390	81	471
2012	13,353	26,100	2,892	42,345	367	77	444

Maintenance of Roadside Corridors

BCPOS staff is responsible for maintaining roadside corridors on behalf of Boulder County. Fuel use data for maintenance of roadside corridors was only available for 2012 but was considered to be representative of fuel use for the study period. Total fuel use was 1,820 gallons of conventional diesel during that time, representing total direct emissions of 18.6 Mg CO_2e. Embodied emissions were 3.9 Mg CO_2e, for a total of 22.5 Mg CO_2e from fuel.

GHG Sources and Sinks from Land Use

Notes Regarding Tillage, Synthetic and Organic Fertilizers, and Organic Systems

In the section that follows we discuss how different tillage, fertilizer systems, conventional and organic systems affect the net greenhouse gas balance of crop production on BCPOS lands. We realize there are many different factors influencing decisions for cropping systems, including equipment and labor costs, interactions between soils/crops/climate, weed and pest management needs, nutrient and residue management needs, market demands, and policies regarding genetic technologies utilized in seed production. The section that follows is intended to offer information independent of those issues.

The carbon and nitrogen in soils used for crop production is heavily dependent upon three key factors: a) past land use and management; b) the amount of carbon inputs into the soil from crop residues, roots, and manure/compost amendments, and d) temperature and moisture from rain/snowfall and irrigation. Figure 3 shows examples for how these factors can influence soil carbon stocks over time in Boulder County.

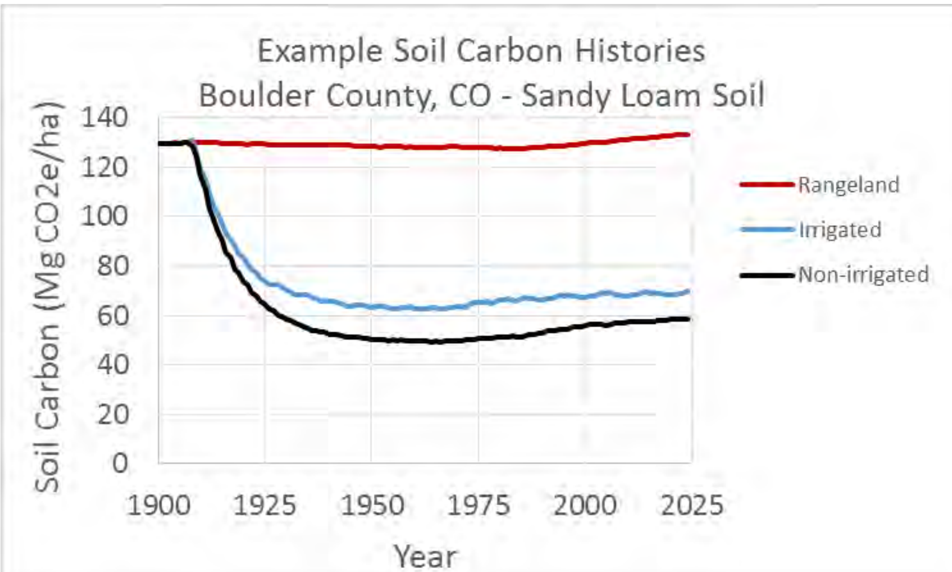

FIGURE 3. EXAMPLE SOIL CARBON TRAJECTORIES FOR THREE AGRICULTURAL HISTORIES ON A SANDY LOAM SOIL IN BOULDER COUNTY, COLORADO.

For this study we examined different aspects of conventional and organic cropping practices. Whereas there are key differences in the types of amendments and farm chemicals used between the two types of systems, from the greenhouse gas balance perspective the two main factors are the extent of tillage and the type of fertilizer used – synthetic or manure/compost. Growers using organic systems tend to rely on tillage to manage weeds, whereas growers in non-organic no-tillage systems rely on broad-spectrum herbicides for weed management. Manufactured, pelletized organic fertilizers are available and are used on some high-value horticultural crops, however organic growers tend to use manure/compost to meet the nutrient needs of their crops while conventional growers use synthetic fertilizers. There are greenhouse gas balance trade-offs for each of these practices.

In the results that follow, *the presence of manure/compost as fertilizer can be regarded as a surrogate for organic cropping systems*. For example, the greenhouse gas balance of a conventional practice crop system using conventional/heavy tillage and manure/compost will have virtually the same greenhouse gas balance as an organic system using the same type of tillage. Likewise, a no-tillage system using herbicides and compost/manure will have a greenhouse gas balance very similar to an organic no-tillage system. The driving factors are, again, the use of manure/compost or synthetic fertilizers, and the type of tillage involved. The energy and embodied energy associated with the manufacture, distribution, and application of herbicides and pesticides in conventional systems is relatively low, and is comparable to the energy and embodied energy associated with the amendments used in organic systems.

Cropland Results

Boulder County Parks and Open Space manages more than 9,900 ha of agricultural lands, including both irrigated and non-irrigated croplands, pasture and rangeland. Figure 4 shows soil organic carbon stocks on these lands in 2013. Figure 5 shows the net GHG balance of cropland management for 2004-2013. Figure 6 shows the predicted net GHG balance of cropland management for 2014-2023.

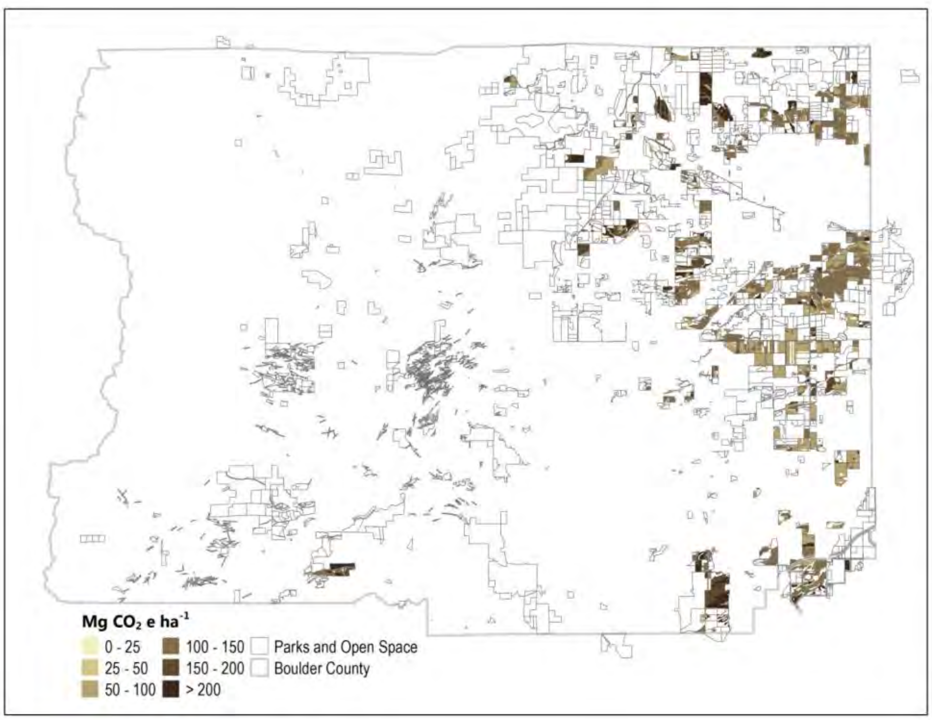

FIGURE 4. SOIL ORGANIC CARBON STOCKS (MG CO2E/HA) IN 2013 ON BCPOS LANDS IN THE 1ST 20CM OF THE SOIL PROFILE.

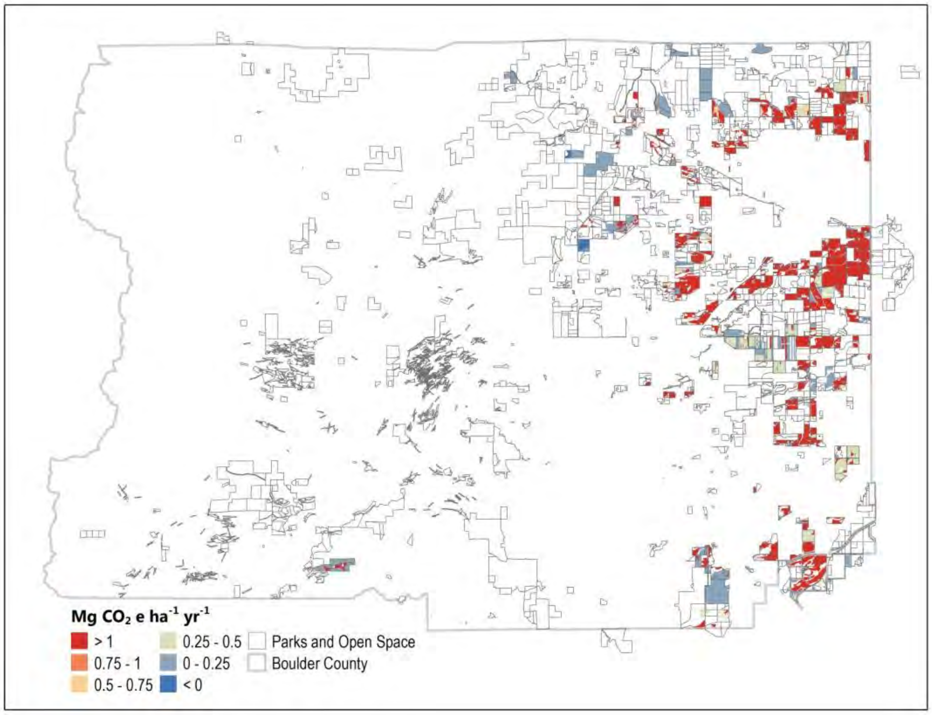

FIGURE 5. NET GHG BALANCE (MG CO_2E/HA/YEAR) FOR 2004-2013 ON BCPOS AGRICULTURAL LANDS.

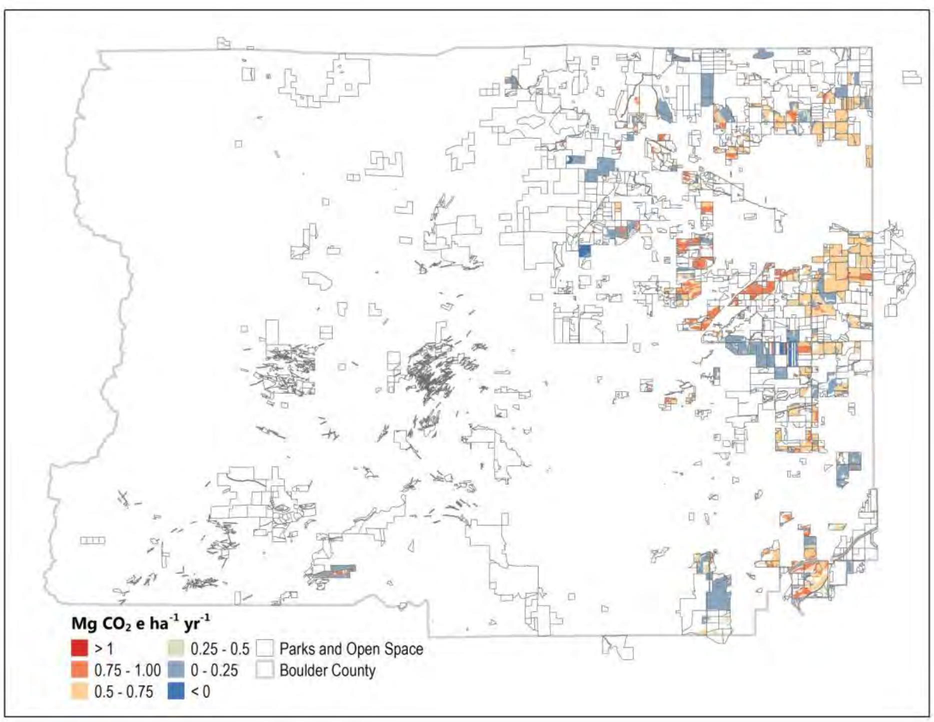

FIGURE 6. PREDICTED NET GHG BALANCE (MG CO2E/HA/YEAR) 2014-2023 ON BCPOS AGRICULTURAL LANDS.

TABLE 13. SUMMARY OF SOIL CARBON STOCKS AND GHG BALANCE OF AGRICULTURAL MANAGEMENT OF BCPOS LANDS.

Category	Area (ha)	2013 Total SOC (Mg CO_2e)	2013 Average SOC (Mg CO_2e/ha)	2003-2014 GHG Balance (Mg/CO_2e)	2014-2023 GHG Balance (Mg CO_2e)
Non-Irrigated Cropland	1,200	96,460	80	384	91
Irrigated cropland	5,111	553,984	108	5,679	3,294
Rangeland	2,983	798,382	182	573	573
Mixed Hay	30	9,482	156	48	33
Total	9,323	1,458,308	-	6,684	3,992

Irrigated Cropland

The net GHG balance on BCPOS irrigated cropland averages 1.11 Mg CO_2e/ha for 2004-2013, for a total of 6,684 Mg CO_2e per year during that period (Figure 7). This represents emissions from a balance of tillage and nutrient management systems comprising 15% conventional tillage, 75% reduced tillage, 5% no tillage, and 5% organic systems during that time (CTIC 2014, BCPOS staff personal communication 2014).

Emissions are likely to drop by 0.49 Mg CO_2e/ha/year to 0.62 Mg CO_2e/ha/year, totaling 3,992 Mg CO_2e per year from 2014-2023 as Boulder County moves towards its goal of managing 20% of BCPOS lands in organic systems by 2020, and as no tillage systems become more widely adopted (Figure 7). This assessment represents a balance of 5% conventional tillage, 45% reduced tillage, 30% no tillage and 20% organic systems (CTIC 2014, BCPOS Staff personal communication 2014).

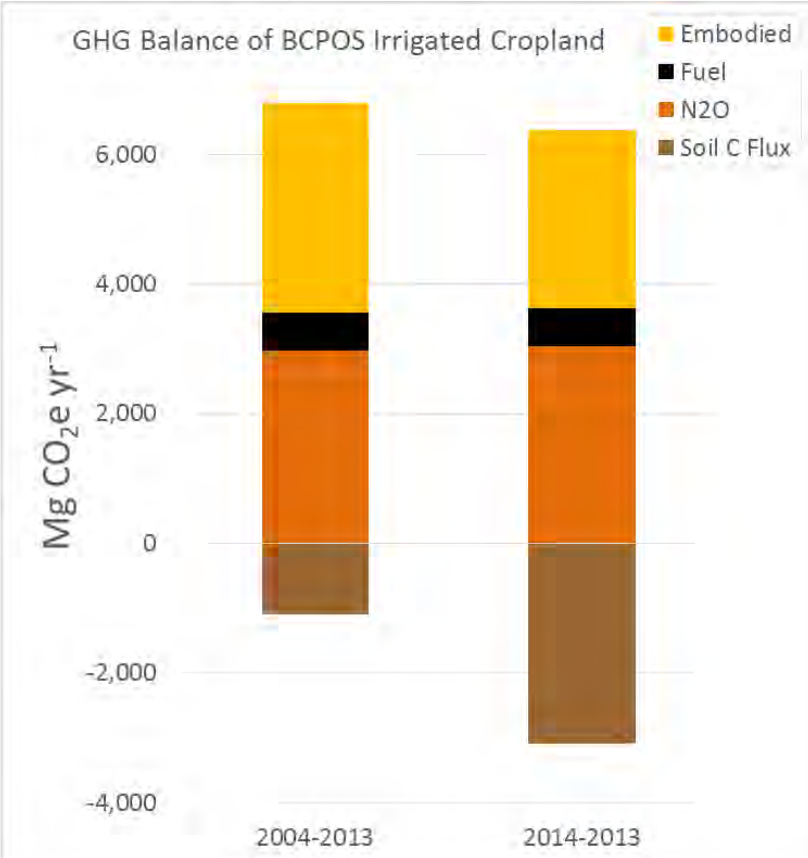

FIGURE 7. SUMMARY OF GHG EMISSIONS FROM BCPOS IRRIGATED CROPLANDS.

The principal greenhouse gases that cycle in irrigated croplands in Colorado are nitrous oxide (from nitrogen in synthetic and organic fertilizers as well as nitrogen in plant residues) and carbon dioxide (from soils and burning fossil fuels). A variety of different management factors affect the balance of these greenhouse gases. Nitrous oxide is the largest source, accounting for 7% of total greenhouse gas emissions in the U.S. National Greenhouse Inventory in 2012 (U.S. EPA 2013). Fossil Fuel use is the next largest source. Carbon dioxide emissions from soils have generally dropped in the past 3 decades, as crop yields improved and tillage intensity decreases. Carbon sequestration in soils and, to a lesser degree, in biomass, represents a key opportunity for reducing emissions and removing carbon from the atmosphere (Paustian *et al*. 1997, Eggleston *et al.* 2006, USEPA 2013).

Soil organic carbon stocks on BCPOS irrigated cropland are relatively high compared with many Front Range counties. Keeping half or more of the total area in alfalfa leads to significantly less tillage, higher carbon stocks, and fewer agricultural inputs with embodied emissions.

The principal factors affecting GHG emissions from cropland management are fertilizer/nutrient amendment type and management, tillage, use of cover crops, and residue management. The actual emissions from these practices can vary widely depending on the interactions of crops, climate, and soils in a particular region (Paustian et al. 1997). To assess potential best management practices for GHG reductions on irrigated cropland we modeled different combinations of these factors on BCPOS lands, as follows:

- Tillage: We evaluated the effects of reducing tillage by modeling the GHG balance of conventional (heavy), reduced, and no tillage systems (Figure 8).
- Conversion from synthetic fertilizers to manure/compost and cover crops: We replaced synthetic N fertilization with manure/compost in amounts that meet the nutrient requirements of the crops and maintain crop yields, and added cover crops into the cropping system where possible (Figure 9 and Figure 10).
- Converting from the alfalfa-annual crop system and mixed hay system to switchgrass, to assess the potential benefits of growing biofuels on BCPOS lands (Figure 9 and Figure 10).

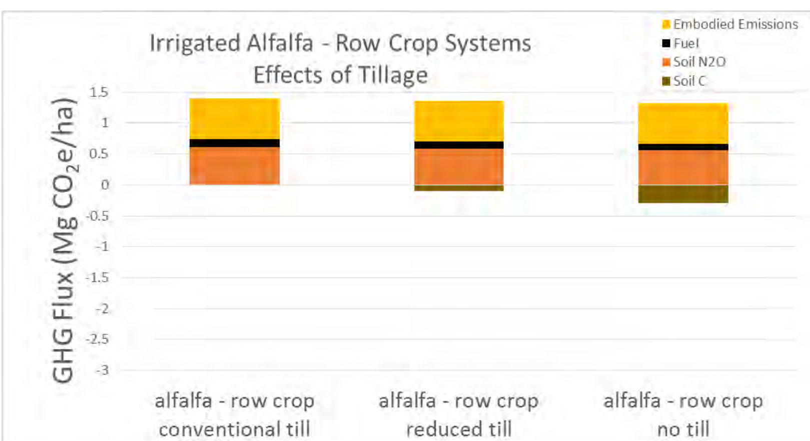

FIGURE 8. EFFECTS OF TILLAGE ON THE GHG BALANCE OF IRRIGATED CROPLAND ON BCPOS LANDS.

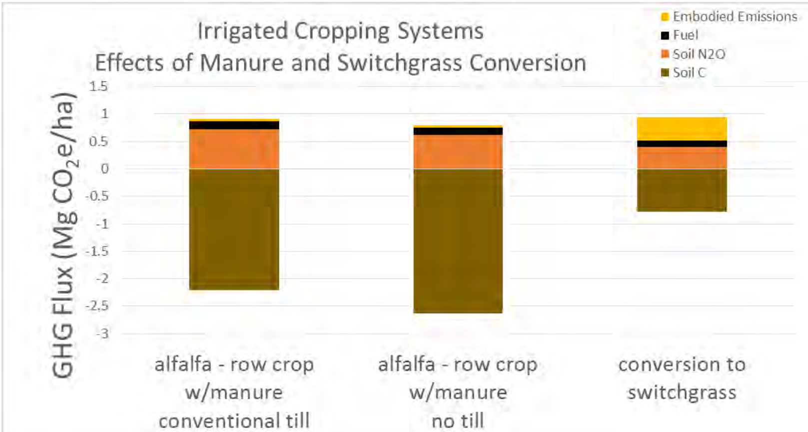

FIGURE 9. EFFECTS OF REPLACING SYNTHETIC FERTILIZER WITH MANURE/COMPOST, AND CONVERTING TO IRRIGATED SWITCHGRASS IN IRRIGATED ROW CROP SYSTEMS ON BCPOS LANDS.

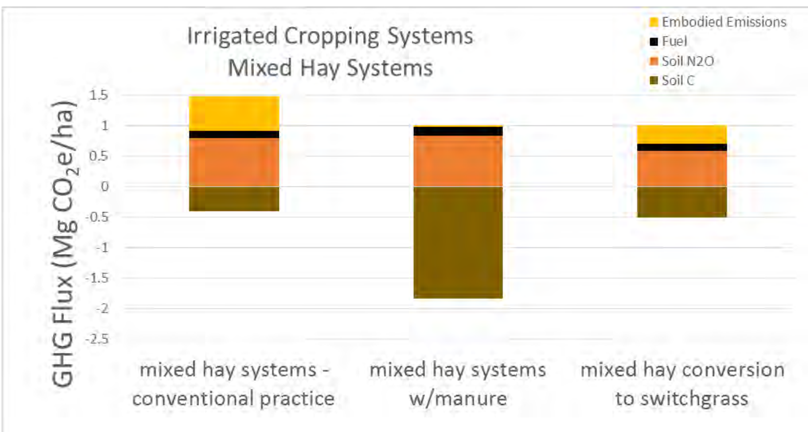

FIGURE 10. EFFECTS OF TILLAGE, REPLACING SYNTHETIC FERTILIZER WITH MANURE/COMPOST, AND CONVERTING TO SWITCHGRASS IN IRRIGATED CROPPING SYSTEMS ON BCPOS LANDS.

Details on these current and potential cropping systems are shown in Table 14.

TABLE 14. SUMMARY OF THE NET GHG BALANCE OF CURRENT AND POTENTIAL IRRIGATED CROPPING SYSTEMS ON BCPOS LANDS.

	Soil C	Soil N2O	Fuel	Embodied Emissions	Total
Tillage					
alfalfa - row crop conventional tillage	0.01	0.61	0.12	0.66	1.40
alfalfa - row crop reduced tillage	-0.10	0.58	0.11	0.66	1.25
alfalfa - row crop no tillage	-0.30	0.56	0.11	0.66	1.03
Conversion to manure/compost and/or Switchgrass					
alfalfa - row crop with manure/compost conventional tillage	-2.21	0.72	0.14	0.05	-1.30
alfalfa - row crop with manure/compost no tillage	-2.63	0.62	0.13	0.05	-1.83
Conversion to Switchgrass	-0.78	0.40	0.12	0.42	0.16
Mixed Hay Systems					
mixed hay systems – synthetic fertilizers	-0.41	0.80	0.12	0.56	1.07
mixed hay systems with manure/compost	-1.83	0.84	0.14	0.02	-0.83
mixed hay conversion to switchgrass	-0.51	0.58	0.12	0.29	0.49

Soil tillage increases the decomposition of organic matter in the soil, and therefore reducing tillage increases carbon sequestration in soils (Paustian et al. 1997). On average, decreasing tillage in BCPOS irrigated systems from conventional/heavy tillage to reduced tillage increases soil organic carbon 0.1 Mg CO_2e/ha/year. Relative to conventional/heavy tillage, no tillage systems increases soil organic carbon by 0.35 Mg CO_2e/ha/year. There is little change in soil nitrous oxide emissions in these tillage scenarios. Emissions from fossil fuel use drop somewhat as tillage intensity decreases from conventional, to reduced, to no tillage systems. One might expect fuel use to drop more than is shown in the results, however the fuel required for harvesting crops is significant, particularly for the hay crops that dominate these irrigated systems, and such fuel requirements remain nearly the same regardless of the tillage system (Figure 8).

Replacing synthetic fertilizer with enough manure/compost to meet the nutrient needs of crops offers the most significant opportunity to reduce GHG emissions in irrigated croplands (Figure 9). There are two key advantages:

- Manure and/or comparable compost applications increase soil organic carbon sequestration, on average by 2.2-2.6 Mg CO_2e/ha/year on BCPOS lands, depending on the tillage system.
- Manufacturing synthetic nitrogen and phosphorus fertilizers is a very energy-intensive process. The embodied emissions associated with manufacturing synthetic fertilizer (Johnson *et al.*, 2013) are approximately as high as the combined direct and indirect nitrous oxide emissions from using the fertilizer in the field. Using manure or comparable compost as a replacement avoids those emissions.

Please note that the nitrous oxide emissions from crops that demand additional nitrogen fertilizers are highly correlated with the amount of N applied or fixed through natural means (e.g. cover crops, alfalfa), regardless of the source. For example, the nitrous oxide emissions associated with a corn crop that requires 110 lbs. of N per year is approximately the same, whether that nitrogen comes from synthetic fertilizer, manure/compost, compost, cover crops, or a combination of these. New materials and techniques are available to reduce these emissions, which we cover in the section titled *Management Practices That Reduce Greenhouse Gas Emissions*.

Converting to switchgrass as a biofuel raw material (Figure 9 and Figure 10) offers the potential to reduce the GHG balance of crop production to close to zero, particularly if manure/compost is used to meet the crop's nutrient requirements.

Fuel Use in Non-Irrigated Cropping Systems

The fuel required for these systems varies with the type of tillage and whether or not manure/compost is applied. Estimated diesel fuel requirements range from 9.7 gallons/acre/year for conventional/heavy tilled alfalfa-row crop systems to 8.9 gallons/acre/year for no-tillage systems. Mixed hay systems and switchgrass typically have little or no tillage after the crop is established, and so fuel use (9.9 gallons/year) is dominated by harvest operations (USDA Energy Calculator 2014).

The net amount of fuel required to haul and spread manure or compost averages 0.25 gallons per ton, with approximately two-thirds of that required for hauling and approximately 1/3 required for spreading (BCPOS staff personal communication 2013, A-1 organics personal communication 2013, Western Disposal Services personal communication 2013).

Embodied Emissions

The embodied GHG emissions described in this analysis (Figure 11) are divided into six categories:

- Energy and process emissions in N fertilizer manufacturing (Johnson *et al.* 2013).
- Energy and process emissions in P fertilizer manufacturing (Johnson *et al.* 2013).
- Indirect emissions from the production, manufacture, and distribution of diesel fuel and gasoline (Burnham et al. 2013).
- Energy required to pump irrigation water used in center pivot and/or other sprinkler systems.
- Energy and process emission in herbicide/pesticide manufacturing (Audsley *et al.* 2009)
- Energy and process emissions, upstream farm-related greenhouse gas emissions from the production of seed (Audsley *et al.* 2009).

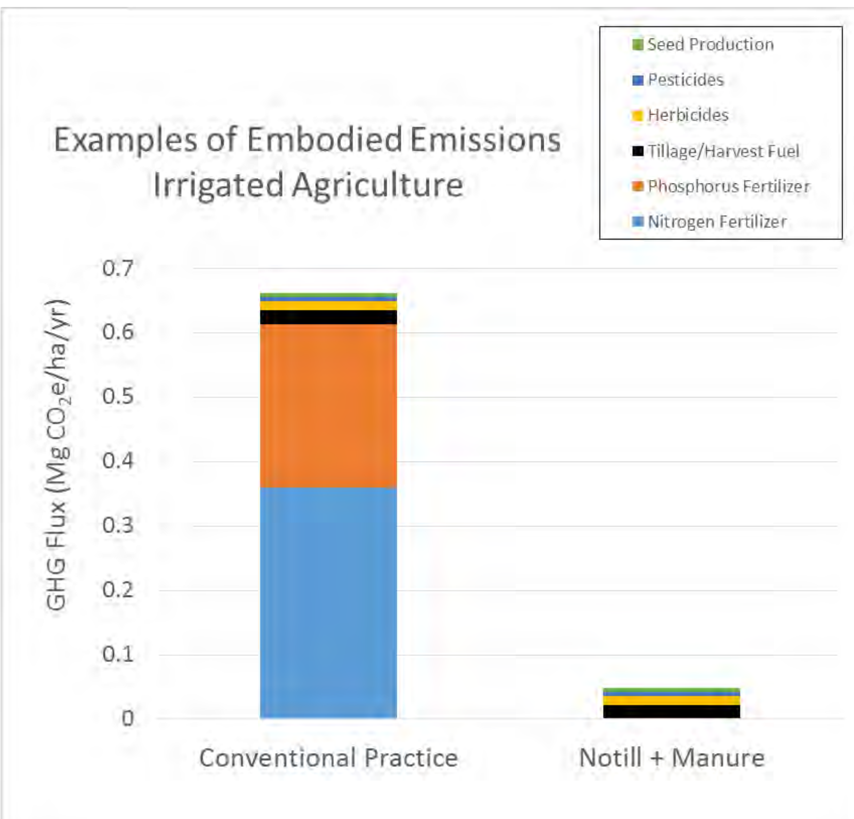

FIGURE 11. EXAMPLE EMBODIED EMISSIONS FROM IRRIGATED AGRICULTURE ON BCPOS LANDS.

As shown in Figure 11, embodied emissions are dominated by the synthetic fertilizer manufacturing emissions. The sum of the remaining embodied emissions are typically less than 0.06 Mg CO_2e in BCPOS irrigated and non-irrigated cropping systems.

Non-Irrigated Cropland

Figure 12 summarizes the greenhouse gas balance on non-irrigated cropland on BCPOS lands for 2004 to 2013. The scale of the y axis is the same as for irrigated lands, so these data may be evaluated in the same context.

We estimate the GHG balance from non-irrigated cropland to average 0.32 Mg CO_2e/ha for 2004-2013, for a total of 384 Mg CO_2e per year during that period. This represents emissions from a balance of tillage and nutrient management systems comprising 15% conventional tillage, 75% reduced tillage, 5% no tillage, and 5% organic systems during that time (CTIC 2014, BCPOS staff personal communication 2014).

The net GHG balance is likely to drop to 0.08 Mg CO_2e per ha per year for an average of 91 Mg CO_2e per year from 2014-2023 as Boulder County moves towards its goal of managing 20% of BCPOS lands in organic systems by 2020, and as no tillage systems become more widely adopted. This assessment for the next 10 years represents a balance of 5% conventional tillage, 45% reduced tillage, 30% no tillage and 20% organic systems (CTIC 2014, BCPOS Staff personal communication 2014).

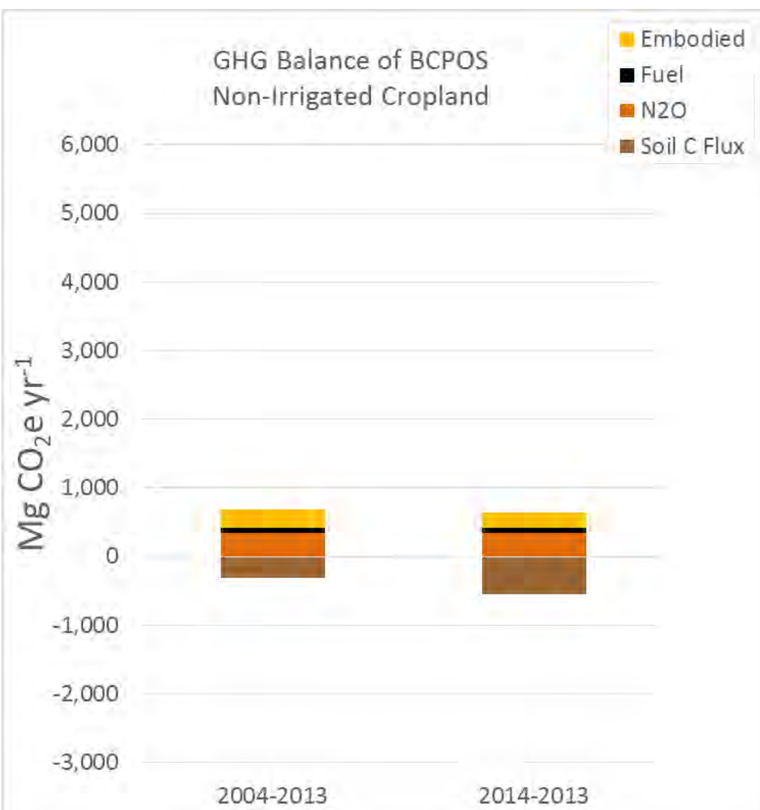

FIGURE 12. SUMMARY OF THE GHG BALANCE ON BCPOS NON-IRRIGATED CROPLANDS.

As with irrigated croplands, we evaluated the effects of tillage (Figure 13), conversion from synthetic to manure/compost fertilizers (Figure 14), and conversion to a switchgrass biofuel system (Figure 14). We additionally added four cropping intensification scenarios (Kaan *et al.* 2014), wherein additional non-irrigated crops are added to traditional fallow-winter wheat systems, grown as no-till with synthetic fertilizer or no-till with manure/compost (Figure 15). Research into cropping intensification on the Front Range and Eastern Plains suggests these practices provide both environmental benefits in the form of an improved greenhouse gas balance, and economic benefits in the form of an improved bottom line.

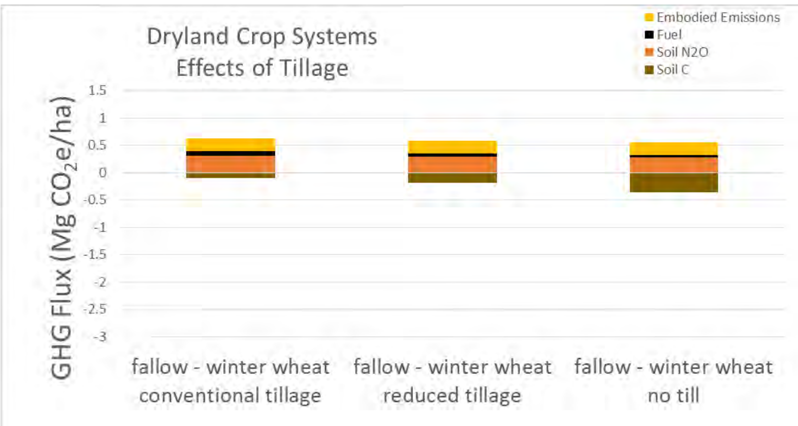

FIGURE 13. EFFECTS OF DIFFERENT TILLAGE SYSTEMS ON NON-IRRIGATED CROPPING SYSTEMS ON BCPOS LANDS.

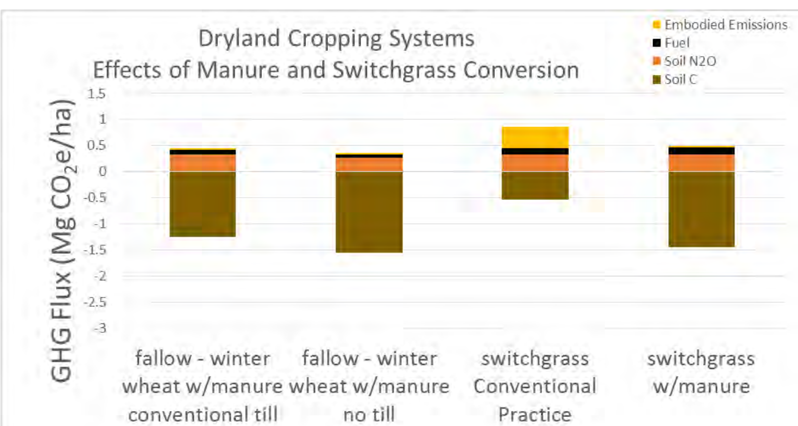

FIGURE 14. EFFECTS OF CONVERSION FROM SYNTHETIC FERTILIZERS TO MANURE/COMPOST IN NON-IRRIGATED CROPPING SYSTEMS ON BCPOS LANDS.

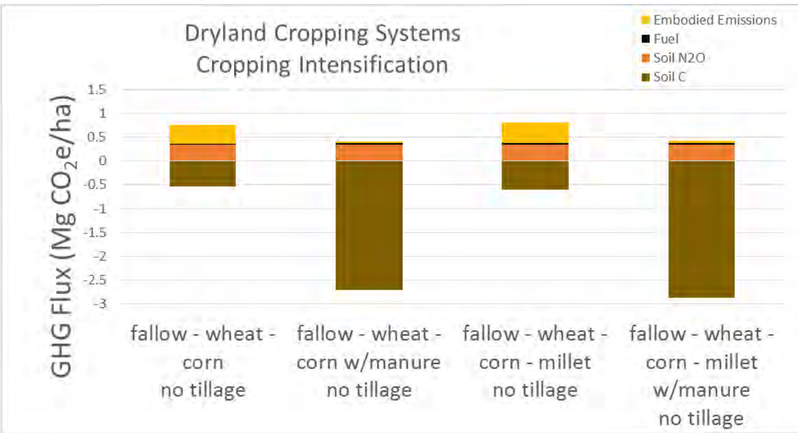

FIGURE 15. EFFECTS OF CROP INTENSIFICATION IN NON-IRRIGATED CROP SYSTEMS ON BCPOS LANDS, WITH AND WITHOUT CONVERSION FROM SYNTHETIC FERTILIZERS TO MANURE/COMPOST.

Table 15 summarizes the greenhouse gas balance of these different cropping system options for non-irrigated systems. Conversion from conventional/heavy tillage to reduced tillage in fallow-wheat systems can reduce the net GHG balance by 0.12 Mg CO_2e/ha/year. Conversion from reduced to no tillage systems can reduce the net GHG balance further by 0.21 Mg CO_2e/ha/year. Conversion from synthetic fertilizers to manure/compost in fallow-wheat systems, regardless of tillage, can improve the greenhouse gas balance by 1.3-1.4 Mg CO_2e/ha/year relative to conventional practices, resulting in a net carbon sequestration of 0.8 to 1.2 Mg CO_2e/ha/year.

TABLE 15. SUMMARY OF THE GREENHOUSE GAS BALANCE OF CURRENT AND POTENTIAL NON-IRRIGATED CROPPING SYSTEMS IN BCPOS LANDS. ALL UNITS ARE IN MG CO_2E.

Cropping System	Soil C	Soil N2O	Fuel	Embodied Emissions	GHG Balance
Tillage					
fallow - winter wheat with synthetic fertilizer, conventional tillage	-0.10	0.31	0.08	0.23	0.52
fallow - winter wheat with synthetic fertilizer, reduced tillage	-0.19	0.30	0.06	0.23	0.40
fallow - winter wheat with synthetic fertilizer, no tillage	-0.36	0.27	0.05	0.23	0.19
Conversion to Manure/Compost					
fallow - winter wheat with manure/compost, conventional till	-1.25	0.33	0.09	0.03	-0.80
fallow - winter wheat with manure/compost, no tillage	-1.55	0.27	0.06	0.03	-1.20

switchgrass with synthetic fertilizer	-0.53	0.33	0.12	0.42	0.33
switchgrass with manure/compost	-1.45	0.33	0.14	0.02	-0.96
Crop Production Intensification					
fallow - wheat – corn with synthetic fertilizer, no tillage	-0.54	0.34	0.03	0.40	0.23
fallow - wheat - corn with manure/compost, no tillage	-2.71	0.34	0.04	0.04	-2.30
fallow - wheat - corn - millet with synthetic fertilizer, no tillage	-0.60	0.34	0.03	0.43	0.21
fallow - wheat - corn - millet with manure/compost no tillage	-2.87	0.34	0.05	0.04	-2.45

Intensifying crop production while replacing synthetic fertilizers with manure/compost can improve the net greenhouse gas balance by 2.75 Mg CO_2e/ha/year relative to conventional practices.

As with the irrigated cropping systems, the dominant influence on the net GHG balance of these systems is in the type of tillage used and whether or not manure/compost is applied.

Fuel Use in Non-Irrigated Cropping Systems

The fuel required for these systems changes with the type of tillage and whether or not manure/compost is applied. Estimated diesel fuel requirements range from 6.5 gallons/acre/year for conventional/heavy tilled fallow-wheat to 3.8 gallons/acre/year for no-tillage systems. In contrast, the crop production intensification scenario (fallow-wheat-corn-millet) requires 7.5 gallons/acre/year (NRCS Energy Calculator 2014).

As with irrigated cropland, hauling and spreading manure on BCPOS croplands averages 0.25 gallons diesel fuel per ton, with approximately two-thirds of that required for hauling and approximately one-third required for spreading (BCPOS staff personal communication 2013, A-1 organics personal communication 2013, Western Disposal Services personal communication 2013).

Embodied Emissions

As with irrigated cropping systems, the embodied emissions in non-irrigated systems are dominated by the emissions associated with synthetic fertilizer production. The relative proportion of embodied emissions from fuel, seed production, and farm chemicals is higher than with irrigated systems, but it still represents less than 10% of the total embodied emissions.

Rangeland

The GHG balance on BCPOS rangeland averages 0.13 Mg CO_2e/ha/year for 2004-2013, for a total of 326 Mg CO_2e per year during that period. This includes soil organic carbon (-437 Mg CO_2e) and soil nitrous oxide (763 Mg CO_2e) with moderate-to-heavy grazing pressure (BCPOS staff personal communication 2014). The soil nitrous oxide figure quoted above includes manure nitrous oxide emissions from grazing livestock (Eggleston *et al.* 2006). We assumed 5% of BCPOS agricultural rangelands are not grazed during any given year (BCPOS staff personal communication).

The difference in the GHG balance of grazed vs. ungrazed rangelands on BCPOS lands is small (Figure 16). Rangelands that are moderately grazed in the Rocky Mountains and Front Range tend to have somewhat higher net primary productivity due to the evolutionary relationship these grassland ecosystems have formed with herbivores (Frank *et al.* 2000). Due to this higher productivity, and the additional nitrogen cycling in the grazers' manure and urine, nitrous oxide emissions are somewhat higher, as are soil organic carbon inputs. The net greenhouse gas balance for well-managed rangelands is very similar.

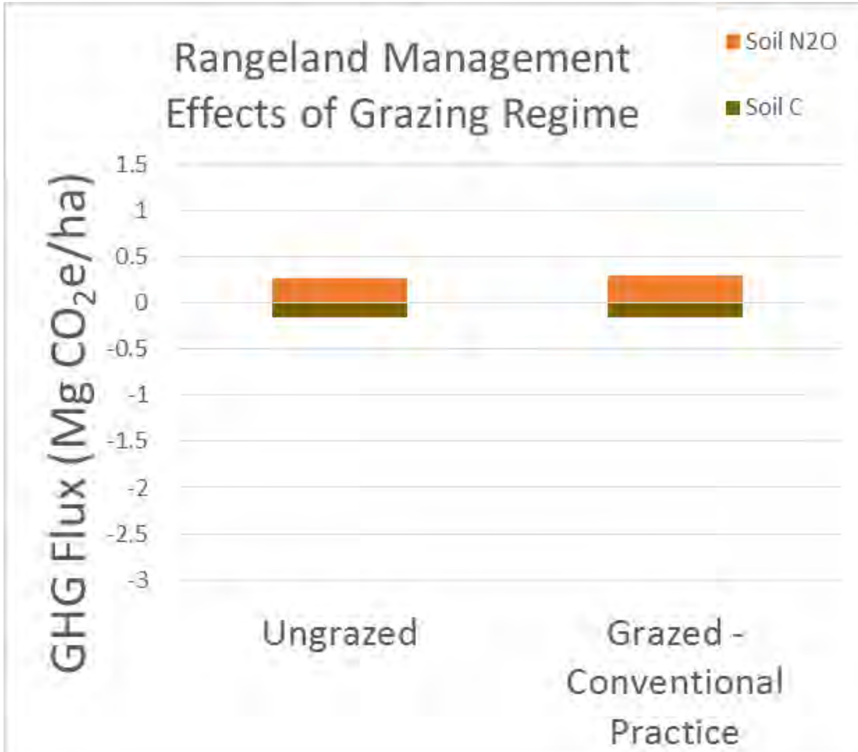

FIGURE 16. EFFECTS OF GRAZING REGIME ON BCPOS RANGELANDS.

Enteric methane emissions are addressed in the livestock section of this report. No data were available on fuel use or use of agricultural amendments on BCPOS rangelands, and therefore they are not addressed.

Rangeland Restoration

BCPOS has implemented programs to restore non-productive or erosive croplands as well as degraded rangelands to native rangeland conditions where conditions warrant. Before the end of 2013, 832 ha of land were restored to functioning grasslands. Some of this work was done before 2004. Additional restoration work is planned for the next 5 years and beyond (BCPOS staff personal communication, 2014).

We evaluated two rangeland restoration scenarios: restoring existing rangeland parcels degraded by overgrazing from localized/confined prairie-dog populations, and parcels of non-irrigated farmland (Figure 17). As explained in the methods section of this report, we simulated rangeland degradation and restoration on all BCPOS rangeland and the area-weighted average results are shown. We also modeled a rangeland restoration scenario in non-irrigated cropland on BCPOS lands, and developed an area-weighted average result.

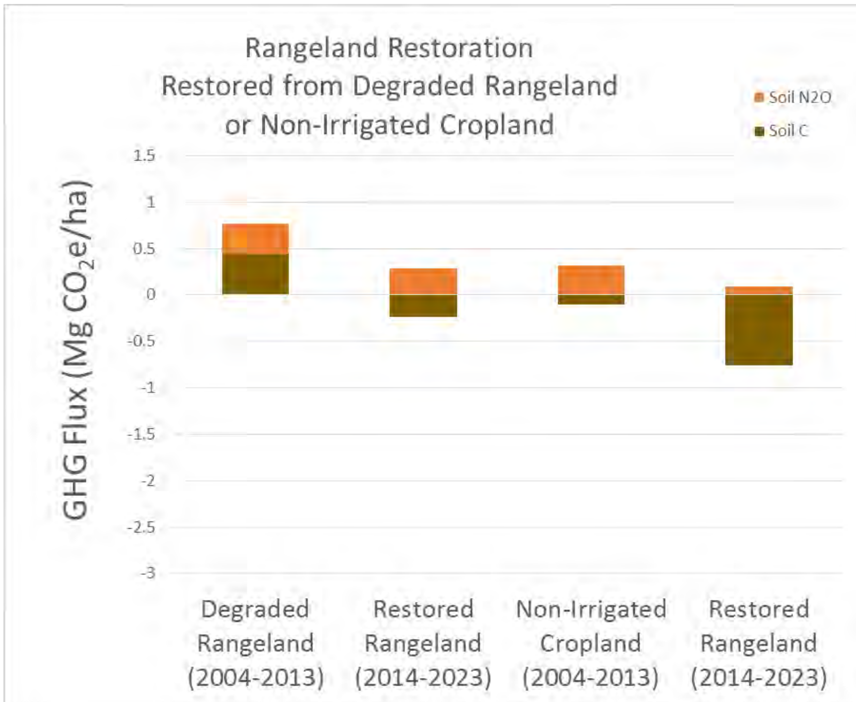

FIGURE 17. SUMMARY OF THE GREENHOUSE GAS BALANCE OF RESTORED RANGELAND USING TWO SCENARIOS: RESTORING FROM DEGRADED RANGELAND (TWO LEFT-HAND BARS) AND RESTORING FROM NON-IRRIGATED CROPLAND (TWO RIGHT-HAND BARS).

Two major differences in the restoration scenarios emerged in our analysis. Soil organic carbon flux into the atmosphere was relatively large on overgrazed sites (averaging 0.45 Mg CO_2e/ha/year) before restoration, as vegetative cover and corresponding carbon inputs were reduced by overgrazing. Nitrous oxide emissions were similar in both pre- and post-restoration periods. This is due to relatively high soil organic carbon and nitrogen content of the soils under this scenario, since the degraded condition had not existed long enough to reduce soil organic carbon and nitrogen to low levels. The net average GHG balance of restoring degraded rangeland under this scenario is -0.7 Mg CO_2e/ha/year on BCPOS rangelands.

In contrast, soil organic carbon was relatively stable on non-irrigated croplands. Though stable, it is also approximately 35% lower than in rangelands found on the same soils (Paustian *et al.* 1997). This is due to the effects of more than a century of tillage as well as at least a half-century of alternating fallow years. The combined effect of tillage and fallow years leads to reduced equilibrium level of soil organic carbon stocks. The nitrous oxide emissions associated with the non-irrigated cropping system are somewhat higher than those on rangeland and restored rangeland (due to added nitrogen fertilizer). After restoration to rangeland, we expect soil organic carbon to increase substantially due to the low-carbon content of the soil relative to that of unplowed grassland, even when that grassland had recently been degraded. Soil nitrous oxide emission are expected to remain relatively low until soil organic carbon stocks are regained and soil fertility improves in the next three to five decades (Paustian *et al.* 1997). The net average GHG balance of restoring non-irrigated cropland to rangeland under this scenario is -0.9 Mg CO_2e/ha/year.

Tillage and restoration process data provided by BCPOS staff were used in analyzing these scenarios. No data were available on fuel use or agricultural amendments during restoration, so fuel use and embodied emissions were not included in the analysis.

Forests, Woodlands and Shrublands

BCPOS manages more than 24,300 hectares of non-agricultural forest, woodlands, shrublands and rangelands, where land use is relatively static and land management focuses on maintaining native ecosystems in a healthy condition. Figure 18 is a map of soil organic carbon stocks on these lands in 2013. Figure 19 is a map of biomass carbon stocks on these lands in 2013. Total soil organic carbon to 30cm and biomass carbon stocks for these lands are shown in Table 16.

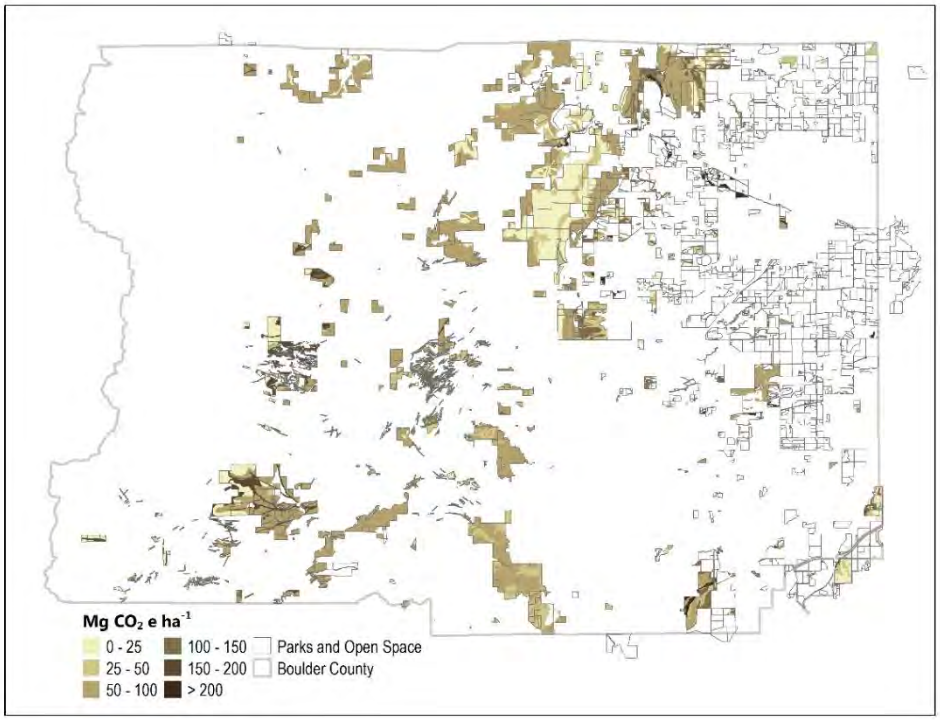

FIGURE 18. SOIL ORGANIC CARBON STOCKS TO 30CM ON BCPOS NON-AGRICULTURAL LANDS IN 2013.

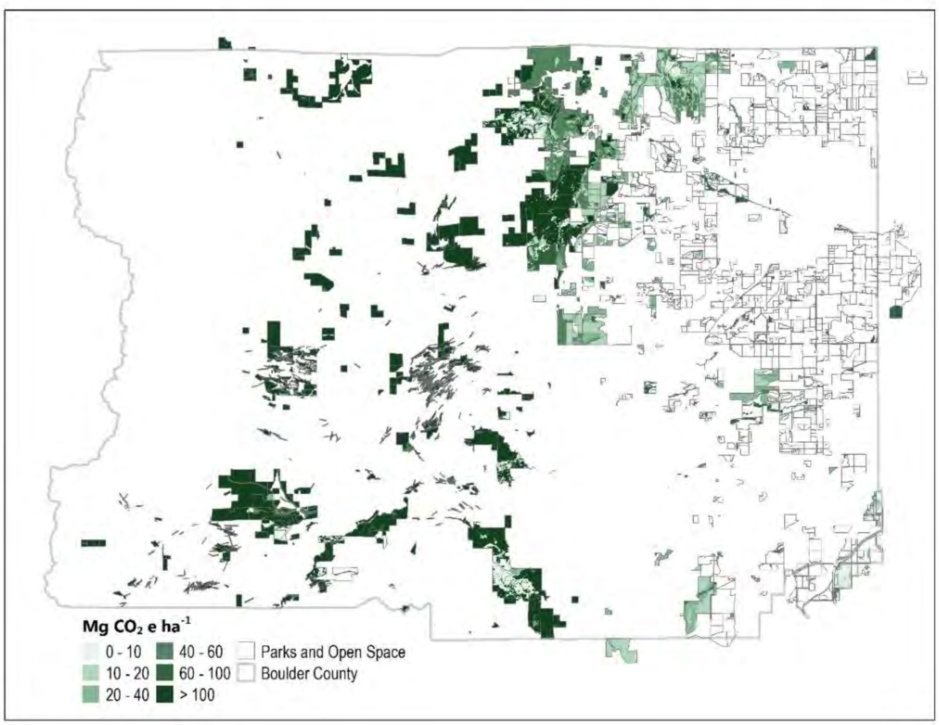

FIGURE 19. BIOMASS CARBON STOCKS ON BCPOS NON-AGRICULTURAL LANDS IN 2013.

TABLE 16. MODELED SOIL AND BIOMASS CARBON STOCKS IN NON-AGRICULTURAL FOREST, AND SHRUB, AND GRASS LANDS OF BOULDER COUNTY PARKS AND OPEN SPACE.

Forest Carbon Stock Category	Carbon Stock (Mg CO_2e)
Soil organic carbon Stocks, 0-30cm	1,361,611
Biomass Carbon Stocks, 2003	2,470,372
Biomass Carbon Stocks, 2013	2,467,224
Biomass Carbon Stocks, 2023	2,431,682

We show soil organic carbon stocks for 2013 only, as we do not expect soil organic carbon stocks to change significantly in these land cover classes in the absence of significant changes in land use or land management. We estimated the soil profile to 30cm to be consistent with IPCC protocol for non-agricultural lands and the Tier 2 analysis done for BCPOS agricultural conservation easements. These soils have an average of 56 Mg CO_2e/ha in the top 30 cm.

Data were not available with which we could estimating the overall biomass growth of all woody vegetation on BCPOS lands, so we confined our analysis of biomass carbon stock change in these categories:

- **Losses due to Wildfire**: The BCPOS land cover data reports twelve named wildfires affecting 2,638 ha of land classified as non-agricultural. These fires burned through a mixture of vegetation alliances. Research summarized in the IPCC 4th Assessment indicates that the average amount of aboveground vegetation consumed by wildfire in different vegetation types ranges from nearly 100% in grasslands to 27% in conifers (Eggleston *et al.* 2006), and we applied these IPCC recommended values to applicable vegetation classes.
- **Losses due to prescribed burning**: The amount of vegetation consumed by prescribed burns varies tremendously depending on the prescription and the effectiveness of the burn process. After discussions with BCPOS staff, we used an average 5% fire consumption rate in prescribed burns.
- **Removals due to mechanical thinning/forest restoration**: BCPOS staff provided results from a number of Forest Vegetation Simulator (FVS) (USDA Forest Service 2014) model runs done for forest restoration projects at Heil Valley Ranch, Hall Ranch and Mud Lake.

The average of the Heil Valley Ranch projects is shown in Figure 20. The simulation data indicate an average of 50% of aboveground biomass is removed in these projects.

- **Growth after fire, prescribed burning, and restoration work**: FVS model runs in BCPOS coniferous forests on Heil Valley Ranch and Reynolds Ranch predict biomass accumulation rates of 3.5 Mg CO_2e/ha/year after forest restoration projects. We could find no other measurements of post-disturbance biomass accumulation rates in these ecosystems, so we have applied that growth rate figure to forests and woodlands disturbed by fire. Biomass accumulation is capped when woody systems reach their expected average biomass stock for the applicable vegetation alliance.

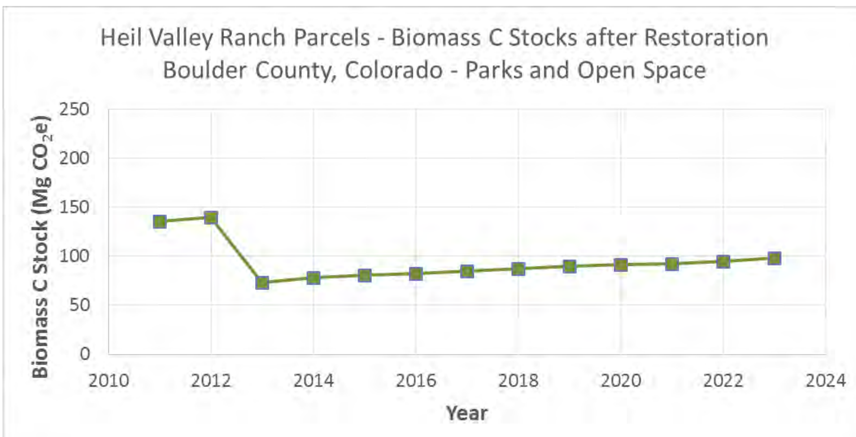

FIGURE 20. FVS MODEL RUNS DEPICTING BIOMASS RESPONSE TO FOREST RESTORATION PROJECTS ON HEIL VALLEY RANCH, BOULDER COUNTY PARKS AND OPEN SPACE.

On a typical biomass thinning operation on Heil Valley Ranch or Hall Ranch, 70 Mg CO_2e of biomass are removed per hectare. The biomass boilers used in Boulder County facilities require chipped material produced primarily from bark-free large branches and boles. Of the amount removed in the thinning process, 27% is typically piled on site for burning or chipped and hauled to a community forest site, while the stem/bole wood (73%, or 51 Mg CO_2e) is available for use in biomass boilers or for other uses (Chajnocky *et al.* in press) (Table 17, Figure 21).

TABLE 17. EXAMPLE GREENHOUSE GAS BALANCE OF RESTORATION OPERATIONS ON HEIL VALLEY RANCH OPEN SPACE.

Forest Biomass/Emission Category	Amount (Mg CO_2e/ha)
Live Biomass Carbon Stock	140.0
Live Biomass Harvested	70.0
Biomass chipped and sent to boilers	51.1
CO_2 from field biomass burning	16.9
CH_4 from field biomass burning	1.3
N_2O from field biomass burning	0.5
CO from field biomass burning	1.5
Fuel Use from Harvest	0.4
Fuel Use from Chipping	0.2
Fuel Use from Hauling	0.1

Diesel fuel required to harvest, chip and haul the biomass to the boilers emits 0.7 Mg CO_2e per hectare. The net non-biogenic emissions total 4 Mg CO2e per Mg CO_2e of biomass removed. When analyzed in the context of metric tonnes (Mg) of biomass, the net emissions for removing trees, processing and chipping, then hauling to a boiler equals 0.1 Mg CO_2e of emissions per metric tonne of dry biomass. Please note these moisture content of the biomass must be taken into account when applying this figure to processing and shipping material to boilers.

Taking all of the above into account, and comparing the efficiency and differences in emissions between biomass boilers and natural gas boilers, burning biomass from BCPOS forests and woodlands in boilers avoids 0.6 Mg CO_2e for each dry metric tonne (Mg) of biomass burned (The Climate Registry 2013, Xcel Energy 2014). Please note these moisture content of the biomass must be taken into account when processing and shipping material to boilers.

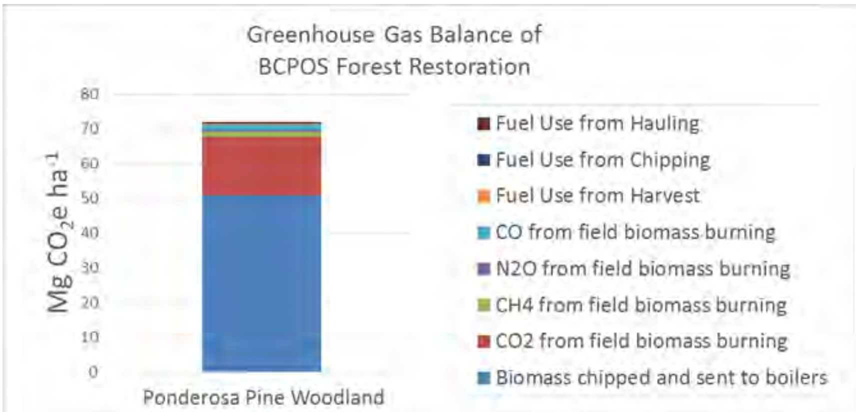

FIGURE 21. EXAMPLE GHG BALANCE OF FOREST MANAGEMENT IN PONDEROSA PINE FOREST AND WOODLANDS ON ONE HECTARE OF THE HEIL VALLEY RANCH, BOULDER COUNTY PARKS AND OPEN SPACE.

Roadside corridors

BCPOS staff manages the roadside corridors of Boulder County's roads, of which 160 miles are primary and 392 miles are paved and unpaved secondary roads. When combined, these roadside corridors represent approximately 324 ha of land. We attempted to model the net greenhouse gas balance of these systems, however for a number of reasons our results do not represent a complete picture of this aspect of BCPOS operations.

BCPOS staff provided good accounting information on fuel use in roadside management (see section titled

Maintenance of Roadside Corridors). They also provided good estimates of roadside corridor width and management details, though they cautioned us on the significant variability in road corridor widths and substrates. They also indicated that roadsides in the foothills and mountainous parts of the county did not generally have significant vegetation on them and were not generally mowed or otherwise managed other than for fallen tree or debris removal, and so we left these road sections out of this analysis. Despite the good faith effort of the staff and our best efforts, analyzing the greenhouse gas balance of these management activities was problematic. A number of issues arose that raise the uncertainty of an effective analysis of this management category. These include:

1) The fate of carbon and nitrogen in soils buried, disturbed, or hauled away during the initial construction of roads is essentially unknown. We expect 40-60% of the soil organic carbon and nitrogen in these buried or otherwise disturbed soils has either mineralized or eventually will mineralize into carbon dioxide and denitrify into nitrous oxide. But a firm number is not clear.

2) A road engineering material generically defined as “road base” is used as the substrate/foundation for most roads, and it extends well into the drainage ditch of most roads. The extent to which it serves as soil for plant growth, and the sand, silt and clay content of the material could only be approximated. Soil organic carbon and nitrogen cycling is highly dependent on the soil texture, and so this presents a major source of uncertainty in our modeling effort.
3) A portion of the rain and snow that falls on paved roads either drains into the roadside corridor or is plowed off into the corridor, while a portion evaporates into the atmosphere. It was unclear how much of that additional moisture was available for plant growth, nor do we know the extent to which de-icing chemicals affect plant growth.
4) Mapped data for existing woody vegetation in the roadside corridors were not available for this study.

With these limitations in mind, we attempted to model the greenhouse gas balance of soil organic carbon and nitrogen in the corridors (Figure 22).

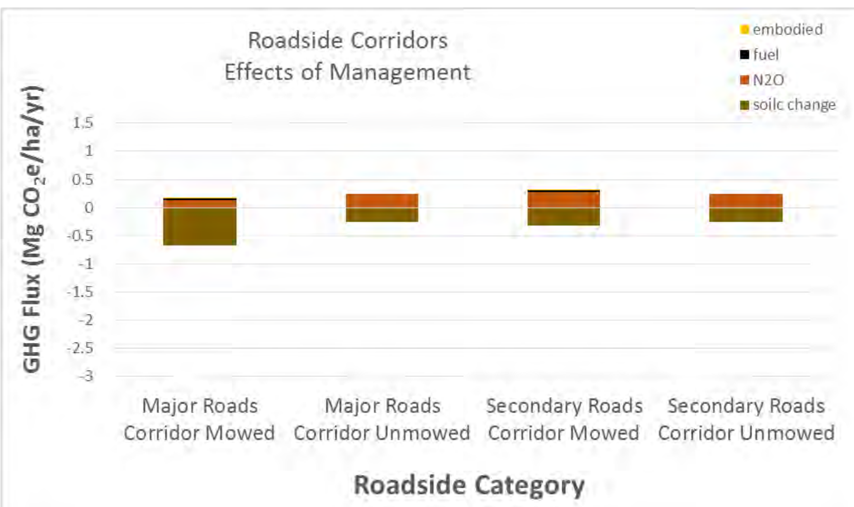

FIGURE 22. GREENHOUSE GAS BALANCE OF ROADSIDE CORRIDOR MANAGEMENT IN BOULDER COUNTY, COLORADO.

After discussions with BCPOS staff, for modeling purposes we classified the corridor of each road type (major and secondary) into a mowed and unmowed section. We assumed all major roads were paved and we increased the precipitation in the mowed section by 50% to estimate additional moisture from runoff and plowed ice and snow. The mowed corridors of major roads had a net greenhouse gas balance of approximately -0.36 Mg CO_2e/ha/year, whereas the other categories had a net greenhouse gas balance of about 0.26 Mg CO_2e/ha/year. Soil carbon sequestration is higher in the mowed section because the substrate is primarily road base, with very low SOC values at the time of construction.

Fuel use in roadside corridors contributed less than 5% to the net greenhouse gas balance of the mowed sections. In total, the net GHG balance from soils in roadside corridors is about 29 Mg CO_2e/ha/year. There is significant uncertainty in this estimate. We encourage caution when using this information to inform land use and management decisions on roadside corridors with respect to their greenhouse gas balance.

Livestock

Based on the IPCC Tier 2 analysis, the livestock on BCPOS lands produce about 1950 Mg CO_2e/year. This includes about 1882 Mg CO_2e/year from enteric methane, and about 69 Mg CO_2e/year from manure methane. On a mass basis, this is equivalent to about 5 kg CO_2e per live weight of cattle raised on BCPOS lands.

Information on fuel use, supplemental feed, or amendments used to support livestock operations were not available. Therefore no calculations for fuel use or embodied emissions are available for livestock.

Cattle production has some of the highest GHG emission rates, primarily due to emissions from enteric fermentation (Eggleston *et al.* 2006). Livestock raised on well-maintained rangeland and irrigated pasture on the Front Range will have relatively low emissions relative to those raised on poorer quality rangelands or pastures, with lower feed digestibility. Direct enteric methane emissions tends to be lower in confined animal feeding operations on a per-pound basis of weight gain, however manure methane and manure nitrous oxide emissions tend to be higher in those situations, and in poorly-managed operations can be on par with enteric methane emissions (Eggleston *et al.* 2006). Additionally, the embodied emissions associated with feed grain and other feed amendments as well as additional equipment and energy costs raise the net GHG balance of such livestock feeding operations.

For comparison purposes, we evaluated the potential emissions from different livestock with economic potential for Boulder County. We evaluated animals being raised for other purposes (horses) or for slaughter (goats and sheep). The results are shown in Figure 23.

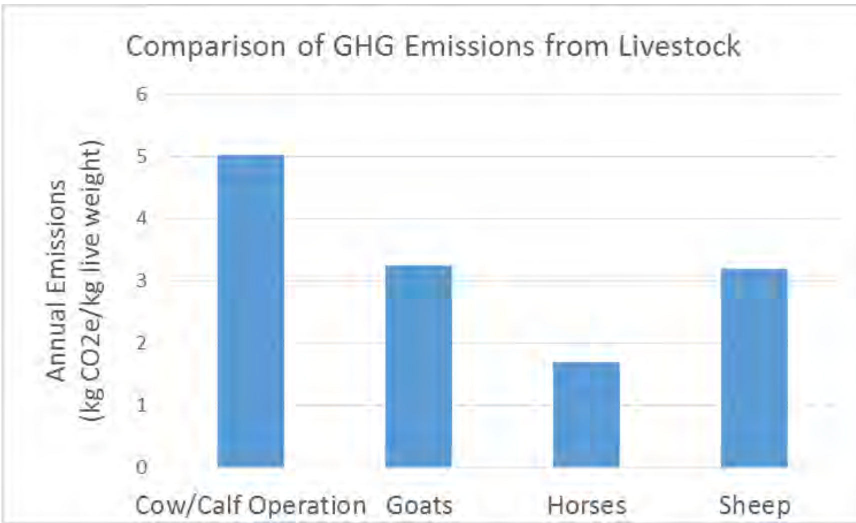

FIGURE 23. ANNUAL GHG EMISSIONS FROM LIVESTOCK COMMONLY GROWN ON THE FRONT RANGE.

Agricultural Conservation Easements and Other Lands

Irrigated Cropland, Non-Irrigated Cropland, and Rangeland

While information on activities on agricultural conservation easements and other lands was limited, current soil organic carbon stocks and nitrous oxide emissions were estimated using IPCC Tier 1 and 2 methods. Because no information was available on land use or management change over the reporting time period for agricultural conservation easements, it was not possible to calculate soil organic carbon stock changes. Soil organic carbon stocks were highest in irrigated croplands and grasslands (154-176 Mg CO_2e ha^{-1}) and lowest on non-irrigated croplands (117 Mg CO_2e ha^{-1}) (Table 18). Total emissions of N_2O were highest on irrigated annual croplands due to higher inputs of N through fertilizer and crop residues.

TABLE 18. TOTAL AREA AND EMISSIONS FOR CROPLANDS AND GRASSLANDS.

	Area (ha)	Average SOC Stocks (Mg CO_2e ha^{-1})	Total SOC Stocks (Mg CO_2e)	Direct N_2O Emissions (Mg CO_2 e yr^{-1})	Indirect N_2O Emissions (Mg CO_2 e yr^{-1})
Irrigated Annual Cropland	2,282	154	351,428	1007	257
Non-irrigated Annual Cropland	342	117	40,014	45	3
Pasture or Hay	4,912	176	864,512	610	0
Rangeland	311	154	47,894	39	0
Total	7,847	166	1,303,848	1,701	260

Forestland and Other Lands

The majority of the land area in agricultural conservation easements was under cropland or grassland, however some small areas of woody wetlands, shrublands and forests were present. For these lands, aboveground and belowground biomass C and soil organic carbon stocks were estimated. No information on land use or management change was available for these categories, therefore we were not able to estimate biomass or soil organic carbon stock changes. Total system carbon (biomass + soil organic carbon stocks) was highest in evergreen forests and woodland systems and lowest in shrublands (Table 19).

TABLE 19. TOTAL AREA AND CARBON STOCKS OF "OTHER LANDS" LOCATED WITHIN THE MATRIX OF AGRICULTURAL CONSERVATION EASEMENTS.

	Area (ha)	Average Total System Carbon (Mg C ha^{-1})
Evergreen Forest	7	115
Shrubland	38	35
Woody Wetlands	218	50

Forecast of Greenhouse Gas Emissions

Energy use in buildings and operations

- Natural Gas: Emissions in this category appear to be trending downward, with average emissions in the period 2010-2012 being 35% lower than the average emissions from the previous three years. It is unclear if there are structural or policy reasons for this decrease, and the extent this trend can be maintained into the future short of replacing equipment utilizing natural gas with those based on renewable fuels or other energy sources.
- Fuel Use: The trend in emissions for 2008-2012 was statistically flat, however the net GHG emissions from 2010-2012 trend downwards as biodiesel is utilized more and other conservation measures described by BCPOS staff are adopted. We are hesitant to predict future fuel use based on this trend, however if it continues, fuel use could drop by 6-9% per year over the next several years.
- Electricity Use: Emissions from this source category have grown steadily at a rate of 2.6% over the period of record. Statistical analysis of this trend ($p < 0.05$, $r^2 = 0.9$) suggest it is will continue in the absence of structural change, sourcing energy from renewable sources, or implementing new conservation measures.
- Biomass Boiler: Fuel values for the biomass boiler over the period of record follow no discernable trend, and so we do not believe a prediction of future emissions is possible at this time.
- Roadside Corridors: Only one year of data on fuel use was available for this study, and so no prediction is possible at this time.
- Recreation Travel to BCPOS lands: Only one year of data on vehicular miles traveled (VMT) was available for this study, and so no prediction is possible at this time.

Cropland

Soil organic carbon flux is directly dependent on tillage intensity, and the historic trend throughout Colorado and the Country for the last three decades has been toward reductions in tillage intensity (CTIC 2014). This is likely to lead to increases in soil organic carbon, but with no long-term change in soil nitrous oxide over the next decade. Weed management in organic systems at the present time largely involves careful timing of tillage events, and as more cropland is moved into organic management, attention should be paid to new innovations in tillage systems or weed management alternatives to keep pace with this trend. New innovations in no-tillage systems under organic management (discussed in the section titled

Management Practices That Reduce Greenhouse Gas Emissions) offer some new opportunities for improving the GHG balance of cropping systems.

Increasing the amount of area under organic systems is very likely to improve the greenhouse gas balance of cropping systems, as manure and compost or other organic nutrient sources replace synthetic fertilizers.

Advances in techniques to reduce nitrous oxide emissions (discussed in the section titled Management Practices That Reduce Greenhouse Gas Emissions) are becoming available now and should become more widely available to producers in Boulder County in the next decade. If implemented, these new techniques have the opportunity to substantially improve the GHG balance of cropping systems using synthetic fertilizers.

Rangeland

The greenhouse gas balance of well-managed pasture and rangeland is generally the most stable of any land use system (Eggleston *et al.* 2006). With no changes in land use or management of these lands, the net greenhouse gas balance is likely to remain constant for the coming decade.

Non-Agricultural Forests, Shrubland, and Rangeland

The likelihood of severe, stand-replacing fires is high on BCPOS lands and is likely to remain high for the foreseeable future (Grissino Mayer and Swetnam 2000). In addition to this, changes in precipitation and temperature due to climate change are likely to affect both the persistence of existing vegetation types and the regeneration of the same vegetation types after disturbance (Feddemaa *et al.* 2013). Whereas soil organic carbon stocks are likely to remain stable in the absence of land use change, there is an increasing likelihood of severe erosional events following stand-replacing fires and changes in vegetation types due to stand regeneration failures. Therefore we are hesitant to predict trends in biomass carbon stocks on BCPOS non-agricultural lands.

The restoration work being done on Heil Valley Ranch and Hall Ranch has potential to improve the habitat and ecological function of these lands while providing a significant feedstock source to offset natural gas emissions. Whereas the restoration work planned for BCPOS forest areas temporarily reduces biomass carbon stocks, diverting biomass for biomass boilers has a net greenhouse gas benefit as long as biomass removal does not exceed forest regeneration rates.

Livestock

Based on conversations with BCPOS staff, livestock populations and management appear likely to remain constant, and therefore the net greenhouse gas balance of these systems is unlikely to change in the near future.

Restored Rangeland

Restoring degraded rangeland and retiring unproductive and/or erosive cropland provides opportunities to improve the overall greenhouse gas balance of BCPOS land use and management. The extent of that benefit will correspond directly with the amount of land restored to rangeland conditions.

Management Practices That Reduce Greenhouse Gas Emissions

Following is a summary of management practices BCPOS may consider applying to their operations and land use and management, if they have not already done so.

Energy use in buildings and operations

Increase use of biomass fuels for heating

Biomass fuels such as wood chips significantly reduce GHG emissions associated with heating buildings because most of the emissions generated during biomass combustion are considered carbon neutral. Biofuels are already in use, but if their use is increased, larger GHG reductions can be achieved.

Upgrade HVAC Equipment

Heating, ventilation, and air conditioning (HVAC) systems typically consume the largest amount of energy in buildings. Depending on the age of the buildings and the HVAC equipment, upgrading to more energy efficient equipment and systems can save significant amounts of energy and reduced GHG emissions. Important considerations for selecting new HVAC equipment include the following:

- <u>Consider evaporative cooling alternatives</u> – In Colorado's climate, evaporative cooling applications can be an attractive alternative to refrigerant based systems. Evaporative cooling can be either a stand-alone application or integrated with existing equipment. This technology can provide 75% energy savings over refrigerant-based air conditioning systems. Evaporative cooling has improved through the years and many of the past issues have been addressed with the new systems. In Colorado, newer technology, such as indirect or indirect/direct evaporative cooling (IDEC), can provide cooling that is comparable to direct expansion (DX) air conditioning but without the additional electricity operating costs. IDEC can reach lower temperatures and does not add as much humidity as traditional evaporative coolers.
- <u>Get the right sized unit</u> – Rather than simply replacing an existing unit with a new unit of the same size (or using standard rules-of-thumb to size the unit), ensure that the installer/contractor considers the various factors that determine the size of a unit, including the building's lighting (and other equipment), area, construction/envelope (insulation, windows, etc.), occupancy, etc.
- <u>Install high-efficiency rooftop units (RTUs)</u> – Installing high-efficiency RTUs with economizers and a high energy efficiency ratio (EER) will result in lower operating costs and higher savings over the life of the units. Potential rebates and electricity cost savings that will result from this action can cover the higher incremental cost of high-efficiency units versus standard-efficiency units.

- Include economizers – Economizers use outdoor air to provide cooling and ventilation as warranted by outdoor conditions. This is an excellent option to consider especially in northern Colorado's climate.

Install Programmable Thermostats

Programmable thermostats can provide significant energy savings by reducing heating and cooling in buildings. Programmable thermostats allow temperatures to be automatically adjusted (set back) when spaces are not in use, generally overnight. In the summer, the amount of energy used for cooling drops 4 to 5% for every degree the thermostat setpoint is increased. In order to realize the most energy and cost savings, it is recommended by ENERGY STAR to program setbacks/setups of 8 or more degrees from occupied setpoints. Generally, the amount saved depends on the magnitude of the setback and the length of time the setback is maintained.

Upgrade Lighting

Lighting accounts for 30% of most facilities' electric bill. If older incandescent and linear fluorescent fixtures (T12) are being used inside buildings, significant energy savings can be realized by replacing those fixtures with compact fluorescent, light emitting diode (LED), and more efficient linear fluorescent (T8) fixtures. LED fixtures also provide longer bulb life and reduce the frequency of replacements. In addition to retrofitting interior lighting, exterior lighting can be upgraded to save energy. This is especially true if outdoor lighting is provided by high wattage fixtures such as high intensity discharge bulbs. These fixtures can be replaced by LED fixtures for significant energy gains.

Manage IT Plug Loads

Power management settings can be implemented on computers, monitors, printers, fax machines, and copiers. ENERGY STAR recommends setting computers to enter system standby after 30 to 60 minutes of inactivity and setting monitors to enter sleep mode after 5 to 20 minutes of inactivity. Many fax machines, printers and copiers also include these features. Depending on manufacturer, equipment age and configuration, these settings can use over 90% less power than the equipment's regular operation, resulting in over a 60% reduction in overall energy use.

Although many products come with power management features, some may require activation. Monitor screensavers, including the blank screen option, use as much power as an active monitor and may even prevent the computer from utilizing enabled power management features. Lastly, no power management feature saves as much energy as turning off the equipment when not in use, especially at night and during weekends.

Weatherize the Building

Depending on the age and condition of buildings, there could be significant air leakage (infiltration), which can greatly increase heating and cooling energy use. It is recommended that areas with significant air leakage be weatherized or sealed with weather stripping, caulking, spray foam, or new door gaskets. Sealing air leaks is usually a low cost project with paybacks between 1 and 2 years.

Cropland

- Replace fertilizer with manure/compost or other organic amendments where possible. When adding manure/compost to fields, apply sub-surface by direct injection or sub-soil banding. Non-irrigated croplands in fallow-winter wheat systems on BCPOS lands amended with manure or compost require 5.4 short tons/acre (12.1 Mg/ha) with a carbon-to-nitrogen ratio of 12 be applied to the wheat crop at the time of planting. This equals an average of 2.7 tons per acre (6 Mg/ha) per year. Irrigated croplands in alfalfa-row crop systems amended with manure or compost require an average of 5.2 short tons/acre (12 Mg/ha) of the same type of material. This is the average of 20 tons/acre applied to corn and sugar beets, and 7 tons/acre applied to wheat and malting barley, with no organic amendments required for alfalfa.
- When using synthetic fertilizers:
    - Apply to soil test, so the amount of nutrients necessary for economic yields are available and excess nitrous oxide and embodied emissions as well as nutrient runoff may be avoided. Precision agriculture can aid in meeting this need.
    - Time fertilizer applications to avoid major precipitation or irrigation events by at least one week, to avoid a flush of nitrous oxide emissions that occur when precipitation or irrigation coincides with fertilization.
    - Slow-release fertilizer is becoming more widely available, and its use has the potential to reduce emissions by 35-38% (Denef *et al.* 2011).
    - As with slow-release fertilizers, nitrification inhibitors are starting to become more widely available. Utilizing them can reduce nitrous oxide emissions by an amount comparable to slow-release fertilizers (35-38%) (Denef *et al.* 2011).
    - Applying fertilizers sub-surface by direct injection, drilling, or sub-soil placement has the potential to reduce indirect nitrous oxide emissions from leaching and volatilization by as much as 35%. Direct nitrous oxide emissions may also be reduced, although current research reports variable results (Denef et al. 2011).
- Reducing tillage on conventionally-managed crops has an almost immediate benefit to improve the greenhouse gas balance of irrigated and non-irrigated croplands (Paustian

et al. 1997). New techniques that integrate reduced and no-tillage systems with organic production are becoming more widespread (Schonbeck 2010, Rodale Institute 2014)

- Intensifying crop production is likely to improve in the greenhouse gas balance of non-irrigated lands (Kaan *et al.* 2014).
- Use cover crops on irrigated lands where possible to reduce the amount of synthetic fertilizer or manure/compost required to meet crop nutrient needs (Kladivko 2011).
- Grow biofuels where it is practical. At present no significant market exists in or near Boulder County for switchgrass as a feedstock for cellulosic ethanol, though cellulosic ethanol biorefineries utilizing switchgrass are under construction in other parts of the U.S. A pilot plant utilizing corn stalks is under construction in Fort Lupton. Switchgrass is a viable biofuel feedstock alternative on the Front Range, particularly on marginal or degraded soils, and could potentially be utilized in certain types of biomass burners to offset natural gas emissions.

Pasture, Rangeland and Livestock

The greenhouse gas balance of BCPOS pasture and rangeland is unlikely to change as long as rangeland is managed well and kept in a non-degraded condition. Grazing offtake should be maintained within recommended levels and timed to fit ecosystem needs (Cook *et al.* 1997).

Forestland

The increasingly unpredictable interactions between the changing climate and Front Range forest fire cycles are likely to make managing BCPOS forest and shrub lands challenging in the near future. Where there are opportunities to be proscriptive, restoration activities that remove tree biomass for chipping and burning in biomass boilers will have a net greenhouse gas benefit.

Roadside Corridors

There is some potential to manage BCPOS roadside corridors to sequester carbon in woody vegetation, in areas where such practices would not reduce visibility or cause other safety concerns. Shrublands such as mountain mahogany grasslands in Boulder County can store up to about 24 Mg CO2e/ha. Managing the unmowed sections of roadside corridors (approximately ½ of the roadside corridor area) for woody shrubs could sequester about 3,900 Mg CO_2e.

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Appendix 1: Woody Species Biomass Carbon Stocks

TABLE 20. BIOMASS CARBON STOCKS ASSIGNED TO SW GAP VEGETATION CLASSES, INCLUDING ABOVEGROUND AND BELOWGROUND CARBON.

SWGAP Class	SWGAP Ecosystem Name	Biomass C (Mg CO_2e)
Forest & Woodland	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	86.9
Forest & Woodland	Rocky Mountain Aspen Forest and Woodland	73.7
Forest & Woodland	Rocky Mountain Lodgepole Pine Forest	348.7
Forest & Woodland	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	471.9
Forest & Woodland	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland	471.9
Forest & Woodland	Rocky Mountain Subalpine-Montane Riparian Woodland	471.9
Forest & Woodland	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	348.7
Forest & Woodland	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	348.7
Forest & Woodland	Southern Rocky Mountain Ponderosa Pine Woodland	100.1
Forest & Woodland	Western Great Plains Riparian Woodland and Shrubland	73.7
Introduced & Semi Natural Vegetation	Introduced Upland Vegetation - Perennial Grassland and Forbland	14.7
Nonvascular & Sparse Vascular Rock Vegetation	Rocky Mountain Alpine Bedrock and Scree	0
Nonvascular & Sparse Vascular Rock Vegetation	Western Great Plains Cliff and Outcrop	0
Semi-Desert	Inter-Mountain Basins Big Sagebrush Shrubland	23.8
Semi-Desert	Inter-Mountain Basins Montane Sagebrush Steppe	23.8
Shrubland & Grassland	Rocky Mountain Alpine-Montane Wet Meadow	14.7
Shrubland & Grassland	Rocky Mountain Lower Montane-Foothill Shrubland	44.7

SWGAP Class	SWGAP Ecosystem Name	Biomass C (Mg CO_2e)
Shrubland & Grassland	Rocky Mountain Subalpine-Montane Riparian Shrubland	44.7
Shrubland & Grassland	Southern Rocky Mountain Montane-Subalpine Grassland	14.7
Shrubland & Grassland	Western Great Plains Foothill and Piedmont Grassland	14.7
Shrubland & Grassland	Western Great Plains Sandhill Steppe	23.8
Shrubland & Grassland	Western Great Plains Shortgrass Prairie	14.7

TABLE 21. BIOMASS CARBON STOCKS FOR VEGETATION ALLIANCE CLASSES, INCLUDING ABOVEGROUND AND BELOWGROUND CARBON.

Alliance	Alliance Description	Biomass C (Mg CO_2e)
A.1104	Winterfat Dwarf-shrubland Alliance	23.7
A.118	Lodgepole Pine Forest Alliance	348.6
A.1191	Big Bluestem - (Bluejoint, Switchgrass) Herbaceous Alliance	14.7
A.1192	Big Bluestem - (Yellow Indiangrass) Herbaceous Alliance	14.7
A.1195	Timothy Herbaceous Alliance	14.7
A.1225	Little Bluestem - Sideoats Grama Herbaceous Alliance	14.7
A.1232	Western Wheatgrass Herbaceous Alliance	14.7
A.1234	Needle-and-Thread - Blue Grama Herbaceous Alliance	14.7
A.124	Ponderosa Pine Forest Alliance	100.1
A.1240	Little Bluestem Herbaceous Alliance	14.7
A.1244	Sideoats Grama Herbaceous Alliance	14.7
A.1252	Sand Dropseed Herbaceous Alliance	14.7
A.1260	Mountain Muhly Herbaceous Alliance	14.7
A.1261	Green Needlegrass Herbaceous Alliance	14.7
A.1262	Indian Ricegrass Herbaceous Alliance	14.7
A.1266	Little Bluestem Bunch Herbaceous Alliance	14.7
A.1270	Needle-and-Thread Bunch Herbaceous Alliance	14.7
A.1271	Nelson's Needlegrass Herbaceous Alliance	14.7
A.1272	New Mexico Needlegrass Herbaceous Alliance	14.7
A.1281	Poverty Oatgrass Herbaceous Alliance	14.7
A.1282	Blue Grama Herbaceous Alliance	14.7
A.1316	Parry's Oatgrass Herbaceous Alliance	100.1
A.1332	Inland Saltgrass Intermittently Flooded Herbaceous Alliance	14.7

Alliance	Alliance Description	Biomass C (Mg CO_2e)
A.1337	Big Bluestem - (Yellow Indiangrass) Temporarily Flooded Herbaceous Alliance	14.7
A.134	Ponderosa Pine - Douglas-fir Forest Alliance	100.1
A.1341	Inland Saltgrass - (Foxtail Barley) Temporarily Flooded Herbaceous Alliance	14.7
A.1351	Rough Bentgrass Temporarily Flooded Herbaceous Alliance	14.7
A.1354	Western Wheatgrass Temporarily Flooded Herbaceous Alliance	14.7
A.1362	Switchgrass Seasonally Flooded Herbaceous Alliance	23.7
A.1374	Baltic Rush Seasonally Flooded Herbaceous Alliance	14.7
A.1381	Reed Canarygrass Seasonally Flooded Herbaceous Alliance	14.7
A.1382	Kentucky Bluegrass Semi-natural Seasonally Flooded Herbaceous Alliance	14.7
A.1417	Nebraska Sedge Seasonally Flooded Herbaceous Alliance	14.7
A.1419	Clustered Field Sedge Seasonally Flooded Herbaceous Alliance	14.7
A.1422	(Common Spikerush, Pale Spikerush) Seasonally Flooded Herbaceous Alliance	14.7
A.1433	Common Threesquare Semipermanently Flooded Herbaceous Alliance	14.7
A.1436	(Narrowleaf Cattail, Broadleaf Cattail) - (Clubrush species) Semipermanently Flooded Herbaceous Alliance	44.7
A.1488	Ponderosa Pine Wooded Tall Herbaceous Alliance	100.1
A.1537	Skunkbush Sumac Shrub Herbaceous Alliance	44.7
A.1538	Alderleaf Mountain-mahogany Shrub Herbaceous Alliance	23.7
A.1540	Soapweed Yucca Shrub Herbaceous Alliance	23.7
A.1546	Rubber Rabbitbrush Shrub Short Herbaceous Alliance	23.7
A.157	Douglas-fir Forest Alliance	100.1
A.1571	Blue Grama Dwarf-shrub Herbaceous Alliance	23.7
A.164	Engelmann Spruce Forest Alliance	472.1
A.1814	Cheatgrass Semi-natural Herbaceous Alliance	14.7
A.1836	Open Cliff Sparsely Vegetated Alliance	23.7
A.1838	Rock Outcrop Sparsely Vegetated Alliance	23.7
A.191	Engelmann Spruce Seasonally Flooded Forest Alliance	100.1
A.2528	(Broom Snakeweed, Threadleaf Snakeweed) Dwarf-shrubland Alliance	23.7
A.2529	Intermediate Wheatgrass Semi-natural Herbaceous Alliance	14.7
A.2565	Fringed Sagebrush Dwarf-shrubland Alliance	23.7
A.2566	Five-petal Cliffbush Shrubland Alliance	44.7
A.2570	Purple Three-awn Herbaceous Alliance	14.7

Alliance	Alliance Description	Biomass C (Mg CO_2e)
A.2578	(American Mannagrass, Fowl Mannagrass) Seasonally Flooded Herbaceous Alliance	14.7
A.2651	Yellow Rabbitbrush Shrubland Alliance	23.7
A.274	Quaking Aspen Forest Alliance	73.9
A.290	Eastern Cottonwood Temporarily Flooded Forest Alliance	73.9
A.300	Quaking Aspen Temporarily Flooded Forest Alliance	73.9
A.310	Narrowleaf Cottonwood Temporarily Flooded Forest Alliance	73.9
A.340	Quaking Aspen Seasonally Flooded Forest Alliance	73.9
A.3521	Green Needlegrass - Needle-and-Thread Herbaceous Alliance	14.7
A.3561	Smooth Brome Semi-natural Herbaceous Alliance	14.7
A.3562	Kentucky Bluegrass Semi-natural Herbaceous Alliance	14.7
A.3563	Crested Wheatgrass Semi-natural Herbaceous Alliance	14.7
A.3569	Skunkbush Sumac Shrubland Alliance	23.7
A.424	Lodgepole Pine - Quaking Aspen Forest Alliance	206.7
A.426	Quaking Aspen - Douglas-fir Forest Alliance	73.9
A.506	Rocky Mountain Juniper Woodland Alliance	39.5
A.512	Lodgepole Pine Woodland Alliance	348.6
A.530	Ponderosa Pine Woodland Alliance	100.1
A.533	Ponderosa Pine - Douglas-fir Woodland Alliance	100.1
A.552	Douglas-fir Woodland Alliance	100.1
A.563	Rocky Mountain Juniper Temporarily Flooded Woodland Alliance	39.5
A.565	Ponderosa Pine Temporarily Flooded Woodland Alliance	100.1
A.567	Blue Spruce Temporarily Flooded Woodland Alliance	100.1
A.568	Douglas-fir Temporarily Flooded Woodland Alliance	100.1
A.572	Engelmann Spruce Seasonally Flooded Woodland Alliance	100.1
A.610	Quaking Aspen Woodland Alliance	73.9
A.632	Netleaf Hackberry Woodland Alliance	73.9
A.636	Eastern Cottonwood Temporarily Flooded Woodland Alliance	73.9
A.641	Narrowleaf Cottonwood Temporarily Flooded Woodland Alliance	73.9
A.642	Box-elder Temporarily Flooded Woodland Alliance	73.9
A.645	Peachleaf Willow Temporarily Flooded Woodland Alliance	73.9
A.825	Antelope Bitterbrush Shrubland Alliance	23.7
A.835	Rubber Rabbitbrush Shrubland Alliance	23.7
A.842	Tamarisk species Semi-natural Temporarily Flooded Shrubland Alliance	44.7
A.869	Fourwing Saltbush Shrubland Alliance	23.7
A.896	Alderleaf Mountain-mahogany Shrubland Alliance	44.7
A.919	Chokecherry Shrubland Alliance	44.7
A.923	Wax Currant Shrubland Alliance	44.7

Alliance	**Alliance Description**	**Biomass C (Mg CO_2e)**
A.938	Skunkbush Sumac Intermittently Flooded Shrubland Alliance	44.7
A.941	Shrubby Seepweed Intermittently Flooded Shrubland Alliance	23.7
A.947	(Coyote Willow, Sandbar Willow) Temporarily Flooded Shrubland Alliance	44.7
A.950	Gray Alder Temporarily Flooded Shrubland Alliance	44.7
A.952	Rocky Mountain Maple Temporarily Flooded Shrubland Alliance	44.7
A.958	Shrubby-cinquefoil Temporarily Flooded Shrubland Alliance	44.7
A.961	Western Snowberry Temporarily Flooded Shrubland Alliance	44.7
A.967	Water Birch Temporarily Flooded Shrubland Alliance	44.7
A.976	Bluestem Willow Temporarily Flooded Shrubland Alliance	44.7
A.979	Shining Willow Temporarily Flooded Shrubland Alliance	44.7
A.981	Park Willow Temporarily Flooded Shrubland Alliance	44.7
A.996	Water Birch Seasonally Flooded Shrubland Alliance	44.7