Rotational Grazing and Greenhouse Gas Reductions: A Case Study in Financial Returns

By

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(ABSTRACT)

Agricultural conservation practices can have a vast number of environmental benefits but adoption of these practices may not be widespread. If farm operators are able to reap financial returns for environmental services, adoption of these conservation practices could increase. One source of potential financial returns is in greenhouse gas (GHG) emission reductions or increased GHG sequestration. An example of a conservation management strategy for beef and dairy operations which has the potential to decrease GHG emissions or increase GHG sequestration is an intensively managed rotational grazing system.

The objective of this study is to estimate potential financial returns from conversion to rotational grazing and the sale of GHG credits by Virginia beef and dairy farms. The three GHGs examined in the study are carbon dioxide, nitrous oxide, and methane. Primary and secondary data are used to simulate financial performance and GHG emissions for three case study farms under different levels of production and pasture utilization. Each case study farm is simulated under three reference conditions to calculate financial performance and three baseline scenarios and a regional performance standard to calculate GHG emissions on both a per farm and a per metric ton of product sold metric. The change in emissions between the scenarios is found and potential returns from the sale of GHG emissions credits are calculated.

Results of the analysis demonstrate that conversion to rotational grazing has the potential to increase overall revenues for the farm operation from $4,197.72 to $50,007.46. GHG emission changes for the farm operation do not show a clear trend towards reduction. The amount of financial return from the sale of GHG reduction credits varies from $37.15 to $76.26 for the three case study farms for the initial calculations, and varies from $24.10 to $755.36 once the study performs sensitivity analysis for methane emissions. Therefore, results indicate that rotational grazing can increase net revenues for farm operations but additional net revenue from the sale of GHG reduction credits is small and dependent on the chosen baseline scenario and metric.

Follow up research should address the following areas: changes in the cost of on-farm labor, risk of conversion to rotational grazing, increased accuracy of the measurement of GHG emissions and soil carbon, the effects of rotational grazing on forage TDN, and the water quality impacts of rotational grazing.

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CHAPTER 1: AN INTRODUCTION TO ROTATIONAL GRAZING

1.1 Introduction

Agricultural conservation practices can have a vast number of environmental benefits but adoption of these practices may not be widespread. If farm operators are able to reap financial returns for environmental services, adoption of these conservation practices could increase. One source of potential financial returns is in greenhouse gas (GHG) emission reductions or increased GHG sequestration. Studies are just now beginning to investigate feasibility of potential reductions of GHGs from farm conservation practices. An intensively managed rotational grazing system for beef and dairy operations is an example of a conservation management strategy with potential for economic pay off.

1.1.1 Conventional versus Rotational Grazing Systems

The predominant type of cattle grazing management system currently in use in Virginia can be characterized as continuous grazing of animals on a single field. In this study, such a management system is defined as a *conventional* system. General characteristics of a conventional grazing system usually include a single water source such as a stream, sporadic and inconsistent pasture rest periods, and inconsistent manure spreading. An alternative grazing management system for cattle operations in Virginia is an intensively managed rotational system, which is identified as a *rotational* system in this study. The objective of a rotational system is to increase production or utilization per unit area or production per animal through a relative increase in stocking rates, forage utilization and labor resources (Groover, 2001). Characteristics of a rotational grazing system include multiple, smaller fields (called paddocks) for rotation of livestock, management-dependent forage rest periods, better water distribution within paddocks, and more investment in structural capital such as fencing and watering systems (Faulkner, 2000).

Rotational grazing systems have the potential to reduce per unit purchased feed, veterinary, and mechanical capital costs such as haying equipment compared to conventional systems. A number of studies conducted on the viability of rotational grazing in the dairy industry have suggested that, if managed properly, under certain circumstances farms with rotational grazing systems can be as, or possibly more, profitable than similar farms using a conventional system despite less production (Knoblauch et al., 1999, Conneman et al, 1998, Jackson-Smith et al., 1996, Benson, 1997, King, 1997, and Groover, 2001). Few such studies have been done for the beef industry, but those available suggest that rotational grazing systems can increase profitability for beef operations (Faulkner, 2000, Fales et al, 1995, Phillip et al, 2001).

Rotational grazing systems may also improve environmental quality in a number of areas. In riparian corridors and sensitive environmental areas, rotational grazing leads to increased water holding capacity, ecosystem stability, and cation exchange while reducing sheet and gully erosion (Gerrish, 1991). Barnes, Miller, and Nelson (1995) state that there are three major ecological benefits of forage-based systems such as rotational grazing: (1) nutrient cycling and storage in pools to minimize nutrient loss, (2) protection and improvement of the hydrologic cycle, and (3) improvement and support of diverse population dynamics of soil and plant organisms. The division of pasture into paddocks improves water quality by controlling livestock access to streams, reducing livestock damage to streams and stream banks (Groover, 2001). Also, rotational grazing can reduce nutrient leaching and sediment runoff from eroded pastures around shade, watering, and supplemental feeding areas.

Despite the many perceived benefits, intensive rotational grazing has not been widely adopted. There are a number of barriers to entering into a rotational grazing system. The first of these is that there is a relatively large structural capital investment required to convert a conventional grazing system into a rotational grazing system since many of the capital investments in a conventional system are fixed and have low salvage values. This makes the marginal capital costs of conversion as high or nearly as high as simply starting with a rotational system from the outset. To subdivide larger pastures into smaller paddocks, farmers must increase the number of cross fences, provide direct access to water in each paddock, and often upgrade cow-lanes to accommodate the increased animal traffic. This means that there is need for a more sophisticated animal handling and watering system than under a conventional system (Faulkner, 2000).

The rotational grazing system also requires increased day-to-day animal management. Managers of rotational grazing systems need to have sound observation skills and pay greater attention to the changing conditions of pasture and livestock than in a conventional system (Faulkner, 2000). The added management time has an associated cost. Much of this increased time cost is due to the fact that decreased machinery investment is replaced by field and observation labor (Frank et al, 1995). This labor may be used in moving the livestock from one paddock to another or for increased fence or pasture maintenance. These time costs can be substantial, especially for part time farmers. In addition, rotational grazing systems can lead to reduced demand for on-farm mechanically harvested forages making much of the current machinery and equipment complement redundant. However, capital investment in machinery and equipment cannot be readily disposed of to offset or support new investment, thus slowing the adoption of rotational grazing systems.

Another barrier to the widespread adoption of rotational grazing systems is social ideology. This is the idea that social pressure will hamper the acceptance of new institutions and/or technologies because they are not the social norm for a region (Hayami and Ruttan, 1985). Since conventional systems are what have been done for generations, the consensus until proven otherwise is that these systems are superior.

1.1.2 Greenhouse Gas Reduction Services

In addition to the variety of environmental benefits mentioned above, intensive rotational grazing may also reduce farm-level GHG emissions, primarily carbon dioxide, nitrous oxide, and methane. Rotational grazing may reduce net carbon dioxide emissions and nitrous oxide emissions by improving forage productivity. Pastures under rotational grazing systems remain longer in the high growth stage (phase two of growth), thus increasing soil carbon sequestration potential and nitrogen utilization (Pratt, 1993). Because of better manure distribution and better grass health, rotational grazing also reduces the use of chemical nutrient inputs. Animals also benefit from rotational grazing, since plants remain in a more vegetative/nutritious state which improves the quality of the total farm forage production over continuous grazing systems. This allows for greater digestibility of the forage, thus reducing the amount of methane created during rumen methanogenesis (Van Nevel and Demeyer, 1996).

While the magnitude of these GHG reductions is only now being investigated for rotational grazing systems, opportunities may exist for farmers to receive financial compensation for reducing GHG emissions. The compensation may come in the form of government-administered cost share programs or market exchange of GHG credits. GHG credits are units of carbon or carbon equivalent which can be bought and sold in a market environment. Faulkner and Stephenson (2001, p. 3) succinctly state how such a market would emerge:

> A carbon market is created when private industries, like electric utilities, face mandatory limits on the amount of GHGs they emit. A discharger may not exceed this limit unless it could buy an equivalent reduction from another party. If, for example, a utility company could buy the carbon sequestered on farms at a lower cost than investing in the technology to reduce its emissions, it would buy the sequestered carbon. The cost attached to discharging GHGs creates incentives to reduce emissions or to find and trade with low cost sources of carbon reduction while meeting the national GHG cap.

The additional financial compensation from entering such a market could, depending on the amount, provide additional financial incentives to adopt intensive rotational grazing systems.

The potential financial contribution to farm income from GHG reduction services depends on the total reduction in GHG emissions achieved through adoption of rotational grazing (in tons) and the payment per ton. GHG reductions for a particular farm are calculated by estimating GHG emissions for some reference condition referred to as the baseline (GHG emissions without rotational grazing) and subtracting GHG emissions released with rotational grazing. Examples of such a baseline would be a historical baseline, which would be the emissions of the farm prior to adoption of a rotational grazing system, the creation of a model of an alternate system for the farm, or possibly the creation of a regional performance standard. Currently, calculating GHG reductions is difficult because there are no established guidelines or reference condition for identifying baseline emissions. Also, there is no metric, or set unit of account, for which the measurement of GHG reductions should take place. This measurement would be used to determine the additionality, or amount of change, between the current farm situation and the baseline. For example, GHG emissions can be calculated in terms of total emissions per unit of land (or per management entity). Using a land-based metric, additionality would be calculated on tons per acre of land basis. Alternatively, GHG emissions could be calculated per unit of product. Here, additionality would be calculated as the difference in emissions per unit of product times the number of units of product after instituting the infrastructure and management changes. In addition to the difficulties provided by the lack of guidelines for the baseline and metric, the price paid per ton of GHG emissions reduced is largely speculative since market development and cost share programs are in their infancy.

1.2 Problem Statement

From the perspective of beef and dairy cattle farmers, policy makers, and program managers, conversion to a rotational grazing system is a relatively large investment of both time and resources without specific farm-level evidence that there will be returns to conversions. This is due to a paucity of information on the subject, as studies on the profitability of rotational grazing systems are not directly transferable to other regions due to differences in growing seasons and adapted forages. The same can be said for GHG sequestration studies. Thus, there is currently a need for more information on the profitability of rotational grazing systems in Virginia. Such a need includes not only the costs and revenues of a rotational grazing system versus a conventional grazing system, but also a need for more information on how much additional income could be gained from a GHG payment scheme and how farms would be affected by the returns from such a scheme. Included in this informational gap is the lack of knowledge about how potential baseline definitions will change potential carbon reduction payments for the farmers and influence their decisions to convert to rotational grazing. It is this information that is necessary for the calculations of returns from GHG reduction payment schemes. If these informational gaps are filled, farmers, program managers, and policymakers will have a greater base of knowledge on which to draw and will be able to make more informed decisions about the conversion to rotational grazing and possible designs for GHG trading programs.

1.3 Objectives

This research is designed to estimate potential financial returns from conversion to rotational grazing and the sale of GHG credits by Virginia beef and dairy farms. Specific objectives of the research are:

- To estimate the net change in the profitability of fixed resources from conversion to rotational grazing using a partial budget framework; and
- To determine the contributions GHG reduction services can make to the profitability of beef and dairy operations given different assumptions of baselines and metrics for calculating changes in GHG emissions.

1.4 Organization of Thesis

Chapter 2 will include the empirical framework of the study, including an in-depth discussion of conventional versus rotational grazing and profitability of the two systems, as well as a discussion of the GHGs which will be examined and the definition of the baselines and metrics which will be used in the examination. Chapter 3 will discuss the empirical procedures used to carry out the study; including discussions of the case study farms, cost-of-production budgets, and how the profitability and GHG changes are calculated. Chapter 4 describes the results of the study, including examination of changes in profitability and additionality under the selected baselines and metrics for each case study farm. Chapter 5 summarizes findings from the study, policy implications, and areas where future research may be needed.

CHAPTER 2: EMPIRICAL FRAMEWORK

Chapter 1 presented a brief introduction to both conventional and rotational grazing systems and the potential GHG reductions from a conversion to rotational grazing. This chapter details these topics, with an emphasis on potential profitability changes between conventional and rotational grazing systems, including an explanation of on-farm GHG sources. Chapter 2 will conclude with an explanation of potential measurement issues when calculating changes in farm-level GHGs.

2.1 Aspects of Grazing

Forage Quality: Forage quality is important to grazing systems because it determines the amount of total digestible nutrition (TDN) the animals receive. Quality forages reflected in the nutrition value allow the animals to grow, reproduce, and produce marketable products. If forages are of poor quality, then the farm operator is forced either to buy and sell cattle seasonally to balance the stocking rate and carrying capacity of the farm or to supplement the farm-grown forages with purchased feeds (Faulkner, 2000, Pratt, 1993). Forcing seasonal buying and selling decisions can be impractical, inefficient, and can limit the farm operator's options and opportunities to profitably manage the farm business. Purchasing feeds to supplement poor quality forages allows the farm operator to keep animals year-round, but can be costly and reduce the farm's profitability.

A conventional grazing system has a greater chance for reduced pasture forage quality than a rotational grazing system. This is due to the fact that "cows are gourmets" and graze selectively, eating the best plants and plant parts first as these are the most nutritious (Pratt, 1993). In single-field conventional systems, cows will graze regrowth, or new growth of plants already grazed, as soon as it is available because this regrowth is highly nutritious. However, there is often not enough of the regrowth to provide adequate nutrition for all animals and herd performance may decline as animals graze less nutritious plants. A rotational grazing system reduces the incidence of regrazing because the animals are rotated to another paddock to feed on fresher, higher quality forage before regrazing occurs. This allows for the animals on average to graze high quality forages throughout the growing season (Pratt, 1993).

The potential benefits of rotational grazing, higher quality and quantities of forages, can lead to increased revenues and reduced costs from adoption of rotational grazing. Revenues may increase because of possible higher productivity under rotational grazing when compared to a conventional system due to greater production of higher quality forages. Production costs may also decline under a rotational system when compared to a conventional system because the higher quality and quantity of forages can reduce the amount of purchased feed needed for supplement or total animal carrying capacity can be increased (Fales et al, 1995).

Harvest Efficiency: Harvest efficiency is the amount of the standing forage crop which is harvested (grazed) by the animals. If the harvest efficiency of the grazing land is too low, it can result in the selective grazing and regrazing of certain spots by the animal and a reduction in overall forage quality, as discussed above (Faulkner, 2000). Low harvest efficiency can also lead to poor manure distribution, an increase in the prevalence of weeds in the pasture, and the need for machine harvesting for hay or frequent clippings. However, if harvest efficiency is too high, overgrazing occurs. Overgrazing is detrimental to forage stand longevity and productivity with the possibility of reduced herd health and performance (Faulkner, 2000, Fales et al, 1995).

Management of conventional grazing systems to achieve optimal harvest efficiency is difficult as herd size is either too small or too large as the quality and quantity of forages change during the grazing season. Rotational grazing has the potential to alleviate this problem because harvest efficiency is managed via the grazing system design with animal numbers and paddock size regulated to provide adequate nutrition for each animal group (Faulkner, 2000).

Harvest efficiency under rotational grazing presents the potential for both increased revenues and decreased costs when compared to a conventional grazing system. There are two potential increased costs when harvest efficiency is operating at a non-optimal level. First, poor manure distribution over the pasture requires additional fertilizer applications to compensate for excess deposition of nutrients around shade and water sources. Second, increased incidence of weeds in the pasture require use of chemical and mechanical control, leading to potentially increased costs. When harvest efficiency exceeds optimal levels (overgrazing) the health of the animals (loss of weight or reduced rates of gain) and pastures (weed invasion and stand survival) can decline. The impacts of overgrazing are higher costs for purchased feeds, lower product sales, and/or increased incidence of pasture renovations (Faulkner, 2000, Pratt, 1993, Fales et al, 1995).

<u>Water Supply</u>: Water is the most important animal nutrient and distance animals must travel to water plays an important role in animal performance. The further an animal must travel to water the less time and energy there is for grazing to support animal growth and maintenance. Distance to water may also affect the quality of forages and harvest efficiency, as areas of pasture located farther away from water sources will be less utilized, thus moving the plants out of optimum growth stage and lessening their TDN level as well as creating an area of low harvest efficiency (Faulkner, 2000, Beetz, 2002). Location of water sources can affect manure distribution patterns (Beetz, 2002, Faulkner, 2000). Direct access to streams may also increase the potential for footrot (Faulkner, 2000).

Many conventional systems have relatively few water sources, with some of these sources being direct access to streams. In contrast, rotational grazing systems provide a greater number of water sources and higher quality water to each of the paddocks limiting the distance animals must travel. Improved water distribution allows for better forage utilization and manure distribution under rotational grazing than conventional grazing (Faulkner, 2000).

Both potential revenue and cost changes can be seen when comparing animal watering systems under conventional and rotational systems. Revenues have the potential to increase as increased availability of water leads to better forage utilization, improved harvest efficiency and less energy requirements for travel time (Faulkner, 2000, Boyer, 2002, Goldwasser, 2002, Dalton, 2002). Conventional and rotational systems have unique costs. Potential increased costs for conventional versus rotational systems include potential increased medical costs associated with decreased herd health from stream access and increased fertilization costs from inconsistent manure spreading, as was mentioned above (Faulkner, 2000, Dalton, 2002, Beetz, 2002). A rotational grazing system has the additional costs of building and maintaining a more sophisticated watering system (Faulkner, 2000, Dalton, 2002, Goldwasser, 2002, Beetz, 2002). Such a cost may offset the potential reduction in costs associated with conventional grazing.

Pasture Rest Periods: Rotational grazing systems rely on pasture rest periods between grazing to allow plants to regenerate without immediately being regrazed by animals. The grazing and rest periods are managed by species and season to maintain plants in an actively growing state providing high quality and quantity forages (Faulkner, 2000, Fales et al, 1995).

Conventional systems have the potential to have inconsistent pasture rest periods, as animals may choose to graze and regraze certain areas, as discussed above, without grazing other areas of the pasture. Rotational grazing has the potential to reduce these inconsistencies, as pasture rest periods are part of the management strategy (Faulkner, 2000, Fales et al, 1995).

Labor Costs: Labor costs include labor to collect and handle animals for sale, artificial insemination, pregnancy checking, or treatment of health concerns (Faulkner, 2000). Labor costs under a rotational system have the potential to be lower than under a conventional system. However, the literature is inconclusive. Animals under a rotational system are trained to move to new paddocks and are easier to handle and require less total labor. Two case study farm operators suggest their labor demands declined with adoption (Boyer, 2002, Goldwasser, 2002).

2.2 Economic Studies

A number of different studies have been done on the profitability of grazing systems. Most of these studies are on pasture-based dairy production, with only a few studies undertaken thus far on pasture-based beef production. Early studies were based mainly on a small number of farms in the northeast U.S. (Emmick and Toomer, 1991, Parker et al, 1991). These studies focused on cost comparisons and demonstrated that farmers adopting pasture-based dairy production could, in a short time frame and under ideal management, generate reasonable farm incomes. More recently, the New York Farm Management Business Summary (Knoblauch et al, 1999, 2002, and Conneman et al, 1997) showed that grazing dairies can be as profitable or unprofitable as conventional dairy operations. A study undertaken in Wisconsin in 1991-92 reported that rotational grazing produced net income of an average of $64 more per cow, despite the fact that cows in a conventional dairy produced 7% more milk (Rust et al, 1995). Lower costs of feeding, facilities, equipment, and labor were the cause of the increase. A later survey of conventional- and rotational-based Wisconsin dairy farms reported that the rotational grazing farms had lower levels of net farm income, but higher economic returns to equity (Jackson-Smith et al., 1996). This conclusion excluded the cost of family labor.

Similarly, rotationally grazed beef operations can be just as, if not more, profitable than conventionally grazed beef operations. A Canadian study demonstrated that rotational cow-calf production had little change in animal performance and substantial benefit in both efficiency of land use and economic performance (Phillip et al, 2001). D'Souza et al (1990) demonstrated that the extended grazing periods associated with rotational grazing can be more profitable for cow/calf farms than traditional conventional grazing systems. A Virginia study of both stocker and cow/calf operations demonstrated that the additional revenues and reduced costs associated with rotational grazing systems have the potential to outweigh the costs of conversion from a conventional to a rotational grazing system (Faulkner, 2000).

2.3 On-Farm GHGs

Rotational grazing has the potential to reduce GHG emissions and provide financial returns to farmers through the sale of GHG emission reduction credits. The aspects of rotational grazing discussed above allow this type of management system to have potential GHG benefits as well as potential financial ones. The main GHGs of interest to livestock producers are methane, nitrous oxide, and carbon dioxide. Farmers who demonstrate reductions in these GHGs create possible GHG credits which can be sold as an alternate source of farm income.

Methane: Methane is emitted from two sources in livestock production, enteric fermentation and the breakdown of animal wastes (IPCC, 2001). Enteric fermentation is the process of microbial digestion of forage in the rumen of cows (Van Nevel and Demeyer, 1996). Microbes in the rumen break down the ingested forage allowing animals to obtain nutrients from plants not readily digestible by monogastrics. Animal-emitted methane is a by-product of this process. Rotational grazing has the potential to reduce methane emissions from the animal by increasing quality of the forage consumed (Faulkner, 2000, Pratt, 1993, Fales et al, 1995). This increase in quality will reduce the amount of enteric fermentation, since there will be less microbial breakdown needed per unit of nutrient. Rotational grazing also reduces the distance that animals have to travel for food and water, reducing total energy required for maintenance.

Methane emitted from the breakdown of animal wastes is a similar process to enteric fermentation. Microbes break down the collected animal waste, and emit methane as a by-product of this breakdown (IPCC, 2001). Increased forage quality also helps to alleviate some of the methane emission, since higher forage quality leads to better digestion and less waste emitted from the animal.

Nitrous Oxide: There are three main sources of nitrous oxide emissions. First, nitrous oxide is emitted from the breakdown of animal wastes, second by direct nitrous oxide emissions from agricultural soils, and third indirect nitrous oxide emissions from agricultural soils (IPCC, 2001). Nitrous oxide emitted from the breakdown of animal wastes includes only the nitrous oxide emitted during the storage and treatment of animal wastes. Emissions from manure applied to the land as fertilizer is included in the direct nitrous oxide emitted from agricultural soils.

Nitrous oxide is emitted from the breakdown of animal wastes in much the same way as methane (IPCC, 2001). Microbes break down the animal wastes and nitrous oxide is emitted as a by-product. As with methane, a higher nutrient content in the forage can reduce the amount of waste, and, thus, the amount of breakdown.

Direct nitrous oxide emitted from agricultural soils is a result of natural microbial nitrification and denitrification processes (IPCC, 2001). The agricultural activities of fertilization and manure spreading add nitrogen to soils, increasing the amount of nitrogen available for these processes, and ultimately the amount of nitrous oxide emitted. Rotational grazing has the potential to reduce direct nitrous oxide emissions from agricultural soils by increasing forage quality and stand health. Improved forage quality improves nutrient cycling and storage in soil pools (Barnes et al, 1995). Improved nutrient cycling helps to minimize nutrient loss. This reduces the need for additional fertilization of grazing lands. This reduction would reduce the amount of nitrogen available for nitrification and denitrification processes, reducing nitrous oxide emissions.

Agricultural soils emit indirect nitrous oxide from two sources. The first of these is the leaching and runoff of applied nitrogen into aquatic systems. The second is the atmospheric volatilization and subsequent deposition of applied nitrogen which fertilizes soils and waters (IPCC, 2001). Each of these indirect sources produces nitrous oxide by enhancing biogenic nitrous oxide formation. Rotational grazing has the potential to decrease indirect nitrous oxide emissions from agricultural soils in the same fashion as direct nitrous oxide emissions. The increased forage quality and stand health reduce the need for nitrogen application (Barnes et al, 1995), thus reducing the amount of nitrogen which could leach or run off into waterways or volatilize and be redeposited.

<u>Carbon Dioxide</u>: Carbon dioxide is used in the photosynthetic processes allowing plants to create energy for maintenance and reproduction (Solomon et al, 1999). Carbon dioxide is taken in by the leaves of plants and is converted to carbon and oxygen. The plant transfers the carbon to its roots, while the oxygen is released as a by-product of the process. Carbon is then expelled by the roots into the soil and is sequestered rather than emitted for the farm (Solomon et al, 1999, Franzlubbers and Stuedemann, 2002, Schuman et al, 2001). Rotational grazing enhances the sequestration process by keeping the forage stand closer to its optimal growth stage (Pratt, 1993). Rotation grazed forages lead to higher total output yielding an increased potential amount of carbon sequestered.

Currently, most studies on GHG reduction in rotational grazing systems only address the increase in carbon sequestered (Franzluebbers and Stuedemann, 2002, Schuman et al, 2001, Campbell et al, 2001, Kimble et al, 2001). Each of these studies conclude that there is the potential for an increase in the amount of carbon sequestered by a rotational grazing system, but both the degree of sequestration and the level of measurement vary. Some studies, such as Franzluebbers and Stuedemann (2002) and Schuman et al (2001) include all carbon in the plants and root systems as well as in the soils, whereas Campbell et al (2001) and Kimble et al (2001) only include the carbon in the soil itself. Only a very few studies have been found which evaluated reductions in methane and nitrous oxide (Wittenberg and Boadi, 2001). These studies conclude that there is the potential for decreases in methane and nitrous oxide emissions from rotational grazing, but no rates of reduction are given.

GHG reductions from rotational grazing have the potential to increase income for the farm operator, but for this to take place, the change in on-farm GHG emissions must be quantified and measured. Issues associated with measurement are discussed below.

2.4 Measurement of Changes in GHG Emissions

Identifying the changes in GHG emissions from a change in farm operations requires comparing the current farm situation (with rotational grazing) against a reference condition called baseline. The net change in GHG emissions -- the difference between the farm operating under rotational grazing and the baseline -- is called additionality. Thus, it is assumed that the farmer would receive payment only for the additional GHG reductions made beyond the reference condition.

Currently, there exists no one specific standard by which baselines, and consequently additionality, are defined, for agriculture and forestry projects, nor for projects in the energy and transportation sectors (Chomitz, 2002; Laurikka, 2002; Moura-Costa and Stuart, 1999; Tipper and De Jong, 1998). While there exists no clear standard or means of defining baselines for land-based and sequestration projects (activities without explicit legal requirements to control discharges), three general approaches may be used for defining the reference condition – historical, business-as-usual, and a sectoral performance baseline.

An *historical baseline* would estimate GHG emissions from a particular farm at some predetermined historical date – either at some fixed reference year (e.g. 1990) or the time period just prior to the adoption of the GHG reducing practice. In this study, the historical baseline is taken as the time period just prior to the adoption of the rotational grazing system. Baselines could be established based on alternative developments that may occur at the farm level in the absence of the GHG-reducing practice. Such a reference condition, called here a "business-as-usual" or *BAU baseline,* is defined by how much GHG emissions are released from the farm operations in absence of the GHG-reducing practice (the BAU could be called a "counter-factual" baseline). The BAU baseline need not be the same as the historical baseline because farm operations may change over time. Finally, baselines could be defined with respect to a regional or industry specific performance standard, or *a sectoral performance baseline.* A sectoral baseline is analogous to establishing a minimum performance standard for particular industries or technologies. For example, air and water regulatory programs define minimum emission standards based on "best available control technology" (BACT) or reasonably achieved control technology (RACT). This study develops a regional GHG performance standard for well managed conventional beef and dairy grazing operations in a mid-Atlantic climatic zone.

Each of the three possible reference conditions can be calculated using different GHG accounting metrics (Groenenberg and Blok, 2002). At least two different accounting metrics could be use to calculate GHG emissions. GHG emissions can be calculated in terms of total emissions per unit of land (or per management entity). For instance, if a 200-acre farm implemented a system of intensive rotational grazing on 75 acres, total GHG emissions would be estimated for the entire land base under the control of the farm operator. Using a land-based metric, additionality would be calculated on tons per acre of land basis. Alternatively, GHG emissions could be calculated per unit of product. For instance, a beef cattle operation may generate X pounds GHG per animal unit (or unit of product) produced as a baseline and Y pounds of GHG per animal unit with intensive rotational grazing. Additionality could be calculated as the difference in emissions per animal unit times the number of units of product after instituting the infrastructure and management changes.

Rotational grazing appears to have the potential to both increase production profitability for cattle farm operations and offer an additional stream of income for these operations through payment for GHG reductions. A test of these hypotheses will be undertaken based on three case study farms in the mid Atlantic region. Chapter 3 lays out the procedures for how this test will be carried out.

CHAPTER 3: PROCEDURES

This chapter describes the procedures used to carry out the study. These procedures include selection and description of a case study farm for each of the three major classes of cattle operation found in the mid-Atlantic: cow-calf, stocker, and dairy; creation of cost-of-production budgets for each reference condition for each of the selected case study farms; description of the calculation of GHG emissions for each baseline; and description of the calculation of potential net returns from GHG reduction services.

3.1 Case Study Farms

This study examines three case study farms representative of the three major types of cattle operations in the mid-Atlantic region: cow-calf, stocker, and dairy. The farms were selected because they had converted from a conventional single-field grazing system to a multi-paddock rotational grazing system and had records of operation under both systems. A description of each case study farm is presented below.

3.1.1 Cow-Calf Case Study Farm

The cow-calf case study farm is located in Grayson County, part of the Ridges and Valleys Region of Virginia. This farm is a part-time operation of 50 acres with many characteristics typical of cow-calf farms in this area. In 1987 the owner converted the farm from conventional to rotational grazing. At this time the 50 acres was divided into seven paddocks and the number of spring-fed watering troughs was increased from one to three. These changes allowed the number of cows on the farm to be increased from 23 cows calving in February and March and one bull to 35 cows, half calving in November and December and half calving in February and March, and one bull. Table 3.1 gives a summary of the pertinent information regarding this farm under each baseline scenario.

Table 3.1: Summary of the Three Reference Conditions for the Cow-Calf Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Cows	23	23	35 with the increase due to rotational grazing
% Calf Crop	85	85	85
% Replacements Kept as a % of Cow Herd	15	15	15
% Annual Culling Rate	15	15	15
% Annual Death Loss	1	1	1
Number of Animals Sold	9.78 steers, 8.17 heifers, 1.38 cull cows, 0.23 cull bulls	4.89 fall-born steers, 4.08 fall-born heifers, 4.89 spring-born steers, 4.08 spring-born heifers, 1.38 cull cows, 0.23 cull bulls	7.44 fall-born steers, 6.21 fall-born heifers, 7.44 spring-born steers, 6.21 spring-born heifers, 2.10 cull cows, 0.35 cull bulls
Average weight of sold calves (kg)	206 kg, selling only spring calves	241 kg with changes due to improved genetics	275 kg with changes due to improved genetics and rotational grazing

Table 3.1 (Cont.)			
Item	**Before Rotational Grazing**[a]	**Without Rotational Grazing**[b]	**With Rotational Grazing**[c]
Average weight of sold cull animals (kg)	538 kg	538 kg	538 kg
Structural Improvements	None	Improved watering system with 2 additional pre-cast concrete watering troughs	Improved watering system with 2 additional pre-cast concrete watering troughs and fences to divide pasture into seven paddocks

[a] This condition is the level at which the case study farm was operating before converting to a rotational grazing system.
[b] This condition is "counter-factual". It is an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This condition is the level at which the farm currently operates.

This farm was chosen because it is a good illustration of a well-managed rotational grazing system and extensive data has been collected prior to this study (Faulkner and Boyer, 2000). The early adoption of the systems allowed time to gather information on observed changes from conventional to an intensive rotational grazing system. Furthermore Faulkner and Boyer (2000) collected substantial economic and environmental data documenting conditions that existed prior to the conversion. Farm interviews and review of technical records including soil maps were used to gather information on the present rotational grazing system.

3.1.2 Stocker Case Study Farm

The stocker case study farm chosen is located in Carroll County, on the east slope of the Blue Ridge Mountains of Virginia. The farm is a full-time stocker operation of 77 acres with characteristics typical of farms in this area. The owner-operator has other farm enterprises on leased land not adjacent to the case study farm. These enterprises will not be included in this study. The owner slowly converted his farm from a conventional to a rotational system over seven years beginning in 1980. After the rotational grazing system was fully in place, the farm had 26 paddocks and 6 watering troughs. Before converting to rotational grazing, the farm had both a 46-animal stocker herd and a 14-animal cow-calf herd. The cow-calf herd was phased out in 1984, and the operation became solely stocker. For this study, the farm is considered to be stocker only. The cow-calf herd was converted to 33 stockers to include the total animal weight of the farm for the *before* rotational grazing reference condition in this analysis. These 33 stockers are a comparable total weight to the cow-calf herd the farm had. Changing to rotational grazing allowed the number of stockers to be increased from a single herd of 79 bought in March and sold in August to a total of 370, with 250 head bought in September and sold in December and 120 head bought in March and sold in August. Tables 3.2 and 3.3 present a summary of the pertinent information for each of these herds.

Table 3.2: Summary of the Three Reference Conditions for the Fall Herd of the Stocker Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Steers	n/a	250	250
Days On Feed	n/a	76	30
Average Daily Gain on Feed (kg)	n/a	0.57	0.91
Hay Purchased (kg)	n/a	233,104	0
Corn Grain Purchased (kg)	n/a	70,946	0
Other Feed (kg)[d]	n/a	0	61,689
Days On Pasture/Hay	n/a	14	60
Average Daily Gain on Pasture/Hay (kg)	n/a	0.11	.91
Purchase Weight (kg)	n/a	159	136
% Death Loss	n/a	3	1 because sickness within the herd could be more easily controlled with rotational grazing
Selling Weight (kg)[e]	n/a	200	213
Number of Animals Sold	n/a	242.50	247.50
Structural Improvements	These are included in the spring budget and are listed in Table 3.3		

[a] This condition is the level at which the case study farm was operating before converting to a rotational grazing system. There is no fall group for the farm under this condition, so no analysis is presented for it.
[b] This condition is "counter-factual". It is an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This condition is the level at which the farm currently operates.
[d] Other Feed is pelleted corn gluten and pelleted soy hulls
[e] Adjusted for a 2% shrink rate

Table 3.3: Summary of the Three Reference Conditions for the Spring Herd of the Stocker Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Steers	79	120	120
Days On Feed	45	45	30 The farm is able to use less feed due to increased forage quality of rotational grazing
Average Daily Gain on Feed (kg)	0.50	0.50	0.91
Hay Purchased (kg)	18,226	27,688	0
Corn Grain Purchased (kg)	5,665	8,611	0
Other Feed (kg)[d]	0	0	5,371
Days On Pasture/Hay	123	123	138
Average Daily Gain on Pasture/Hay (kg)	0.68	0.68	0.91
Purchase Weight (kg)	181	193	193

Table 3.3 (Cont.)			
Item	**Before Rotational Grazing**[a]	**Without Rotational Grazing**[b]	**With Rotational Grazing**[c]
% Death Loss	2	2	1 because sickness within the herd could be more easily controlled with rotational grazing
Selling Weight (kg)[e]	282	293	338
Number of Animals Sold	77.42	117.60	118.80
Structural Improvements	None	Added 6 watering troughs and a ram pump	Added 6 watering troughs and a ram pump as well as permanent electric fence to divide 3 separate pastures into 22 paddocks

[a] This condition is the level at which the case study farm was operating before converting to a rotational grazing system. Before converting to a rotational grazing system, the stocker case study farm did not have a fall stocker herd. The farm instead had a cow-calf herd. This herd is not examined since a more complete cow-calf case study farm is presented above.
[b] This condition is "counter-factual". It is an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This condition is the level at which the farm currently operates.
[d] Other Feed is pelleted corn gluten and pelleted soy hulls
[e] Adjusted for a 2% shrink rate

This stocker farm was chosen because it is a good illustration of a well-managed rotational grazing system and extensive data has been collected prior to this study (Faulkner et al., 2000a). The early adoption of the systems allowed time to gather information on observed changes from conventional to an intensive rotational grazing system. Furthermore Faulkner et al. (2000a) collected substantial economic and environmental data documenting conditions that existed prior to the conversion. Farm interviews and review of technical records including soil maps were used to gather information on the present rotational grazing system.

3.1.3 Dairy Case Study Farm

The dairy case study farm chosen is located in Carroll County, Virginia. This is a full-time dairy operation of 40 acres with characteristics typical of dairy farms in this area. The owner converted from conventional to rotational grazing in 1998. At this time, the 40 acres of pasture were divided into 7 permanent paddocks. Polywire is also used for smaller strip grazing units. These two fencing systems allow for approximately 30 paddocks to be in use at any time. A new underground watering system with 5 freeze-proof troughs and portable 40-gallon polytubs was also added to the farm during conversion, replacing direct access to streams as the animal water source. Also at this time, a travel lane was installed for the animals, and the owner began to give the animals bST injections and joined the DHIA record keeping system. These changes allowed the number of animals on the farm to increase from 54 cows and one bull for clean-up to 70 cows and one bull for clean-up. Table 3.4 presents a summary of the pertinent information for each of the baseline scenarios for the farm.

Table 3.4: Summary of the Three Reference Conditions for the Dairy Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Cows	54	70	70
Average Milk Production (kg/yr/cow)	8,013	9,526	8,845
Silage Fed (kg)	582,428	754,999	472,050
Silage Purchased (kg)[d]	116,457	302,830	-2,749
Hay Fed (kg)	108,395	140,513	47,208
Hay Purchased (kg)	113,817	147,537	49,569
SBOM 48% (kg)	30,472	39,499	39,499
Summer Supplement Purchased (kg)	74,707	96,843	96,843
Winter Supplement Purchased (kg)	74,707	96,843	96,843
Cull Cows Sold	5.40	7	8.40
Bull Calves Sold	25.65	33.25	33.25
Cull Heifers Sold	10	10	10
Structural Changes	None	Added travel lane and some additional watering facilities, as well as beginning bST injections and joining the DHIA record keeping program	Added travel lane, additional watering facilities, and added fencing (both permanent and mobile) as well as beginning bST injections and joining the DHIA record keeping program

[a] This condition is the level at which the case study farm was operating before converting to a rotational grazing system.
[b] This condition is "counter-factual". It is an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This condition is the level at which the farm currently operates.
[d] It is assumed that there is 12.14 hectares (30 acres) of corn grown on the case study farm. This corn land produces 512,565 kg of corn silage annually. The difference between the amount fed and the amount purchased is due to harvest, storage, and feeding losses. Under the *with rotational grazing* scenario, the farm produces more corn silage than it needs, so the extra silage is assumed to be sold. Therefore, the amount of corn silage purchased is negative.

This dairy farm was chosen because it is a good illustration of a well-managed rotational grazing system and extensive data has been collected prior to this study (Faulkner et al., 2000b). The early adoption of the systems allowed time to gather information on observed changes from conventional to an intensive rotational grazing system. Furthermore Faulkner et al. (2000b) collected substantial economic and environmental data documenting conditions that existed prior to the conversion. Farm interviews and review of technical records including soil maps were used to gather information on the present rotational grazing system.

3.2 Cost-of-Production Budgets

Partial budgets for each of the case study farms were developed to examine the changes in net income from conversion to rotational grazing, selling of GHG credits, and comparison to each of the baselines. The partial budget comparisons are based on Virginia Cooperative Extension Farm Management Cost-of-Production Budgets and the Economics Section of the Virginia Forage and Grasslands Council Grazing Handbook.

3.2.1 Cow-Calf Case Study Farm

Changes in net returns from the adoption of rotational grazing for the cow-calf case study farm are calculated based on two perspectives. First, the partial farm budgets are computed by comparing the historical practices (*before rotational grazing*) against current practices (*with rotational grazing*). For this case study, the historical period is characterized by a lower stocking rate and less calf growth. Thus, the value of beef and cull cows sold is expected to increase. Non-forage costs such as salt and mineral and hauling and marketing are expected to increase, while vet and medicine costs are expected to decrease due to the more even manure spreading, reduced risk of endophyte poisoning, and reduced footrot. Replacement bull costs are not expected to change, nor are building and fence repair costs. Purchased feed costs and pasture maintenance costs are expected to fall because of the increase in forage quality under the current scenario. Annualized capital costs are expected to increase under the current scenario due to the additional fencing and improvements in the watering system.

Second, partial budgets are computed by comparing current practices with what behavior would likely occur if the farm operator remained under conventional management (*without rotational grazing*). This scenario assumes that the farm owner would improve the genetics of the herd and the watering system, but would not be able to increase the herd size because forage quality and quantity would limit stocking rates. Budget changes under conventional management are expected to be the same as those for the historical scenario except for the watering system, which is in place in the *without* scenario. Table 3.5 presents a summary of expected changes under each scenario.

Table 3.5: Summary of Farm Budget and Expected Cost or Revenue Changes in the Cow-Calf Case Study Farm[a]

Budget Category	Historical to Current	Without to Current
Revenues		
Kg of Beef Produced	+	+
Cull Cows	+	+
Non-Forage Variable Costs		
Salt and Mineral	+	+
Vet and Medicine	-	-
Replacement Bull	n/c	n/c
Hauling and Marketing	+	+
Building and Fence Repair	n/c	n/c
Forage Costs		
Forage Purchases	-	-
Pasture Maintenance	-	-

Table 3.5 (Cont.)		
Budget Category	**Historical to Current**	**Without to Current**
Capital Costs		
Fencing	+	+
Watering System	+	n/c

[a] A '+' indicates anticipated increase from the indicated baseline with rotational grazing, a '-' indicates a decrease, and 'nc' indicates no change expected.

3.2.2 Stocker Case Study Farm

Changes in net returns from the adoption of rotational grazing for the stocker case study farm are calculated based on two perspectives. First, the partial budgets are computed by comparing the historical practices (*before rotational grazing*) against current practices (*with rotational grazing*). The historical period for the stocker case study is characterized by a lower stocking rate and less calf growth. Thus, the value of beef sold is expected to increase under the current practices as compared to the historical practices. Acquirement costs are also expected to increase for the current scenario compared to the historical one due to the increase in the number of animals purchased. Non-forage variable costs such as mineral with Bovatec® (BOV) or Rumensin® (RUM), vet and medicine, supplies, hauling and marketing, and building and fence repair are all expected to increase due to the greater number of animals. Likewise, purchased feed and pasture maintenance costs should also increase because of the increase in animals. Annualized capital costs are assumed to increase due to the increased fencing and watering investment required for rotational grazing.

Second, partial budgets are computed by comparing current practices with what behavior would likely occur if the farm operator remained under conventional management (*without rotational grazing*). This study assumes that the farm operator would maintain the same number of animals in the without scenario as under the current scenario, but would increase the purchased feed inputs in the without scenario to support the animals. Also, the study assumes that the improved watering system would be in place. Here, the value of beef produced is expected to increase due to the higher quality forage available under rotational grazing. Acquirement costs should remain equal since the number of animals purchased is the same. Non-forage variable costs such as mineral with BOV or RUM, supplies, and building and fence repair are expected not to change, while vet and medicine costs are expected to decrease due to rotational grazing and hauling and marketing costs are expected to rise because of the higher weight per animal. Purchased feed and pasture maintenance costs should decrease from the higher quality of the forage. Annual capital costs should increase due to the addition of the cross fencing that creates the paddocks. Table 3.6 presents a summary of the expected changes under each scenario.

Table 3.6: Summary of Farm Budget and Expected Cost or Revenue Changes in the Stocker Case Study Farm[a]

Budget Category	Historical to Current	Without to Current
Revenues		
Kg of Beef Produced	+	+

Table 3.6 (Cont.)		
Budget Category	**Historical to Current**	**Without to Current**
Acquirement Costs		
Acquirement Costs	+	n/c
Variable Costs		
Mineral with BOV or RUM	+	n/c
Vet and Medicine	+	-
Supplies	+	n/c
Hauling and Marketing	+	+
Building and Fence Repair	+	n/c
Forage Costs		
Forage Purchases	+	-
Pasture Maintenance	+	-
Capital Costs		
Fencing	+	+
Watering System	+	n/c

[a] A '+' indicates anticipated increase from the indicated baseline with rotational grazing, a '-' indicates a decrease, and 'nc' indicates no change expected.

3.2.3 Dairy Case Study Farm

Changes in net returns from the adoption of rotational grazing for the dairy case study farm are calculated based on two perspectives. First, the partial farm budgets are computed by comparing the historical practices (*before rotational grazing*) against current practices (*with rotational grazing*). For the dairy case study farm, the historical period is characterized by a lower stocking rate and less milk production. Thus, the value of milk sold, value of bull calves sold, and value of cull animals sold are expected to increase. Non-forage variable costs such as summer and winter protein rations, minerals, milk replacers, calf growers, breeding, supplies, hauling and marketing milk and cull animals, building and fence repair for structures existing both before and after the change to rotational grazing, machinery, utilities and custom hire are all expected to rise because of the increase in the number of animals and milk production per animal. DHIA record keeping costs and bST injection costs also will increase since these costs were added after the change to rotational grazing. Vet and medicine costs are expected to decrease because of the travel lane and the rotational grazing system. Bull and hired labor costs are not expected to change. Purchased feed and pasture maintenance costs are expected to decrease because of the increase in forage quality. Annual capital costs are expected to increase due to the increased watering and fencing costs associated with rotational grazing.

Second, partial farm budgets are also computed by comparing current practices with what behavior would likely occur if the farm operator remained under conventional management (*without rotational grazing*). This study assumes that the farm operator would maintain the same number of animals in the without scenario as under the current scenario, but would have a higher level of milk production per animal. This increase is brought about because the study assumes that the farm would operate with the bST injections and the DHIA record keeping program. The study also assumes that the travel lane and improved watering system are in place in the without scenario. The value of milk sold is expected to decrease under the current scenario, while the value of cull animals is expected to increase and the value of bull calves is expected to stay the same. Non-forage variable costs are expected to stay the same for summer and winter protein rations, minerals, milk replacers, calf growers, breeding, bull for cleanup, supplies, bST, DHIA, building and fence repair for structures existing in both scenarios, machinery, utilities, custom hire, and hired labor. Vet and medicine costs are expected to decrease because of the conversion to rotational grazing, while hauling and marketing costs of milk should decrease due to the decrease in the amount of milk produced. Hauling and marketing costs of cull animals are expected to increase due to the increase in the number of cull animals. Purchased feed and pasture maintenance costs are expected to decrease due to increased forage quality. Annual capital costs are expected to increase due to the need for cross fencing to create paddocks. A summary of expected changes for each of the scenarios is presented in Table 3.7.

Table 3.7: Summary of Farm Budget and Expected Cost or Revenue Changes in the Dairy Case Study Farm[a]

Budget Category	Historical to Current	Without to Current
Revenues		
Kg of Milk Produced	+	-
Cull Animals Sold	+	+
Bull Calves Sold	+	n/c
Variable Costs		
Summer and Winter Protein	+	n/c
Minerals	+	n/c
Milk Replacers	+	n/c
Calf Growers	+	n/c
Breeding	+	n/c
Bull (Clean-up)	n/c	n/c
Vet and Medicine	-	-
Supplies	+	n/c
bST	+	n/c
DHIA	+	n/c
Milk Hauling and Marketing	+	-
Cull Hauling and Marketing	+	+
Building and Fence Repair	+	n/c
Machinery	+	n/c
Utilities	+	n/c
Custom Hire	+	n/c
Hired Labor	n/c	n/c
Forage Costs		
Forage Purchases	-	-
Pasture Maintenance	-	-
Capital Costs		
Fencing	+	+
Travel Lane	+	n/c
Watering System	+	n/c

[a] A '+' indicates anticipated increase from the indicated baseline with rotational grazing, a '-' indicates a decrease, and 'nc' indicates no change expected.

3.3 Selection of Baselines

There are currently no standard baseline conditions to base calculations of additionality for land-based sequestration projects. This study will use the three possible baseline scenarios described in Chapter 2. Each of these three baselines will be calculated using both a land-based metric and a product-based metric, presenting a total of six GHG additionality options. Table 3.8 presents a summary of these options. The land-based metric will examine GHG emissions for each farm. The product-based metric will examine per metric ton of product sold GHG emissions for each farm.

Table 3.8: Summary of the GHG Additionality Options Examined in this Study

	Unit of Account	
Baseline	*GHG per Farm Operation (land area)*	*GHG per unit of product*
Historical Baseline	$(GHG/farm)_{t=preadoption} - (GHG/farm)_{t=present}$	$(GHG/unit\ of\ output)_{t=preadoption} - (GHG/unit\ of\ output)_{t=present}$
Business-as-Usual Baseline	$(GHG/farm)_{bau} - (GHG/farm)_{present}$	$(GHG/unit\ of\ output)_{bau} - (GHG/unit\ of\ output)_{present}$
Performance Standard Baseline	$(GHG/farm)_{industry} - (GHG/farm)_{farm}$	$(GHG/unit\ of\ output)_{industry} - (GHG/unit\ of\ output)_{farm}$

3.3.1 Calculation of GHG Emissions for Each Baseline Scenario

The net changes in GHG emissions for each case study farm are calculated using the Pasture Land Management System (PLMS) (Stone et al, 2000) program for each of the baseline scenarios. The PLMS program uses a graphic user interface which provides visual comparisons of alternative management scenarios and collects and displays data about each farm. This data consists of a map of the farm with field information, basic climatic data, and information about livestock operations. Based on the inputted data, PLMS uses data and algorithms from the Forage Adaptation Data System (FORADS, Sharp, et al, 1985) and the Cornell Nutrient Management Planning System (Fox, et al., 1998), to simulate forage growth and animal demand.

PLMS calculates the changes in net emissions for three GHG gases: methane, nitrous oxide, and carbon dioxide. Estimation of net change in methane production is based on relationships described in the *IPCC Good Practice Guidance and Uncertainty Management in Greenhouse Gas Inventories* (2001). Methods for estimating changes in nitrous oxide are based on the *IPCC Good Practice Guidance and Uncertainty Management in Greenhouse Gas Inventories* (2001) and modified based on research from Colorado State University (Phetteplace, 2002). Methods for estimating changes in carbon are based on a synthesis of available literature and research from Colorado State University (Phetteplace, 2002).

Methane emissions are calculated for both enteric methane and methane from manure management. PLMS uses daily gross energy and a methane conversion rate to calculate enteric methane. PLMS calculates daily gross energy using Equation 3.1 and enteric methane using Equation 3.2. PLMS calculates methane from manure management using Equation 3.3. This equation uses the volatile solid excretion rate, calculated by Equation 3.4, the maximum methane producing capacity for manure, the type of manure handling system, and the climate of the region where the farm is located to calculate methane from manure management.

Equation 3.1: PLMS Calculation of Daily Gross Energy[1]

$$GE = \frac{ENG/MR + GRE/GR}{TDN}$$

Where: GE = Total daily gross energy
ENG = Energy demand
MR = Maintenance ratio
GRE = Growth energy
GR = Growth ratio
TDN = Digestible energy

In rotational grazing, the amount of digestible energy (TDN) in the forage is higher than it would be under a conventional grazing system. Therefore, the total daily gross energy requirement (GE) will lessen as the TDN increases.

Equation 3.2: PLMS Calculation of Enteric Methane

$$Emissions = \sum_{animals} \sum_{days} GE(a,d) \cdot Y_m(a,d) / 55.65$$

Where: Emissions = Enteric methane emissions per year for the farm
GE = Total daily gross energy for an animal
a = Animals
d = Days
Y_m = A methane conversion rate which is the fraction of gross energy in feed converted to methane

Enteric methane emissions will decrease per animal under rotational grazing because of the decrease in gross energy discussed above. However, if there is an increase in the number of animals due to conversion to rotational grazing, the total farm emissions may still increase.

Equation 3.3: PLMS Calculation of Methane from Manure Management

$$Emissions = \sum_{animals} \sum_{days} VS(a,d) \cdot B_o \cdot 0.67 \cdot \sum_i \left(MCF_i \cdot MS_i\right)$$

Where: VS = The volatile solid excretion rate
a = Animals
d = Days
B_0 = The maximum methane producing capacity for manure produced by an animal within the defined population
MCF_i = Methane conversion factors for each manure management system by climate region
MS_i = The proportion of manure in a given management category (pasture, pit, daily spread, etc.)

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[1] This equation does follow the equation given in the *IPCC Guidelines*. The energy demand represents the sum of the net energy required for maintenance, the energy mobilized due to weight loss, net energy for animal activity, net energy for lactation, net energy for work, and net energy required for pregnancy.

Equation 3.4: PLMS Calculation of the Volatile Solid Excretion Rate

$$VS = \left(GE - DEI + 0.04 \cdot GE\right)/20.1$$

Where: VS = The volatile solid excretion rate

GE = Daily gross energy for an animal

DEI = The digestible energy intake, equal to TDN · GE

Methane from manure management will decrease per animal under rotational grazing because of the decrease in gross energy discussed above. This reduction lowers the volatile solid excretion rate, which in turn lowers the methane emissions from manure management.

Nitrous oxide emissions are based on both direct and indirect sources. The direct sources are calculated as the nitrous oxide released from manure and nitrous oxide released from agricultural soils. The indirect sources are nitrous oxide from atmospheric deposition and nitrous oxide from leaching and runoff. PLMS calculates nitrous oxide released from manure using Equation 3.5. PLMS calculates direct nitrous oxide emissions from agricultural soils using Equation 3.6. This calculation includes total synthetic fertilizer used and the proportion of manure that is collected and used for fertilizer after volatilization. PLMS calculates indirect nitrous emissions using Equation 3.7. This equation calculates nitrous oxide from atmospheric deposition.

Equation 3.5: PLMS Calculation of Nitrous Oxide from Manure Management

$$N_2O - N = N_{ex} \sum_i \left(MS_i \cdot EF_{3_i}\right)$$

Where: N_2O-N = Nitrous oxide emissions from manure management

N_{ex} = The annual nitrogen excretion rate for an animal class (70 kg for non-dairy animals, 100 kg for dairy animals)

MS_i = The proportion of manure in a given management category (pasture, pit, daily spread, etc.)

EF_3 = An emission factor for each manure management category listed in Table 3.9

Table 3.9: Nitrous Oxide Emission Factors for Manure Management Systems

System	Description	EF_3
Pasture, Dry Lot, or Solid Storage	Manure deposited on unpaved lot or paddock	0.02
Daily Spread	Little or no storage but active spreading	0.0
Liquid Slurry or Lagoon, including open pits below	Typical of Virginia Dairies	0.001

The conversion to rotational grazing will not change the amount of nitrous oxide released from manure management per animal for the beef operations. Therefore, only a change in animal numbers will adjust the amount of nitrous oxide from manure for these farms. Conversion to rotational grazing may change in the dairy operation because of a possible shift in the amount of manure deposited in the pasture versus the other management systems.

Equation 3.6: PLMS Calculation of Direct Nitrous Oxide Emissions from Agricultural Soils[2]

$$N_2O - N = 0.0125(F_{SN} + F_{AM})$$

Where: F_{SN} = The total amount of synthetic fertilizer used

F_{AM} = The proportion of manure nitrogen that is collected and used for fertilizer after volatilization

Conversion to rotational grazing will reduce the amount of direct nitrous oxide emissions from agricultural soils by improving forage quality. Improved forage quality will reduce the need for synthetic fertilizer, reducing the overall direct nitrous oxide emissions.

Equation 3.7: PLMS Calculation of Indirect Nitrous Oxide Emissions from Agricultural Soils[3]

$$N_2O - N = N_{ex} \cdot Frac_{GASM}$$

Where: N_{ex} = The average annual nitrogen excretion per head

$Frac_{GASM}$ = The fraction of animal manure nitrogen that volatilizes as NH_3 and NO_x

Conversion to rotational grazing will not change the amount of indirect nitrous oxide emissions from agricultural soils as it is reported in PLMS. This is due to the fact that both of the values in Equation 3.7 are constants.

PLMS calculates carbon dioxide based on fossil fuel consumption on the farm and the amount of carbon which is sequestered by the forage on the farm. PLMS calculates carbon dioxide from fossil fuel consumption as 18.9 metric tons of carbon per Terra-Joule and 20.2 metric tons of carbon per Terra-Joule of fuel burned. Conversion to rotational grazing will reduce these emissions by reducing on-farm fuel consumption. The higher quality forage under rotational grazing will reduce the need for fertilizer to be spread, and the more even pasture utilization by the animals will reduce the need for mowing/haying of the fields.

PLMS calculates the amount of carbon sequestered by a field by determining where on a scale of 0.12 to 0.40 Megagrams (Mg) per hectare of carbon sequestered the field is based on the intensity of its utilization. The amount of carbon sequestered for a field under a conventional grazing system is 0.12 Mg per hectare and the amount of carbon sequestered by a field if animals are rotated every day is 0.40 Mg per hectare. If animals are rotated less frequently, carbon sequestered is lowered proportionally. Rotational grazing will increase the amount of carbon sequestered by keeping forage closer to its optimal stage of growth. This high rate of growth will increase the energy requirements for the forage, and the forage will maintain a high level of photosynthesis and carbon sequestration.

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[2] The IPCC equation also includes the amount of nitrogen fixed by legumes, the nitrogen in crop residue returned to the soil, and the amount of nitrogen in the soil that is emitted directly. However, as these are not present in PLMS, they are not listed as part of the equation here.

[3] The IPCC equation also includes nitrous oxide from leaching and runoff. PLMS does not include this, so it is removed from the equation here.

PLMS only calculates the GHG emissions for the part of the farm converted to rotational grazing. For a summary of the PLMS inputs for each reference condition, please see Appendix A. Other farm level changes such as changes in corn acres planted or purchased feeds are not included in PLMS. These changes are calculated outside PLMS in a spreadsheet using the IPCC calculations (2001). The values are then added to those calculated by PLMS to find the total GHG emissions for the farm. For an in-depth view of these side calculations, please see Appendix B.

The regional performance standard also uses the IPCC calculations (2001) to calculate GHG emissions. However, since the performance standard is not farm-specific, PLMS is not used in the calculation of the regional performance standard. Instead, the IPCC equations are manipulated in a spreadsheet using regional data obtained from Virginia Cooperative Extension Farm Management Budgets and expert opinion. For a detailed description of the performance standard as applied to the cow-calf, stocker, and dairy operations, please see appendices C, D, and E, respectively.

3.4 Calculation of Potential Net Returns from GHG Reduction Services

The study calculates net returns from GHG reduction services by estimating the reduction in the GHGs. These reductions are reported in *total carbon equivalent*, a metric measure used to compare emissions of different greenhouse gases based on their global warming potential (GWP). GWPs are used to convert greenhouse gases to carbon dioxide equivalents, and then are converted to carbon equivalents by multiplying by 12/44 (the ratio of the molecular weight of carbon to carbon dioxide).

Payments are based on the reductions of total carbon equivalent in metric tons (Antle et al, 2001). There is currently no market for a metric ton of carbon reduction so the market price must be estimated. Estimates of the market price range from $14-23 per metric ton by the Council of Economic Advisors to $20-30 per metric ton by Sandor and Skees (Antle et al., 2001). A value of $20 per metric ton will be used here. Total payment will be compared to the revenue of each farm under its historical and current scenarios to find the percent increase in total farm revenue generated by GHG emission reduction payments.

CHAPTER 4: RESULTS OF THE ANALYSIS

Chapter 4 presents the results of the study for each case study farm. A summary of the partial budget results are presented, followed by the GHG emissions for each farm under each baseline scenario. The budget and GHG emission values are then used to calculate the potential additional net revenue the farm may receive from the sale of GHG emission reduction credits.

4.1 Cow-Calf Case Study Farm Results

4.1.1 Budget Results

For the cow-calf case study farm, conversion to rotational grazing resulted in a positive net change in farm returns compared to both the historical and business-as-usual initial conditions. Table 4.1 presents a summary of the changes that define each reference condition presented in chapter three. Table 4.2 presents a summary of the cow-calf case study partial budget for each of these reference conditions.[4] Positive net returns occurred without any compensation for potential GHG reduction services. Rotational grazing yielded $12,263.45, compared to $3,050.53 for the historical initial condition and $4,348.68 for the business-as usual initial condition. Tables 4.3 and 4.4 give the annual changes in net returns for the cow-calf case study farm from the conversion to rotational grazing.

Table 4.1: Summary of the Differences between the Three Reference Conditions for the Cow-Calf Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Cows	23	23	35 with the increase due to rotational grazing
% Calf Crop	85	85	85
% Replacements Kept as a % of Cow Herd	15	15	15
% Annual Culling Rate	15	15	15
% Annual Death Loss	1	1	1
Hay Purchased (kg)	45,350	47,419	31,543
Corn Grain Purchased (Bushels)	146	146	97
Number of Animals Sold	9.78 steers, 8.17 heifers, 1.38 cull cows, 0.23 cull bulls	4.89 fall-born steers, 4.08 fall-born heifers, 4.89 spring-born steers, 4.08 spring-born heifers, 1.38 cull cows, 0.23 cull bulls	7.44 fall-born steers, 6.21 fall-born heifers, 7.44 spring-born steers, 6.21 spring-born heifers, 2.10 cull cows, 0.35 cull bulls
Average weight of sold calves (kg)	206 kg, selling only spring calves	241 kg with changes due to improved genetics	275 kg with changes due to improved genetics and rotational grazing
Average weight of sold cull animals (kg)	538 kg	538 kg	538 kg

[4] For the complete cow-calf case study farm budgets, please see Appendix F. The budgets in Appendix F have not been converted to metric values for reporting purposes as the values in Table 4.1 have.

Table 4.1 (Cont.)			
Item	**Before Rotational Grazing**[a]	**Without Rotational Grazing**[b]	**With Rotational Grazing**[c]
Structural Improvements	None	Improved watering system with 2 additional pre-cast concrete watering troughs	Improved watering system with 2 additional pre-cast concrete watering troughs and fences to divide pasture into seven paddocks

[a] This defines the level at which the case study farm was operating before converting to a rotational grazing system.
[b] This is a "counter-factual" condition, that is, an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This defines the current farm operations.

Table 4.2: Summary of the Cow-Calf Case Study Farm Partial Budget under Each Reference Condition

Budget Category	Reference Condition		
	Before Rotational Grazing	Without Rotational Grazing	With Rotational Grazing
Revenues			
1. Value of Beef Produced	$ 7,178.60	$ 8,704.95	$ 15,136.70
2. Cull Cows	$ 1,472.00	$ 1,472.00	$ 2,240.00
A. Total Revenues (Lines 1&2)	$ 8,650.60	$ 10,176.95	$ 17,376.70
Variable Costs (Non-Forage)			
1. Salt and Mineral	$ 344.08	$ 344.08	$ 523.60
2. Vet and Medicine	$ 402.27	$ 402.27	$ 411.25
3. Replacement Bull	$ 368.00	$ 368.00	$ 560.00
4. Hauling and Marketing	$ 318.03	$ 348.55	$ 568.21
5. Building and Fence Repair[a]	$ 14.76	$ 14.76	$ 14.76
B. Total Variable Costs (Lines 1-5)	$ 1,447.13	$ 1,477.66	$ 2,077.82
Forage Costs			
1. Grain and Forage Purchases	$ 2,828.66	$ 2,942.65	$ 1,957.03
2. Pasture Maintenance	$ 1,324.28	$ 1,324.28	$ 660.39
C. Total Forage Costs (Lines 1&2)	$ 4,152.94	$ 4,266.93	$ 2,617.42
Added Capital Costs			
1. Cross Fencing[b]	$ 0	$ 0	$ 334.34
2. Watering System	$ 0	$ 83.68	$ 83.68
D. Total Added Capital Costs (Lines 1&2)	$ 0	$ 83.68	$ 418.01
Net Revenues			
Net Revenues (A-[B+C+D])	$ 3,050.53	$ 4,348.68	$ 12,263.45

[a] All fencing changes made for the *with* condition are accounted for in the capital costs section of the budget. Fencing repair costs are assumed not to change because animals are frequently handled and do less damage per animal unit.
[b] Only cross fencing costs are included. Perimeter fencing is included under the *Building and Fence Repair* category of Non-Forage Variable Costs.

Table 4.3: Partial Budget for Annual Change in Cow-Calf Case Study Farm Net Returns from the Adoption of Rotational Grazing under the *Before Rotational Grazing* Reference Condition

Partial Budget			
Additional Costs:		**Additional Revenue**	
Salt and Mineral	$179.52	Value of Beef Produced	$7,958.10
Vet and Medicine	$8.98	Cull Cows	$ 768.00
Replacement Bull	$192.00		
Hauling and Marketing	$250.18		
Cross Fencing	$334.34		
Watering System	$83.68		
Reduced Revenue:		**Reduced Costs:**	
None		Grain and Forage Purchases	$871.63
		Pasture Maintenance	$663.89
Total Additional Costs and Reduced Revenue	$1,048.70	Total Additional Revenue and Reduced Costs	$10,261.62
		Net Change in Net Revenue	**$9,212.92**

Table 4.4: Partial Budget for Annual Change in Cow-Calf Case Study Farm Net Returns from the Adoption of Rotational Grazing under the *Without Rotational Grazing* Reference Condition

Partial Budget			
Additional Costs:		**Additional Revenue**	
Salt and Mineral	$179.52	Value of Beef Produced	$6,431.75
Vet and Medicine	$8.98	Cull Cows	$768.00
Replacement Bull	$192.00		
Hauling and Marketing	$219.66		
Cross Fencing	$334.34		
Reduced Revenue:		**Reduced Costs:**	
None		Grain and Forage Purchases	$985.62
		Pasture Maintenance	$663.89
Total Additional Costs and Reduced Revenue	$934.50	Total Additional Revenue and Reduced Costs	$8,849.26
		Net Change in Net Revenue	**$7,914.76**

Overall, the *with rotational grazing* (*with*) condition generates $9,212.92 (Table 4.3) more in net revenue than the *before rotational grazing* (*before*) condition and $7,914.76 (Table 4.4) more in net revenue than the *without rotational grazing* (*without*) condition. This analysis does not reflect changes in on-farm labor costs nor any changes in financial risk associated with adoption of intensive rotational grazing. These factors could influence the financial attractiveness of rotational grazing.

Revenues increase under the *with* reference condition compared to both the *before* and *without* reference conditions. The increase from the *before* condition is due to both improved genetics and a higher stocking rate under the *with* condition (See Tables 4.3

and 4.4). The *without* condition includes the improved genetics in place under the *with* condition; the increased stocking rate and higher quality forage from rotational grazing account for the increase in revenues for the *with* condition compared to the *without*.

Non-forage variable costs increase under the *with* condition when compared to both the *before* and *without* conditions. These increases are due to increases in purchases of salt and minerals, increased vet and medicine costs, increased replacement bull costs, and increases in the cost of hauling and marketing the cattle sold. Annual salt and mineral costs increase by a total of $179.52 under the *with* reference condition compared to both the *before* and *without* conditions due to the increased animal weight and increased herd size. Veterinary and medicine costs also increased under the *with* condition compared to the *before* and *without* conditions, though by only a total of $8.98. This increase can be attributed to the increase in the number of animals rather than treatment costs per animal, which decreased from $17.49 per animal in the *before* and *without* conditions to $11.75 per animal in the *with* condition. This decrease in cost per animal is from a decrease in the frequency of veterinarian visits for endophyte poisoning, footrot, and pinkeye (Faulkner and Boyer, 2000). The risk of these problems is reduced because of improved forage stand condition, controlled grazing, and sanitation around watering troughs under rotational grazing. Annual replacement bull costs increase by $192.00 under the *with* reference condition compared to both the *before* and *without* conditions due to the increased herd size. Hauling and marketing costs increase from $318.03 under the *before* reference condition to $348.55 under the *without* reference condition to $568.21 under the *with* condition. The increase from the *before* condition to the *without* condition is due to the increased weight of the animals sold from the improvement in genetics. The increase from the *without* condition to the *with* condition is due to the increased herd numbers and better forage quality brought about by the rotational grazing system. Building and fence repair is only for structures which existed prior to the adoption of rotational grazing. There is no change in these costs among the three conditions because animals are moved frequently to new pasture and do not challenge fencing, leading to fewer repair costs per animal (Boyer, 2002). Repair costs for the additional cross fencing present in the *with* condition are included in the *Added Capital Costs* section of the partial budget.

Forage costs decreased considerably under the *with* condition from both the *before* and *without* conditions. Increased forage quality under the *with* condition decreased the need for purchased feed. Thus, annual purchased feed costs under the *with* condition decreased by a total of $871.63 compared to the *before* condition and by a total of $985.62 compared to the *without* condition. The greater reduction of the *with* condition in comparison to the *without* condition comes from the increased body weight of animals in the *without* condition, which stems from the improved genetics. Pasture maintenance costs also decreased by $663.89 under the *with* scenario compared to the other two as better forage health and more even spreading of manure reduced the amount of synthetic fertilizer applied to the pasture from 448.36 kg (988.44 lbs) of 10-10-10 [44.84 kg (98.84 lbs) each of nitrogen, phosphorus, and potash] per hectare under the *before* and *without* reference conditions to 28.02 kg (61.78 lbs) of 18-46-0 [5.49 kg (12.08 lbs) of nitrogen, 14.01 kg (30.86 lbs) of phosphorus, and 0 kg of potash] per hectare under the *with* reference condition.

Total annualized capital costs increased by $83.68 (Table 4.2) under the *without* condition due to the improved watering systems compared to the *before* condition. Capital costs increase under the *with* condition compared to the *before* condition due to the addition of both the watering system present in the *without* condition and increased cross fencing to create smaller paddocks needed for rotational grazing. Total annualized costs for the watering system and the cross fencing under the *with* condition are $83.68 and $334.34 (Table 4.2), respectively. Repair costs for the structural improvements in the *without* and *with* reference conditions are included in the *Added Capital Costs* section of the partial budget. The capital costs under the *with* condition do not reflect the one time sale of haying equipment.

4.1.2 GHG Emission Results

Identifying the changes in GHG emissions from a change in farm operations requires comparing the current farm situation (with rotational grazing) against a reference condition called a baseline. The net change in GHG emissions -- the difference between the farm operating under rotational grazing and the baseline -- is called additionality. Thus, it is assumed that the farmer would receive payment only for the additional GHG reductions made beyond the reference condition.

Currently, there exists no one specific standard by which baselines, and consequently additionality, are defined. Thus, three possible baseline conditions will be used to calculate the net change in GHG emissions. The first of these is the *historical* baseline, taken as the time period just prior to the adoption of the rotational grazing system. This baseline corresponds to the *before rotational grazing* budget reference condition. The second baseline is the *business-as-usual*, or *BAU*, baseline. This baseline is based on how much GHG emissions are released from the farm operations in absence of the GHG-reducing practice. This baseline corresponds to the *without rotational grazing* budget reference condition. The third GHG baseline is the *performance standard* baseline. This baseline uses regional performance data to calculate emissions based on what a "well-managed" cow-calf farm representative of the region would be emitting.[5] The *performance standard* baseline does not correspond to any budget reference condition as it is based on the region rather than the case study farm.

Each of the three possible reference conditions can be calculated using different GHG accounting metrics. GHG emissions can be calculated per unit of land or per unit of product. For this study, two metrics will be used. The first metric will be the amount of GHG emitted for the farm (land-based metric). The second will be the amount of GHG emitted per animal unit sold (product-based metric). These two metrics, along with the three baselines discussed above, create six possible additionality scenarios for the case study cow-calf farm.

[5] For a description of how the cow-calf performance standard is calculated, please see Appendix C.

Additionality for the cow-calf case study farm is first calculated for the whole farm (land-based metric). These calculations are presented in Table 4.5, with the calculations per metric ton of product sold presented in Table 4.6. These calculations include a calculation of the GHGs embedded in any feed produced or purchased for use on the farm.

Table 4.5: GHG Emissions (metric tons/yr) for the Cow-Calf Case Study Farm under the Different Baseline Assumptions (Changes from Current Are Listed in Parentheses)

		Baseline		
	Current	Historical	BAU	Performance Standard
Carbon Emissions	-3.49	-2.62 (+0.87)	-2.62 (+0.87)	-2.61 (+0.88)
Nitrous Oxides	0.21	0.16 (-0.05)	0.16 (-0.05)	0.15 (-0.04)
Methane	3.51	1.56 (-1.95)	1.90 (-1.61)	1.76 (-1.75)
Carbon Equivalent[a]	*34.36*	*19.84 (-14.52)*	*21.79 (-12.57)*	*20.15 (-14.21)*

[a] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix C for an in-depth explanation.

The change in emissions for each baseline scenario from the *current* scenario behaves as expected. The amount of carbon emitted for each scenario is negative because there is a greater amount of carbon being sequestered than emissions occurring from carbon dioxide respiration. The amount of carbon sequestered is higher at 3.49 Mg under the *current* scenario than the other scenarios due to the better forage quality and the forage staying closer to the optimal stage of growth under rotational grazing. At this stage of growth, more carbon is removed from the atmosphere and transferred to the soil by the roots.

The amount of nitrous oxides emitted per hectare under the *current* scenario is higher at 0.21 Mg compared to the other scenarios despite the reduction in synthetic fertilizer used. This increase is due to the increase in the number of animals, and the resulting increase in the amount of manure. The part of this manure that volatilizes as nitrous oxide drives the emission level higher.

The increase in methane emissions per hectare under the *current* scenario compared to the other scenarios is partly due to increased number of animals. Although the emissions per animal unit are expected to decrease under rotational grazing, this decrease is outweighed by the increase in the herd size. There also may be another factor related to management assumptions in PLMS driving the increase in emissions per hectare. For an in-depth description of this factor, please see below.

Total carbon equivalent represents the total emissions per hectare for the farm reported in terms of how much atmospheric carbon it would take to equal the amount of GHG being emitted by the farm. The *current* scenario is higher at 34.36 Mg despite the higher rate of carbon sequestration. This is due to the fact that nitrous oxide and methane emissions, both of which increase under the current scenario, have a higher global warming potential than carbon does and increase with the higher stocking rate associated with rotational grazing. These greater emissions greatly outweigh the carbon sequestered for the farm, and drive the carbon equivalent much higher for the *current* scenario than the other scenarios.

Table 4.6 shows GHG emissions per metric ton of product sold. Metric tons of product sold are calculated by taking the total amount of product sold in pounds calculated in the budgets, dividing by 2.2046 to change the amount to kilograms, and dividing this value by 1000 to convert from kilograms to metric tons. The GHG values are obtained by dividing the carbon, nitrous oxide, and methane values from Table 4.5 by the number of metric tons of product sold. Use these values to calculate the total carbon equivalent for each baseline scenario per metric ton of product sold. Under the *current* scenario, the cow-calf case study farm sells 9.565 metric tons live weight annually. The farm sells 5.179 metric tons live weight under the *historical* scenario, and 5.730 metric tons of live weight of product under the *BAU* scenario. The farm should sell 7.197 metric tons live weight of product under the *performance standard*. The live weight sold includes both calves and cull animals.

Table 4.6: GHG Emissions (metric tons/yr) Per Metric Ton Sold for the Cow-Calf Case Study Farm under the Different Baseline Assumptions (Changes from Current Are Listed in Parentheses)

		Baselines		
	Current	Historical	BAU	Performance Standard
Carbon Emissions	-0.365	-0.506 (-0.141)	-0.457 (-0.092)	-0.362 (+0.003)
Nitrous Oxides	0.022	0.031 (+0.009)	0.028 (+0.006)	0.021 (-0.001)
Methane	0.367	0.301 (-0.066)	0.272 (-0.095)	0.245 (-0.122)
Carbon Equivalent[a]	*3.597*	*3.839 (+0.242)*	*3.468 (-0.129)*	*2.816 (-0.781)*

[a] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix C for an in-depth explanation.

The change in carbon emissions per metric ton of product sold for each baseline scenario from the *current* scenario behaves as expected. The amount of carbon sequestered per metric ton of product sold is lower under the *current* scenario than the others. This is due to the fact that carbon sequestration is based solely on the land and thus is independent of herd size. Therefore, even with the increased rate of sequestration under rotational grazing, a larger sale weight of the herd can more than offset the gains and can even, as is the case here, cause the amount of sequestration per metric ton of product sold to decrease compared to the other baseline scenarios.

Once herd number differences are accounted for, the amount of nitrous oxide emissions per metric ton of product sold has changed. The *current* scenario has changed from being the highest emitter to falling below the *historical* and *BAU* scenarios as producer of nitrous oxides, emitting only 0.022 Mg per metric ton of product sold. This is due to two factors. First, the higher nutrient content of pasture under rotational grazing allows for more of the forage to be utilized for energy, thus reducing the amount of manure excreted by the animal. This means there is less manure which will volatilize as nitrous oxide. Second, the higher quality pasture under rotational grazing allows for a greater percentage of the energy needed for growth to come from the pasture. This reduces the amount of other types of feed (either produced on the farm or purchased) that the animals will need to supplement their diet. The reduced feed means a reduction in the amount of fertilizer needed for these other types of feed. The *performance standard* is still slightly below the *current* scenario. This is contrary to expected and will need further study. It may be due to incomplete accounting for nitrogen from crop residue, nitrogen fixation by nitrogen fixing plants, and leaching and runoff from agricultural soils if conventional systems require more feed or due to the high default TDN value given in the *IPCC Guidelines* (2001).

Methane levels under the *current* baseline scenario are at 0.367 Mg per metric ton of product sold. This is still higher than the other baseline scenarios when examined per metric ton of product sold and is contrary to what was expected. However, PLMS simulates forage management to ensure high quality feed for animals. It assumes that the farm operator would hay at the ideal time, thus keeping a higher level of forage quality in the pasture than might happen in practice under a conventional system. Actual practice will typically fall below that quality. Thus, PLMS may overestimate TDN content of conventional systems. Therefore, sensitivity analysis for methane at a high TDN level for the *current* scenario and a low TDN level for the other scenarios is run below.

The level of carbon equivalent is still higher for the *current* scenario than the *BAU* and *performance standard* scenarios at 3.597 Mg per metric ton of product sold, though it has moved below the 3.839 Mg emitted under the *historical* scenario. This is contrary to what was expected. However, the heightened methane level discussed above drives this increase.

In the initial analysis, the TDN values vary according to the plant stage of growth. A sensitivity analysis is performed here on the amount of TDN for the case study farm using an experimental version of PLMS which allows the user to define the TDN level. The study used two levels of TDN to see if the amount of TDN in the forage has a significant impact on the amount of methane emitted from ruminant methanogenesis and the microbial breakdown of animal wastes. The low level of TDN is 58%.[6] This is the level of TDN represented by the *historical* and *BAU* baseline scenarios and the *performance standard*. The high level of TDN is 72%.[7] This is the level of TDN represented by the *current* scenario. Table 4.7 presents a summary of the methane emissions at these different levels for the case study cow-calf farm. Table 4.8 presents a summary of the emissions at these different levels per metric ton of product sold for the case study cow-calf farm.

Table 4.7: Sensitivity Analysis of TDN on Methane Emissions (metric tons/year) for the Cow-Calf Case Study Farm

		Baseline		
	Current (72% TDN)	Historical (58% TDN)	BAU (58% TDN)	Performance Standard[a] (58% TDN)
Carbon Emissions	-3.49	-2.62 (+0.87)	-2.62 (+0.87)	-2.61 (+0.88)
Nitrous Oxides	0.21	0.16 (-0.05)	0.16 (-0.05)	0.15 (-0.04)
Methane	2.76	1.60 (-1.16)	1.95 (-0.81)	2.35 (-0.41)

[6] Source: Expert opinion from Gordon E. Groover, Virginia Polytechnic Institute and State University.
[7] *ibid.*

Table 4.7 (Cont.)				
		Baseline		
Carbon Equivalent[b]	*30.07*	*20.06 (-10.01)*	*22.07 (-8.00)*	*23.53 (-6.54)*

[a] The performance standard TDN level is changed by changing the *Digestible Energy as a Percentage of Gross Energy* value under the Gross Energy Calculation in Appendix B from its default value of 70 to 58.
[b] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix C for an in-depth explanation.

Table 4.8: Sensitivity Analysis of TDN on Methane Emissions (metric tons/year) per Metric Ton of Product Sold for the Cow-Calf Case Study Farm

		Baselines		
	Current (72% TDN)	Historical (58% TDN)	BAU (58% TDN)	Performance Standard[a] (58% TDN)
Carbon Emissions	-0.365	-0.506 (-0.141)	-0.457 (-0.092)	-0.362 (+0.003)
Nitrous Oxides	0.022	0.031 (+0.009)	0.028 (+0.006)	0.021 (-0.001)
Methane	0.289	0.309 (+0.020)	0.340 (+0.051)	0.327 (+0.038)
Carbon Equivalent[b]	*3.160*	*3.885 (+0.725)*	*3.857 (+0.697)*	*3.286 (+0.126)*

[a] The performance standard TDN level is changed by changing the *Digestible Energy as a Percentage of Gross Energy* value under the Gross Energy Calculation in Appendix B from its default value of 70 to 58.
[b] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix C for an in-depth explanation.

The farm methane values for the *historical* and *BAU* scenarios are higher in the sensitivity analysis than in the calculations in Table 4.5. This is due to the haying of the farm in PLMS driving the pasture quality and TDN values higher than the 58% level. The sensitivity analysis shows that there is a significant reduction in the amount of methane from an increase in the amount of TDN associated with an increase in forage quality. Such a change narrows the gap between the carbon equivalent numbers for the farm as a whole under the different scenarios, and puts the per metric ton of product sold carbon equivalent for the *current* scenario well below that of the *historical* and *BAU* scenarios and the *performance standard*.

4.1.3 Net Farm Revenue from GHG Reduction Credits

The amount of financial compensation for selling carbon equivalent reduction credits depends on the baseline and metric from which the change is taken. Table 4.9 presents the potential financial returns from selling GHG reduction credits for the cow calf case study farm. Table 4.10 presents the potential financial returns from selling GHG reduction credits for the cow-calf case study farm using the GHG values from the sensitivity analysis. The price for a metric ton of carbon reduction currently must be estimated as there is currently no market to determine the price. Estimates range from $14-23 per metric ton by the Council of Economic Advisors to $20-30 per metric ton by Sandor and Skees (Antle et al., 2001). A value of $20 per metric ton is used here.

Table 4.9: Potential Financial Returns from Selling Carbon Equivalent Reduction Credits for the Cow-Calf Case Study Farm

Baseline	Per Farm	Per Metric Ton of Product Sold
Historical	n/a	$46.29
BAU	n/a	n/a
Performance Standard	n/a	n/a

"n/a" is appropriate because there is not a reduction in overall GHG emissions for the farm under this baseline and metric. Therefore, the farm will not be able to receive payment for GHG reduction services.

For the case study cow-calf farm, GHG reduction credits could only be sold by the farm operator under the *historical* scenario under the *per metric ton of product sold* metric. Selling credits under this scenario and metric would create additional net revenue of $46.29 (0.242 metric tons of GHG sequestered per metric ton of product sold · 9.565 metric tons of product sold · $20 per metric ton). The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Before Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.50%. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Without Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.58%. This percent change is greater due to the fact that the overall change in net returns for the farm is less for the change from *Without Rotational Grazing* to *With Rotational Grazing*.

Table 4.10: Potential Financial Returns from Selling Carbon Equivalent Reduction Credits for the Cow-Calf Case Study Farm Using the GHG Values Calculated in the Sensitivity Analysis

Baseline	Per Farm	Per Metric Ton of Product Sold
Historical	n/a	$138.69
BAU	n/a	$133.34
Performance Standard	n/a	$24.10

"n/a" is appropriate because there is not a reduction in overall GHG emissions for the farm under this baseline and metric. Therefore, the farm will not be able to receive payment for GHG reduction services.

For the case study cow-calf farm, GHG reduction credits could be sold by the farm operator under the historical scenario in the initial run and under all three sensitivity analysis scenarios under the *per metric ton of product sold* metric. Selling credits under these baseline scenarios would create additional net revenue of from $24.10 to $138.69. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Before Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.26% to 1.51%. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Without Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.30% to 1.75%. This percent change is greater for the Without Rotational Grazing reference condition due to the fact that the overall change in net returns for the farm is $1,298.16 less for the change from *Without Rotational Grazing* to *With Rotational Grazing*.

4.2 Stocker Case Study Farm Results

4.2.1 Budget Results

For the stocker case study farm, conversion to rotational grazing resulted in a positive net change in farm returns compared to both the historical and business-as-usual initial conditions. Positive net returns occurred without any compensation for potential GHG reduction services. Tables 4.11 and 4.12 present a summary of the changes that define each reference condition presented in chapter three for the fall and spring groups, respectively. Table 4.13 presents a summary of the stocker case study farm partial budget for each of these reference conditions.[8] Tables 4.14 and 4.15 give the annual changes in net returns for the stocker case study farm from the conversion to rotational grazing.

Table 4.11: Summary of the Differences between the Three Reference Conditions for the Fall Herd of the Stocker Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Steers	n/a	250	250
Days On Feed	n/a	76	30
Average Daily Gain on Feed (kg)	n/a	0.57	0.91 kg
Hay Purchased (kg)	n/a	233,104	0
Corn Grain Purchased (Bushels)	n/a	2,793	0
Other Feed (kg)[d]	n/a	0	61,689
Days On Pasture/Hay	n/a	14	60
Average Daily Gain on Pasture/Hay (kg)	n/a	0.11	.91
Purchase Weight (kg)	n/a	159	136
% Death Loss	n/a	3	1 because sickness within the herd could be more easily controlled with rotational grazing
Selling Weight (kg)[e]	n/a	200	213
Number of Animals Sold	n/a	242.50	247.50
Structural Improvements	These are included in the spring budget and are listed there		

[a] This condition is the level at which the case study farm was operating before converting to a rotational grazing system. There is no fall group for the farm under this condition, so no analysis is presented for it.
[b] This condition is "counter-factual". It is an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This condition is the level at which the farm currently operates.
[d] Other Feed is pelleted corn gluten and pelleted soy hulls
[e] Adjusted for a 2% shrink rate

[8] For the complete stocker case study farm budget, please see Appendix F. The budget in Appendix F has not been converted to metric values for reporting purposes as the values in Table 4.11 and 4.12 have.

Table 4.12: Summary of the Differences between the Three Reference Conditions for the Spring Herd of the Stocker Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Steers	79	120	120
Days On Feed	45	45	30 The farm is able to use less feed due to increased forage quality of rotational grazing
Average Daily Gain on Feed (kg)	0.50	0.50	0.91
Hay Purchased (kg)	18,226	27,688	0
Corn Grain Purchased (Bushels)	223	339	0
Other Feed (kg)[d]	0	0	5,371
Days On Pasture/Hay	123	123	138
Average Daily Gain on Pasture/Hay (kg)	0.68	0.68	0.91
Purchase Weight (kg)	181	193	193
% Death Loss	2	2	1 because sickness within the herd could be more easily controlled with rotational grazing
Selling Weight (kg)[e]	282	293	338
Number of Animals Sold	77.42	117.60	118.80
Structural Improvements	None	Added 6 watering troughs and a ram pump	Added 6 watering troughs and a ram pump as well as permanent electric fence to divide 3 separate pastures into 22 paddocks

[a] This defines the level at which the case study farm was operating before converting to a rotational grazing system. Before converting to a rotational grazing system, the stocker case study farm did not have a fall stocker herd. The farm instead had a cow-calf herd. This herd is not examined since a more complete cow-calf case study farm is presented above.
[b] This is a "counter-factual" condition, that is, an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This condition is the level at which the farm currently operates.
[d] Other Feed is pelleted corn gluten and pelleted soy hulls
[e] Adjusted for a 2% shrink rate

Table 4.13: Summary of the Stocker Case Study Farm Partial Budget under Each Reference Condition

Budget Category	Reference Condition		
	Before Rotational Grazing	Without Rotational Grazing	With Rotational Grazing
Revenues			
1. Value of Stockers Sold	$ 47,693.88	$ 178,729.01	$ 197,621.45
A. Total Revenues (Line 1)	$ 47,693.88	$ 178,729.01	$ 197,621.45

Table 4.13 (Cont.)			
Budget Category	Reference Condition		
	Before Rotational Grazing	Without Rotational Grazing	With Rotational Grazing
Acquirement Costs			
1. Steers	$ 33,963.68	$ 140,573.55	$ 128,322.30
2. Interest on Steers	$ 1,446.02	$ 4,289.76	$ 4,010.34
3. Procurement	$ 296.25	$ 1,387.50	$ 1,387.50
B. Total Acquirement Costs (Lines 1-3)	$ 35,705.95	$ 146,250.81	$ 133,720.14
Variable Costs (Non-Forage)			
1. Mineral w/ BOV or RUM	$ 414.75	$ 1,333.13	$ 1,333.13
2. Vet & Medicine	$ 533.25	$ 2,497.50	$ 1,497.50
3. Supplies	$ 158.00	$ 740.00	$ 740.00
4. Haul Calves	$ 348.39	$ 1,620.45	$ 1,625.85
5. Market Calves	$ 1,224.85	$ 5,326.51	$ 5,527.42
6. Building and Fence Repair	$ 79.00	$ 370.00	$ 370.00
C. Total Variable Costs (Lines 1-6)	$ 2,758.24	$ 11,887.59	$ 11,093.90
Forage Costs			
1. Grain and Forage Purchases	$ 1,506.38	$ 21,824.80	$ 7,569.54
2. Pasture Maintenance	$ 530.77	$ 4,431.85	$ 499.04
D. Total Forage Costs (Lines 1&2)	$ 2,037.15	$ 26,256.65	$ 8,068.58
Added Capital Costs			
1. Cross Fencing[a]	$ 0	$ 0	$ 397.41
2. Watering System	$ 0	$ 457.41	$ 457.41
E. Total Added Capital Costs (Lines 1&2)	$ 0	$ 457.41	$ 854.82
Net Revenues			
Net Revenues (A-[B+C+D+E])	$ 7,192.55	$ -6,123.45	$ 43,884.01

[a] This does not include perimeter fencing. Perimeter fencing is included under the *Building and Fence Repair* category of Non-Forage Variable Costs.

Table 4.14: Partial Budget for Annual Change in Stocker Case Study Farm Net Returns from the Adoption of Rotational Grazing under the *Before Rotational Grazing* Reference Condition

Partial Budget			
Additional Costs:		**Additional Revenue**	
Steers	$ 94,358.62	Value of Stockers Sold	$149,927.57
Interest on Steers	$ 2,564.32		
Procurement	$ 1,091.25		
Mineral w/ BOV or RUM	$ 918.38		
Vet and Medicine	$ 964.25		
Supplies	$ 582.00		
Haul Calves	$ 1,277.46		
Market Calves	$ 4,302.57		
Building and Fence Repair	$ 291.00		
Forage Purchases	$ 6,063.16		
Cross Fencing	$ 397.41		
Watering System	$ 457.41		

Table 4.14 (Cont.)			
Reduced Revenue:		**Reduced Costs:**	
None		Pasture Maintenance	$ 31.73
Total Additional Costs and Reduced Revenue	$113,267.83	Total Additional Revenue and Reduced Costs	$149,959.30
		Net Change in Net Returns	**$ 36,691.47**

Table 4.15: Partial Budget for Annual Change in Stocker Case Study Farm Net Returns from the Adoption of Rotational Grazing under the *Without Rotational Grazing* Reference Condition

Partial Budget			
Additional Costs:		**Additional Revenue**	
Haul Calves	$ 5.40	Value of Stockers Sold	$ 18,892.44
Market Calves	$ 200.91		
Cross Fencing	$ 397.41		
Reduced Revenue:		**Reduced Costs:**	
None		Steers	$ 12,251.25
		Interest on Steers	$ 279.42
		Vet and Medicine	$ 1,000.00
		Forage Purchases	$ 14,255.26
		Pasture Maintenance	$ 3,932.81
Total Additional Costs and Reduced Revenue	$ 603.72	Total Additional Revenue and Reduced Costs	$ 50,611.18
		Net Change in Net Returns	**$ 50,007.46**

Overall, the *with rotational grazing* (*with*) condition generates $36,691.47 (Table 4.14) more than the *before rotational grazing* (*before*) condition and $50,007.46 (Table 4.15) more than the *without rotational grazing* (*without*) condition. The partial budget does not reflect changes in on-farm labor costs nor any changes in financial risk associated with adoption of intensive rotational grazing. These factors could influence the financial attractiveness of rotational grazing.

Revenues increase under the *with* reference condition by $149,927.57 compared to the *before* reference condition. The increase from the *before* condition is due to a higher stocking rate, including running a second group in the fall. Revenues increase for the *with* condition by $18,892.44 when compared to the *without* condition. The *without* condition includes the higher stocking rate in place under the *with* condition; the higher weight per animal sold under the *with* condition is the cause of this increase.

Acquirement costs increase for the *with* reference condition when compared to the *before* condition. These costs include the purchasing of steers, which increases by $94,358.62, and the interest associated with the purchase of the steers, which increases by $2,564.32. Both of these increases are driven by the increase in herd size. The acquirement costs decrease, however, when the *with* condition is compared to the *without* condition. The cost of purchasing the steers decreases by $12,251.25 and the interest on the steers decreases by $279.42. This decrease is due to the difference in purchase weight for the fall group.

Non-forage variable costs increase under the *with* condition when compared to the *before* condition. These increases are due to increased purchases of $918.38 for minerals with BOV or RUM, increased vet and medicine costs of $964.25, increased supplies costs of $582.00, increases in the cost of hauling and marketing the cattle sold by $1,227.46 and $4,302.57, respectively, and increases in the cost of building and fence repair of $291.00. All of these increases are due to the increase in herd size for the farm.

Certain non-forage variable costs increase and certain ones decrease under the *with* reference condition when compared to the *without* reference condition. The costs which increase are those that are measured by the amount of animals sold, hauling and marketing of cattle. These costs increase by $5.40 for hauling and $200.91 for marketing of cattle. This increase is due to the lower death rate for the herd under rotational grazing, which allows for more of the purchased animals to be sold. Vet and medicine costs are the only costs which decrease under the *with* condition when compared to the *without*. These costs go down because rotational grazing provides improved sanitation around streams and water troughs and a reduction in care costs of one lost calf and one avoided vet visit and medication (Faulkner et al., 2000a).

Forage purchases increase by $6,063.13 under the *with* condition from the *before* condition even though pasture maintenance costs decrease by $31.73. Forage purchases increase due to the increase in the herd size, while the pasture maintenance costs decrease because the improved health of the forage stand under rotational grazing reduces the need for overseeding of red clover and innoculant by 0.45 kg (1.0 lb) per hectare. Forage costs are lower for the *with* condition for both forage purchases and pasture maintenance when compared to the *without* condition. The cost of forage purchases decreases by $14,255.26. The cost of pasture maintenance decreases by $3,932.81. These decreases are due to the increase in the quality of forage being produced in the pasture. This higher quality forage reduces the need for other feed to be purchased.

Capital costs increased by $457.41 under the *without* condition due to the betterment of the farm's watering systems compared to the *before* condition. Capital costs increase under the *with* condition compared to the *before* condition due to the addition of both the watering system present in the *without* condition and increased cross fencing to create the smaller paddocks needed for rotational grazing. The costs for the watering system and the cross fencing under the *with* condition are $457.41 and $397.41, respectively. Repair costs for the structural improvements in the *without* and *with* reference conditions are included in the *Added Capital Costs* section of the partial budget.

4.2.2 GHG Emission Results

Identifying the changes in GHG emissions from a change in farm operations requires comparing the current farm situation (with rotational grazing) against a reference condition called a baseline. The net change in GHG emissions -- the difference between the farm operating under rotational grazing and the baseline -- is called additionality. Thus, it is assumed that the farmer would receive payment only for the additional GHG reductions made beyond the reference condition.

Similar to the cow-calf case study farm, three baselines and two accounting metrics are analyzed. Additionality results for the stocker case study on a whole farm basis are presented in Table 4.16, with the calculations per metric ton of product sold presented in Table 4.17. All additionality results include both on-farm emissions and emissions embedded in purchased feeds.

Table 4.16: GHG Emissions (metric tons/yr) for the Stocker Case Study Farm under the Different Baseline Assumptions (Changes from Current Are Listed in Parentheses)

		Baseline		
	Current	Historical	BAU	Performance Standard[b]
Carbon Emissions	-8.286	-4.331 (+3.955)	-9.295 (-1.009)	-4.158 (+4.128)
Nitrous Oxides	0.621	0.179 (-0.442)	0.586 (-0.035)	0.152 (-0.469)
Methane	6.694	1.381 (-5.313)	4.187 (-2.507)	1.635 (-5.059)
Carbon Equivalent[a]	*82.555*	*18.712 (-63.843)*	*64.229 (-18.326)*	*18.057 (-64.498)*

[a] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix D for an in-depth explanation.

[b] The levels for the performance standard are lower than the Current and BAU scenarios because they are constructed from the carrying capacity of the land the farm is on. The farm operator is running a number of animals which greatly exceeds this capacity, making the GHG emissions for the farm much higher.

The change in emissions for each baseline scenario from the *current* scenario behaves as expected. The amount of carbon emitted for each scenario is negative because there is a greater amount of carbon being sequestered than emission occurring. The *current* scenario is sequestering 8.286 Mg of carbon. This is higher than the *historical* scenario and *performance standard* because the forage is being kept closer to the optimal stage of growth in the *current* scenario. At this stage of growth, more carbon is removed from the atmosphere and transferred to the soil by the roots. The *BAU* scenario is higher than the *current* scenario at 9.295 Mg sequestered despite the forage being farther from the optimal stage of growth. This increase is due to the carbon sequestration associated with the large amount of purchased feed which is necessary under this baseline scenario.

The amount of nitrous oxides emitted under the *current* scenario is higher at 0.621 Mg compared to the other scenarios. This increase is due to the increase in the number and weight of animals, and the resulting increase in the amount of manure. It is the part of this manure that volatilizes as nitrous oxide that drives the emission level higher, outweighing the nitrous oxide reductions from reduced fertilization.

Methane emissions are higher under the *current* scenario at 6.694 Mg compared to the other scenarios. This is partly due to increase in the number and weight of the animals. Although the emissions per animal unit are expected to decrease under rotational grazing, this decrease is outweighed by the increase in the animal size and number per herd. There also may be another factor related to management assumptions in PLMS driving the increase in emissions per hectare. For an in-depth description of this factor, please see below.

The total carbon equivalent represents the total emissions for the farm reported in terms of how much atmospheric carbon it would take to equal the amount of GHG being emitted by the farm. The *current* scenario is higher at 82.555 Mg despite the higher rate of carbon sequestration. This is due to the fact that nitrous oxide and methane emissions, both of which increase under the *current* scenario, have a higher global warming potential than carbon does. These greater emissions greatly outweigh the carbon sequestered for the farm, and drive the carbon equivalent much higher for the *current* scenario than the other scenarios.

Table 4.17 shows GHG emissions per metric ton of product sold. Metric tons of product sold are calculated by taking the total amount of product sold in pounds calculated in the budgets, dividing by 2.2046 to change the amount to kilograms, and dividing this value by 1000 to convert from kilograms to metric tons. The GHG values are obtained by dividing the carbon, nitrous oxide, and methane values from Table 4.16 by the number of metric tons of product sold. These values are used to calculate the total carbon equivalent for each baseline scenario per metric ton of product sold. Under the *current* scenario, the stocker case study farm sells 92.998 metric tons annually. The farm sells 21.835 metric tons under the *historical* scenario, and 82.820 metric tons of product under the *BAU* scenario. The farm should sell 18.598 metric tons of product under the *performance standard*.

Table 4.17: GHG Emissions (metric tons/yr) Per Metric Ton of Product Sold for the Stocker Case Study Farm under the Different Baseline Assumptions (Changes from Current Are Listed in Parentheses)

		Baselines		
	Current	Historical	BAU	Performance Standard
Carbon Emissions	-0.089	-0.198 (-0.109)	-0.112 (-0.023)	-0.224 (-0.135)
Nitrous Oxides	0.007	0.008 (+0.001)	0.007 (±0.000)	0.008 (+0.001)
Methane	0.072	0.063 (-0.009)	0.051 (-0.021)	0.088 (+0.016)
Carbon Equivalent[a]	*0.915*	*0.839 (-0.076)*	*0.772 (-0.143)*	*0.956 (+0.041)*

[a] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix D for an in-depth explanation.

The change in carbon emissions for each baseline scenario from the *current* scenario behaves as expected. The amount of carbon sequestered per metric ton of product sold is lower under the *current* than the *historical* and *BAU* scenarios and the *performance standard*. This is due to the fact that carbon sequestration is based solely on the land and thus is independent of herd size. Therefore, even with the increased rate of sequestration under rotational grazing, a larger herd of animals can more than offset the gains and can even, as is the case here, cause the amount of sequestration per metric ton of product sold to decrease compared to the other baseline scenarios.

The amount of nitrous oxide emissions per metric ton of product sold has moved the *current* scenario from the highest emitter to below the *historical* scenario and *performance standard* and equivalent to the *BAU* scenario as producer of nitrous oxides now that herd number differences are accounted for. This is due to two factors. First, the higher quality forage in the pasture under rotational grazing allows for more of the forage to be utilized for energy, thus reducing the amount of manure excreted by the animal.

This means there is less manure which will volatilize as nitrous oxide. Second, the higher quality pasture under rotational grazing allows for a greater percentage of the energy needed for growth to come from the pasture. This reduces the amount of other types of feed (either produced on the farm or purchased) that the animals will need to supplement their diet. The reduced feed means a reduction in the amount of fertilizer needed for these other types of feed.

Methane levels under the *current* baseline scenario have fallen to 0.072 Mg per metric ton of product sold. This is below the *performance standard*, but still higher than the other baseline scenarios when examined per metric ton of product sold. This is contrary to what was expected. However, PLMS simulates forage management to ensure high quality feed for animals. It may assume that the farm operator would hay at the ideal time, thus keeping a higher level of forage quality in the pasture than might happen in practice under a conventional system. Actual practice will typically fall below that quality. Thus, PLMS may overestimate TDN content of conventional systems. Therefore, sensitivity analysis for methane at a high TDN level for the *current* scenario and a low TDN level for the other scenarios is run below.

The level of carbon equivalent is still higher for the *current* scenario at 0.915 Mg per metric ton of product sold than the *historical* and *BAU* scenarios, though it has moved below the *performance standard* scenario. This is contrary to what was expected. However, the heightened methane level discussed above keeps the carbon equivalent of the *current* scenario higher.

The study performed sensitivity analysis on the amount of TDN for the case study farm. The study used two levels of TDN to see if the amount of TDN in the forage has a significant impact on the amount of methane emitted from ruminant methanogenesis and the microbial breakdown of animal wastes. The low level of TDN is 58%.[9] This is the level of TDN represented by the *historical* and *BAU* baseline scenarios and the *performance standard*. The high level of TDN is 72%.[10] This is the level of TDN represented by the *current* scenario. Table 4.18 presents a summary of the methane emissions at these different levels for the case study cow-calf farm. Table 4.19 presents a summary of the methane emissions at these different levels per metric ton of product sold for the stocker case study farm.

Table 4.18: Sensitivity Analysis of TDN on Methane Emissions (metric tons/year) for the Stocker Case Study Farm

		Baseline		
	Current (72% TDN)	Historical (58% TDN)	BAU (58% TDN)	Performance Standard[a] (58% TDN)
Carbon Emissions	-8.286	-4.331 (+3.955)	-9.295 (-1.009)	-4.158 (+4.128)
Nitrous Oxides	0.621	0.179 (-0.442)	0.586 (-0.035)	0.152 (-0.469)
Methane	4.933	1.137 (-3.796)	4.212 (-0.721)	2.270 (-2.663)

[9] Source: Expert opinion from Gordon E. Groover, Virginia Polytechnic Institute and State University.
[10] *ibid.*

Table 4.18 (Cont.)				
Carbon Equivalent[b]	*72.470*	*17.135 (-55.335)*	*64.372 (-8.098)*	*21.694 (-50.776)*

[a] The performance standard TDN level is changed by changing the *Digestible Energy as a Percentage of Gross Energy* value under the Gross Energy Calculation in Appendix B from its default value of 70 to 58.
[b] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix D for an in-depth explanation.

Table 4.19: Sensitivity Analysis of TDN on Methane Emissions (metric tons/year) per Metric Ton Sold for the Stocker Case Study Farm

		Baselines		
	Current (72% TDN)	Historical (58% TDN)	BAU (58% TDN)	Performance Standard[a] (58% TDN)
Carbon Emissions	-0.089	-0.198 (-0.109)	-0.112 (-0.023)	-0.224 (-0.135)
Nitrous Oxides	0.007	0.008 (+0.001)	0.007 (±0.000)	0.008 (+0.001)
Methane	0.053	0.052 (-0.001)	0.051 (-0.002)	0.122 (+0.069)
Carbon Equivalent[b]	*0.807*	*0.776 (-0.031)*	*0.772 (-0.035)*	*1.151 (+0.344)*

[a] The performance standard TDN level is changed by changing the *Digestible Energy as a Percentage of Gross Energy* value under the Gross Energy Calculation in Appendix C from its default value of 70 to 58.
[b] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix D for an in-depth explanation.

The farm methane value for the *current* scenario is lower in the sensitivity analysis than in the calculations in Table 4.16. The sensitivity analysis shows that there is a significant reduction in the amount of methane from an increase in the amount of TDN associated with an increase in forage quality. Such a change narrows the gap between the carbon equivalent numbers for the farm as a whole under the different scenarios, and puts the per metric ton of product sold carbon equivalent for the *current* scenario closer to that of the *historical* and *BAU* scenarios and well below the *performance standard*.

4.2.3 Net Farm Revenue from GHG Reduction Credits

The amount of financial compensation for selling carbon equivalent reduction credits depends on the baseline and metric from which the change is taken. Table 4.20 presents the potential financial returns from selling GHG reduction credits for the stocker case study farm. Table 4.21 presents the potential financial returns from selling GHG reduction credits for the stocker case study farm using the GHG values from the sensitivity analysis. The price for a metric ton of carbon reduction currently must be estimated as there is currently no market to determine the price. Estimates range from $14-23 per metric ton by the Council of Economic Advisors to $20-30 per metric ton by Sandor and Skees (Antle et al., 2001). A value of $20 per metric ton is used for carbon credits.

Table 4.20: Potential Financial Returns from Selling Carbon Equivalent Reduction Credits for the Stocker Case Study Farm

Baseline	Per Farm	Per Animal Unit
Historical	n/a	n/a
BAU	n/a	n/a
Performance Standard	n/a	$76.26

"n/a" is appropriate because there is not a reduction in overall GHG emissions for the farm under this baseline and metric. Therefore, the farm will not be able to receive payment for GHG reduction services.

For the case study stocker farm, GHG reduction credits could only be sold by the farm operator under the *performance standard* under the *per metric ton of product sold* metric. Selling credits under this scenario and metric would create additional net revenue of $76.26 (0.041 metric tons of GHG sequestered per metric ton of product sold · 92.998 metric tons of product sold · $20 per metric ton). The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Before Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.21%. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Without Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.15%. This percent change is lower than the *Before Rotational Grazing* scenario due to the fact that the overall change in net returns for the farm is higher.

Table 4.21: Potential Financial Returns from Selling Carbon Equivalent Reduction Credits for the Stocker Case Study Farm Using the GHG values Calculated in the Sensitivity Analysis

Baseline	Per Farm	Per Animal Unit
Historical	n/a	n/a
BAU	n/a	n/a
Performance Standard	n/a	$639.83

"n/a" is appropriate because there is not a reduction in overall GHG emissions for the farm under this baseline and metric. Therefore, the farm will not be able to receive payment for GHG reduction services.

For the case study stocker farm, GHG reduction credits could only be sold by the farm operator under the *performance standard* under the *per metric ton of product sold* metric. Selling credits under this scenario and metric would create additional net revenue of $639.83 (0.344 metric tons of GHG sequestered per metric ton of product sold · 92.998 metric tons of product sold · $20 per metric ton). The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Before Rotational Grazing* operation to the *With Rotational Grazing* operation by 1.73%. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Without Rotational Grazing* operation to the *With Rotational Grazing* operation by 1.28%. This percent change is lower than the *Before Rotational Grazing* scenario due to the fact that the overall change in net returns for the farm is higher.

4.3 Dairy Case Study Farm Results

4.3.1 Budget Results

For the dairy case study farm, conversion to rotational grazing resulted in a positive net change in farm returns compared to both the historical and business-as-usual initial conditions. Positive net returns occurred without any compensation for potential GHG reduction services. Table 4.22 presents a summary of the changes that define each reference condition presented in chapter three. Table 4.23 presents a summary of the cow-calf case study farm partial budget for each of these reference conditions.[11] Tables 4.24 and 4.25 give the annual changes in net returns for the dairy case study farm from the conversion to rotational grazing.

Table 4.22: Summary of the Differences between the Three Reference Conditions for the Dairy Case Study Farm

Item	Before Rotational Grazing[a]	Without Rotational Grazing[b]	With Rotational Grazing[c]
Number of Cows	54	70	70
Average Milk Production (kg/yr/cow)	8,013	9,526	8,845
Silage Fed (kg)	582,428	754,999	472,050
Silage Purchased (kg)[d]	116,457	302,830	-2,749
Hay Fed (kg)	108,395	140,513	47,208
Hay Purchased (kg)	113,817	147,537	49,569
SBOM 48% (kg)	30,472	39,499	39,499
Summer Supplement Purchased (kg)	74,707	96,843	96,843
Winter Supplement Purchased (kg)	74,707	96,843	96,843
Cull Cows Sold	5.40	7	8.40
Bull Calves Sold	25.65	33.25	33.25
Cull Heifers Sold	10	10	10
Structural Changes	None	Added travel lane and some additional watering facilities, as well as beginning bST injections and joining the DHIA record keeping program	Added travel lane, additional watering facilities, and added fencing (both permanent and mobile) as well as beginning bST injections and joining the DHIA record keeping program

[a] This defines the level at which the case study farm was operating before converting to a rotational grazing system.
[b] This is a "counter-factual" condition, that is, an estimation of how the farm would be operating if all improvements under rotational grazing were implemented other than the increase in the number of paddocks.
[c] This defines current farm operations.
[d] It is assumed that there is 12.14 hectares (30 acres) of corn grown on the case study farm. This corn land produces 512,565 kg of corn silage annually.

Table 4.23: Summary of the Dairy Case Study Farm Partial Budget under Each Reference Condition

Budget Category	Reference Condition		
	Before Rotational Grazing	Without Rotational Grazing	With Rotational Grazing
Revenues			
1. Value of Milk Sold	$ 138,324.78	$ 213,150.00	$ 197,925.00
2. Value of Cull Cows Sold	$ 2,457.00	$ 3,185.00	$ 3,822.00
3. Value of Bull Calves Sold	$ 1,923.75	$ 2,493.75	$ 2,493.75

[11] For the complete cow-calf case study farm budget, please see Appendix F. The budget in Appendix F has not been converted to metric values for reporting purposes as the values in Table 4.22 have.

Table 4.23 (Cont.)						
Budget Category	Reference Condition					
	Before Rotational Grazing		Without Rotational Grazing		With Rotational Grazing	
4. Value of Cull Heifers Sold	$	8,481.00	$	11,000.00	$	11,000.00
5. Patronage Dividends	$	1,921.18	$	2,960.42	$	2,748.96
A. Total Revenues (Lines 1-5)	$	153,107.71	$	232,789.17	$	217,989.71
Variable Costs (Non-Forage)						
1. Summer Ration (12% Protein)	$	13,587.75	$	17,613.75	$	17,613.75
2. Winter Ration (24% Protein)	$	16,140.60	$	20,923.00	$	20,923.00
3. Minerals	$	2,565.00	$	3,325.00	$	3,325.00
4. Milk Replacer	$	1,180.98	$	1,530.90	$	1,530.90
5. Calf Grower	$	1,649.70	$	2,138.50	$	2,138.50
6. Breeding (Up to 2 services per cow)	$	2,160.00	$	2,800.00	$	2,800.00
7. Bull (Cleanup)	$	1,600.00	$	1,600.00	$	1,600.00
8. Vet and Medicine	$	4,320.00	$	1,661.10	$	1,639.40
9. Supplies	$	8,370.00	$	10,850.00	$	10,850.00
10. bST	n/a		$	6,000.75	$	6,000.75
11. DHIA	n/a		$	1,540.00	$	1,540.00
12. Milk Haul	$	7,631.71	$	11,760.00	$	10,920.00
13. Assessment and Advertising	$	2,480.31	$	3,822.00	$	3,549.00
14. Haul and Market Culls	$	356.84	$	406.78	$	418.09
15. Building and Fence Repair	$	4,860.00	$	6,300.00	$	6,300.00
16. Machinery	$	3,240.00	$	4,200.00	$	4,200.00
17. Utilities	$	3,510.00	$	4,550.00	$	4,550.00
18. Custom Hire	$	1,728.00	$	2,240.00	$	2,240.00
19. Hired Labor	$	6,240.00	$	6,240.00	$	6,240.00
B. Total Variable Costs (Lines 1-19)	$	81,620.89	$	109,501.78	$	108,378.39
Forage Costs						
1. Grain and Forage Purchases	$	23,758.15	$	35,401.29	$	15,230.78
2. Pasture Maintenance	$	475.32	$	475.32	$	475.32
C. Total Forage Costs (Lines 1&2)	$	24,233.46	$	35,876.62	$	15,706.10
Added Capital Costs						
1. Cross Fencing[a]	$	0	$	0	$	1,137.93
2. Travel Lane	$	0	$	794.66	$	794.66
3. Watering System	$	0	$	331.26	$	1,490.05
D. Total Added Capital Costs (Lines 1-3)	$	0	$	1,125.92	$	3,422.64
Net Revenues						
Net Revenues (A-[B+C+D])	$	47,253.36	$	86,284.85	$	90,482.58

[a] This does not include perimeter fencing. Perimeter fencing is included under the *Building and Fence Repair* category of Non-Forage Variable Costs.

Table 4.24: Partial Budget for Annual Change in Dairy Case Study Farm Net Returns from the Adoption of Rotational Grazing under the *Before Rotational Grazing* Reference Condition

Partial Budget			
Additional Costs:		**Additional Revenue**	
Summer Ration	$ 4,026.00	Value of Milk Sold	$ 59,600.22
Winter Ration	$ 4,782.40	Value of Cull Cows Sold	$ 1,365.00
Minerals	$ 760.00	Value of Bull Calves Sold	$ 570.00
Milk Replacer	$ 349.92	Value of Cull Heifers Sold	$ 2,519.00
Calf Grower	$ 488.80	Patronage Dividends	$ 827.78
Breeding	$ 640.00		
Supplies	$ 2,480.00		
bST	$ 6,000.75		
DHIA	$ 1,540.00		
Milk Haul	$ 3,288.29		
Assessment and Advertising	$ 1,068.69		
Haul and Market Culls	$ 61.25		
Building and Fence Repair	$ 1,440.00		
Machinery	$ 960.00		
Utilities	$ 1,040.00		
Custom Hire	$ 512.00		
Cross fencing	$ 1,137.93		
Travel Lane	$ 794.66		
Watering System	$ 1,490.05		
Reduced Revenue:		**Reduced Costs:**	
None		Vet and Medicine	$ 2,680.60
		Grain and Forage Purchases	$ 8,527.36
Total Additional Costs and Reduced Revenue	$ 32,860.74	Total Additional Revenue and Reduced Costs	$ 76,089.96
		Net Change in Net Revenue	**$ 43,229.22**

Table 4.25: Partial Budget for Annual Change in Dairy Case Study Farm Net Returns from the Adoption of Rotational Grazing under the *Without Rotational Grazing* Reference Condition

Partial Budget			
Additional Costs:		**Additional Revenue**	
Haul and Market Culls	$ 11.31	Value of Cull Cows Sold	$ 637.00
Cross fencing	$ 1,137.93		
Watering System	$ 1,158.79		
Reduced Revenue:		**Reduced Costs:**	
Value of Milk Sold	$ 15,225.00	Vet and Medicine	$ 21.70
Patronage Dividends	$ 211.46	Milk Haul	$ 840.00
		Assessment and Advertising	$ 273.00
		Grain and Forage Purchases	$ 20,170.51
Total Additional Costs and Reduced Revenue	$ 17,744.49	Total Additional Revenue and Reduced Costs	$ 21,942.21
		Net Change in Net Revenue	**$ 4,197.72**

Overall, the *with rotational grazing* (*with*) condition generates $43,229.22 (Table 4.24) more than the *before rotational grazing* (*before*) condition and $4,197.72 (Table 4.25) more than the *without rotational grazing* (*without*) condition. The partial budget analysis does not reflect changes in on-farm labor costs nor any changes in financial risk associated with adoption of intensive rotational grazing. These factors could influence the financial attractiveness of rotational grazing.

Revenues increase under the *with* reference condition compared to the *before* reference condition. The increase from the *before* condition is due to both a higher stocking rate and higher productivity per animal unit under the *with* condition. The *without* condition generates higher revenues than the *with* condition. This increase is due to a higher level of productivity per animal under the *without* condition than under the *with* condition. There is a decrease in milk production under rotational grazing for dairy operations because of the reduced use of supplemental feed compared to a conventional system.

Non-forage variable costs increase for almost every category under the *with* condition when compared to the *before* condition. This increase is due to the higher stocking rate, the use of bST and the DHIA record keeping system under the *with* condition. Under the *with* condition, purchases of summer rations increase by $4,026.00, purchases of winter rations increase by $4,782.40, mineral purchases increase by $760.00, milk replacers increase by $349.92, calf grower purchases increase by $488.80, breeding costs increase by $640.00, supplies purchased increase by $2,480.00, milk hauling costs increase by $3,288.29, assessment and advertising costs increase by $1,068.69, the cost of hauling and marketing of cull animals increase by $61.25, building and fence repair costs increase by $1,440.00, machinery costs increase by $960.00, utilities costs increase by $1,040.00, and custom hire costs increases by $512.00. All of these cost increases are driven by the increase in the stocking rate for the dairy case study farm. The costs of bST injections and being part of the DHIA record keeping program are $6,000.75 and $1,540.00, respectively. The only non-forage variable cost to decrease under the *with* condition when compared to the *before* condition is vet and medicine. This cost decreased by $2,680.60 due to reduced footrot preventative health care and treatment costs brought about by the construction of the travel lane and a reduced incidence of twisted-stomach problems due to the increase of forage as a component of the animals' diet (Faulkner, 2000).

Non forage variable costs decrease under the *with* condition when compared to the *without* condition. This decrease is due to two factors. First, vet and medicine costs decrease by $21.70 due to the reduced incidence of twisted-stomach problems. The footrot problems are not present in the *without* condition because the travel lane is present in this condition. Second, the costs of milk hauling and assessment and advertising are reduced by $840.00 and $273.00, respectively due to the decrease in the milk production per animal for the dairy case study farm. These decreases more than offset the slight increase of $11.31 for hauling and marketing cull animals brought about by the increase in number of cull animals sold.

Forage costs decrease considerably under the *with* condition from both the *before* and *without* conditions. Increased forage quality under the *with* condition decreased the need for purchased feed. Thus, purchased feed costs under the *with* condition decreased by $8,527.36 compared to the *before* condition and by $20,170.51 compared to the *without* condition. Pasture maintenance costs remain unchanged throughout the three reference conditions.

Annualized capital costs increased by $1,125.92 (Table 4.23) under the *without* condition due to the addition of the travel lane and the digging of a new well for water compared to the *before* condition. Capital costs increase under the *with* condition compared to the *before* condition due to the addition of the travel lane and well present in the *without* condition, increased cross fencing to create smaller paddocks needed for rotational grazing, and further improvement in the watering system to have water available in every paddock. The costs for the travel lane, the watering system, and the cross fencing under the *with* condition are $794.66, $1,409.05 and $1,137.93 (Table 4.23), respectively. Repair costs for the structural improvements in the *without* and *with* reference conditions are included in the *Added Capital Costs* section of the partial budget.

4.3.2 GHG Emission Results

Identifying the changes in GHG emissions from a change in farm operations requires comparing the current farm situation (with rotational grazing) against a reference condition called a baseline. The net change in GHG emissions -- the difference between the farm operating under rotational grazing and the baseline -- is called additionality. Thus, it is assumed that the farmer would receive payment only for the additional GHG reductions made beyond the reference condition.

Similar to the cow-calf and stocker case study farms, three baselines and two accounting metrics are analyzed. However, additionality results for the dairy case study farm are only presented in GHG emissions per metric ton of milk produced because land for dairy operations varies depending on the required quantity of purchased feeds. These emissions include all emissions used in the growth and processing of the feed given to the animals as well as emissions from the animals themselves. Table 4.26 presents the additionality results per metric ton of milk produced.

Table 4.26 shows GHG emissions per metric ton of product sold. Metric tons of product sold are calculated by taking the total amount of product sold in pounds calculated in the budgets, dividing by 2.2046 to change the amount to kilograms, and dividing this value by 1000 to convert from kilograms to metric tons. The GHG values are obtained by dividing the carbon, nitrous oxide, and methane values generated in PLMS by the number of metric tons of product sold. These values are used to calculate the total carbon equivalent for each baseline scenario per metric ton of product sold. Under the *current* scenario, the dairy case study farm produces 8.845 metric tons of milk per animal annually. The farm produces 8.013 metric tons of milk per animal under the *historical* scenario, and 9.526 metric tons of milk per animal under the *BAU* scenario. The farm should sell 9.072 metric tons of milk per animal under the *performance standard*.

Table 4.26: GHG Emissions (metric tons/yr) Per Metric Ton of Milk Produced for the Dairy Case Study Farm under the Different Baseline Assumptions (Changes from Current Are Listed in Parentheses)

		Baselines		
	Current	Historical	BAU	Performance Standard
Carbon Emissions	-0.004	-0.007 (-0.003)	-0.006 (-0.002)	- 0.012 (-0.008)
Nitrous Oxides	0.001	0.001 (±0.000)	0.001 (±0.000)	0.001 (±0.000)
Methane	0.013	0.014 (+0.001)	0.012 (-0.001)	0.014 (+0.001)
Carbon Equivalent[a]	*0.155*	*0.158 (+0.003)*	*0.148 (-0.007)*	*0.153 (-0.002)*

[a] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix E for an in-depth explanation.

The change in carbon emissions for each baseline scenario from the *current* scenario behaves as expected. The amount of carbon sequestered per metric ton sold is lowest under the *current* scenario at 0.004 Mg per metric ton of product sold. This is due to two factors. First, carbon sequestration is based solely on the land and thus is independent of herd size. Therefore, even with the increased rate of sequestration under rotational grazing, a larger herd of animals can more than offset the gains obtained through rotational grazing. Second, the higher TDN of the pasture under rotational grazing fills a greater percentage of the energy requirement for the animals. This reduces the amount of other feed needed by the animal, and thus the *current* scenario loses the sequestration associated with this outside feed.

The amount of nitrous oxide emissions has leveled out between the *current*, *historical*, *BAU*, and *performance standard* scenarios. Now that herd numbers are discounted, the reduction in the amount of synthetic fertilizer offsets the increase in nitrogen oxides volatilized from the manure. This allows for the nitrous oxide levels to be even par for the different scenarios.

Methane levels under the *current* baseline scenario are 0.013 Mg per metric ton of product sold. These levels are below the *historical* scenario and *performance standard*, yet higher than the *BAU* scenario. This is contrary to what was expected. It was expected that the methane levels for the *current* scenario would be lower than all others. However, PLMS simulates forage management to ensure high quality feed for animals. It assumes that the farm operator would hay at the ideal time, thus keeping a higher level of forage quality in the pasture than might happen in practice under a conventional system. Actual practice will typically fall below that quality. Thus, PLMS may overestimate TDN content of conventional systems. Therefore, sensitivity analysis for methane at a high TDN level for the *current* scenario and a low TDN level for the other scenarios is run below.

At 0.155 Mg per metric ton of product sold, the level of carbon equivalent is still higher for the *current* scenario than the *BAU* scenario and the *performance standard*, though it has moved below the *historical* scenario. This is contrary to what was expected. However, the increased methane level discussed above drives this increase relative to the *BAU* scenario and the *performance standard*.

The study performed sensitivity analysis on the amount of TDN for the case study farm. The study used two levels of TDN to see if the amount of TDN in the forage has a significant impact on the amount of methane emitted from ruminant methanogenesis and the microbial breakdown of animal wastes. The low level of TDN is 58%.[12] This is the level of TDN represented by the *historical* and *BAU* baseline scenarios and the *performance standard*. The high level of TDN is 72%.[13] This is the level of TDN represented by the *current* scenario. Table 4.27 presents a summary of the methane emissions at these different levels per metric ton of milk produced for the dairy case study farm.

Table 4.27: Sensitivity Analysis of TDN on Methane Emissions (metric tons/year) per Metric Ton of Milk Produced for the Dairy Case Study Farm

		Baselines		
	Current (72% TDN)	Historical (58% TDN)	BAU (58% TDN)	Performance Standard[b] (58% TDN)
Carbon Emissions	-0.004	-0.007 (-0.003)	-0.006 (-0.002)	- 0.012 (-0.008)
Nitrous Oxides	0.001	0.001 (±0.000)	0.001 (±0.000)	0.001 (±0.000)
Methane	0.010	0.014 (+0.004)	0.012 (+0.002)	0.022 (+0.012)
Carbon Equivalent[a]	*0.138*	*0.158 (+0.020)*	*0.148 (+0.010)*	*0.199 (+0.061)*

[a] Carbon equivalent is found by the formula [amount of gas · global warming potential · (12/44)]. See Appendix E for an in-depth explanation.
[b] The performance standard TDN level is changed by changing the *Digestible Energy as a Percentage of Gross Energy* value under the Gross Energy Calculation in Appendix D from its default value of 70 to 58.

The sensitivity analysis shows that there is a significant reduction in the amount of methane resulting from assuming an increased amount of TDN associated with an increase in forage quality. Such a change narrows the gap between the carbon equivalent numbers for the farm as a whole under the different scenarios, and puts the per metric ton of product sold carbon equivalent for the *current* scenario well below that of the *historical* and *BAU* scenarios and the *performance standard*.

4.3.3 Net Farm Revenue from GHG Reduction Credits

The amount of financial compensation for selling carbon equivalent reduction credits depends on the baseline and metric from which the change is taken. Table 4.28 presents the potential financial returns from selling GHG reduction credits for the dairy case study farm. Table 4.29 presents the potential financial returns from selling GHG reduction credits for the dairy case study farm using the GHG values from the sensitivity analysis. The price for a metric ton of carbon reduction currently must be estimated as there is currently no market to determine the price. Estimates range from $14-23 per metric ton by the Council of Economic Advisors to $20-30 per metric ton by Sandor and Skees (Antle et al., 2001). A value of $20 per metric ton is used for carbon credits.

[12] Source: Expert opinion from Gordon E. Groover, Virginia Polytechnic Institute and State University.
[13] *ibid.*

Table 4.28: Potential Financial Returns from Selling Carbon Equivalent Reduction Credits for the Dairy Case Study Farm

Baseline	Per Metric Ton of Milk Sold
Historical	$37.15
BAU	n/a
Performance Standard	n/a

For the case study dairy farm, GHG reduction credits could only be sold by the farm operator under the *historical* scenario. Selling credits under this scenario would create additional net revenue of $37.15 (0.003 metric tons of GHG sequestered per metric ton of milk produced · 8.845 metric tons of milk per animal · 70 lactating cows · $20 per metric ton). The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Before Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.09%. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Without Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.88%. This change is higher than under the *Before Rotational Grazing* scenario due to the fact that the overall percent change in net returns for the farm is lower under this budget reference condition.

Table 4.29: Potential Financial Returns from Selling Carbon Equivalent Reduction Credits for the Dairy Case Study Farm Using the GHG values Calculated in the Sensitivity Analysis

Baseline	Per Metric Ton of Milk Sold
Historical	$247.66
BAU	$123.83
Performance Standard	$755.36

For the case study dairy farm, GHG reduction credits could only be sold by the farm operator under each of the three scenarios. Selling credits under these scenarios would create additional net revenue of $123.83 to $755.36. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Before Rotational Grazing* operation to the *With Rotational Grazing* operation by 0.28% to 1.75%. The revenue from the GHGs sold would increase the change in the overall annual net revenue for conversion from the *Without Rotational Grazing* operation to the *With Rotational Grazing* operation by 2.95% to 17.99%. This change is higher than under the *Before Rotational Grazing* scenario due to the fact that the overall change in net returns for the farm is lower under this budget reference condition.

Conversion to rotational grazing has the potential to increase net revenue for each of the three case study farms. However, the sale of GHG emission reduction credits does not seem to be a very large part of these revenues. Even with the adjustments made in the sensitivity analysis, farm operators received less than 3% additional income from the sale of GHG reduction credits in all but one instance. This level of return does not seem likely to convince farmers to attempt to sell GHG reduction credits.

CHAPTER 5: SUMMARY AND CONCLUSIONS

Chapter 5 presents a summary of the results and conclusions which can be drawn from these results. This includes areas where the results can be applied, including policy implications. It also presents areas of future research which were beyond the scope of this study.

5.1 Summary of Results

The results show two important findings. First, rotational grazing has a substantial positive impact on the annual net returns for the farm despite the increase in capital costs associated with converting to a rotational grazing system. This increase was seen for all three case study farms across the three budget reference conditions, as is shown in Table 5.1.

Table 5.1: Summary of Net Returns for the Three Budget Reference Conditions for Each of the Case Study Farms

Case Study Farm	Budget Reference Condition		
	Before Rotational Grazing	Without Rotational Grazing	With Rotational Grazing
Cow-Calf	$ 3,050.53	$ 4,348.68	$ 12,263.45
Stocker	$ 7,192.55	$ -6,123.45	$ 43,874.01
Dairy	$ 47,253.36	$ 86,284.85	$ 90,482.58

The case study farms had two areas that improved in efficiency which allowed them to increase their net returns. First, rotational grazing allowed the farm operators to increase their stocking rates and animal growth for the same-sized farms. These increases meant that more product could be sold, increasing the amount of gross revenue which the farms received. Second, costs decreased for the farms relative to the amount of increase in stocking rate and animal weight under rotational grazing. The decreases in cost further increased net revenue.

Second, rotational grazing has the potential to decrease GHG emissions for the farm under certain baselines. The study found reductions only under the product sold metric for the case study farms. This is to be expected, as the increase in herd size and animal weight for each of the case study farms would outweigh any reductions in GHG emissions for the overall farm. Each case study farm has one baseline which emits more GHG per metric ton of product sold than under the current scenario in the initial run. This baseline is the *historical* for the cow-calf and dairy case study farms, and the *performance standard* for the stocker case study farm.

Returns from the sale of GHG emissions credits under these three baselines are present but small. At the $20 per metric ton of carbon sale price, the farms receive in the range of $37.15 to $76.26 of total additional income. This income results in a less than one percent increase in the amount of overall net revenue change for conversion from a large-pasture conventional system to a multi-paddock rotational grazing system. However, calculating returns using the sensitivity analysis on the TDN level of the forage and assuming a greater increase of TDN from rotational grazing results in increased total additional income ranging from $24.10 to $755.36. Therefore, the conversion to rotational grazing has the potential to increase profitability for cattle farms in the mid-Atlantic region but the potential returns from entering into a GHG credit market seem to make only a small difference in creating additional revenue for these farms.

5.2 Policy Implications

The study indicates two major implications which should be of interest to policymakers. First, carbon sequestration does increase under rotational grazing compared to a conventional grazing system. However, this increase does not necessarily mean that overall GHG levels decrease under rotational grazing compared to conventional grazing systems. Most farm operators will be able to better utilize their pasturelands using a rotational grazing system and will therefore increase the number of animals raised on that pastureland. Such a change will not only bring about an increase in the sequestration of carbon for the pastureland, but will also bring about an increase in the amount of nitrous oxide and methane emissions associated with that pastureland. Because of this fact, gains in sequestration rates may be more than offset by the increases in the other GHG emissions for the farm, and therefore a rotational grazing system will not be able to generate reductions in GHG emissions.

Policymakers need to look at entire system effects of conversion to rotational grazing. For example, nitrous oxide emissions drive most of the change in the overall GHG emissions because nitrous oxide has a carbon equivalent level of 310, while carbon emissions (as carbon dioxide) only have a carbon equivalent level of 1. Therefore, a change in nitrous oxide levels has 310 times the effect in overall GHG emissions that the same change in carbon levels would have. Thus, rather than concentrating exclusively on increased carbon sequestration for cattle operations, a better course of study for future funding and policies should consider nitrous oxide and methane effects as well as carbon sequestration. A small change in nitrous oxide and methane emissions would have a greater impact on total GHG reductions than larger increases in carbon sequestration as carbon dioxide, and would have the possibility of generating higher net financial returns for cattle operations from the selling of GHG reduction credits.

5.3 Areas for Future Research

There are a number of areas in which future research is needed to increase the understanding of how farm operators might be able to generate additional revenue from the selling of GHG reduction credits. These areas can be broken down into two distinct areas: farm behavior issues and measurement issues.

5.3.1 Farm Behavior Issues

There are two main farm behavior issues associated with the conversion to rotational grazing. These are changes in the cost of labor and management and the risk associated with new technology. Labor and management costs include costs associated with improving management skill to the level necessary for successful rotational grazing, the opportunity cost of family labor, and learning curve costs as the new system is implemented. If these costs are taken into account, there could be a change in the attractiveness of conversion to rotational grazing. Risk associated with rotational grazing may also change the attractiveness of this type of grazing system. Studies demonstrate that farm operators are usually risk averse (Bosch and Pease, 2000). Therefore, costs associated with both labor and risk need to be examined to gain a clearer understanding of the full costs associated with rotational grazing.

5.3.2 Measurement Issues

There are a number of measurement issues associated with rotational grazing in both the GHG and overall environmental arenas. The first of these involves the GHG estimation equations used in this study. The study relies on IPCC equations which are designed for estimating the GHG emissions on a country level rather than a farm level. This presents some difficulty in measuring emissions accurately, as these equations may not accurately reflect variations in spatial farm characteristics or farm management practices. An adjustment of these equations to suit farm level activities would be helpful in increasing the accuracy of measurement of on-farm GHG emissions.

The second area where measurement can be improved is in the development of farm-level models of GHG emissions. Further adaptation of PLMS would assist in this effort. Currently, PLMS reports only total emissions for nitrogen, total emissions and emissions per animal for methane, and total carbon sequestered. This reporting method creates some difficulty for the user in trying to examine specific areas of change for each GHG emitted. It would be helpful to future users of PLMS if the system could report GHG emissions in total as well as in the categories used by the IPCC equations such as enteric methane and methane from manure management.

A particular practice which needs to be examined is how the change in forage quality from conversion to rotational grazing may affect GHG emissions for the farm. The sensitivity analysis presented in Chapter 4 demonstrated the effect of change in TDN levels for forage on methane emissions for the farm operation. These values are based on what a logical TDN value for rotational grazing might be. Further study needs to be undertaken to more accurately measure the TDN content of differing types of forage under different climatic conditions in a rotational grazing system. Such studies would be helpful in more accurately estimating GHG emissions for rotational grazing operations and the potential financial contributions which the selling of GHG emission credits could make to cattle farm operations.

The final measurement issue is that of the other environmental benefits which are associated with rotational grazing systems. Rotational grazing systems can have a major impact on water quality. Further study needs to be undertaken to assess the full impacts of rotational grazing on water quality.

Rotational grazing has the potential increase net revenues for cattle farms in the mid-Atlantic region as well as create GHG reduction credits for farm operators. However, there are still many factors which need to be addressed before a true market for these GHG reduction credits can occur.

APPENDIX A: PLMS ENTRIES FOR THE THREE CASE STUDY FARMS

This appendix presents the information entered into PLMS for each case study farm under each reference scenario. These numbers are equivalent for both the initial run and the sensitivity analysis run.

A.1 Cow-Calf Case Study Farm

A.1.1 Cow-Calf Rotational

Operations:
No. of Cows: 35
Frame Size: 5
Target Weaning Weight: 600 lbs
Cull Rates: 2 Cows, 0 Heifers
Calving %: 85
Mortality: 1
Calving Pattern: Nov-Dec and Feb-Mar

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover-orchardgrass
Maintenance: All quantities zero for alfalfa; nitrogen quantity at 4.89, phosphorus quantity at 12.49, gasoline quantity at 0.06, all other quantities zero for red clover-orchardgrass.

Field 1:
Acres: 5.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 10.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: 700-1300 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 2:
Acres: 10.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Northerly

Slope: 10.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 3:
Acres: 5.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 3.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 4:
Acres: 5.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Northerly
Slope: 5.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 5:
Acres: 15.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 8.0 degrees

Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 6:
Acres: 8.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 3.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 7:
Acres: 7.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 3.0 degrees
Field Use: Grazing for all months
Soil Drainage: Moderately Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

A.1.2 Cow-Calf Historical

Operations:
No. of Cows: 23
Frame Size: 4
Target Weaning Weight: 450 lbs
Cull Rates: 2 Cows, 0 Heifers

Calving %: 85
Mortality: 1
Calving Pattern: Nov-Dec and Feb-Mar

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover-orchardgrass
Maintenance: All quantities zero for alfalfa; nitrogen quantity at 40, phosphorus quantity at 40, potash quiantity at 40, gasoline quantity at 0.06, all other quantities zero for red clover-orchardgrass.

Field 1:
Acres: 50.0
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 7.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: 700-1300 ft
Shade: Somewhat Clumped, Somewhat Absent

A.1.3 Cow-Calf BAU

Operations:
No. of Cows: 23
Frame Size: 5
Target Weaning Weight: 525 lbs
Cull Rates: 2 Cows, 0 Heifers
Calving %: 85
Mortality: 1
Calving Pattern: Nov-Dec and Feb-Mar

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover-orchardgrass
Maintenance: All quantities zero for alfalfa; nitrogen quantity at 4.89, phosphorus quantity at 12.49, gasoline quantity at 0.06, all other quantities zero for red clover-orchardgrass.

Field 1:
Acres: 5.0

Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 10.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: 700-1300 ft
Shade: Somewhat Clumped, Somewhat Absent

A.2 Stocker Case Study Farm

A.2.1 Stocker Rotational

Operations:
Lot ID: Lot 1
Purchase Month: March
Number of Animals: 120
Total Weight: 51,000 lbs
Body Condition: 5
Frame Size: 4
Price: $85.0 per hundred weight (This is the default value. Prices were calculated separately in the budgets)
Type: Steers
Target Weight: 761 lbs
Target Sell Month: August

Lot ID: Lot 2
Purchase Month: September
Number of Animals: 250
Total Weight: 75,000 lbs
Body Condition: 5
Frame Size: 4
Price: $85.0 per hundred weight (This is the default value. Prices were calculated separately in the budgets)
Type: Steers
Target Weight: 480 lbs
Target Sell Month: December

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover-orchardgrass

Maintenance: All quantities zero for alfalfa; phosphorus quantity at 14.29, potash quantity at 14.29, gasoline quantity at 0.08, all other quantities zero for red clover-orchardgrass.

Fields 1-10:
Acres: 3.5
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 3.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Fields 11-19:
Acres: 3.5
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 10.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Fields 20-22:
Acres: 3.5
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 15 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other

Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

A.2.2 Stocker Historical

Operations:
Lot ID: Lot 1
Purchase Month: March
Number of Animals: 79
Total Weight: 31,600 lbs
Body Condition: 5
Frame Size: 4
Price: $85.0 per hundred weight (This is the default value. Prices were calculated separately in the budgets)
Type: Steers
Target Weight: 621.76 lbs
Target Sell Month: September

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover-orchardgrass
Maintenance: All quantities zero for alfalfa; phosphorus quantity at 14.29, potash quantity at 14.29, gasoline quantity at 0.08, all other quantities zero for red clover-orchardgrass.

Field 1:
Acres: 25
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 3 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 2:
Acres: 26
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 8 degrees

Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 3:
Acres: 26
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 12 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

A.2.3 Stocker BAU

Operations:
Lot ID: Lot 1
Purchase Month: March
Number of Animals: 120
Total Weight: 51,000 lbs
Body Condition: 5
Frame Size: 4
Price: $85.0 per hundred weight (This is the default value. Prices were calculated separately in the budgets)
Type: Steers
Target Weight: 659 lbs
Target Sell Month: August

Lot ID: Lot 2
Purchase Month: September
Number of Animals: 250
Total Weight: 87,500 lbs
Body Condition: 5
Frame Size: 4

Price: $85.0 per hundred weight (This is the default value. Prices were calculated separately in the budgets)
Type: Steers
Target Weight: 448 lbs
Target Sell Month: December

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover-orchardgrass
Maintenance: All quantities zero for alfalfa; nitrogen quantity at 40.00, phosphorus quantity at 40.00, potash quantity at 40.00, gasoline quantity at 0.08, all other quantities zero for red clover-orchardgrass.

Field 1:
Acres: 25
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 3 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 2:
Acres: 26
Surface pH: 6.8
Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 8 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Field 3:
Acres: 26
Surface pH: 6.8

Forage Crop: Red Clover-Orchardgrass
Aspect: Southerly
Slope: 12 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

A.3 Dairy Case Study Farm

A.3.1 Dairy Rotational

Operations:
Rolling Herd Average: 19,500 lbs
Milk Fat: 0.035
Days in Milk: 305
Cow Mature Weight: 1,300 lbs
Number of Milking Cows: 70
Manure System: Solid Storage
Percent Confined: 25

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover
Maintenance: All quantities zero for alfalfa; red clover seed quantity at 6.00, nitrogen quantity at 0.90, phosphorus quantity at 2.70, potash quantity at 5.40, gasoline quantity at 1.56, all other quantities zero for red clover.

Fields 1-7:
Acres: 3.5
Surface pH: 6.8
Forage Crop: Red Clover
Aspect: Southerly
Slope: 8.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Fields 8-10:
Acres: 1.5
Surface pH: 6.8
Forage Crop: Red Clover
Aspect: Southerly
Slope: 8.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

Fields 11-30:
Acres: 0.55
Surface pH: 6.8
Forage Crop: Red Clover
Aspect: Southerly
Slope: 8.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

A.3.2 Dairy Historical

Operations:
Rolling Herd Average: 17,666 lbs
Milk Fat: 0.035
Days in Milk: 305
Cow Mature Weight: 1,300 lbs
Number of Milking Cows: 54
Manure System: Solid Storage
Percent Confined: 25

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover-tall fescue

Maintenance: All quantities zero for alfalfa; red clover seed quantity at 6.00, nitrogen quantity at 0.90, phosphorus quantity at 2.70, potash quantity at 5.40, gasoline quantity at 1.56, all other quantities zero for red clover- tall fescue.

Field 1:
Acres: 40
Surface pH: 6.8
Forage Crop: Red Clover-Tall Fescue
Aspect: Southerly
Slope: 8.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches
Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: 700-1300 ft
Shade: Somewhat Clumped, Somewhat Absent

A.3.3 Dairy BAU

Operations:
Rolling Herd Average: 21,000 lbs
Milk Fat: 0.035
Days in Milk: 305
Cow Mature Weight: 1,300 lbs
Number of Milking Cows: 70
Manure System: Solid Storage
Percent Confined: 25

Economics:
Forage Budget:
Establishment: All quantities at zero for both alfalfa and red clover
Maintenance: All quantities zero for alfalfa; red clover seed quantity at 6.00, nitrogen quantity at 0.90, phosphorus quantity at 2.70, potash quantity at 5.40, gasoline quantity at 1.56, all other quantities zero for red clover.

Field 1:
Acres: 40
Surface pH: 6.8
Forage Crop: Red Clover
Aspect: Southerly
Slope: 8.0 degrees
Field Use: Grazing for all months
Soil Drainage: Well Drained
Profile Total AWC: 8 inches

Subsurface pH: 6.0
Frost Heave: Medium
Water Availability: Other
Distance to water: <700 ft
Shade: Somewhat Clumped, Somewhat Absent

APPENDIX B: CALCULATION OF GHGS EMBEDDED IN GROWN OR PURCHASED FEED

PLMS does not calculate the GHGs which are embedded in any non-pasture feed such as corn grain, corn silage, hay, and other feeds which would be used to supplement the daily nutritional requirements of the animal. The GHGs embedded in these feeds are direct and indirect nitrous oxides and carbon sequestered. The calculated values are added to the GHG values generated by PLMS to give the total GHG emissions for the case study farm under each baseline condition.

There are four steps in the calculation of the GHG emissions embedded in grown or purchased feed. First, calculate the total number of animal units (AUs) for the case study farm. Second, calculate the total amount of grown or purchased feed needed per AU. Third, calculate the total nitrogen used on the grown or purchased feed. Fourth, calculate the total GHG emissions for the grown or purchased feed. A graphical depiction of these steps is presented in Figure B.1.

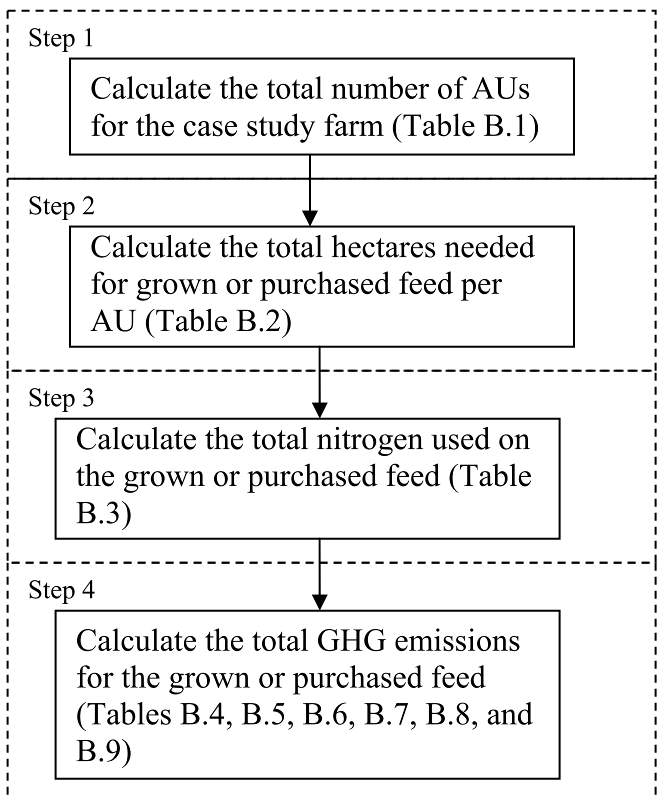

Figure B.1: Schematic for the Calculation of the GHGs embedded in Grown or Purchased Feed

<u>Step 1</u>: Calculate the total number of AUs for the case study farm. The calculation for the cow-calf case study farm under the *current* scenario is presented in Table B.1.

Table B.1: Calculation of the Total Number of Animals for the Cow Calf Case Study Farm under the *Current* Baseline Scenario

Type	Number	Average Weight (kg)	Time On Farm	Total Weight by Type (kg)
Cows	35	521.64	1	18257.28
Bulls	2	771.11	1	1542.23
Calves (steer)[a]	14.88	136.08	0.5	1012.09
Calves (heifer)[a]	14.88	136.08	0.5	1012.09
Weaned to Bred Heifers[b]	5.25	272.16	1	1428.83
Bred to Calving Heifers[c]	5.25	408.24	1	2143.25
		Total Farm Weight		25395.76
		Number of AUs on Farm		55.99

[a] It is assumed that the calf crop will be 50% male and 50% female
[b] This category is named 'Replacement Heifers' in the Farm Management Budgets
[c] This category is named 'Spring Heifers' in the Farm Management Budgets

The total number of cow-calf AUs is determined by combining animal class, weight, and number of head. This is accomplished by obtaining the number of each type of animal (e.g., cows, heifers, bulls, etc.) (Number), average weight of each animal class (Average Weight), and the percentage of the year each animal type is on the farm (Time on Farm)[14]. The product of Number, Time-on-farm, and Average Weight yields the total weight for each type (Total Weight by Type). Total Farm Weight is the sum of all total weights by type. This number is then divided by the weight of one AU, 453.597 kg, to find the number of AUs on the farm. The total number of AUs for the cow-calf case study farm under the *current* baseline scenario is 55.99.

<u>Step 2</u>: Calculate the total hectares needed for grown or purchased feed per AU. The calculation for the cow-calf case study farm under the *current* scenario is presented in Table B.2.

Table B.2: Calculation of the Total Hectares Needed for Grown or Purchased Feed for the Cow-Calf Case Study Farm under the *Current* Baseline Scenario (Percentage of Loss is in Parentheses)

Crop[a]	Amount Fed (kg)[a]	Adjusted for Feeding Loss[b]	Adjusted for Storage Loss[b]	Adjusted for Harvest Loss[c]	Amount Grown (kg)[d]	Amount Needed per AU (kg)	Hectares Needed for Crop per AU
Corn Grain	2467.57	2570.38 (4%)	2855.98 (10%)	2944.31 (3%)	2944.31	52.59	0.006
Corn Silage	0.00	0.00 (3%)	0.00 (6%)	0.00 (4%)	0.00	0.00	0.000
Orchardgrass Hay	31543.14	34662.79 (9%)	38090.98 (9%)	41858.22 (9%)	41858.22	747.64	0.017
Alfalfa Haylage	0.00	0.00 (9%)	0.00 (9%)	0.00 (9%)	0.00	0.00	0.000

[14] Calves' time on farm is not expressed in whole numbers because calves only reside on the farm or in that class for a year or less.

Table B.2 (Cont.)							
Crop[a]	Amount Fed (kg)[a]	Adjusted for Feeding Loss[b]	Adjusted for Storage Loss[b]	Adjusted for Harvest Loss[c]	Amount Grown (kg)[d]	Amount Needed per AU (kg)	Hectares Needed for Crop per AU
Soybean Meal	0.00	0.00 (4%)	0.00 (10%)	0.00 (5%)	0.00	0.00	0.000
					Total Hectares per AU		0.023

[a] Source: These values are "as fed" values. Dry matter (DM) values are as follows: corn grain = 85% DM, corn silage = 35% DM, hay = 89% DM, haylage = 45% DM, and soybean meal = 90% DM.
[b] Source: Martin, P. (1980) and Smith, T. (1997)
[c] Source: Harvest loss for corn grain and soybean meal are from Dr. Robert Grisso, Biological Systems Engineering, Virginia Polytechnic Institute and State University. All others are Martin, P. (1980) and Smith, T. (1997)
[c] The amount grown differs for the soybean meal here due to removal of soybean hulls and oil. This removal accounts for a loss of 26 percent of the total weight of the soybeans (Source: Central Soya)

The hectares are determined by calculating the amount of each type of crop used to feed the animals on the representative farm, adjusting for feeding, storage and harvest losses to find the total amount of the crops grown, finding the amount of each crop needed per AU, and calculating the number of hectares needed for each crop. This is done by obtaining the amount of each crop fed to the animals on the farm from the calculated farm budgets (Amount Fed). This amount must then be adjusted for losses. To calculate the amount of each crop lost during feeding (Adjusted for Feeding Loss), find the percentage loss during feeding and multiply this by the amount fed. To calculate the amount of each crop lost during storage (Adjusted for Storage Loss), find the percentage loss during storage and multiply this by the amount fed plus the feeding loss. To calculate the amount of each crop lost during harvest (Adjusted for Harvest Loss), find the percentage loss of each crop during harvest and multiply this by the sum of the amount fed, feeding loss, and storage loss. The sum of amount fed, feeding loss, storage loss, and harvest loss is equal to the amount of crop originally grown (Amount Grown). This number is divided by the number of AUs on the farm[15] to get the amount of crop needed per AU (Amount Needed per AU). The number of hectares used to grow the amount of each crop needed per AU (Hectares Needed for Crop per AU) is calculated by dividing the amount needed per AU by the amount of that crop that can be grown on one hectare of land. These values are given in Table I-2 of the Virginia DCR publication Virginia Nutrient Management Standards and Criteria (1995). [16] The representative hectares are the sum of the hectares needed for each crop (Total Hectares per AU).

Step 3: Calculate the amount of nitrogen used to fertilize the grown or purchased feeds. Table B.3 presents the calculation for the cow-calf case study farm under the *current* scenario.

[15] This is found by dividing the total weight of the farm by the weight of one representative AU.
[16] It is assumed that all crops are grown on type one or type two soils, thus the midpoint of these two types is used.

Table B.3: Calculation of the Amount of Nitrogen Used to Fertilize Grown or Purchased Feeds

Crop	Hectares/AU	Nitrogen/ Hectare (kg)	Nitrogen/Crop (kg)
Corn Grain	0.006	162.528	0.975
Corn Silage	0.000	174.858	0.000
Orchardgrass Hay	0.017	88.270	1.501
Alfalfa Haylage	0.000	0.000	0.000
Soybean Meal	0.000	0.000	0.000
Total Nitrogen per AU for the Farm			2.476
Total Nitrogen for the Farm			138.631

The calculation is done by taking default nitrogen values for each crop from Virginia Nutrient Management Standards and Criteria Handbook and multiplying those values by the number of hectares needed per AU for each crop found in Table B.2. This gives the total nitrogen per AU for each crop. These values are summed to give the total nitrogen per AU for the farm. This value is then multiplied by the number of AUs found in Table B.1 to find the total nitrogen used for fertilization of grown or purchased feeds for the farm.

Step 4: Calculate the GHG emissions for nitrous oxide and carbon sequestered. Tables B.4, B.5, B.6, B.7, B.8 and B.9 present these calculations.

The first equation calculates direct nitrous oxide from harvested cropland. This includes nitrous oxide from synthetic fertilizers and manure intentionally applied to soils. A description of the equation and its inputs is given in Table B.4 and the calculation of direct nitrous oxide emissions from harvested cropland in Table B.5. PLMS does not include *nitrogen by nitrogen fixing crops*, *nitrogen in crop residues returned to soils*, or the *emission factor for emissions from organic soil cultivation* in its calculation of direct nitrous oxide emissions from agricultural soils, though these are components of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for direct nitrous oxide emissions from agricultural soils, these components of the equation are left out of the performance standard calculation. Upon brief review of these calculations, they seem to have a relatively small effect (less than 3%) on the total, but further examination would be necessary to fully determine the effects of these values.

Table B.4: Equations Used to Calculate Annual Direct Nitrous Oxide Emissions from Agricultural Soils

Calculation	Equation[a]	Source[b]
Nitrogen From Annual Synthetic Fertilizer Application (kg)	$N_{FERT} \cdot (1 - Frac_{GASF})$ Where: N_{FERT} = the total amount of synthetic fertilizer consumed annually $Frac_{GASF}$ = the fraction of the applied nitrogen that volatilizes as NH_3 and NO_X (default value = 0.1)	p. 4.56

Table B.4 (Cont.)		
Calculation	**Equation**[a]	**Source**[b]
Nitrogen From Annual Animal Manure Application (kg)	$\sum_T (N_{(T)} \cdot Nex_{(T)}) \cdot (1 - Frac_{GASM})[1-(Frac_{FUEL-AM} + Frac_{PRP})]$ Where: $\sum_T (N_{(T)} \cdot Nex_{(T)})$ is the amount of animal manure nitrogen produced annually $Frac_{GASM}$ = the amount of animal manure volatilized as NH_3 and NO_X (default value = 0.2) $Frac_{FUEL-AM}$ = the amount of manure burned for fuel $Frac_{PRP}$ = the amount of manure deposited onto soils by grazing livestock	p. 4.56
Annual Direct Nitrous Oxide Emissions from Soils (kg)	$\{[(F_{SN} + F_{AM} + F_{BN} + F_{CR}) \cdot EF_1] + (F_{OS} \cdot EF_2)\}(44/28)$ Where: F_{SN} = Annual amount of synthetic fertilizer nitrogen applied to soils F_{AM} = Annual amount of animal manure nitrogen intentionally applied to soils F_{BN} = Amount of nitrogen by N-fixing crops cultivated annually F_{CR} = Amount of nitrogen in crop residues returned to soils annually EF_1 = Emission factor for emissions from N inputs, kg/kg N input F_{OS} = Area of organic soils cultivated annually EF_2 = Emission factor for emissions from organic soil cultivation, kg/ha/yr	p. 4.54

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table B.5: Calculation of Annual Direct Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Direct N_2O Emissions from Harvested Cropland (kg)	64.037	IPCC Good Practice p. 4.54
N From Synthetic Fertilizer Application	124.768	IPCC Good Practice p. 4.56
Amount Of Synthetic Nitrogen Consumed Annually (kg)	138.631	Expert opinion
Fraction of Applied Nitrogen That Volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
N From Animal Manure Application	3135.300	IPCC Good Practice p. 4.56
Fraction of Manure Volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
Fraction of Manure Burned For Fuel	0.000	Assume that no manure is burned as fuel on Virginia farms

Table B.5 (Cont.)		
Item	**Value**	**Source**
Fraction of Manure Deposited by Grazing Livestock	0.000	Assume that there is no grazing livestock in the crop areas

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The equations calculate direct nitrous oxide emissions from harvested cropland for the cow-calf operation as 64.037 kg/year. The value is reported in the first row of Table B.5 with intermediate equations and input values used below it.

The second equation calculates indirect nitrous oxide from pasture soils and harvested cropland. This includes atmospheric deposition of nitrogen, leaching and runoff of N applied to or deposited on soils, and disposal of sewage nitrogen. A description of this equation and its inputs is located in Table B.6 and the calculation of indirect nitrous oxide from harvested cropland is in Table B.7. PLMS does not include *deposited nitrogen from leaching/runoff* or *nitrous oxide from discharge of human sewage* in its calculation of indirect nitrous oxide emissions from agriculture, though this is a component of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for indirect nitrous oxide emissions from agriculture, this component of the equation is left out in the performance standard calculation. Upon brief review of these calculations, they could have a noticeable impact on the total, but further examination would be necessary to fully determine the effects of these values.

Table B.6: Equations Used to Calculate Annual Indirect Nitrous Oxide Emissions from Agriculture

Calculation	Equation[a]	Source[b]
N_2O From Atmospheric Deposition of N (kg N/yr)	$[(N_{FERT} \cdot Frac_{GASF}) + (\sum_T N_{(T)} \cdot Nex_{(T)}) \cdot Frac_{GASM})] \cdot EF_4$ Where: N_{FERT} = the total amount of synthetic fertilizer applied to soils $Frac_{GASF}$ = the fraction of synthetic N fertilizer that volatilizes as NH_3 and NO_x $\sum_T N_{(T)} \cdot Nex_{(T)}$ = the total amount of manure nitrogen excreted $Frac_{GASM}$ = the fraction of animal manure N that volatilizes as NH_3 and NO_x EF_4 = the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (default value = 0.1)	p. 4.68

Table B.6 (Cont.)		
Calculation	**Equation[a]**	**Source[b]**
Annual Indirect Nitrous Oxide Emissions from Agriculture (kg)	$(N_2O_{(G)} + N_2O_{(L)} + N_2O_{(S)})(44/28)$ Where: $N_2O_{(G)}$ = N_2O from atmospheric deposition of volatilized applied fertilizer and manure, kg N/yr $N_2O_{(L)}$ = N_2O from leaching and runoff of applied fertilizer and manure, kg N/yr $N_2O_{(S)}$ = N_2O from discharge of human sewage N, kg N/yr	p. 4.67

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table B.7: Calculation of Annual Indirect Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Indirect N_2O Emissions From Agriculture (kg)	12.533	IPCC Good Practice p. 4.67
N_2O From Atmospheric Deposition of N (kg N/yr)	7.975	IPCC Good Practice p. 4.68
Emission Factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates indirect nitrous oxide from harvested cropland for the cow-calf operation as 12.533 kg/year. This value is reported in the first row of Table B.7 with intermediate equations and input values used below it.

The third calculation, carbon sequestered by harvested cropland, does not use the IPCC equations. They instead use equations provided by Dr. Hope Phetteplace of Colorado State University. Table B.8 includes a description of the equation for harvested cropland. Table B.9 presents the calculation of carbon sequestered by harvested cropland.

Table B.8: Equation Used to Calculate Annual Carbon Sequestered by Harvested Cropland

Calculation	Equation	Source[a]
Carbon Sequestered (Mg/yr)	$.10 \cdot Ha \cdot AUs$ Where: Ha = Area of soil for crops needed to feed one AU in hectares AUs = The number of AUs in the cow-calf operation	Hope Phetteplace

[a] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table B.9: Calculation of Annual Sequestered Carbon for Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Carbon Sequestered (Mg/yr)	0.129	Hope Phetteplace

Table B.9 (Cont.)		
Item	**Value**	**Source**
Number of Hectares per AU	0.023	Calculated from representative hectare (see Table 3 above)
Number of AUs in the Cow-Calf Operation	55.99	Calculated from soil class carrying capacity (see Table 1 above)
Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002		

The performance standard calculates carbon sequestered for harvested cropland for the cow-calf operation as 0.129 Mg/year or 129 kg/year. This value is reported in the first row of Table B.9 with input values below it.

Table B.10 presents a summary of the GHG emissions embedded in grown or purchased feeds under each of the three baselines for each case study farm.

Table B.10: Summary of the GHG Emissions Embedded in Grown or Purchased Feeds for Each of the Baseline Scenarios for the Three Case Study Farms

Case Study Farm	Baseline	Nitrous Oxide (kg)[a]	Carbon Emitted (kg)
Cow-Calf	Current	76.570	129.000
Cow-Calf	Historical	49.371	185.000
Cow-Calf	BAU	51.312	194.000
Stocker	Current	152.979	2945.000
Stocker	Historical	37.120	366.000
Stocker	BAU	245.031	5286.000
Dairy	Current	271.731	2033.000
Dairy	Historical	249.507	3359.000
Dairy	BAU	323.436	4354.000

[a] This is the sum of direct and indirect emissions from harvested cropland.

These values are added to the emissions embedded in pasture soils calculated by PLMS to arrive at the overall change in GHG emissions for the case study farms under the three baseline scenarios.

APPENDIX C: THE PERFORMANCE STANDARD FOR A COW-CALF OPERATION

The performance standard estimates GHG emissions for well managed conventional grazing operations. Performance standards are defined for soil classes. The performance standard calculations are based on recommendations and technical information from NRCS, Virginia DCR, and Virginia Agricultural Extension Farm Management Budgets. GHG calculations are produced by using IPCC equations (IPCC, 2001). These calculations are based on grassland/pastureland land use by a farm enterprise for a single year.

C.1 Calculation of GHG Emissions

The performance standard is reported as net GHG emissions per acre and per unit of product for a region. Net GHG missions include methane, nitrous oxide, and carbon dioxide. Figure C.1 below gives a graphical depiction of the calculation of the performance standard. Details of the calculation are discussed in the subsequent sections of this appendix.

The first step in the creation of the performance standard is to calculate the animal carrying capacity for each soil class. This is a required input in the calculation of enteric methane, methane from manure management, and nitrous oxide from manure management by the IPCC equations. The second step is to create a representative animal for the region. This representative animal combines the different classes of animals (cows, calves, replacement heifers, etc.) and is used to calculate gross energy, a second input needed in calculating enteric methane, methane from manure management, and nitrous oxide from manure management by the IPCC equations. Step three is to create representative hectares to account for the feed either produced by the farm or purchased from an outside source. Step four combines animal carrying capacity from step one, the representative animal from step two, and other regional factors into the IPCC equations to estimate the net GHG emissions for each soil class. The final step converts net GHGs for each soil class into carbon equivalents, creating the performance standard for each soil class.

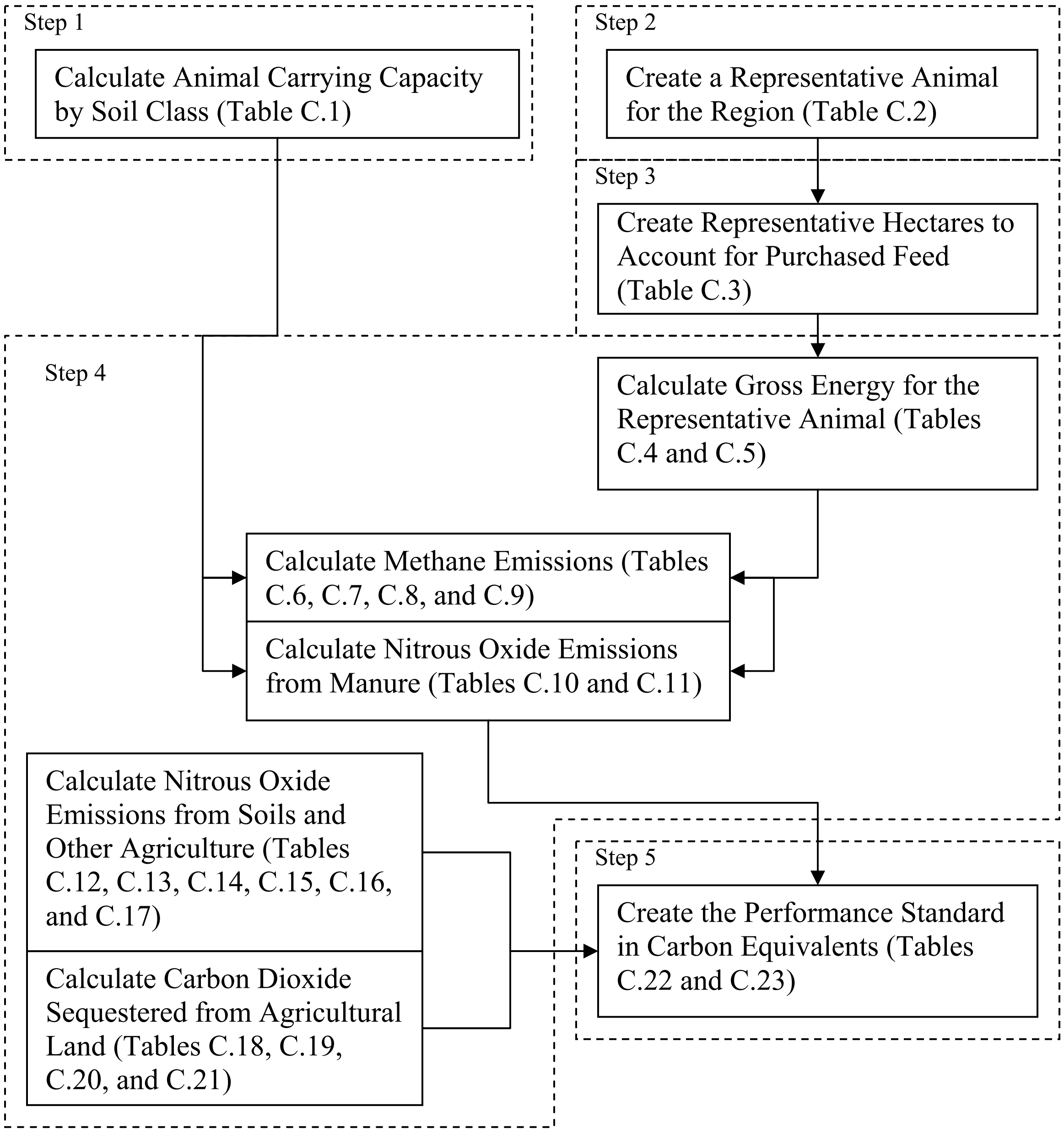

Figure C.1: Schematic for Net GHG Performance Standard for a Cow-Calf Operation

Step 1: Calculate the animal carrying capacity of each soil class. Carrying capacity is expressed in the number of animal units[17] (AU) per hectare; and the inverse of the carrying capacity defines the number of hectares needed to sustain one AU. These calculations are based on recommended practices for a conventional grazing system. Table I-2 on page 23 of Virginia DCR publication Virginia Nutrient Management Standards and Criteria (1995) is used to define carrying capacity for each soil class. DCR expresses carrying capacities in a range of values, and for the purpose of this method the mid-point was assumed to be the point estimate. Since the points were expressed in acres, it was necessary to convert them to hectares for use in the IPCC equations. Table

[17] An AU is defined as a single 453.597 kg (1000 lb) animal.

C.1 below contains the calculations for soil classes I-IV. Classes above IV are not included because they are not considered suitable for grazing.

Table C.1: Carrying Capacity by Soil Class

Land Class	AU's Supported/hectare	Hectares needed/AU
I	2.471	0.405
II	1.900	0.526
III	1.075	0.931
IV	0.514	1.943

Source: Virginia Nutrient Management Standards and Criteria, 1995

Step 2: Create a representative AU for the region. An example for a representative cow-calf AU is given in Table C.2:

Table C.2: Creation of a Representative Cow-Calf AU for the Region

Type	Number[a]	Average Weight (kg)[b]	Time On Farm	Total Weight by Type (kg)	Percent of Total Farm Weight	Weight By Type in Representative Animal (kg)
Cows	85	521.64	1	44339.11	71%	322.17
Bulls	4	771.11	1	3084.46	5%	22.41
Calves (steer)[c]	45	106.60	0.5	2398.39	4%	17.43
Calves (heifer)[c]	45	106.60	0.5	2398.39	4%	17.43
Weaned to Bred Heifers[d]	15	272.16	1	4082.37	7%	29.66
Bred to Calving Heifers[e]	15	408.24	1	6123.56	10%	44.49
		Total Farm Weight		62426.29	Representative AU	453.59

[a] Source: Virginia Cooperative Extension Farm Management Budgets, Beef Cows Calving in Spring, Hay Ration

[b] Source: Virginia Cooperative Extension Farm Management Budgets, Beef Cows Calving in Spring, Hay Ration and Expert Opinion from Gordon E. Groover, Virginia Polytechnic Institute and State University

[c] It is assumed that the calf crop will be 50% male and 50% female

[d] This category is named 'Replacement Heifers' in the Farm Management Budgets

[e] This category is named 'Spring Heifers' in the Farm Management Budgets

The representative cow-calf AU is based on stocking rates and weights provided by Virginia Cooperative Extension Farm Management Budget number 8, Beef Cows Calving in Spring, Hay Ration. These values provide a "representative farm" for the region. This representative cow-calf farm is a 101.17 ha (250 acre), 100 head farm using a hay ration. The farm has a 90% calf crop, a 15% heifer replacement rate, a 15% annual culling rate, and a 1% annual death loss.

The representative cow-calf AU is determined by combining animal class, weight, and number of head from this representative farm into a composite cow-calf AU. This is accomplished by obtaining the number of each type of animal (e.g., cows, heifers, bulls, etc.) (Number), average weight of each animal class (Average Weight), and the percentage of the year each animal type is on the farm (Time on Farm)[18]. The product

[18] Calves' time on farm is not expressed in whole numbers because calves only reside on the farm or in that class for a year or less.

of Number, Time-on-farm, and Average Weight yields the total weight for each type (Total Weight by Type). Total Farm Weight is the sum of all total weights by type. To obtain the percentage of total farm weight, each type is divided by total farm weight and expressed in a percentage. This percentage equals the percent of representation each class has in the representative cow-calf AU. Each percent is then multiplied by 453.597 kg to find the proportional makeup of the representative cow-calf AU (Weight by Type in Representative AU). The representative cow-calf AU is the sum of these weights.

Step 3: Create representative hectares to account for the GHG emissions embedded in the growing of home-raised and purchased feed. An example of representative hectares for a cow-calf operation is given in Table C.3:

Table C.3: Creation of Representative Hectares for Growing of Feed (Percentage of Loss is in Parentheses)

Crop[a]	Amount Fed (kg)[a]	Adjusted for Feeding Loss[b]	Adjusted for Storage Loss[b]	Adjusted for Harvest Loss[c]	Amount Grown (kg)	Amount Needed per AU (kg)	Hectares Needed for Crop per AU
Corn Grain	16148.05	16820.89 (4%)	18689.88 (10%)	19267.91 (3%)	19267.91	140.00	0.015
Orchardgrass Hay	206205.21	226599.13 (9%)	249010.03 (9%)	273637.40 (9%)	273637.40	1988.28	0.045
					Total Hectares per AU		0.060

[a] Source: Virginia Cooperative Extension Farm Management Budgets, Beef Cows Calving in Spring, Hay Ration. These values are "as fed" values. Dry matter (DM) values are as follows: corn grain = 85% DM and hay = 89% DM.
[b] Source: Martin, P. (1980) and Smith, T. (1997)
[c] Source: Harvest loss for corn grain is from Dr. Robert Grisso, Biological Systems Engineering, Virginia Polytechnic Institute and State University. All others are Martin, P. (1980) and Smith, T. (1997)

The representative hectares are determined by calculating the amount of each type of crop used to feed the animals on the representative farm, adjusting for feeding, storage and harvest losses to find the total amount of the crops grown, finding the amount of each crop needed per representative AU, and calculating the number of hectares needed for each crop. This is done by obtaining the amount of each crop fed to the animals on the farm from the Virginia Cooperative Extension Farm Management Budgets (Amount Fed). This amount must then be adjusted for losses. To calculate the amount of each crop lost during feeding (Adjusted for Feeding Loss), find the percentage loss during feeding and multiply this by the amount fed. To calculate the amount of each crop lost during storage (Adjusted for Storage Loss), find the percentage loss during storage and multiply this by the amount fed plus the feeding loss. To calculate the amount of each crop lost during harvest (Adjusted for Harvest Loss), find the percentage loss of each crop during harvest and multiply this by the sum of the amount fed, feeding loss, and storage loss. The sum of amount fed, feeding loss, storage loss, and harvest loss is equal to the amount of crop originally grown (Amount Grown). This number is divided by the number of representative AUs on the farm[19] to get the amount of crop needed per representative AU (Amount Needed per AU). The number of hectares used to grow the amount of each crop needed by the representative AU (Hectares Needed for Crop per AU) is calculated by dividing the amount needed per AU by the amount of that crop that

[19] This is found by dividing the total weight of the farm by the weight of one representative AU.

can be grown on one hectare of land. These values are given in Table I-2 of the Virginia DCR publication Virginia Nutrient Management Standards and Criteria (1995).[20] The representative hectares are the sum of the hectares needed for each crop (Total Hectares per AU).

Step 4: Use the calculated animal carrying capacity, representative AU, representative hectares, and other regional factors to calculate gross energy, enteric methane, methane from manure management, nitrous oxide from manure management, direct nitrous oxide from agricultural soils, indirect nitrous oxide from agriculture, and carbon sequestered. Gross energy for the representative AU is the first factor calculated. The daily gross energy equation and its components are listed in Table C.4 and Table C.5 summarizes the specific inputs to the gross energy equation.

Table C.4: Equations Used to Calculate Daily Gross Energy Required for the Representative AU

Calculation	**Equation**	**Source[a]**
Net Energy Required By Animal For Maintenance in mega Joules (MJ) per day	$Cf_i \cdot (Weight)^{0.75}$ Where: Cf_i = a coefficient for the animal category (0.322 for non-lactating cattle and 0.335 for lactating cattle) Weight = the live weight of the animal in kg	p. 4.13
Net Energy For Activity (MJ/day)	$C_a \cdot NE_m$ Where: C_a = a coefficient corresponding to the animal's feeding situation (stall = 0, pasture = 0.17, and grazing large areas = 0.36) NE_m = the net energy required by the animal for maintenance	p. 4.14
Net Energy For Growth (MJ/day)	$4.18 \cdot \{0.0635 \cdot [0.891 \cdot (BW \cdot 0.96) \cdot (478/(C \cdot MW))]^{0.75} \cdot (WG \cdot 0.92)^{1.097}\}$ Where: BW = the live body weight of the growing animal C = a gender coefficient (females = 0.8, castrates = 1.0, and bulls = 1.2) MW = the mature weight of the animal WG = the daily weight gain of the animal in kg	p. 4.15
Net Energy Due To Weight Loss for Lactating Dairy Cows (MJ/day)	$19.7 \cdot$ Weight loss Where: Weight loss = the animal weight loss per day in kg	p.4.16
Net Energy Due To Weight Loss for Other Cattle (MJ/day)	$NE_g \cdot (-0.8)$ Where: NE_g = the net energy needed for growth in MJ/day	p. 4.17

[20] It is assumed that all crops are grown on type one or type two soils, thus the midpoint of these two types is used.

Table C.4 (Cont.)		
Calculation	**Equation**	**Source**[a]
Net Energy For Lactation (MJ/day)	kg milk/day · (1.47 + (0.4 · Fat)) Where: Fat = the fat content of milk by percentage	p. 4.17
Net Energy For Work (MJ/day)	$0.10 \cdot NE_m \cdot$ hours of work per day Where: NE_m = net energy required by the animal for maintenance	p. 4.18
Net Energy For Pregnancy (MJ/day)	$C_{pregnancy} \cdot NE_m$ Where: $C_{pregnancy}$ = a pregnancy coefficient (cattle = 0.10) NE_m = the net energy required by the animal for maintenance	p. 4.18
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	$1.123 – (4.092 \cdot 10^{-3} \cdot DE) + [1.126 \cdot 10^{-5} \cdot (DE)^2] – (25.4/DE)$ Where: DE = digestible energy expressed as a percentage of gross energy	p. 4.19
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	$1.164 – (5.16 \cdot 10^{-3} \cdot DE) + (1.308 \cdot 10^{-5} \cdot (DE)^2) – (37.4/DE)$ Where: DE = digestible energy expressed as a percentage of gross energy	p. 4.19
Gross Energy (MJ/day)	$\{[(NE_m + NE_{mobilized} + NE_a + NE_l + NE_w + NE_p)/ (NE_{ma}/DE)] + [NE_g /(NE_{ga}/DE)]\}/(DE/100)$ Where: NE_m = net energy required by the animal for maintenance, MJ/day $NE_{mobilized}$ = net energy due to weight loss, MJ/day NE_a = net energy for animal activity, MJ/day NE_l = net energy for lactation, MJ/day NE_w = net energy for work, MJ/day NE_p = net energy required for pregnancy, MJ/day NE_{ma}/DE = ratio of net energy available in a diet for maintenance to digestible energy consumed NE_g = net energy needed for growth, MJ/day NE_{ga}/DE = ratio of net energy available for growth in a diet to digestible energy consumed DE = digestible energy expressed as a percentage of gross energy	p. 4.20

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table C.5: Summary of Inputs for Calculation of Daily Gross Energy Requirements for the Representative AU

Equation	Item	Value	Source
Net Energy for Maintenance	Animal category coefficient[a]	0.331	IPCC Good Practice Table 4.4
	Weight of animal (kg)	453.597	One animal unit assumption
Net Energy For Activity	Feeding situation coefficient	0.170	IPCC Good Practice Table 4.5
Net Energy For Growth	Gender coefficient[b]	0.864	IPCC Good Practice p. 4.15
	Live body weight of a growing animal (kg)	125.020	One animal unit assumption
	Daily weight gain (kg/day)	0.356	Expert opinion
Net Energy Due to Weight Loss For Lactating Dairy Cows	Weight loss (kg/day)	0.000	Assumed to be zero since this is for a beef operation
Net Energy For Lactation	Milk produced (kg/day)	5.897	Robert E. Taylor p. 294
	Fat content of milk (%)	4.000	Robert E. Taylor p. 294
Net Energy For Work	Hours of work per day	0.000	Assumed to be zero since cattle are not draught animals in Virginia
Net Energy For Pregnancy	Pregnancy coefficient	0.100	IPCC Good Practice Table 4.7
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	Digestible energy expressed as a percentage of gross energy	70.000	Expert opinion
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	Digestible energy expressed as a percentage of gross energy	70.000	Expert opinion

[a] This value is adjusted to reflect that only 71% of the representative AU is lactating
[b] This value is adjusted to reflect that 91% of the representative AU is female and 9% is male
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Educated opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
Robert E. Taylor = Taylor, Robert E. Beef Production and Management Decisions, Second Edition. Macmillan, New York, 1994.

Gross energy is used as a variable in the second and third equations to calculate enteric methane and methane from manure management.

The equations for calculating annual enteric methane and its components are given in Table C.6. The first calculation, the *Emission Factor for Enteric Methane*, is used in the second calculation, *Annual Enteric Methane Emissions*. A summary of inputs for the calculation of enteric methane is given in Table C.7.

The equation for methane from manure management and its components are listed in Table C.8. In this table, the first calculation, the *Volatile Solid Excretion Rate*, is an input in the second calculation, *Emissions Factor from Manure Management*. Likewise, *Emissions Factor from Manure Management* is an input in the final calculation, *Annual Methane Emissions from Manure Management*. In this study, the manure management system, *j*, is defined as a system where the manure is left where it is deposited by the animal. Table C.9 presents a summary of the inputs used to calculate methane from manure management.

Table C.6: Equations Used to Calculate Annual Enteric Methane Emissions for the Representative AU

Calculation	**Equation**	**Source**[a]
Enteric Methane Emission Factor	$(GE \cdot Y_m \cdot 365\ days/year)/\ (55.65\ MJ/Kg\ CH_4)$ Where: GE = gross energy intake in MJ/head/day Y_m = a methane conversion rate which is the fraction of gross energy in feed converted to methane (feedlot fed cattle = 0.04 ± 0.005 and all other cattle = 0.06 ± 0.005)	p. 4.26
Annual Enteric Methane Emissions in Kilograms (kg)	EF_i x POP Where: EF_i = emission factor for the specific population, kg/head/year POP = the number of animals, head	p. 4.25

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table C.7: Summary of Inputs for the Calculation of Annual Enteric Methane Emissions for the Representative AU

Equation	**Item**	**Value**	**Source**
Methane Emissions From a Representative Animal	Number of animals	Varies by soil class	Calculated from soil class (See Table 1 Above)
Methane Emission Factor	Methane conversion rate	0.060	IPCC Good Practice Table 4.8

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

Table C.8: Equations Used to Calculate Annual Methane Emissions from Manure Management

Calculation	**Equation**	**Source**[a]
Volatile Solid Excretion Rate (kg/day)	$(GE - DEI + 0.04 \cdot GE)/20.1$ Where: GE = gross energy intake in MJ/head/day DEI = the digestible energy intake, equal to $GE \cdot DE$ where DE is digestible energy expressed as a percentage of gross energy	Hope Phetteplace[b]

Table C.8 (Cont.)		
Calculation	**Equation**	**Source**[a]
Emission Factor from Manure Management (kg)	$(VS \cdot 365 \text{ days/yr}) \cdot (B_{oi} \cdot 0.67 \text{ kg/m}^3) \cdot \sum_{jk} MCF_{jk} \cdot MS_{ijk}$ Where: VS = the daily amount of volatile solids excreted by the representative animal B_{oi} = the maximum methane producing capacity for manure produced by the representative animal (dairy cattle = 0.24, all non-dairy cattle = 0.17) MCF_{jk} = the methane conversion factor for each manure management system *j* by climate region *k* (temperate zone pasture/range/paddock = 0.015) MS_{ijk} = the fraction of animal species/category *i*'s manure using manure system *j* in climate region *k*	p. 4.34
Annual Methane Emissions from Manure (kg)	$EF_{i,m}$ x POP Where: $EF_{i,m}$ = emission factor for manure (m) for the specific population, kg/head/yr POP = the number of animals, head	p. 4.30

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.
[b] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table C.9: Summary of Inputs for the Calculation of Annual Methane Emissions from Manure Management

Equation	Item	Value	Source
Methane Emission Factor from Manure Management	Maximum methane producing capacity for manure produced by an animal	0.170	IPCC Reference Manual Appendix B
	Methane conversion factors for manure management system	0.015	IPCC Good Practice Table 4.10
	Fraction of animals' manure handled by manure system	1.000	Assume all manure is allowed to lie where deposited by animal
Annual Methane Emissions from Manure	Number of animals	Varies by soil class	Calculated from soil class (See Table 1 Above)

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The fourth equation calculates nitrous oxide from manure management. Table C.10 supplies the equation and its components for nitrous oxide. In this equation, S is defined as a management system where the manure is allowed to lay where it is deposited and T is defined as cattle. Table C.11 includes a summary of the inputs used in the calculation of nitrous oxide from manure management.

Table C.10: Equations Used to Calculate Annual Nitrous Oxide Emissions from Manure Management

Calculation	Equation	Source[a]
Annual Nitrous Oxide Emissions from Manure in kg	$(\sum_{(S)} \{[\sum_{(T)} ((N_{(T)})(Nex_{(T)})(MS_{(T,S)})] EF_{3(S)}\})(44/28)$ Where: $N_{(T)}$ = Number of head of livestock species/category *T* $Nex_{(T)}$ = Annual average N excretion per head of species/category *T* (non-dairy cattle = 70 and dairy cattle = 100) $MS_{(T,S)}$ = Fraction of the total annual excretion for each livestock species category *T* that is managed in manure management system *S* $EF_{3(S)}$ = N_2O emission factor for manure system *S* (pasture/range/paddock = 0.02) S = Manure management system T = Species/category of livestock	p. 4.42

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table C.11: Summary of Inputs Used in the Calculation of Annual Nitrous Oxide Emissions from Manure Management

Equation	Item	Value	Source
Nitrous Oxide Emissions From Manure Management	Number of animals	Varies by soil class	Calculated from soil class (See Table 1 Above)
	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of the total annual excretion for each livestock species category *T* that is managed in manure management system *S*	1.000	Assume all manure is managed by a single system (all manure is left where it is deposited by the animal)
	Emission factor for manure management system	0.020	IPCC Good Practice Table 4.12

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The fifth equation calculates direct nitrous oxide from pasture soils and harvested cropland. This includes nitrous oxide from synthetic fertilizers and manure intentionally applied to soils. A description of the equation and its inputs is given in Table C.12 and a summary of inputs used in the calculation of direct nitrous oxide emissions from pasture soils in Table C.13. Table C.14 presents a summary of inputs used in the calculation of nitrous oxide emissions from harvested cropland. PLMS does not include *nitrogen by nitrogen fixing crops*, *nitrogen in crop residues returned to soils*, or the *emission factor for emissions from organic soil cultivation* in its calculation of direct nitrous oxide emissions from agricultural soils, though these are components of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for direct nitrous oxide emissions from agricultural soils, these components of the equation are left out of the performance standard calculation. Upon brief review of these calculations, they seem to have a relatively small effect (less than 3%) on the total, but further examination would be necessary to fully determine the effects of these values.

Table C.12: Equations Used to Calculate Annual Direct Nitrous Oxide Emissions from Agricultural Soils

Calculation	Equation[a]	Source[b]
Nitrogen From Annual Synthetic Fertilizer Application (kg)	$N_{FERT} \cdot (1 - Frac_{GASF})$ Where: N_{FERT} = the total amount of synthetic fertilizer consumed annually $Frac_{GASF}$ = the fraction of the applied nitrogen that volatilizes as NH_3 and NO_X (default value = 0.1)	p. 4.56
Nitrogen From Annual Animal Manure Application (kg)	$\sum_T (N_{(T)} \cdot Nex_{(T)}) \cdot (1- Frac_{GASM})[1-(Frac_{FUEL-AM} + Frac_{PRP})]$ Where: $\sum_T (N_{(T)} \cdot Nex_{(T)})$ is the amount of animal manure nitrogen produced annually $Frac_{GASM}$ = the amount of animal manure volatilized as NH_3 and NO_X (default value = 0.2) $Frac_{FUEL-AM}$ = the amount of manure burned for fuel $Frac_{PRP}$ = the amount of manure deposited onto soils by grazing livestock	p. 4.56
Annual Direct Nitrous Oxide Emissions from Soils (kg)	$\{[(F_{SN} + F_{AM} + F_{BN} + F_{CR}) \cdot EF_1] + (F_{OS} \cdot EF_2)\}(44/28)$ Where: F_{SN} = Annual amount of synthetic fertilizer nitrogen applied to soils F_{AM} = Annual amount of animal manure nitrogen intentionally applied to soils F_{BN} = Amount of nitrogen by N-fixing crops cultivated annually F_{CR} = Amount of nitrogen in crop residues returned to soils annually EF_1 = Emission factor for emissions from N inputs, kg/kg N input F_{OS} = Area of organic soils cultivated annually EF_2 = Emission factor for emissions from organic soil cultivation, kg/ha/yr	p. 4.54

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table C.13: Summary of Inputs Used in the Calculation of Annual Direct Nitrous Oxide Emissions from Pasture Soils

Equation	Item	Value	Source
Nitrogen From Synthetic Fertilizer Application	Amount of synthetic nitrogen consumed annually	56.440	Expert opinion
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19

Table C.13 (Cont.)			
Equation	**Item**	**Value**	**Source**
Nitrogen From Animal Manure Application	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Fraction of manure burned for fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
	Fraction of manure deposited by grazing livestock	1.000	Assume all manure is deposited by grazing livestock

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

Table C.14: Summary of Inputs Used in the Calculation of Annual Direct Nitrous Oxide Emissions from Harvested Cropland

Equation	**Item**	**Value**	**Source**
Nitrogen From Synthetic Fertilizer Application	Amount of synthetic nitrogen consumed annually (kg)	Varies by soil class	Calculated from Virginia Nutrient Management Standards and Criteria Handbook[a]
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
Nitrogen From Animal Manure Application	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Fraction of manure burned for fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
	Fraction of manure deposited by grazing livestock	0.000	Assume that there is no grazing livestock in the crop areas

[a] This was calculated by taking default nitrogen values for each crop from Virginia Nutrient Management Standards and Criteria Handbook, multiplying those values by the number of hectares needed for each crop found in Table C.3, summing the calculated values together, and multiplying by the soil carrying capacity per hectare found in Table C.1
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The sixth equation calculates indirect nitrous oxide from pasture soils and harvested cropland. This includes atmospheric deposition of nitrogen, leaching and runoff of N applied to or deposited on soils, and disposal of sewage nitrogen. A description of this equation and its inputs is located in Table C.15 and a summary of inputs used in the calculation of indirect nitrous oxide from pasture soils is in Table C.16. Table C.17 gives a summary of inputs used in the calculation of indirect nitrous oxide from harvested cropland. PLMS does not include *deposited nitrogen from leaching/runoff* or *nitrous oxide from discharge of human sewage* in its calculation of indirect nitrous oxide emissions from agriculture, though this is a component of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for indirect nitrous oxide emissions from agriculture, this component of the equation is left out in the performance standard calculation. Upon brief review of these calculations, they could have a noticeable impact on the total, but further examination would be necessary to fully determine the effects of these values.

Table C.15: Equations Used to Calculate Annual Indirect Nitrous Oxide Emissions from Agriculture

Calculation	Equation[a]	Source[b]
N_2O From Atmospheric Deposition of N (kg N/yr)	$[(N_{FERT} \cdot Frac_{GASF}) + (\sum_T N_{(T)} \cdot Nex_{(T)}) \cdot Frac_{GASM})] \cdot EF_4$ Where: N_{FERT} = the total amount of synthetic fertilizer applied to soils $Frac_{GASF}$ = the fraction of synthetic N fertilizer that volatilizes as NH_3 and NO_x $\sum_T N_{(T)} \cdot Nex_{(T)}$ = the total amount of manure nitrogen excreted $Frac_{GASM}$ = the fraction of animal manure N that volatilizes as NH_3 and NO_x EF_4 = the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (default value = 0.1)	p. 4.68
Annual Indirect Nitrous Oxide Emissions from Agriculture (kg)	$(N_2O_{(G)} + N_2O_{(L)} + N_2O_{(S)})(44/28)$ Where: $N_2O_{(G)}$ = N_2O from atmospheric deposition of volatilized applied fertilizer and manure, kg N/yr $N_2O_{(L)}$ = N_2O from leaching and runoff of applied fertilizer and manure, kg N/yr $N_2O_{(S)}$ = N_2O from discharge of human sewage N, kg N/yr	p. 4.67

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table C.16: Summary of Inputs Used in the Calculation of Annual Indirect Nitrous Oxide Emissions from Pasture Soils

Equation	Item	Value	Source
Nitrous Oxide From Atmospheric Deposition of Nitrogen	Amount of synthetic nitrogen consumed annually	56.440	Expert opinion
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Emission factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

Table C.17: Summary of Inputs Used in the Calculation of Annual Indirect Nitrous Oxide Emissions from Harvested Cropland

Equation	Item	Value	Source
Nitrous Oxide From Atmospheric Deposition of Nitrogen	Amount of synthetic nitrogen consumed annually	Varies by soil class	Calculated from Virginia Nutrient Management Standards and Criteria Handbook[a]
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Emission factor	0.010	IPCC Good Practice Table 4.18

[a] This was calculated by taking default nitrogen values for each crop from Virginia Nutrient Management Standards and Criteria Handbook, multiplying those values by the number of hectares needed for each crop found in Table B.2, and summing the calculated values together.
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The final calculations, carbon sequestered by pasture soils and carbon sequestered by harvested cropland, do not use the IPCC equations. They instead use equations provided by Dr. Hope Phetteplace of Colorado State University. Table C.18 includes a description of the equation for pasture soils and its inputs. Table C.19 includes a description of the equation for harvested cropland. Table C.20 contains a summary of the inputs used in the calculation of carbon sequestered by pasture soils. Table C.21 presents a summary of inputs used in the calculation of carbon sequestered by harvested cropland.

Table C.18: Equation Used to Calculate Annual Carbon Sequestered by Pasture Soils

Calculation	Equation	Source[a]
Carbon Sequestered (Mg/yr)	.12 · Ha Where: Ha = Area of soil for pastureland/rangeland in hectares	Hope Phetteplace

[a] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table C.19: Equation Used to Calculate Annual Carbon Sequestered by Harvested Cropland

Calculation	Equation	Source[a]
Carbon Sequestered (Mg/yr)	.10 · Ha · AUs Where: Ha = Area of soil for crops needed to feed one representative AU in hectares AUs = The number of representative AUs per hectare in the cow-calf operation	Hope Phetteplace

[a] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table C.20: Summary of the Inputs Used in the Calculation of Annual Carbon Sequestration by Pasture Soils

Equation	Item	Value	Source
Carbon Sequestered	Area of soil for pastureland/rangeland for in hectares	Varies by soil class	Calculated from soil class (See Table 1 Above)

Table C.21: Summary of the Inputs Used in the Calculation of Annual Carbon Sequestration by Harvested Cropland

Equation	Item	Value	Source
Carbon Sequestered	Area of soil for crops needed to feed one representative AU in hectares	0.061	Calculated from representative hectare (see Table 3 above)
	Number of representative AUs per hectare in the cow-calf operation	Varies by soil class	Calculated from soil class carrying capacity (see Table 1 above)

Step 4: Convert the net GHG emissions to their carbon equivalents to find the total carbon equivalent for each soil class. The equation for converting the GHGs to their carbon equivalents is:
[metric tonnes of the gas · its global warming potential · (12/44)][21]
The global warming potentials for methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are 21, 310, and 1, respectively[22], and 12/44 is the ratio of the molecular

[21] Source: ChangingClimate.org, 2002.
[22] Source: Environmental Protection Agency, 2002.

weight of carbon to carbon dioxide. Tables C.22 and C.23 give the calculated net GHG emissions for each type of GHG and the total carbon equivalent by soil type. Table C.22 gives these values when the performance standard is calculated per hectare. The lesser amount of cattle, and thus the lesser amount of enteric methane, manure, and produced feed per animal each soil class can support explains the drop-off in the amount of carbon equivalent emitted when calculating the performance standard per hectare. Table C.23 gives the performance standard values when the performance standard is calculated per metric ton of product sold. The amount of carbon equivalent emitted slightly decreases for each soil class when calculating the performance standard per metric ton of product sold. In this case, the increase in nitrous oxide amounts from fertilization and atmospheric deposition is more than offset by the increased carbon sequestration from having more land per metric ton.

Table C.22: Performance Standard GHG Values by Soil Class per Hectare for a Cow-Calf Operation

	Soil Class			
GHG (kg)	Class I	Class II	Class III	Class IV
CH_4	147.663	113.541	64.240	30.716
N_2O	11.503	9.094	5.615	3.274
CO_2	-135.000	-132.000	-127.000	-123.000
Carbon Equivalent	1,683.232	1,287.136	715.414	329.721

Table C.23: Performance Standard GHG Values by Soil Class per Metric Ton of Product Sold for a Cow-Calf Operation

	Soil Class			
GHG	Class I	Class II	Class III	Class IV
CH_4	244.863	244.872	244.882	244.881
N_2O	19.075	19.613	21.404	26.102
CO_2	-223.864	-284.682	-484.122	-980.608
Carbon Equivalent	2,791.238	2,775.957	2,727.995	2,628.697

C.2 Illustration of the Performance Standard Calculation

This illustration calculates the performance standard GHGs per hectare for a cow-calf operation using type II soils.[23]

Table C.24: Calculation of Daily Gross Energy Required by Representative AU (Areas in Gray are Inputs)

Item	**Value**	**Source**
Gross Energy (MJ/day)	147.887	IPCC Good Practice p. 4.20
Net Energy Required By Animal For Maintenance (MJ/day)	32.533	IPCC Good Practice p. 4.13

[23] This example is based on the spreadsheet in which the calculations were done, thus some values which are used in multiple equations will only appear once though they are embedded in each equation which uses them.

Table C.24 (Cont.)		
Item	**Value**	**Source**
Animal Category Coefficient	0.331	IPCC Good Practice Table 4.4
Weight of Animal (kg)	453.597	One animal unit assumption
Net Energy For Activity (MJ/day)	5.531	IPCC Good Practice p. 4.14
Feeding Situation Coefficient	0.170	IPCC Good Practice Table 4.5
Net Energy For Growth (MJ/day)	0.753	IPCC Good Practice p. 4.15
Gender Coefficient	0.864	IPCC Good Practice p. 4.15
Live Body Weight of a Growing Animal (kg)	125.020	One animal unit assumption
Daily Weight Gain (kg/day)	0.356	Expert opinion
Net Energy Due To Weight Loss for Lactating Dairy Cows (MJ/day)	0.000	IPCC Good Practice p. 4.16
Weight Loss (kg/day)	0.000	Not a dairy operation
Net Energy Due To Weight Loss for Other Cattle (MJ/day)	0.000	IPCC Good Practice p. 4.17 (Assumed to be zero since beef cattle should not lose weight)
Net Energy For Lactation (MJ/day)	12.854	IPCC Good Practice p. 4.17
Milk Produced (kg/day)	5.897	Robert E. Taylor, p. 294
Fat Content of Milk (%)	4.000	Robert E. Taylor, p. 294
Net Energy For Work (MJ/day)	0.000	IPCC Good Practice p. 4.18
Hours of Work Per Day	0.000	Assumed to be zero since animals are not draught animals in Virginia
Net Energy For Pregnancy (MJ/day)	2.635	IPCC Good Practice p. 4.18
Pregnancy Coefficient	0.100	IPCC Good Practice Table 4.7
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	0.529	IPCC Good Practice p. 4.19

Table C.24 (Cont.)		
Item	**Value**	**Source**
Digestible Energy Expressed as a Percentage of Gross Energy	70.000	Expert opinion
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	0.333	IPCC Good Practice p. 4.19

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Educated opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
Robert E. Taylor = Taylor, Robert E. Beef Production and Management Decisions, Second Edition. Macmillan, New York, 1994.

The performance standard calculation of gross energy per hectare for Type II soils is 147.887 Mj/day. This value is reported in the first row of Table C.24 with input values and intermediate equations used below it. It is necessary to adjust some intermediate calculation values for the representative AU to reflect that not all parts of the representative AU are in that calculation. The adjustments use the animal types, weights, and percentages found in Table C.2. The intermediate calculations where this action is taken are the Animal Category Coefficient used in the *Net Energy Required for Animal Maintenance* intermediate equation, the Gender Coefficient used in the *Net Energy for Growth* intermediate equation, the *Net Energy for Growth* calculated value, the *Net Energy for Lactation* calculated value, and the *Net Energy for Pregnancy* calculated value. The Animal Category Coefficient is adjusted by finding a weighted average of lactating and non-lactating cows to reflect that both are represented in the representative AU. The Gender Coefficient is adjusted by weighted average to reflect that there are both genders of animal represented in the representative AU. The *Net Energy for Growth* calculated value is adjusted to represent that only 25% of the representative AU is growing. The *Net Energy for Lactation* calculated value is adjusted to reflect that only 71% of the representative AU is lactating. The *Net Energy for Pregnancy* calculated value is adjusted to reflect that only 81% of the representative AU is pregnant.

Table C.25: Calculation of Annual Enteric Methane Released per Hectare for Representative AU (Areas in Gray are Inputs)

Item	**Value**	**Source**
Enteric Methane Emissions from a Representative Animal (kg CH4/year)	110.577	IPCC Good Practice p. 4.25
Number of Animals	1.900	Calculated from soil class II (See Table 1 Above)
Emission Factor	58.198	IPCC Good Practice p. 4.26
Methane Conversion Rate	0.060	IPCC Good Practice Table 4.8

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates enteric methane per hectare for Type II soils as 110.577 kg/year. This value is reported in the first row of Table C.25 with intermediate equations and input values used below it. The performance standard calculation uses the value of 1.900, found in Table C.1, as the number of animals. This number corresponds to the animal carrying capacity per hectare for Type II soils.

Table C.26: Calculation of Annual Methane Emitted from Manure Deposited per Hectare by Representative AU (Areas in Gray are Inputs)

Item	Value	Source
Methane Emissions From Manure Management (kg/year)	2.964	IPCC Good Practice p. 4.30
Volatile Solid Excretion Rate (kg/day)	2.502	Hope Phetteplace
Emission factor From Manure Management (kg)	1.560	IPCC Good Practice p. 4.34
Maximum CH4 Producing Capacity for Manure Produced by an Animal (m^3)	0.170	IPCC Reference Manual Appendix B
Methane Conversion Factors For Manure Management System	0.015	IPCC Good Practice Table 4.10
Fraction of Animals' Manure Handled By Manure System	1.000	Assume all manure is allowed to lie where deposited by animal

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates methane from manure management as 2.964 kg/year per hectare for Type II soils. This value is reported in the first row of Table C.26 with the intermediate equations and input values used below it.

Table C.27: Calculation of Annual Nitrous Oxide Emitted from Manure Deposited per Hectare by Representative AU (Areas in Gray are Inputs)

Item	Value	Source
N_2O Emissions From Manure Management (kg/yr)	4.180	IPCC Good Practice p. 4.42
Annual Average N Excretion Per Head (kg N/Animal/Year)	70.000	IPCC Reference Table 4-20
Emission Factor for Manure Management System	0.020	IPCC Good Practice Table 4.12

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates nitrous oxide from manure management as 4.180 kg/year per hectare for Type II soils. This value is reported in the first row of Table C.27 with input values used below it.

Table C.28: Calculation of Annual Direct Nitrous Oxide Emitted from Pasture Soils per Hectare (Areas in Gray are Inputs)

Item	Value	Source
Direct N_2O Emissions from Ag Soils (kg)	0.991	IPCC Good Practice p. 4.54
N From Synthetic Fertilizer Application	50.440	IPCC Good Practice p. 4.56
Amount Of Synthetic Nitrogen Consumed Annually (kg)	56.044	Expert opinion
Fraction of Applied Nitrogen That Volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
N From Animal Manure Application	0.000	IPCC Good Practice p. 4.56
Fraction of Manure Volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
Fraction of Manure Burned For Fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
Fraction of Manure Deposited by Grazing Livestock	1.000	Assume that there is only grazing livestock on the farm

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates direct nitrous oxide emissions from pasture soils per hectare for Type II soils as 0.991 kg/year. The value is reported in the first row of Table C.28 with intermediate equations and input values used below it.

Table C.29: Calculation of Annual Direct Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Direct N_2O Emissions from Ag Soils (kg)	2.925	IPCC Good Practice p. 4.54
N From Synthetic Fertilizer Application	42.525	IPCC Good Practice p. 4.56
Amount Of Synthetic Nitrogen Consumed Annually (kg)	47.250	Expert opinion
Fraction of Applied Nitrogen That Volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
N From Animal Manure Application	106.400	IPCC Good Practice p. 4.56
Fraction of Manure Volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19

Table C.29 (Cont.)		
Item	**Value**	**Source**
Fraction of Manure Burned For Fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
Fraction of Manure Deposited by Grazing Livestock	0.000	Assume that there is no grazing livestock in the crop areas

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates direct nitrous oxide emissions from harvested cropland for the cow-calf operation as 2.925 kg/year. The value is reported in the first row of Table C.29 with intermediate equations and input values used below it.

Table C.30: Calculation of Annual Indirect Nitrous Oxide Emitted from Pasture per Hectare (Areas in Gray are Inputs)

Item	**Value**	**Source**
Indirect N_2O Emissions From Agriculture (kg)	0.506	IPCC Good Practice p. 4.67
N_2O From Atmospheric Deposition of N (kg N/yr)	0.322	IPCC Good Practice p. 4.68
Emission Factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates indirect nitrous oxide from pasture per hectare as 0.506 kg/year for Type II soils. This value is reported in the first row of Table C.30 with intermediate equations and input values used below it.

Table C.31: Calculation of Annual Indirect Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	**Value**	**Source**
Indirect N_2O Emissions From Agriculture (kg)	0.492	IPCC Good Practice p. 4.67
N_2O From Atmospheric Deposition of N (kg N/yr)	0.313	IPCC Good Practice p. 4.68
Emission Factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates indirect nitrous oxide from harvested cropland for the cow-calf operation as 5.797 kg/year. This value is reported in the first row of Table C.31 with intermediate equations and input values used below it.

Table C.32: Calculation of Annual Sequestered Carbon per Hectare for Pasture Soils (Areas in Gray are Inputs)

Item	Value	Source
Carbon Sequestered (Mg/ha)	0.120	Hope Phetteplace
Number of Hectares	1.000	Calculated from soil class II (See Table 1 Above)

Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

The performance standard calculates carbon sequestered per hectare for Type II soils as 0.12 Mg/year or 120 kg/year. This value is reported in the first row of Table C.32 with input values below it.

Table C.33: Calculation of Annual Sequestered Carbon for Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Carbon Sequestered (Mg/yr)	0.012	Hope Phetteplace
Number of Hectares per Representative AU	0.061	Calculated from representative hectare (see Table 3 above)
Number of Representative AUs per Hectare in the Cow-Calf Operation	1.900	Calculated from soil class carrying capacity (see Table 1 above)

Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

The performance standard calculates carbon sequestered for harvested cropland for the cow-calf operation as 0.012 Mg/year or 12 kg/year. This value is reported in the first row of Table C.33 with input values below it.

Summing the values for each type of gas provides the performance standard per hectare for Type II soils for that gas. The performance standard is 113.541 kg/year for methane, 9.094 kg/year for nitrous oxide, and -132 kg/year for carbon since this is the rate at which carbon is sequestered. To find the net GHG emissions per hectare for Type II soils, the values above must be converted to their carbon equivalents. This is done for methane and nitrous oxide using the formula [metric tonnes of the gas · its global warming potential · (12/44)][24]. Carbon sequestered does not need to be converted since it is already in carbon equivalent format. The carbon equivalents per hectare for Type II soils for methane, nitrous oxide, and carbon dioxide are 650.280 kg, 768.856 kg, and -132 kg, respectively. The total performance standard carbon equivalent per hectare for Type II soils is the sum of these values, 1,287.136 kg.

[24] One metric ton = 1 megagram (Mg) = 1000 kg

APPENDIX D: THE PERFORMANCE STANDARD FOR A STOCKER OPERATION

The performance standard estimates GHG emissions for well managed conventional grazing operations. Performance standards are defined for soil classes. The performance standard calculations are based on recommendations and technical information from NRCS, Virginia DCR, and Virginia Agricultural Extension Farm Management Budgets. GHG calculations are produced by using IPCC equations (IPCC, 2001). These calculations are based on grassland/pastureland land use by a farm enterprise for a single year.

D.1 Calculation of GHG Emissions

The performance standard is reported as net GHG emissions per acre and per unit of product for a region. Net GHG missions include methane, nitrous oxide, and carbon dioxide. Figure D.1 below gives a graphical depiction of the calculation of the performance standard. Details of the calculation are discussed in the subsequent sections of this appendix.

The first step in the creation of the performance standard is to calculate the animal carrying capacity for each soil class. This is a required input in the calculation of enteric methane, methane from manure management, and nitrous oxide from manure management by the IPCC equations. The second step is to create a representative animal for the region. This representative animal combines the different classes of animals (cows, calves, replacement heifers, etc.) and is used to calculate gross energy, a second input needed in calculating enteric methane, methane from manure management, and nitrous oxide from manure management by the IPCC equations. Step three creates representative hectares to account for the GHG emissions associated with feed either produced on the farm or purchased from an outside source. Step four combines animal carrying capacity from step one, the representative animal from step two, the representative hectares from step three, and other regional factors into the IPCC equations to estimate the net GHG emissions for each soil class. The final step converts net GHGs for each soil class into carbon equivalents, creating the performance standard for each soil class.

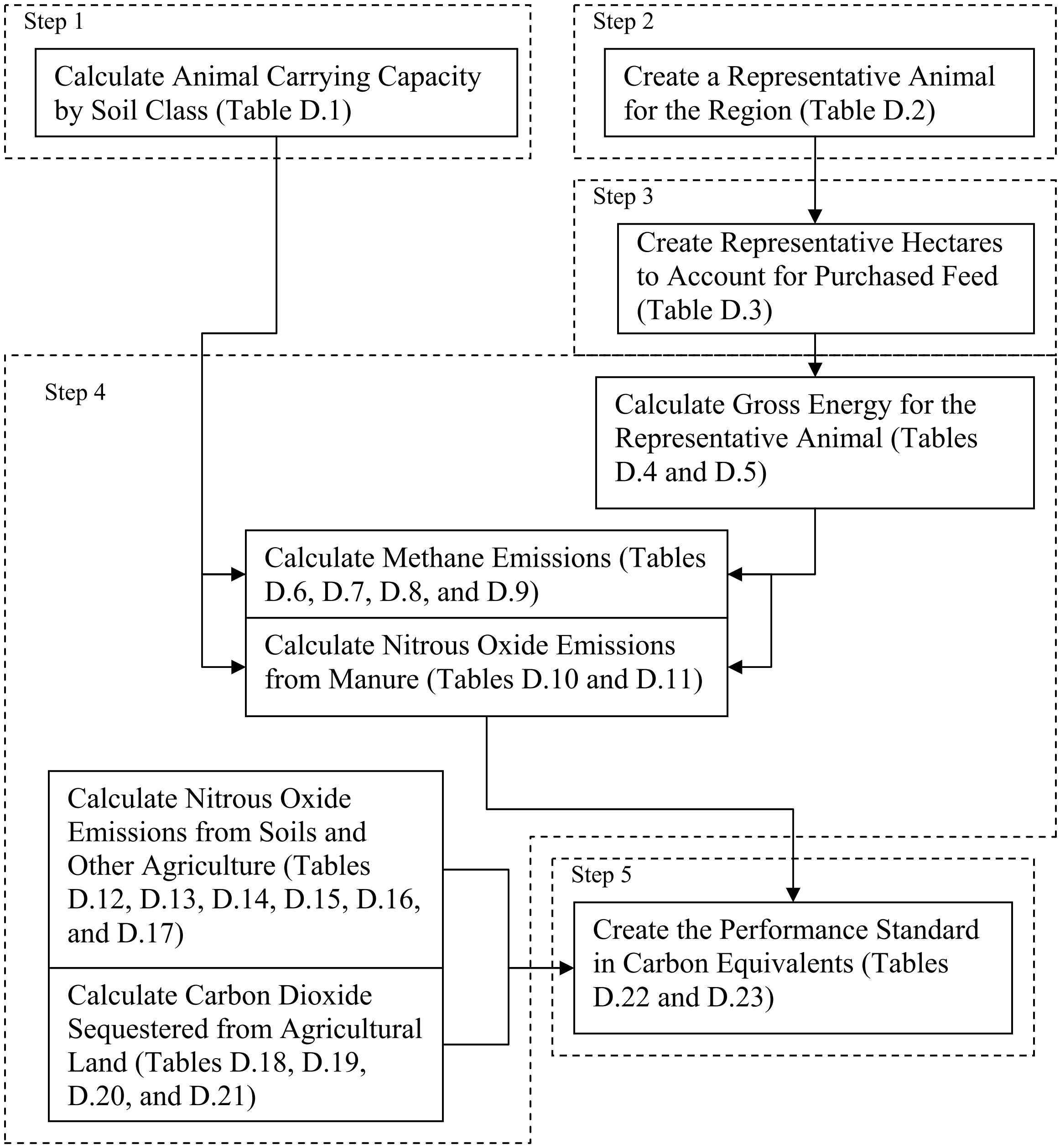

Figure D.1: Schematic for Net GHG Performance Standard for a Stocker Operation

Step 1: Calculate the animal carrying capacity of each soil class. Carrying capacity is expressed in the number of animal units[25] (AU) per hectare; and the inverse of the carrying capacity defines the number of hectares needed to sustain one AU. These calculations are based on recommended practices for a conventional grazing system. Table I-2 on page 23 of Virginia DCR publication Virginia Nutrient Management Standards and Criteria (1995) is used to define carrying capacity for each soil class. DCR expresses carrying capacities in a range of values, and for the purpose of this method the mid-point was assumed to be the point estimate. Since the points were expressed in

[25] An AU is defined as a single 453.597 (1000 lb) kg animal.

acres, it was necessary to convert them to hectares for use in the IPCC equations. Table D.1 below contains the calculations for soil classes I-IV. Classes above IV are not included because they are not considered suitable for grazing.

Table D.1: Carrying Capacity by Soil Class

Land Class	AU's Supported/hectare	Hectares needed/AU
I	2.471	0.405
II	1.900	0.526
III	1.075	0.931
IV	0.514	1.943

Source: Virginia Nutrient Management Standards and Criteria, 1995

Step 2: Create a representative AU for the region. An example for a representative stocker AU is given in Table D.2:

Table D.2: Creation of a Representative Stocker AU for the Region

Type	Number[a]	Average Weight (kg)[b]	Time On Farm	Total Weight by Type (kg)	Percent of Total Farm Weight	Weight By Type in Representative Animal (kg)
Steers	60	262.18	0.5	7865.37	61%	274.72
Heifers	40	256.10	0.5	5121.11	39%	178.87
		Total Farm Weight		12986.48	Representative AU	453.59

[a] Source: Virginia Cooperative Extension Farm Management Budgets, Stocker Steers, Early March to Fall and Virginia Cooperative Extension Farm Management Budgets, Stocker Heifers, Spring to Fall
[b] Source: Virginia Cooperative Extension Farm Management Budgets, Stocker Steers, Early March to Fall, Virginia Cooperative Extension Farm Management Budgets, Stocker Heifers, Spring to Fall, and Expert Opinion from Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University

The representative stocker AU is based on stocking rates and weights provided by Virginia Cooperative Extension Farm Management Budgets number 20, Stocker Steers, Spring to Fall and number 21, Stocker Heifers, Spring to Fall. These values provide a "representative farm" for the region. This representative stocker farm is a 54.63 ha (135 acre), 100 head farm with animals on pasture for 180 days. Animals are bought at 204.12 kg (450 lbs). Heifers have an average daily growth of .61 kg (1.35 lbs) and steers have an average daily growth of .68 kg (1.5 lbs). The farm has a death loss of 2% and a shrink rate of 2%.

The representative stocker AU is determined by combining animal class, weight, and number of head from this representative farm into a composite stocker AU. This is accomplished by obtaining the number of steers and heifers (Number), average weight of each animal class (Average Weight), and the percentage of the year each animal type is on the farm (Time on Farm)[26]. The product of Number, Time-on-farm, and Average Weight yields the total weight for each type (Total Weight by Type). Total Farm Weight is the sum of all total weights by type. To obtain the percentage of total farm weight, each type is divided by total farm weight and expressed in a percentage. This percentage

[26] Stockers' time on farm is not expressed in whole numbers because calves only reside on the farm or in that class for a year or less.

equals the percent of representation each class has in the representative cow-calf AU. Each percent is then multiplied by 453.597 kg to find the proportional makeup of the representative cow-calf AU (Weight by Type in Representative AU). The representative cow-calf AU is the sum of these weights.

Step 3: Create representative hectares to account for the GHG emissions embedded in the growing of home-raised and purchased feed. An example of representative hectares for a stocker operation is given in Table D.3:

Table D.3: Creation of Representative Hectares for Growing of Feed (Percentage of Loss is in Parentheses)

Crop[a]	Amount Fed (kg)[a]	Adjusted for Feeding Loss[b]	Adjusted for Storage Loss[b]	Adjusted for Harvest Loss[c]	Amount Grown (kg)	Amount Needed per AU (kg)	Hectares Needed for Crop per AU
Corn Grain	6894.67	7181.95 (4%)	7979.95 (10%)	8226.75 (3%)	8226.75	287.35	0.032
Orchardgrass Hay	20928.97	22998.86 (9%)	25273.48 (9%)	27773.05 (9%)	27773.05	970.07	0.124
					Total Hectares per AU		0.155

[a] Source: Virginia Cooperative Extension Farm Management Budgets, Stocker Steers, Early March to Fall. These values are "as fed" values. Dry matter (DM) values are as follows: corn grain = 85% DM and hay = 89% DM.
[b] Source: Martin, P. (1980) and Smith, T. (1997)
[c] Source: Harvest loss for corn grain is from Dr. Robert Grisso, Biological Systems Engineering, Virginia Polytechnic Institute and State University. All others are Martin, P. (1980) and Smith, T. (1997)

The representative hectares are determined by calculating the amount of each type of crop used to feed the animals on the representative farm, adjusting for feeding, storage and harvest losses to find the total amount of the crops grown, finding the amount of each crop needed per representative AU, and calculating the number of hectares needed for each crop. This is done by obtaining the amount of each crop fed to the animals on the farm from the Virginia Cooperative Extension Farm Management Budgets (Amount Fed). This amount must then be adjusted for losses. To calculate the amount of each crop lost during feeding (Adjusted for Feeding Loss), find the percentage loss during feeding and multiply this by the amount fed. To calculate the amount of each crop lost during storage (Adjusted for Storage Loss), find the percentage loss during storage and multiply this by the amount fed plus the feeding loss. To calculate the amount of each crop lost during harvest (Adjusted for Harvest Loss), find the percentage loss of each crop during harvest and multiply this by the sum of the amount fed, feeding loss, and storage loss. The sum of amount fed, feeding loss, storage loss, and harvest loss is equal to the amount of crop originally grown (Amount Grown). This number is divided by the number of representative AUs on the farm[27] to get the amount of crop needed per representative AU (Amount Needed per AU). The number of hectares used to grow the amount of each crop needed by the representative AU (Hectares Needed for Crop per AU) is calculated by dividing the amount needed per AU by the amount of that crop that can be grown on one hectare of land. These values are given in Table I-2 of the Virginia

[27] This is found by dividing the total weight of the farm by the weight of one representative AU.

DCR publication Virginia Nutrient Management Standards and Criteria (1995).[28] The representative hectares are the sum of the hectares needed for each crop (Total Hectares per AU).

Step 4: Use the calculated animal carrying capacity, representative AU, and other regional factors to calculate gross energy, enteric methane, methane from manure management, nitrous oxide from manure management, direct nitrous oxide from agricultural soils, indirect nitrous oxide from agriculture, and carbon sequestered. Gross energy for the representative AU is the first factor calculated. The daily gross energy equation and its components are listed in Table D.4 and Table D.5 summarizes the specific inputs to the gross energy equation.

Table D.4: Equations Used to Calculate Daily Gross Energy Required for the Representative AU

Calculation	Equation	Source[a]
Net Energy Required By Animal For Maintenance in mega Joules (MJ) per day	$Cf_i \cdot (\text{Weight})^{0.75}$ Where: Cf_i = a coefficient for the animal category (0.322 for non-lactating cattle and 0.335 for lactating cattle) Weight = the live weight of the animal in kg	p. 4.13
Net Energy For Activity (MJ/day)	$C_a \cdot NE_m$ Where: C_a = a coefficient corresponding to the animal's feeding situation (stall = 0, pasture = 0.17, and grazing large areas = 0.36) NE_m = the net energy required by the animal for maintenance	p. 4.14
Net Energy For Growth (MJ/day)	$4.18 \cdot \{0.0635 \cdot [0.891 \cdot (BW \cdot 0.96) \cdot (478/(C \cdot MW))]^{0.75} \cdot (WG \cdot 0.92)^{1.097}\}$ Where: BW = the live body weight of the growing animal C = a gender coefficient (females = 0.8, castrates = 1.0, and bulls = 1.2) MW = the mature weight of the animal WG = the daily weight gain of the animal in kg	p. 4.15
Net Energy Due To Weight Loss for Lactating Dairy Cows (MJ/day)	$19.7 \cdot \text{Weight loss}$ Where: Weight loss = the animal weight loss per day in kg	p.4.16
Net Energy Due To Weight Loss for Other Cattle (MJ/day)	$NE_g \cdot (-0.8)$ Where: NE_g = the net energy needed for growth in MJ/day	p. 4.17

[28] It is assumed that all crops are grown on type one or type two soils, thus the midpoint of these two types is used.

Table D.4 (Cont.)		
Calculation	**Equation**	**Source**[a]
Net Energy For Lactation (MJ/day)	kg milk/day · (1.47 + (0.4 · Fat)) Where: Fat = the fat content of milk by percentage	p. 4.17
Net Energy For Work (MJ/day)	$0.10 \cdot NE_m \cdot$ hours of work per day Where: NE_m = net energy required by the animal for maintenance	p. 4.18
Net Energy For Pregnancy (MJ/day)	$C_{pregnancy} \cdot NE_m$ Where: $C_{pregnancy}$ = a pregnancy coefficient (cattle = 0.10) NE_m = the net energy required by the animal for maintenance	p. 4.18
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	$1.123 – (4.092 \cdot 10^{-3} \cdot DE) + [1.126 \cdot 10^{-5} \cdot (DE)^2] – (25.4/DE)$ Where: DE = digestible energy expressed as a percentage of gross energy	p. 4.19
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	$1.164 – (5.16 \cdot 10^{-3} \cdot DE) + (1.308 \cdot 10^{-5} \cdot (DE)^2) – (37.4/DE)$ Where: DE = digestible energy expressed as a percentage of gross energy	p. 4.19
Gross Energy (MJ/day)	$\{[(NE_m + NE_{mobilized} + NE_a + NE_l + NE_w + NE_p)/ (NE_{ma}/DE)] + [NE_g /(NE_{ga}/DE)]\}/(DE/100)$ Where: NE_m = net energy required by the animal for maintenance, MJ/day $NE_{mobilized}$ = net energy due to weight loss, MJ/day NE_a = net energy for animal activity, MJ/day NE_l = net energy for lactation, MJ/day NE_w = net energy for work, MJ/day NE_p = net energy required for pregnancy, MJ/day NE_{ma}/DE = ratio of net energy available in a diet for maintenance to digestible energy consumed NE_g = net energy needed for growth, MJ/day NE_{ga}/DE = ratio of net energy available for growth in a diet to digestible energy consumed DE = digestible energy expressed as a percentage of gross energy	p. 4.20

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table D.5: Summary of Inputs for Calculation of Daily Gross Energy Requirements for the Representative AU

Equation	Item	Value	Source
Net Energy for Maintenance	Animal category coefficient[a]	0.322	IPCC Good Practice Table 4.4
	Weight of animal (kg)	453.597	One animal unit assumption
Net Energy For Activity	Feeding situation coefficient	0.170	IPCC Good Practice Table 4.5
Net Energy For Growth	Gender coefficient[b]	0.920	IPCC Good Practice p. 4.15
	Live body weight of a growing animal (kg)	259.117	One animal unit assumption
	Daily weight gain (kg/day)	0.653	Expert opinion
Net Energy Due to Weight Loss For Lactating Dairy Cows	Weight loss (kg/day)	0.000	Assumed to be zero since this is for a beef operation
Net Energy For Lactation	Milk produced (kg/day)	0.000	Assume no stocker heifers will be bred
	Fat content of milk (%)	0.000	Assume no stocker heifers will be bred
Net Energy For Work	Hours of work per day	0.000	Assumed to be zero since cattle are not draught animals in Virginia
Net Energy For Pregnancy	Pregnancy coefficient	0.000	Assume no stocker heifers will be bred
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	Digestible energy expressed as a percentage of gross energy	70.000	Expert opinion
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	Digestible energy expressed as a percentage of gross energy	70.000	Expert opinion

[a] This value is adjusted to reflect that none of the representative AU is lactating
[b] This value is adjusted to reflect that 40% of the representative AU is female and 60% is male
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Educated opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
Robert E. Taylor = Taylor, Robert E. Beef Production and Management Decisions, Second Edition. Macmillan, New York, 1994.

Gross energy is used as a variable in the second and third equations to calculate enteric methane and methane from manure management.

The equation for calculating annual enteric methane and its components are given in Table D.6. The first calculation, the *Emission Factor for Enteric Methane*, is used in the second calculation, *Annual Enteric Methane Emissions*. A summary of inputs for the calculation of enteric methane is given in Table D.7.

The equation for calculating annual methane from manure management and its components are listed in Table D.8. In this table, the first calculation, the *Volatile Solid Excretion Rate*, is an input in the second calculation, *Emissions Factor from Manure Management*. Likewise, *Emissions Factor from Manure Management* is an input in the final calculation, *Annual Methane Emissions from Manure Management*. In this study, the manure management system, *j*, is defined as a system where the manure is left where it is deposited by the animal. Table D.9 presents a summary of the inputs used to calculate methane from manure management.

Table D.6: Equations Used to Calculate Annual Enteric Methane Emissions for the Representative AU

Calculation	Equation	Source[a]
Enteric Methane Emission Factor	$(GE \cdot Y_m \cdot 365$ days/year$)/(55.65$ MJ/Kg $CH_4)$ Where: GE = gross energy intake in MJ/head/day Y_m = a methane conversion rate which is the fraction of gross energy in feed converted to methane (feedlot fed cattle = 0.04 ± 0.005 and all other cattle = 0.06 ± 0.005)	p. 4.26
Annual Enteric Methane Emissions in Kilograms (kg)	EF_i x POP Where: EF_i = emission factor for the specific population, kg/head/year POP = the number of animals, head	p. 4.25

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table D.7: Summary of Inputs for the Calculation of Annual Enteric Methane Emissions for the Representative AU

Equation	Item	Value	Source
Methane Emissions From a Representative Animal	Number of animals	Varies by soil class	Calculated from soil class (See Table 1 Above)
Methane Emission Factor	Methane conversion rate	0.060	IPCC Good Practice Table 4.8

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

Table D.8: Equations Used to Calculate Annual Methane Emissions from Manure Management

Calculation	Equation	Source[a]
Volatile Solid Excretion Rate (kg/day)	$(GE - DEI + 0.04 \cdot GE)/20.1$ Where: GE = gross energy intake in MJ/head/day DEI = the digestible energy intake, equal to $GE \cdot DE$ where DE is digestible energy expressed as a percentage of gross energy	Hope Phetteplace[b]

Table D.8 (Cont.)		
Calculation	**Equation**	**Source[a]**
Emission Factor from Manure Management (kg)	$(VS \cdot 365 \text{ days/yr}) \cdot (B_{oi} \cdot 0.67 \text{ kg/m}^3) \cdot \sum_{jk} MCF_{jk} \cdot MS_{ijk}$ Where: VS = the daily amount of volatile solids excreted by the representative animal B_{oi} = the maximum methane producing capacity for manure produced by the representative animal (dairy cattle = 0.24, all non-dairy cattle = 0.17) MCF_{jk} = the methane conversion factor for each manure management system *j* by climate region *k* (temperate zone pasture/range/paddock = 0.015) MS_{ijk} = the fraction of animal species/category *i*'s manure using manure system *j* in climate region *k*	p. 4.34
Annual Methane Emissions from Manure in kg	$EF_{i,m}$ x POP Where: $EF_{i,m}$ = emission factor for manure (m) for the specific population, kg/head/yr POP = the number of animals, head	p. 4.30

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.
[b] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table D.9: Summary of Inputs for the Calculation of Annual Methane Emissions from Manure Management

Equation	Item	Value	Source
Methane Emission Factor from Manure Management	Maximum methane producing capacity for manure produced by an animal	0.170	IPCC Reference Manual Appendix B
	Methane conversion factors for manure management system	0.015	IPCC Good Practice Table 4.10
	Fraction of animals' manure handled by manure system	1.000	Assume all manure is allowed to lie where deposited by animal
Annual Methane Emissions From Manure	Number of animals	Varies by soil class	Calculated from soil class (See Table 1 Above)

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The fourth equation calculates nitrous oxide from manure management. Table D.10 supplies the equation and its components for nitrous oxide. In this equation, S is defined as a management system where the manure is allowed to lay where it is deposited and T is defined as cattle. Table D.11 includes a summary of the inputs used in the calculation of nitrous oxide from manure management.

Table D.10: Equations Used to Calculate Annual Nitrous Oxide Emissions from Manure Management

Calculation	Equation	Source[a]
Annual Nitrous Oxide Emissions from Manure in kg	$(\sum_{(S)} \{[\sum_{(T)} ((N_{(T)})(Nex_{(T)})(MS_{(T,S)})]\ EF_{3(S)}\})(44/28)$ Where: $N_{(T)}$ = Number of head of livestock species/category *T* $Nex_{(T)}$ = Annual average N excretion per head of species/category *T* (non-dairy cattle = 70 and dairy cattle = 100) $MS_{(T,S)}$ = Fraction of the total annual excretion for each livestock species category *T* that is managed in manure management system *S* $EF_{3(S)}$ = N_2O emission factor for manure system *S* (pasture/range/paddock = 0.02) S = Manure management system T = Species/category of livestock	p. 4.42

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table D.11: Summary of Inputs Used in the Calculation of Annual Nitrous Oxide Emissions from Manure Management

Equation	Item	Value	Source
Nitrous Oxide Emissions From Manure Management	Number of animals	Varies by soil class	Calculated from soil class (See Table 1 Above)
	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of the total annual excretion for each livestock species category *T* that is managed in manure management system *S*	1.000	Assume all manure is managed by a single system (all manure is left where deposited by animal)
	Emission factor for manure management system	0.020	IPCC Good Practice Table 4.12

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The fifth equation calculates direct nitrous oxide from pasture soils and harvested cropland. This includes nitrous oxide from synthetic fertilizers and manure intentionally applied to soils. A description of the equation and its inputs is given in Table D.12 and a summary of inputs used in the calculation of direct nitrous oxide emissions from pasture soils in Table D.13. Table D.14 presents a summary of inputs used in the calculation of nitrous oxide emissions from harvested cropland. PLMS does not include *nitrogen by nitrogen fixing crops*, *nitrogen in crop residues returned to soils*, or the *emission factor for emissions from organic soil cultivation* in its calculation of direct nitrous oxide emissions from agricultural soils, though these are components of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for direct nitrous oxide emissions from agricultural soils, these components of the equation are left out of the performance standard calculation. Upon brief review of these calculations, they seem to have a relatively small effect (less than 3%) on the total, but further examination would be necessary to fully determine the effects of these values.

Table D.12: Equations Used to Calculate Annual Direct Nitrous Oxide Emissions from Agricultural Soils

Calculation	Equation[a]	Source[b]
Nitrogen From Annual Synthetic Fertilizer Application (kg)	$N_{FERT} \cdot (1 - Frac_{GASF})$ Where: N_{FERT} = the total amount of synthetic fertilizer consumed annually $Frac_{GASF}$ = the fraction of the applied nitrogen that volatilizes as NH_3 and NO_X (default value = 0.1)	p. 4.56
Nitrogen From Annual Animal Manure Application (kg)	$\sum_T (N_{(T)} \cdot Nex_{(T)}) \cdot (1- Frac_{GASM})[1-(Frac_{FUEL-AM} + Frac_{PRP})]$ Where: $\sum_T (N_{(T)} \cdot Nex_{(T)})$ is the amount of animal manure nitrogen produced annually $Frac_{GASM}$ = the amount of animal manure volatilized as NH_3 and NO_X (default value = 0.2) $Frac_{FUEL-AM}$ = the amount of manure burned for fuel $Frac_{PRP}$ = the amount of manure deposited onto soils by grazing livestock	p. 4.56
Annual Direct Nitrous Oxide Emissions from Soils (kg)	$\{[(F_{SN} + F_{AM} + F_{BN} + F_{CR}) \cdot EF_1] + (F_{OS} \cdot EF_2)\}(44/28)$ Where: F_{SN} = Annual amount of synthetic fertilizer nitrogen applied to soils F_{AM} = Annual amount of animal manure nitrogen intentionally applied to soils F_{BN} = Amount of nitrogen by N-fixing crops cultivated annually F_{CR} = Amount of nitrogen in crop residues returned to soils annually EF_1 = Emission factor for emissions from N inputs, kg/kg N input F_{OS} = Area of organic soils cultivated annually EF_2 = Emission factor for emissions from organic soil cultivation, kg/ha/yr	p. 4.54

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table D.13: Summary of Inputs Used in the Calculation of Annual Direct Nitrous Oxide Emissions from Pasture Soils

Equation	Item	Value	Source
Nitrogen From Synthetic Fertilizer Application	Amount of synthetic nitrogen consumed annually	56.440	Expert opinion
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19

Table D.13 (Cont.)			
Equation	**Item**	**Value**	**Source**
Nitrogen From Animal Manure Application	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Fraction of manure burned for fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
	Fraction of manure deposited by grazing livestock	1.000	Assume all manure is deposited by grazing livestock

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Gordon E. Groover, Virginia Polytechnic Institute and State University
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

Table D.14: Summary of Inputs Used in the Calculation of Annual Direct Nitrous Oxide Emissions from Harvested Cropland

Equation	Item	Value	Source
Nitrogen From Synthetic Fertilizer Application	Amount of synthetic nitrogen consumed annually (kg)	Varies by soil class	Calculated from Virginia Nutrient Management Standards and Criteria Handbook[a]
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
Nitrogen From Animal Manure Application	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Fraction of manure burned for fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
	Fraction of manure deposited by grazing livestock	0.000	Assume that there is no grazing livestock in the crop areas

[a] This was calculated by taking default nitrogen values for each crop from Virginia Nutrient Management Standards and Criteria Handbook, multiplying those values by the number of hectares needed for each crop found in Table D.3, summing the calculated values together, and multiplying by the soil carrying capacity per hectare found in Table D.1
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Gordon E. Groover, Virginia Polytechnic Institute and State University
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The sixth equation calculates indirect nitrous oxide from pasture soils and harvested cropland. This includes atmospheric deposition of nitrogen, leaching and runoff of N applied to or deposited on soils, and disposal of sewage nitrogen. A description of this equation and its inputs is located in Table D.15 and a summary of inputs used in the calculation of indirect nitrous oxide from pasture soils is in Table D.16. Table D.17 gives a summary of inputs used in the calculation of indirect nitrous oxide from harvested cropland. PLMS does not include *deposited nitrogen from leaching/runoff* or *nitrous oxide from discharge of human sewage* in its calculation of indirect nitrous oxide emissions from agriculture, though this is a component of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for indirect nitrous oxide emissions from agriculture, this component of the equation is left out in the performance standard calculation. Upon brief review of these calculations, they could have a noticeable impact on the total, but further examination would be necessary to fully determine the effects of these values.

Table D.15: Equations Used to Calculate Annual Indirect Nitrous Oxide Emissions from Agriculture

Calculation	Equation[a]	Source[b]
N_2O From Atmospheric Deposition of N (kg N/yr)	$[(N_{FERT} \cdot Frac_{GASF}) + (\sum_T N_{(T)} \cdot Nex_{(T)}) \cdot Frac_{GASM})] \cdot EF_4$ Where: N_{FERT} = the total amount of synthetic fertilizer applied to soils $Frac_{GASF}$ = the fraction of synthetic N fertilizer that volatilizes as NH_3 and NO_x $\sum_T N_{(T)} \cdot Nex_{(T)}$ = the total amount of manure nitrogen excreted $Frac_{GASM}$ = the fraction of animal manure N that volatilizes as NH_3 and NO_x EF_4 = the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (default value = 0.1)	p. 4.68
Annual Indirect Nitrous Oxide Emissions from Agriculture (kg)	$(N_2O_{(G)} + N_2O_{(L)} + N_2O_{(S)})(44/28)$ Where: $N_2O_{(G)}$ = N_2O from atmospheric deposition of volatilized applied fertilizer and manure, kg N/yr $N_2O_{(L)}$ = N_2O from leaching and runoff of applied fertilizer and manure, kg N/yr $N_2O_{(S)}$ = N_2O from discharge of human sewage N, kg N/yr	p. 4.67

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table D.16: Summary of Inputs Used in the Calculation of Annual Indirect Nitrous Oxide Emissions from Pasture Soils

Equation	Item	Value	Source
Nitrous Oxide From Atmospheric Deposition of Nitrogen	Amount of synthetic nitrogen consumed annually	56.440	Expert opinion
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Emission factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

Table D.17: Summary of Inputs Used in the Calculation of Annual Indirect Nitrous Oxide Emissions from Harvested Cropland

Equation	Item	Value	Source
Nitrous Oxide From Atmospheric Deposition of Nitrogen	Amount of synthetic nitrogen consumed annually	Varies by soil class	Calculated from Virginia Nutrient Management Standards and Criteria Handbook[a]
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
	Annual average nitrogen excretion per head (kg N/AU/yr)	70.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Emission factor	0.010	IPCC Good Practice Table 4.18

[a] This was calculated by taking default nitrogen values for each crop from Virginia Nutrient Management Standards and Criteria Handbook, multiplying those values by the number of hectares needed for each crop found in Table D.2, and summing the calculated values together.
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The final calculations, carbon sequestered by pasture soils and carbon sequestered by harvested cropland, do not use the IPCC equations. They instead use equations provided by Dr. Hope Phetteplace of Colorado State University. Table D.18 includes a description of the equation for pasture soils and its inputs. Table D.19 includes a description of the equation for harvested cropland. Table D.20 contains a summary of the inputs used in the calculation of carbon sequestered by pasture soils. Table D.21 presents a summary of inputs used in the calculation of carbon sequestered by harvested cropland.

Table D.18: Equation Used to Calculate Annual Carbon Sequestered by Pasture Soils

Calculation	Equation	Source[a]
Carbon Sequestered (Mg/yr)	.12 · Ha Where: Ha = Area of soil for pastureland/rangeland in hectares	Hope Phetteplace

[a] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table D.19: Equation Used to Calculate Annual Carbon Sequestered by Harvested Cropland

Calculation	Equation	Source[a]
Carbon Sequestered (Mg/yr)	.10 · Ha · AUs Where: Ha = Area of soil for crops needed to feed one representative AU in hectares AUs = The number of representative AUs per hectare in the cow-calf operation	Hope Phetteplace

[a] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table D.20: Summary of the Inputs Used in the Calculation of Annual Carbon Sequestration by Pasture Soils

Equation	Item	Value	Source
Carbon Sequestered	Area of soil for pastureland/rangeland for in hectares	Varies by soil class	Calculated from soil class (See Table 1 Above)

Table D.21: Summary of the Inputs Used in the Calculation of Annual Carbon Sequestration by Harvested Cropland

Equation	Item	Value	Source
Carbon Sequestered	Area of soil for crops needed to feed one representative AU in hectares	0.155	Calculated from representative hectare (see Table 3 above)
	Number of representative AUs per hectare in the stocker operation	Varies by soil class	Calculated from soil class carrying capacity (see Table 1 above)

Step 4: Convert the net GHG emissions to their carbon equivalents to find the total carbon equivalent for each soil class. The equation for converting the GHGs to their carbon equivalents is:
[metric tonnes of the gas · its global warming potential · (12/44)][29]
The global warming potentials for methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are 21, 310, and 1, respectively[30], and 12/44 is the ratio of the molecular

[29] Source: ChangingClimate.org

weight of carbon to carbon dioxide. Tables D.22 and D.23 give the calculated net GHG emissions for each type of GHG and the total carbon equivalent by soil type. Table D.22 gives these values when the performance standard is calculated per hectare. The lesser amount of cattle, and thus the lesser amount of enteric methane, manure, and outside feed, each soil class can support explains the drop-off in the amount of carbon equivalent emitted when calculating the performance standard per hectare. Table D.23 gives the performance standard values when the performance standard is calculated per metric ton of product sold. The amount of carbon equivalent emitted slightly increases from Class I to Class II. This is because the increase in carbon sequestration is not great enough to offset the increase in nitrous oxide emissions per metric ton of product sold. After this, the increase in nitrous oxide amounts from fertilization and atmospheric deposition is more than offset by the increased carbon sequestration from having more land per metric ton of product sold.

Table D.22: Performance Standard GHG Values by Soil Class per Hectare for a Stocker Operation

	Soil Class			
GHG (kg)	Class I	Class II	Class III	Class IV
CH_4	141.625	108.622	61.457	29.385
N_2O	11.084	9.402	5.432	3.160
CO_2	-158.000	-149.000	-136.000	-127.000
Carbon Equivalent	1590.227	1268.004	675.232	308.460

Table D.23: Performance Standard GHG Values by Soil Class per Metric Ton of Product Sold for a Stocker Operation

	Soil Class			
GHG	Class I	Class II	Class III	Class IV
CH_4	176.575	176.073	176.232	176.406
N_2O	13.819	14.657	15.577	18.970
CO_2	-196.991	-241.525	-389.989	-762.419
Carbon Equivalent	1982.636	1998.467	1936.305	1851.733

D.2 Illustration of the Performance Standard Calculation

This illustration calculates the performance standard GHGs per hectare for a stocker operation using type II soils.[31]

Table D.24: Calculation of Daily Gross Energy Required by Representative AU (Areas in Gray are Inputs)

Item	**Value**	**Source**
Gross Energy (MJ/day)	141.480	IPCC Good Practice p. 4.20

[30] Source: Environmental Protection Agency

[31] This example is based on the spreadsheet in which the calculations were done.

Table D.24 (Cont.)		
Item	Value	Source
Net Energy Required By Animal For Maintenance (MJ/day)	31.649	IPCC Good Practice p. 4.13
Animal Category Coefficient	0.322	IPCC Good Practice Table 4.4
Weight of Animal (kg)	453.597	One animal unit assumption
Net Energy For Activity (MJ/day)	5.380	IPCC Good Practice p. 4.14
Feeding Situation Coefficient	0.170	IPCC Good Practice Table 4.5
Net Energy For Growth (MJ/day)	9.653	IPCC Good Practice p. 4.15
Gender Coefficient	0.920	IPCC Good Practice p. 4.15
Live Body Weight of a Growing Animal (kg)	259.117	One animal unit assumption
Daily Weight Gain (kg/day)	0.653	Expert opinion
Net Energy Due To Weight Loss for Lactating Dairy Cows (MJ/day)	0.000	IPCC Good Practice p. 4.16
Weight Loss (kg/day)	0.000	Not a dairy operation
Net Energy Due To Weight Loss for Other Cattle (MJ/day)	0.000	IPCC Good Practice p. 4.17 (Assumed to be zero since beef cattle should not lose weight)
Net Energy For Lactation (MJ/day)	0.000	IPCC Good Practice p. 4.17
Milk Produced (kg/day)	0.000	Assume no stocker heifers will be bred
Fat Content of Milk (%)	0.000	Assume no stocker heifers will be bred
Net Energy For Work (MJ/day)	0.000	IPCC Good Practice p. 4.18
Hours of Work Per Day	0.000	Assumed to be zero since animals are not draught animals in Virginia
Net Energy For Pregnancy (MJ/day)	0.000	IPCC Good Practice p. 4.18
Pregnancy Coefficient	0.000	Assume no stocker heifers will be bred

Table D.24 (cont.)		
Item	Value	Source
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	0.529	IPCC Good Practice p. 4.19
Digestible Energy Expressed as a Percentage of Gross Energy	70	Expert opinion
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	0.333	IPCC Good Practice p. 4.19

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Educated opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
Robert E. Taylor = Taylor, Robert E. Beef Production and Management Decisions, Second Edition. Macmillan, New York, 1994.

The performance standard calculation of gross energy per hectare for Type II soils is 141.480 Mj/day. This value is reported in the first row of Table D.24 with input values and intermediate equations used below it. It is necessary to adjust the Gender Coefficient used in the *Net Energy for Growth* intermediate equation value for the representative AU by taking a weighted average of the gender makeup of the herd to reflect that both genders are represented in the representative AU. The adjustments use the animal types, weights, and percentages found in Table D.2.

Table D.25: Calculation of Annual Enteric Methane Released per Hectare for Representative AU (Areas in Gray are Inputs)

Item	Value	Source
Enteric Methane Emissions from a Representative Animal (kg CH4/year)	105.786	IPCC Good Practice p. 4.25
Number of Animals	1.900	Calculated from soil class II (See Table 1 Above)
Emission Factor	55.677	IPCC Good Practice p. 4.26
Methane Conversion Rate	0.060	IPCC Good Practice Table 4.8

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates enteric methane per hectare for Type II soils as 105.786 kg/year. This value is reported in the first row of Table D.25 with intermediate equations and input values used below it. The performance standard calculation uses the value of 1.900, found in Table D.1, as the number of animals. This number corresponds to the animal carrying capacity per hectare for Type II soils.

Table D.26: Calculation of Annual Methane Emitted from Manure Deposited per Hectare by Representative AU (Areas in Gray are Inputs)

Item	Value	Source
Methane Emissions From Manure Management (Gg/year)	2.836	IPCC Good Practice p. 4.30

Table D.26 (Cont.)		
Item	**Value**	**Source**
Volatile Solid Excretion Rate (kg/day)	2.393	Hope Phetteplace
Emission factor From Manure Management (kg)	1.492	IPCC Good Practice p. 4.34
Maximum CH4 Producing Capacity for Manure Produced by an Animal (m^3)	0.170	IPCC Reference Manual Appendix B
Methane Conversion Factors For Manure Management System	0.015	IPCC Good Practice Table 4.10
Fraction of Animals' Manure Handled By Manure System	1.000	Assume all manure is allowed to lie where deposited by animal

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates methane from manure management as 2.836 kg/year per hectare for Type II soils. This value is reported in the first row of Table D.26 with the intermediate equations and input values used below it.

Table D.27: Calculation of Annual Nitrous Oxide Emitted from Manure Deposited per Hectare by Representative AU (Areas in Gray are Inputs)

Item	**Value**	**Source**
N_2O Emissions From Manure Management (kg/yr)	4.180	IPCC Good Practice p. 4.42
Annual Average N Excretion Per Head (kg N/Animal/Year)	70.000	IPCC Reference Table 4-20
Emission Factor for Manure Management System	0.020	IPCC Good Practice Table 4.12

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates nitrous oxide from manure management as 4.180 kg/year per hectare for Type II soils. This value is reported in the first row of Table D.27 with input values used below it.

Table D.28: Calculation of Annual Direct Nitrous Oxide Emitted from Pasture Soils per Hectare (Areas in Gray are Inputs)

Item	**Value**	**Source**
Direct N_2O Emissions from Ag Soils (kg)	0.991	IPCC Good Practice p. 4.54
N From Synthetic Fertilizer Application	50.440	IPCC Good Practice p. 4.56
Amount Of Synthetic Nitrogen Consumed Annually (kg)	56.044	Expert opinion

Table D.28 (Cont.)		
Item	**Value**	**Source**
Fraction of Applied Nitrogen That Volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
N From Animal Manure Application	0.000	IPCC Good Practice p. 4.56
Fraction of Manure Volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
Fraction of Manure Burned For Fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
Fraction of Manure Deposited by Grazing Livestock	1.000	Assume that there is only grazing livestock on the farm

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates direct nitrous oxide emissions from pasture soils per hectare for Type II soils as 0.991 kg/year. The value is reported in the first row of Table D.28 with intermediate equations and input values used below it.

Table D.29: Calculation of Annual Direct Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	**Value**	**Source**
Direct N_2O Emissions from Ag Soils (kg)	2.629	IPCC Good Practice p. 4.54
N From Synthetic Fertilizer Application	27.436	IPCC Good Practice p. 4.56
Amount Of Synthetic Nitrogen Consumed Annually (kg)	30.484	Expert opinion
Fraction of Applied Nitrogen That Volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
N From Animal Manure Application	106.400	IPCC Good Practice p. 4.56
Fraction of Manure Volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
Fraction of Manure Burned For Fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
Fraction of Manure Deposited by Grazing Livestock	0.000	Assume that there is no grazing livestock in the crop areas

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates direct nitrous oxide emissions from harvested cropland for the cow-calf operation as 2.629 kg/year. The value is reported in the first row of Table D.29 with intermediate equations and input values used below it.

Table D.30: Calculation of Annual Indirect Nitrous Oxide Emitted from Pasture Soils per Hectare (Areas in Gray are Inputs)

Item	Value	Source
Indirect N_2O Emissions From Agriculture (kg)	0.506	IPCC Good Practice p. 4.67
N_2O From Atmospheric Deposition of N (kg N/yr)	0.322	IPCC Good Practice p. 4.68
Emission Factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates indirect nitrous oxide from pasture soils per hectare as 0.506 kg/year for Type II soils. This value is reported in the first row of Table D.30 with intermediate equations and input values used below it.

Table D.31: Calculation of Annual Indirect Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Indirect N_2O Emissions From Agriculture (kg)	0.466	IPCC Good Practice p. 4.67
N_2O From Atmospheric Deposition of N (kg N/yr)	0.296	IPCC Good Practice p. 4.68
Emission Factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates indirect nitrous oxide from harvested cropland for the cow-calf operation as 0.466 kg/year. This value is reported in the first row of Table D.31 with intermediate equations and input values used below it.

Table D.32: Calculation of Annual Sequestered Carbon per Hectare for Pasture Soils (Areas in Gray are Inputs)

Item	Value	Source
Carbon Sequestered (Mg/ha)	0.120	Hope Phetteplace
Number of Hectares	1.000	Calculated from soil class II (See Table 1 Above)

Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

The performance standard calculates carbon sequestered per hectare for Type II soils as 0.12 Mg/year or 120 kg/year. This value is reported in the first row of Table D.32 with input values below it.

Table D.33: Calculation of Annual Sequestered Carbon for Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Carbon Sequestered (Mg/yr)	0.029	Hope Phetteplace
Number of Hectares per Representative AU	0.155	Calculated from representative hectare (see Table 3 above)
Number of Representative AUs per Hectare in the Cow-Calf Operation	1.900	Calculated from soil class carrying capacity (see Table 1 above)

Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

The performance standard calculates carbon sequestered for harvested cropland for the cow-calf operation as 0.029 Mg/year or 29 kg/year. This value is reported in the first row of Table D.33 with input values below it.

Summing the values for each type of gas provides the performance standard per hectare for Type II soils for that gas. The performance standard is 108.622 kg/year for methane, 9.402 kg/year for nitrous oxide, and -149.000 kg/year for carbon dioxide since this is the rate at which carbon is sequestered. To find the net GHG emissions per hectare for Type II soils, the values above must be converted to their carbon equivalents. This is done using the formula [metric tonnes of the gas · its global warming potential · (12/44)][32]. Carbon sequestered does not need to be converted since it is already in carbon equivalent format. The carbon equivalents per hectare for Type II soils for methane, nitrous oxide, and carbon dioxide are 622.108 kg, 794.896 kg, and -149.000 kg, respectively. The total performance standard carbon equivalent per hectare for Type II soils is the sum of these values, 1268.004 kg.

[32] One metric ton = 1 megagram (Mg) = 1000 kg

APPENDIX E: THE PERFORMANCE STANDARD FOR A DAIRY OPERATION

E.1 Calculation of GHG Emissions

The performance standard estimates GHG emissions for well managed conventional dairy operations. Performance standard calculations are based on recommendations and technical information from NRCS, Virginia DCR, and Virginia Agricultural Extension Farm Management Budgets. GHG calculations are produced by using IPCC equations (IPCC, 2001). The performance standards are based on an annualized dairy farm enterprise for the Mid-Atlantic region. The performance standard is reported as net GHG emissions per hundred weight of milk. Figure E.1 gives a graphical depiction of the calculation of the performance standard. Details of the calculation are discussed in the subsequent sections of this appendix.

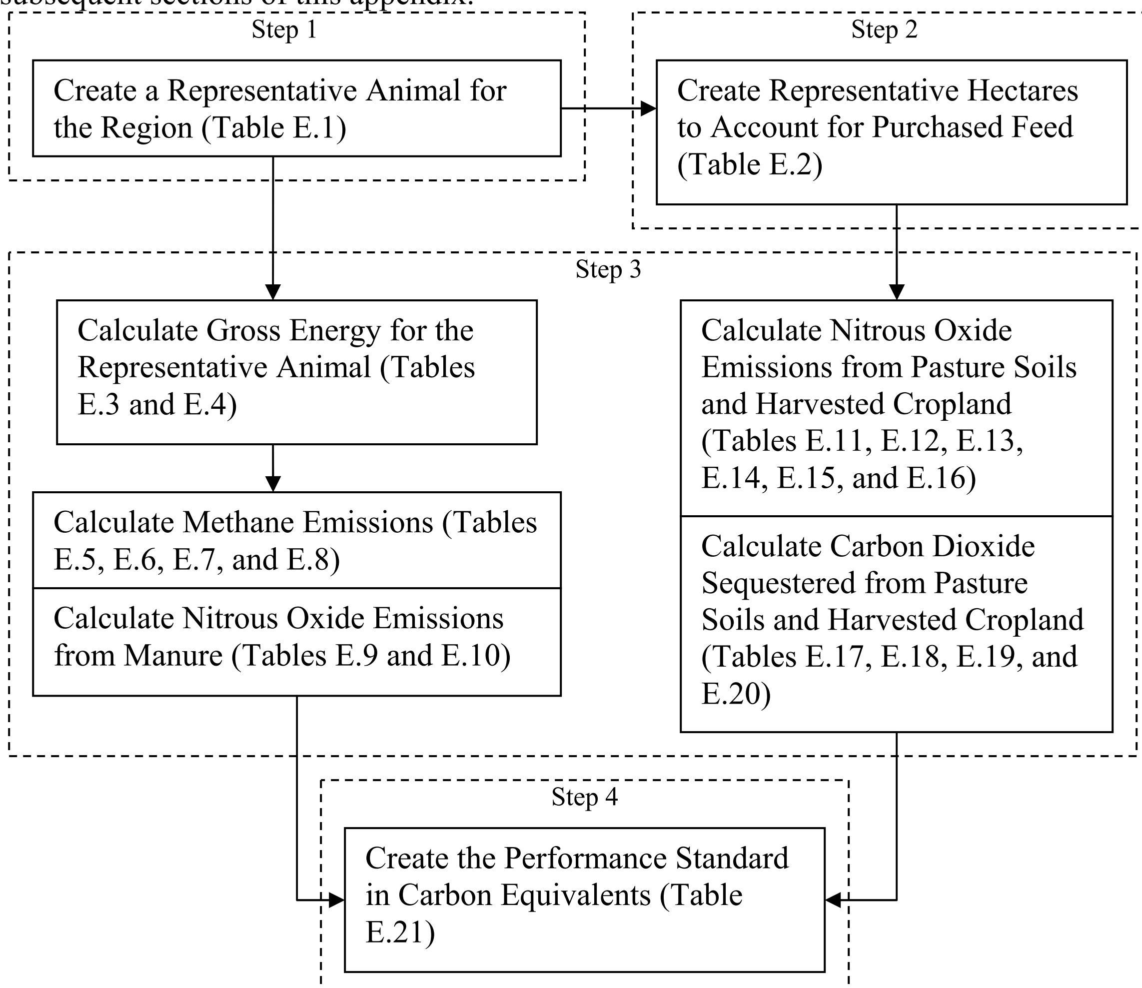

Figure E.1: Schematic for Creation of Net GHG Performance Standard for a Dairy Operation

Net GHG emissions include methane, nitrous oxide, and carbon dioxide. The first step in the creation of the performance standard is to create a representative animal for the region. This representative animal combines the different classes of animals (lactating cows, dry cows, bred heifers, etc.) and is used to calculate gross energy, an input needed in calculating enteric methane, methane from manure management, and nitrous oxide from manure management by the IPCC equations. The second step is to create representative hectares to account for the GHG emissions embedded in the growing of feed produced on farm or purchased. The feed includes corn grain, corn silage, orchardgrass hay, alfalfa hay, soybean meal, and pasture. Step three combines the representative animal from step one, the representative hectares from step two, and other regional factors into the IPCC equations to estimate the net GHG emissions for well managed conventional dairy operations. The final step converts net GHGs for these operations into carbon equivalents, creating the performance standard for regional dairy operations.

Step 1: Create a representative animal unit[33] (AU) for the region. An example for a representative dairy AU is given in Table E.1:

Table E.1: Creation of a Representative Dairy AU for the Region

Type[a]	Number[b]	Average Weight (kg)[c]	Time On Farm	Total Weight by Type (kg)	Percent of Total Farm Weight	Weight By Type in Representative Animal (kg)
Lactating Cow[d]	100	589.68	0.84	49274.31	55%	247.61
Dry Cow[d]	100	589.68	0.16	9693.31	11%	48.71
Bred Heifers	30	408.24	1.00	12247.12	14%	61.54
Open Heifers	32	294.84	1.00	9434.82	10%	47.41
Heifers	34	181.44	1.00	6168.92	7%	31.00
Calves	38	90.72	1.00	3447.34	4%	17.32
		Total Farm Weight		90265.81	Representative AU	453.60

[a]The representative dairy AU is based on all female animals. It is assumed that all bull calves are sold. The cows are all bred by artificial insemination.
[b] Source: Virginia Cooperative Extension Farm Management Budgets, Dairy Cow, Corn Silage/Alfalfa Haylage
[c] Source: Virginia Cooperative Extension Farm Management Budgets, Dairy Cow, Corn Silage/Alfalfa Haylage and Expert Opinion from Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
[d] The lactating cows and dry cows are the same animals. It is assumed that these animals lactate 305 days per year and are dry 60 days per year.

The representative dairy AU is based on stocking rates and weights provided by Virginia Cooperative Extension Farm Management Budget number 28, 'Dairy Cows, Corn Silage/Alfalfa Haylage.' These values provide the basis for a "representative farm" for the region. This representative dairy farm is a 149.488 ha (369.399-acre) 100-lactating-cow farm using a predominantly corn silage and alfalfa haylage ration. The farm has 50.58 hectares (125 acres) of pastureland. The rest of the land is assumed to grow different types of feed. The farm produces 20,000 lbs of milk per animal annually with 30% of the animals leaving the herd annually and a 4% annual death loss. Lactating cows are fed in confinement and dry cows are kept on pasture with supplemental feeding.

[33] An AU is defined as a single 453.597 kg (1000 lb) animal.

The representative dairy AU is determined by combining animal class, weight, and number of head from this representative farm into a composite dairy AU. This is accomplished by obtaining the number of each type of animal (e.g., lactating cows, dry cows, bred heifers, etc.) (Number), average weight of each animal class (Average Weight), and the percentage of the year each animal type is on the farm (Time on Farm). The product of Number, Time-on-farm, and Average Weight yields the total weight for each type (Total Weight by Type). Total Farm Weight is the sum of all total weights by type. To obtain the percentage of total farm weight, each type is divided by total farm weight and expressed in a percentage. This percentage equals the percent of representation each class has in the representative dairy AU. Each percent is then multiplied by 453.597 kg to find the proportional makeup of the representative dairy AU (Weight by Type in Representative AU). The representative dairy AU is the sum of these weights.

Step 2: Create representative hectares to account for the GHG emissions embedded in the growing of home-raised and purchased feed. An example of representative hectares for a dairy operation is given in Table E.2:

Table E.2: Creation of Representative Hectares for Growing of Feed (Percentage of Loss is in Parentheses)

Crop[a]	Amount Fed (kg)[a]	Adjusted for Feeding Loss[b]	Adjusted for Storage Loss[b]	Adjusted for Harvest Loss[c]	Amount Grown (kg)[d]	Amount Needed per AU (kg)	Hectares Needed for Crop per AU
Corn Grain	221355.35	230578.49 (4%)	256198.32 (10%)	264121.98 (3%)	264121.98	1327.25	0.146
Corn Silage	1035743.45	1067776.75 (3%)	1135932.71 (6%)	1183263.24 (4%)	1183263.24	5946.05	0.136
Orchardgrass Hay	202304.27	222312.39 (9%)	244299.33 (9%)	268460.80 (9%)	268460.80	1349.05	0.172
Alfalfa Haylage	318243.67	349718.32 (9%)	384305.85 (9%)	422314.12 (9%)	422314.12	2122.18	0.189
Soybean Meal	44996.82	46871.69 (4%)	52079.66 (10%)	54820.69 (5%)	74082.02	372.27	0.178
					Total Hectares per AU		0.821

[a] Source: Virginia Cooperative Extension Farm Management Budgets, Dairy Cow, Corn Silage/Alfalfa Haylage. These values are "as fed" values. Dry matter (DM) values are as follows: corn grain = 85% DM, corn silage = 35% DM, hay = 89% DM, haylage = 45% DM, and soybean meal = 90% DM.
[b] Source: Martin, P. (1980) and Smith, T. (1997)
[c] Source: Harvest loss for corn grain and soybean meal are from Dr. Robert Grisso, Biological Systems Engineering, Virginia Polytechnic Institute and State University. All others are Martin, P. (1980) and Smith, T. (1997)
[c] The amount grown differs for the soybean meal here due to removal of soybean hulls and oil. This removal accounts for a loss of 26 percent of the total weight of the soybeans (Source: Central Soya)

The representative hectares are determined by calculating the amount of each type of crop used to feed the animals on the representative farm, adjusting for feeding, storage and harvest losses to find the total amount of the crops grown, finding the amount of each crop needed per representative AU, and calculating the number of hectares needed for each crop. This is done by obtaining the amount of each crop fed to the animals on the farm from the Virginia Cooperative Extension Farm Management Budgets (Amount Fed). This amount must then be adjusted for losses. To calculate the amount of each crop lost during feeding (Adjusted for Feeding Loss), find the percentage loss during feeding and multiply this by the amount fed. To calculate the amount of each crop lost during storage (Adjusted for Storage Loss), find the percentage loss during storage and multiply this by the amount fed plus the feeding loss. To calculate the amount of each crop lost during harvest (Adjusted for Harvest Loss), find the percentage loss of each crop during harvest and multiply this by the sum of the amount fed, feeding loss, and storage loss. The sum of amount fed, feeding loss, storage loss, and harvest loss is equal to the amount of crop originally grown (Amount Grown). This number is divided by the number of representative AUs on the farm[34] to get the amount of crop needed per representative AU (Amount Needed per AU). The number of hectares used to grow the amount of each crop needed by the representative AU (Hectares Needed for Crop per AU) is calculated by dividing the amount needed per AU by the amount of that crop that can be grown on one hectare of land. These values are given in Table I-2 of the Virginia DCR publication Virginia Nutrient Management Standards and Criteria (1995).[35] The representative hectares are the sum of the hectares needed for each crop (Total Hectares per AU).

Step 3: Use the representative AU, representative hectares, and other regional factors to calculate gross energy, enteric methane, methane from manure management, nitrous oxide from manure management, direct nitrous oxide from pasture soils and harvested cropland, indirect nitrous oxide from pasture soils and harvested cropland, and carbon sequestered by pasture soils and harvested cropland. Gross energy for the representative AU is the first factor calculated. The daily gross energy equation and its components are listed in Table E.3 and Table E.4 summarizes the specific inputs into the gross energy equation.

Table E.3: Equations Used to Calculate Daily Gross Energy Required for the Representative AU

Calculation	Equation	Source[a]
Net Energy Required By Animal For Maintenance in mega Joules (MJ) per day	$Cf_i \cdot (\text{Weight})^{0.75}$ Where: Cf_i = a coefficient for the animal category (0.322 for non-lactating cattle and 0.335 for lactating cattle) Weight = the live weight of the animal in kg	p. 4.13
Net Energy For Activity (MJ/day)	$C_a \cdot NE_m$ Where: C_a = a coefficient corresponding to the animal's feeding situation (stall = 0, pasture = 0.17, and grazing large areas = 0.36) NE_m = the net energy required by the animal for maintenance	p. 4.14

[34] This is found by dividing the total weight of the farm by the weight of one representative AU.
[35] It is assumed that all crops are grown on type one or type two soils, thus the midpoint of these two types is used.

Table E.3 (Cont.)		
Calculation	**Equation**	**Source**[a]
Net Energy For Growth (MJ/day)	$4.18 \cdot \{0.0635 \cdot [0.891 \cdot (BW \cdot 0.96) \cdot (478/(C \cdot MW))]^{0.75} \cdot (WG \cdot 0.92)^{1.097}\}$ Where: BW = the live body weight of the growing animal C = a gender coefficient (females = 0.8, castrates = 1.0, and bulls = 1.2) MW = the mature weight of the animal WG = the daily weight gain of the animal in kg	p. 4.15
Net Energy Due To Weight Loss for Lactating Dairy Cows (MJ/day)	$19.7 \cdot$ Weight loss Where: Weight loss = the animal weight loss per day in kg	p.4.16
Net Energy Due To Weight Loss for Other Cattle (MJ/day)	$NE_g \cdot (-0.8)$ Where: NE_g = the net energy needed for growth in MJ/day	p. 4.17
Net Energy For Lactation (MJ/day)	kg milk/day $\cdot$ (1.47 + (0.4 $\cdot$ Fat)) Where: Fat = the fat content of milk by percentage	p. 4.17
Net Energy For Work (MJ/day)	$0.10 \cdot NE_m \cdot$ hours of work per day Where: NE_m = net energy required by the animal for maintenance	p. 4.18
Net Energy For Pregnancy (MJ/day)	$C_{pregnancy} \cdot NE_m$ Where: $C_{pregnancy}$ = a pregnancy coefficient (cattle = 0.10) NE_m = the net energy required by the animal for maintenance	p. 4.18
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	$1.123 - (4.092 \cdot 10^{-3} \cdot DE) + [1.126 \cdot 10^{-5} \cdot (DE)^2] - (25.4/DE)$ Where: DE = digestible energy expressed as a percentage of gross energy	p. 4.19
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	$1.164 - (5.16 \cdot 10^{-3} \cdot DE) + (1.308 \cdot 10^{-5} \cdot (DE)^2) - (37.4/DE)$ Where: DE = digestible energy expressed as a percentage of gross energy	p. 4.19

Table E.3 (Cont.)		
Calculation	**Equation**	**Source**[a]
Gross Energy (MJ/day)	$\{[(NE_m + NE_{mobilized} + NE_a + NE_l + NE_w + NE_p)/ (NE_{ma}/DE)] + [NE_g /(NE_{ga}/DE)]\}/(DE/100)$ Where: NE_m = net energy required by the animal for maintenance, MJ/day $NE_{mobilized}$ = net energy due to weight loss, MJ/day NE_a = net energy for animal activity, MJ/day NE_l = net energy for lactation, MJ/day NE_w = net energy for work, MJ/day NE_p = net energy required for pregnancy, MJ/day NE_{ma}/DE = ratio of net energy available in a diet for maintenance to digestible energy consumed NE_g = net energy needed for growth, MJ/day NE_{ga}/DE = ratio of net energy available for growth in a diet to digestible energy consumed DE = digestible energy expressed as a percentage of gross energy	p. 4.20

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table E.4: Summary of Inputs for Calculation of Daily Gross Energy Requirements for the Representative AU

Equation	Item	Value	Source
Net Energy for Maintenance	Animal category coefficient[a]	0.328	IPCC Good Practice Table 4.4
	Weight of animal (kg)	453.597	One animal unit assumption
Net Energy For Activity	Feeding situation coefficient[b]	0.077	IPCC Good Practice Table 4.5
Net Energy For Growth	Gender coefficient	0.800	IPCC Good Practice p. 4.15
	Live body weight of a growing animal (kg)	243.808	One animal unit assumption
	Daily weight gain (kg/day)	0.454	Expert opinion
Net Energy Due to Weight Loss For Lactating Dairy Cows	Weight loss (kg/day)	-0.181	Expert opinion
Net Energy For Lactation	Milk produced (kg/day)	29.744	Calculated from Virginia Cooperative Extension Farm Management budgets
	Fat content of milk (%)	3.5	Expert opinion
Net Energy For Work	Hours of work per day	0.000	Assumed to be zero since cattle are not draught animals in Virginia
Net Energy For Pregnancy	Pregnancy coefficient	0.100	IPCC Good Practice Table 4.7

Table E.4 (Cont.)			
Equation	**Item**	**Value**	**Source**
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	Digestible energy expressed as a percentage of gross energy	70.000	Expert opinion
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	Digestible energy expressed as a percentage of gross energy	70.000	Expert opinion

[a] This value is adjusted to reflect that only 55% of the representative AU is lactating
[b] This value is adjusted to reflect that 55% of the representative animal is in a confinement feeding system and 45% is on pasture
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University

Gross energy is used as a variable in the second and third equations to calculate enteric methane and methane from manure management.

The equations for calculating annual enteric methane and its components are given in Table E.5. The first calculation, the *Emission Factor for Enteric Methane*, is used in the second calculation, *Annual Enteric Methane Emissions*. A summary of inputs for the calculation of enteric methane is given in Table E.6.

The equation for methane from manure management and its components are listed in Table E.7. In this table, the first calculation, the *Volatile Solid Excretion Rate*, is an input in the second calculation, *Emissions Factor from Manure Management*. Likewise, *Emissions Factor from Manure Management* is an input in the final calculation, *Annual Methane Emissions from Manure Management*. In this study, the manure management system, *j*, is defined as a system where the manure is left where it is deposited by the animal for the part of the representative AU which is on pasture, and as a liquid/slurry system for the part of the representative animal in confinement. Table E.8 presents a summary of the inputs used to calculate methane from manure management.

Table E.5: Equations Used to Calculate Annual Enteric Methane Emissions for the Representative AU

Calculation	Equation	Source[a]
Enteric Methane Emission Factor	$(GE \cdot Y_m \cdot 365 \text{ days/year})/(55.65 \text{ MJ/Kg } CH_4)$ Where: GE = gross energy intake in MJ/head/day Y_m = a methane conversion rate which is the fraction of gross energy in feed converted to methane (feedlot fed cattle = 0.04 ± 0.005 and all other cattle = 0.06 ± 0.005)	p. 4.26

Table E.5 (Cont.)		
Calculation	**Equation**	**Source[a]**
Annual Enteric Methane Emissions in Kilograms	EF_i x POP Where: EF_i = emission factor for the specific population, kg/head/year POP = the number of animals, head	p. 4.25

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table E.6: Summary of Inputs for the Calculation of Annual Enteric Methane Emissions for the Representative AU

Equation	Item	Value	Source
Methane Emissions From a Representative Animal	Number of animals	199.000	This is the number of representative AU's on the farm (calculated by dividing total farm weight by 453.597)
Methane Emission Factor	Methane conversion rate[a]	0.049	IPCC Good Practice Table 4.8

[a] This rate is corrected to reflect that 55% of the representative AU is in a confined feeding system and 45% is on pasture

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

Table E.7: Equations Used to Calculate Annual Methane Emissions from Manure Management

Calculation	Equation	Source[a]
Volatile Solid Excretion Rate (kg/day)	$(GE - DEI + 0.04 \cdot GE)/20.1$ Where: GE = gross energy intake in MJ/head/day DEI = the digestible energy intake, equal to $GE \cdot DE$ where DE is digestible energy expressed as a percentage of gross energy	Hope Phetteplace[b]
Emission Factor from Manure Management (kg)	$(VS \cdot 365\ \text{days/yr}) \cdot (B_{oi} \cdot 0.67\ \text{kg/m}^3) \cdot \sum_{jk} MCF_{jk} \cdot MS_{ijk}$ Where: VS = the daily amount of volatile solids excreted by the representative animal B_{oi} = the maximum methane producing capacity for manure produced by the representative animal (dairy cattle = 0.24, all non-dairy cattle = 0.17) MCF_{jk} = the methane conversion factor for each manure management system *j* by climate region *k* (temperate zone temperate zone pasture/range/paddock = 0.015) MS_{ijk} = the fraction of animal species/category *i*'s manure using manure system *j* in climate region *k*	p. 4.34

Table E.7 (Cont.)		
Annual Methane Emissions from Manure (kg)	$EF_{i,m}$ x POP Where: $EF_{i,m}$ = emission factor for manure (m) for the specific population, kg/head/yr POP = the number of animals, head	p. 4.30

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.
[b] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table E.8: Summary of Inputs for the Calculation of Annual Methane Emissions from Manure Management

Equation	Item	Value	Source
Methane Emission Factor from Manure Management	Maximum methane producing capacity for manure produced by an animal	0.240	IPCC Reference Manual Appendix B
	Methane conversion factor for pasture manure management system	0.015	IPCC Good Practice Table 4.10
	Fraction of animals' manure handled by pasture manure system	0.450	IPCC Good Practice Table 4.10
	Methane conversion factor for barn manure management system	0.450	One animal unit assumption
	Fraction of animals' manure handled by barn manure system	0.550	One animal unit assumption
Annual Methane Emissions from Manure	Number of animals	199.000	This is the number of representative AU's on the farm (calculated by dividing total farm weight by 453.597)

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The fourth equation calculates nitrous oxide from manure management. Table D.9 supplies the equation and its components for nitrous oxide. In this equation, S is defined as a management system where the manure is allowed to lay where it is deposited for the part of the representative AU that is on pasture and as a slurry system for the part of the representative AU that is in confinement. T is defined as dairy cattle. Table D.10 includes a summary of the inputs used in the calculation of nitrous oxide from manure management.

Table E.9: Equations Used to Calculate Annual Nitrous Oxide Emissions from Manure Management

Calculation	Equation	Source[a]
Annual Nitrous Oxide Emissions from Manure in kg	$(\sum_{(S)} \{[\sum_{(T)} ((N_{(T)})(Nex_{(T)})(MS_{(T,S)})] EF_{3(S)}\})(44/28)$ Where: $N_{(T)}$ = Number of head of livestock species/category *T* $Nex_{(T)}$ = Annual average N excretion per head of species/category *T* (non-dairy cattle = 70 and dairy cattle = 100) $MS_{(T,S)}$ = Fraction of the total annual excretion for each livestock species category *T* that is managed in manure management system *S* $EF_{3(S)}$ = N_2O emission factor for manure system *S* (pasture/range/paddock = 0.02) S = Manure management system T = Species/category of livestock	p. 4.42

[a] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table E.10: Summary of Inputs Used in the Calculation of Annual Nitrous Oxide Emissions from Manure Management

Equation	Item	Value	Source
Nitrous Oxide Emissions From Manure Management	Number of animals	1.000	Calculated from soil class (See Table 1 Above)
	Annual average nitrogen excretion per head (kg N/AU/yr)	100.000	IPCC Reference Manual Table 4-20
	Fraction of the total annual excretion for each livestock species category *T* that is managed in pasture manure management system	0.450	One animal unit assumption
	Emission factor for pasture manure management system	0.020	IPCC Good Practice Table 4.12
	Fraction of the total annual excretion for each livestock species category *T* that is managed in barn manure management system	0.550	One animal unit assumption
	Emission factor for barn manure management system	0.001	IPCC Good Practice Table 4.12

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The fifth equation calculates direct nitrous oxide from pasture soils and harvested cropland. This includes nitrous oxide from synthetic fertilizers and manure intentionally applied to soils. A description of the equation and its inputs is given in Table E.11 and a summary of inputs used in the calculation of direct nitrous oxide emissions from pasture soils in Table E.12. Table E.13 presents a summary of inputs used in the calculation of nitrous oxide emissions from harvested cropland. PLMS does not include *nitrogen by nitrogen fixing crops*, *nitrogen in crop residues returned to soils*, or the *emission factor for emissions from organic soil cultivation* in its calculation of direct nitrous oxide emissions from agricultural soils, though these are components of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for direct nitrous oxide emissions from agricultural soils, these components of the equation are left out of the performance standard calculation. Upon brief review of these calculations, they seem to have a relatively small effect (less than 3%) on the total, but further examination would be necessary to fully determine the effects of these values.

Table E.11: Equations Used to Calculate Annual Direct Nitrous Oxide Emissions from Agricultural Soils

Calculation	**Equation**[a]	**Source**[b]
Nitrogen From Annual Synthetic Fertilizer Application (kg)	$N_{FERT} \cdot (1 - Frac_{GASF})$ Where: N_{FERT} = the total amount of synthetic fertilizer consumed annually $Frac_{GASF}$ = the fraction of the applied nitrogen that volatilizes as NH_3 and NO_X (default value = 0.1)	p. 4.56
Nitrogen From Annual Animal Manure Application (kg)	$\sum_T (N_{(T)} \cdot Nex_{(T)}) \cdot (1- Frac_{GASM})[1-(Frac_{FUEL-AM} + Frac_{PRP})]$ Where: $\sum_T (N_{(T)} \cdot Nex_{(T)})$ is the amount of animal manure nitrogen produced annually $Frac_{GASM}$ = the amount of animal manure volatilized as NH_3 and NO_X (default value = 0.2) $Frac_{FUEL-AM}$ = the amount of manure burned for fuel $Frac_{PRP}$ = the amount of manure deposited onto soils by grazing livestock	p. 4.56
Annual Direct Nitrous Oxide Emissions from Soils (kg)	$\{[(F_{SN} + F_{AM} + F_{BN} + F_{CR}) \cdot EF_1] + (F_{OS} \cdot EF_2)\}(44/28)$ Where: F_{SN} = Annual amount of synthetic fertilizer nitrogen applied to soils F_{AM} = Annual amount of animal manure nitrogen intentionally applied to soils F_{BN} = Amount of nitrogen by N-fixing crops cultivated annually F_{CR} = Amount of nitrogen in crop residues returned to soils annually EF_1 = Emission factor for emissions from N inputs, kg/kg N input F_{OS} = Area of organic soils cultivated annually EF_2 = Emission factor for emissions from organic soil cultivation, kg/ha/yr	p. 4.54

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table E.12: Summary of Inputs Used in the Calculation of Annual Direct Nitrous Oxide Emissions from Pasture Soils

Equation	Item	Value	Source
Nitrogen From Synthetic Fertilizer Application	Amount of synthetic nitrogen consumed annually	0.000	Expert opinion
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
Nitrogen From Animal Manure Application	Annual average nitrogen excretion per head (kg N/AU/yr)	100.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Fraction of manure burned for fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
	Fraction of manure deposited by grazing livestock	1.000	Assume all manure is deposited by grazing livestock

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

Nitrogen from synthetic fertilizer application is zero in Table 12 because it is assumed that no synthetic fertilizers will be used on the pastures since this is not a primary source of feed for the animals.

Table E.13: Summary of Inputs Used in the Calculation of Annual Direct Nitrous Oxide Emissions from Harvested Cropland

Equation	Item	Value	Source
Nitrogen From Synthetic Fertilizer Application	Amount of synthetic nitrogen consumed annually (kg)	12,469.340	Calculated from Virginia Nutrient Management Standards and Criteria Handbook[a]
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
Nitrogen From Animal Manure Application	Annual average nitrogen excretion per head (kg N/AU/yr)	100.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Fraction of manure burned for fuel	0.000	Assume that no manure is burned as fuel on Virginia farms

Table E.13 (Cont.)			
Equation	Item	Value	Source
	Fraction of manure deposited by grazing livestock	0.000	Assume that there is no grazing livestock in the crop areas

[a] This was calculated by taking default nitrogen values for each crop from Virginia Nutrient Management Standards and Criteria Handbook, multiplying those values by the number of hectares needed for each crop found in Table D.2, summing the calculated values together, and multiplying by the number of representative AUs.
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The sixth equation calculates indirect nitrous oxide from pasture soils and harvested cropland. This includes atmospheric deposition of nitrogen, leaching and runoff of N applied to or deposited on soils, and disposal of sewage nitrogen. A description of this equation and its inputs is located in Table E.14 and a summary of inputs used in the calculation of indirect nitrous oxide from pasture soils is in Table E.15. Table E.16 gives a summary of inputs used in the calculation of indirect nitrous oxide from harvested cropland. PLMS does not include *deposited nitrogen from leaching/runoff* or *nitrous oxide from discharge of human sewage* in its calculation of indirect nitrous oxide emissions from agriculture, though this is a component of the IPCC Equation for such a calculation. In order to have accurate comparison of the values found in the performance standard and in PLMS for indirect nitrous oxide emissions from agriculture, this component of the equation is left out in the performance standard calculation. Upon brief review of these calculations, they could have a noticeable impact on the total, but further examination would be necessary to fully determine the effects of these values.

Table E.14: Equations Used to Calculate Annual Indirect Nitrous Oxide Emissions from Agriculture

Calculation	Equation[a]	Source[b]
N_2O From Atmospheric Deposition of N (kg N/yr)	$[(N_{FERT} \cdot Frac_{GASF}) + (\sum_T N_{(T)} \cdot Nex_{(T)}) \cdot Frac_{GASM})] \cdot EF_4$ Where: N_{FERT} = the total amount of synthetic fertilizer applied to soils $Frac_{GASF}$ = the fraction of synthetic N fertilizer that volatilizes as NH_3 and NO_x $\sum_T N_{(T)} \cdot Nex_{(T)}$ = the total amount of manure nitrogen excreted $Frac_{GASM}$ = the fraction of animal manure N that volatilizes as NH_3 and NO_x EF_4 = the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (default value = 0.1)	p. 4.68

Table E.14 (Cont.)		
Calculation	**Equation[a]**	**Source[b]**
Annual Indirect Nitrous Oxide Emissions from Agriculture (kg)	$(N_2O_{(G)} + N_2O_{(L)} + N_2O_{(S)})(44/28)$ Where: $N_2O_{(G)}$ = N_2O from atmospheric deposition of volatilized applied fertilizer and manure, kg N/yr $N_2O_{(L)}$ = N_2O from leaching and runoff of applied fertilizer and manure, kg N/yr $N_2O_{(S)}$ = N_2O from discharge of human sewage N, kg N/yr	p. 4.67

[a] This is using the Tier 1a method and set of equations. PLMS uses this set of equations in its calculation of direct nitrous oxide emissions from soils, so to be consistent it is used in the performance standard.
[b] All equations are found in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2001 unless otherwise noted.

Table E.15: Summary of Inputs Used in the Calculation of Annual Indirect Nitrous Oxide Emissions from Pasture Soils

Equation	Item	Value	Source
Nitrous Oxide From Atmospheric Deposition of Nitrogen	Amount of synthetic nitrogen consumed annually	0.000	Expert opinion
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
	Annual average nitrogen excretion per head (kg N/AU/yr)	100.000	IPCC Reference Manual Table 4-20
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Emission factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

Table E.16: Summary of Inputs Used in the Calculation of Annual Indirect Nitrous Oxide Emissions from Harvested Cropland

Equation	Item	Value	Source
Nitrous Oxide From Atmospheric Deposition of Nitrogen	Amount of synthetic nitrogen consumed annually	12,469.340	Calculated from Virginia Nutrient Management Standards and Criteria Handbook[a]
	Fraction of applied nitrogen that volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
	Annual average nitrogen excretion per head (kg N/AU/yr)	100.000	IPCC Reference Manual Table 4-20

Table E.16 (Cont.)			
Equation	**Item**	**Value**	**Source**
	Fraction of manure volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
	Emission factor	0.010	IPCC Good Practice Table 4.18

[a] This was calculated by taking default nitrogen values for each crop from Virginia Nutrient Management Standards and Criteria Handbook, multiplying those values by the number of hectares needed for each crop found in Table E.2, and summing the calculated values together.
IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The final calculations, carbon sequestered by pasture soils and carbon sequestered by harvested cropland, do not use the IPCC equations. They instead use equations provided by Dr. Hope Phetteplace of Colorado State University. Table E.17 includes a description of the equation for pasture soils and its inputs. Table E.18 includes a description of the equation for harvested cropland. Table E.19 contains a summary of the inputs used in the calculation of carbon sequestered by pasture soils. It is assumed that each representative AU will require only 0.254 hectares (0.628 acres) since grazing will not be the main source of nutrition. Table E.20 presents a summary of inputs used in the calculation of carbon sequestered by harvested cropland.

Table E.17: Equation Used to Calculate Annual Carbon Sequestered by Pasture Soils

Calculation	Equation	Source[a]
Carbon Sequestered (Mg/yr)	$.12 \cdot Ha \cdot AUs$ Where: Ha = Area of soil for pastureland/rangeland per representative AU in hectares AUs = The number of representative AUs in the dairy operation	Hope Phetteplace

[a] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table E.18: Equation Used to Calculate Annual Carbon Sequestered by Harvested Cropland

Calculation	Equation	Source[a]
Carbon Sequestered (Mg/yr)	$.10 \cdot Ha \cdot AUs$ Where: Ha = Area of soil for crops needed to feed one representative AU in hectares AUs = The number of representative AUs in the dairy operation	Hope Phetteplace

[a] Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

Table E.19: Summary of the Inputs Used in the Calculation of Annual Carbon Sequestration by Pasture Soils

Equation	Item	Value	Source
Carbon Sequestered	Area of soil for pastureland/rangeland for one AU in hectares	0.254	Calculated by dividing the number of pasture hectares by the number of AUs
	Number of representative AUs in the dairy operation	199.000	This is the number of representative AU's on the farm (calculated by dividing total farm weight by 453.597)

Table E.20: Summary of the Inputs Used in the Calculation of Annual Carbon Sequestration by Harvested Cropland

Equation	Item	Value	Source
Carbon Sequestered	Area of soil for crops needed to feed one representative AU in hectares	0.821	Calculated from representative hectare (see Table 2 above)
	Number of representative AUs in the dairy operation	199.000	This is the number of representative AU's on the farm (calculated by dividing total farm weight by 453.597)

Step 4: Convert the net GHG emissions to their carbon equivalents to find the total carbon equivalent for each soil class. The equation for converting the GHGs to their carbon equivalents is:
[metric tonnes of the gas · its global warming potential · (12/44)][36]
The global warming potentials for methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are 21, 310, and 1, respectively[37], and 12/44 is the ratio of the molecular weight of carbon to carbon dioxide. Table E.21 gives the calculated net GHG emissions for each type of GHG and the total carbon equivalent per metric ton of milk produced.

Table E.21: Performance Standard GHG Values per Metric Ton of Milk for a Dairy Operation

GHG	Methane	Nitrous Oxide	Carbon Dioxide	Carbon Equivalent
Value (kg)	14.323	0.541	-12.410	115.361

E.2 Illustration of the Performance Standard Calculation

This illustration calculates the performance standard GHGs per hundred weight of milk for a dairy operation.[38] GHGs are first calculated for the full dairy operation. These numbers are then used to calculate the GHGs per hundred weight of milk.

[36] Source: ChangingClimate.org
[37] Source: Environmental Protection Agency
[38] This example is based on the spreadsheet in which the calculations were done, thus some values which are used in multiple equations will only appear once though they are embedded in each equation which uses them.

Table E.22: Calculation of Daily Gross Energy Required by Representative AU (Areas in Gray are Inputs)

Item	Value	Source
Gross Energy (MJ/day)	226.464	IPCC Good Practice p. 4.20
Net Energy Required By Animal For Maintenance (MJ/day)	32.239	IPCC Good Practice p. 4.13
Animal Category Coefficient	0.328	IPCC Good Practice Table 4.4
Weight of Animal (kg)	453.597	One animal unit assumption
Net Energy For Activity (MJ/day)	2.482	IPCC Good Practice p. 4.14
Feeding Situation Coefficient	0.077	IPCC Good Practice Table 4.5
Net Energy For Growth (MJ/day)	2.406	IPCC Good Practice p. 4.15
Gender Coefficient	0.800	IPCC Good Practice p. 4.15
Live Body Weight of a Growing Animal (kg)	243.808	One animal unit assumption
Daily Weight Gain (kg/day)	0.454	Expert opinion
Net Energy Due To Weight Loss for Lactating Dairy Cows (MJ/day)	-3.566	IPCC Good Practice p. 4.16
Weight Loss (kg/day)	-0.181	Expert opinion
Net Energy Due To Weight Loss for Other Cattle (MJ/day)	0.000	IPCC Good Practice p. 4.17 (Assumed to be zero since non-lactating dairy cattle should not lose weight)
Net Energy For Lactation (MJ/day)	46.951	IPCC Good Practice p. 4.17
Milk Produced (kg/day)	29.744	Calculated from Virginia Cooperative Extension Farm Management budgets
Fat Content of Milk (%)	3.5	Expert opinion
Net Energy For Work (MJ/day)	0.000	IPCC Good Practice p. 4.18

Table E.22 (Cont.)		
Item	Value	Source
Hours of Work Per Day	0.000	Assumed to be zero since animals are not draught animals in Virginia
Net Energy For Pregnancy (MJ/day)	1.909	IPCC Good Practice p. 4.18
Pregnancy Coefficient	0.100	IPCC Good Practice Table 4.7
Ratio of Net Energy Available in a Diet For Maintenance to Digestible Energy Consumed	0.529	IPCC Good Practice p. 4.19
Digestible Energy Expressed as a Percentage of Gross Energy	70.000	Expert opinion
Ratio of Net Energy Available for Growth in a Diet to Digestible Energy Consumed	0.333	IPCC Good Practice p. 4.19

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Expert Opinion = Opinion of Dr. Gordon E. Groover, Virginia Polytechnic Institute and State University

The performance standard calculation of daily gross energy for the representative AU is 226.464 Mj/day. This value is reported in the first row of Table E.22 with input values and intermediate equations used below it. It is necessary to adjust some intermediate calculation values for the representative AU to reflect that not all parts of the representative AU are in that equation. The adjustments use the animal types, weights, and percentages found in Table E.1. The intermediate calculations where this action is taken are the Animal Category Coefficient used in the *Net Energy Required for Animal Maintenance* intermediate equation, the Feeding Situation Coefficient used in the *Net Energy for Activity* intermediate equation, the *Net Energy for Growth* calculated value, the *Net Energy for Lactation* calculated value, and the *Net Energy for Pregnancy* calculated value. The Animal Category Coefficient is adjusted by finding a weighted average of lactating and non-lactating cows to reflect that both are represented in the representative AU. The Feeding Situation Coefficient is adjusted by finding a weighted average of confined and on-pasture cows to reflect that both are represented in the representative AU. The *Net Energy for Growth* calculated value is adjusted to represent that only 35% of the representative AU is growing. The *Net Energy for Lactation* calculated value is adjusted to reflect that only 55% of the representative AU is lactating. The *Net Energy for Pregnancy* calculated value is adjusted to reflect that only 59.2% of the representative AU is pregnant. This value is based on 80% of the herd being pregnant for 270 days.

Table E.23: Calculation of Annual Enteric Methane Released from the Dairy Operation (Areas in Gray are Inputs)

Item	Value	Source
Enteric Methane Emissions for the Dairy Operation (kg CH_4/year)	14,483.557	IPCC Good Practice p. 4.25

Table E.23 (Cont.)		
Item	Value	Source
Number of Animals	199.000	This is the number of representative AU's on the farm (calculated by dividing total farm weight by 453.597)
Emission Factor	72.782	IPCC Good Practice p. 4.26
Methane Conversion Rate	0.049	IPCC Good Practice Table 4.8

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates enteric methane for the dairy operation as 14,483.557 kg/year. This value is reported in the first row of Table E.23 with intermediate equations and input values used below it. The performance standard calculation uses the value of 199.000 as the number of animals. This number represents the number of representative AU's on the dairy operation. It is found by dividing the total weight of the animals on the farm by the weight of one representative AU.

Table E.24: Calculation of Annual Methane Emitted from Manure Deposited on the Dairy Operation (Areas in Gray are Inputs)

Item	Value	Source
Methane Emissions From Manure Management (kg/year)	11,375.597	IPCC Good Practice p. 4.30
Volatile Solid Excretion Rate (kg/day)	3.831	Hope Phetteplace
Emission factor From Manure Management (kg)	57.164	IPCC Good Practice p. 4.34
Maximum CH4 Producing Capacity for Manure Produced by an Animal (m^3)	0.170	IPCC Reference Manual Appendix B
Methane Conversion Factor For Pasture Manure Management System	0.015	IPCC Good Practice Table 4.10
Methane Conversion Factor For Pasture Manure Management System	0.450	IPCC Good Practice Table 4.10
Fraction of Animals' Manure Handled By Pasture Manure System	0.450	One animal unit assumption
Fraction of Animals' Manure Handled By Barn Manure System	0.550	One animal unit assumption

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates methane from manure management as 11,375.597 kg/year for the dairy operation. This value is reported in the first row of Table E.24 with the intermediate equations and input values used below it.

Table E.25: Calculation of Annual Nitrous Oxide Emitted from Manure Deposited on the Dairy Operation (Areas in Gray are Inputs)

Item	Value	Source
N_2O Emissions From Manure Management (kg/yr)	298.642	IPCC Good Practice p. 4.42
Annual Average N Excretion Per Head (kg N/Animal/Year)	100.000	IPCC Reference Table 4-20
Emission Factor for Pasture Manure Management System	0.020	IPCC Good Practice Table 4.12
Emission Factor for Barn Manure Management System	0.001	IPCC Good Practice Table 4.12

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates nitrous oxide from manure management as 298.642 kg/year for the dairy operation. This value is reported in the first row of Table E.25 with input values used below it.

Table E.26: Calculation of Annual Direct Nitrous Oxide Emitted from Pasture Soils (Areas in Gray are Inputs)

Item	Value	Source
Direct N_2O Emissions from Ag Soils (kg)	0.000	IPCC Good Practice p. 4.54
N From Synthetic Fertilizer Application	0.000	IPCC Good Practice p. 4.56
Amount Of Synthetic Nitrogen Consumed Annually (kg)	0.000	Expert opinion
Fraction of Applied Nitrogen That Volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
N From Animal Manure Application	0.000	IPCC Good Practice p. 4.56
Fraction of Manure Volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
Fraction of Manure Burned For Fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
Fraction of Manure Deposited by Grazing Livestock	1.000	

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates direct nitrous oxide emissions from pasture agricultural soils for the dairy operation as 0.000 kg/year. The value is reported in the first row of Table E.26 with intermediate equations and input values used below it. The value is zero because the pasture on the farm is not fertilized and all manure is deposited by animals. The nitrogen from this deposition is calculated in Table E.25 above and is not included here to eliminate double counting.

Table E.27: Calculation of Annual Direct Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Direct N_2O Emissions from Ag Soils (kg)	533.154	IPCC Good Practice p. 4.54
N From Synthetic Fertilizer Application	11,222.406	IPCC Good Practice p. 4.56
Amount Of Synthetic Nitrogen Consumed Annually (kg)	12,469.34	Expert opinion
Fraction of Applied Nitrogen That Volatilizes as NH_3 and NO_X	0.100	IPCC Reference Table 4.19
N From Animal Manure Application	15,920.000	IPCC Good Practice p. 4.56
Fraction of Manure Volatilized As NH_3 and NO_X	0.200	IPCC Reference Table 4.19
Fraction of Manure Burned For Fuel	0.000	Assume that no manure is burned as fuel on Virginia farms
Fraction of Manure Deposited by Grazing Livestock	0.000	Assume that there is no grazing livestock in the crop areas

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC Reference Manual = Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual

The performance standard calculates direct nitrous oxide emissions from harvested cropland for the dairy operation as 533.154 kg/year. The value is reported in the first row of Table E.27 with intermediate equations and input values used below it.

Table E.28: Calculation of Annual Indirect Nitrous Oxide Emitted from Pasture Soils (Areas in Gray are Inputs)

Item	Value	Source
Indirect N_2O Emissions From Agriculture (kg)	62.543	IPCC Good Practice p. 4.67
N_2O From Atmospheric Deposition of N (kg N/yr)	39.800	IPCC Good Practice p. 4.68

Table E.28 (Cont.)		
Item	**Value**	**Source**
Emission Factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates indirect nitrous oxide from pasture soils for the dairy operation as 62.543 kg/year. This value is reported in the first row of Table E.28 with intermediate equations and input values used below it.

Table E.29: Calculation of Annual Indirect Nitrous Oxide Emitted from Harvested Cropland (Areas in Gray are Inputs)

Item	**Value**	**Source**
Indirect N_2O Emissions From Agriculture (kg)	82.138	IPCC Good Practice p. 4.67
N_2O From Atmospheric Deposition of N (kg N/yr)	52.269	IPCC Good Practice p. 4.68
Emission Factor	0.010	IPCC Good Practice Table 4.18

IPCC Good Practice = IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories

The performance standard calculates indirect nitrous oxide from harvested cropland for the dairy operation as 82.138 kg/year. This value is reported in the first row of Table E.29 with intermediate equations and input values used below it.

Table E.30: Calculation of Annual Sequestered Carbon for Pasture Soils (Areas in Gray are Inputs)

Item	**Value**	**Source**
Carbon Sequestered (Mg/yr)	6.066	Hope Phetteplace
Number of Hectares per Representative AU	0.254	Assume that animals on pasture only need 0.203 hectares (0.5 acres) since most feed is supplemental
Number of Representative AUs in the Dairy Operation	199.000	This is the number of representative AU's on the farm (calculated by dividing total farm weight by 453.597)

Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

The performance standard calculates carbon sequestered for pasture soils for the dairy operation as 6.066 Mg/year or 6,066 kg/year. This value is reported in the first row of Table E.30 with input values below it.

Table E.31: Calculation of Annual Sequestered Carbon for Harvested Cropland (Areas in Gray are Inputs)

Item	Value	Source
Carbon Sequestered (Mg/yr)	16.338	Hope Phetteplace
Number of Hectares	0.821	Calculated from representative hectare (see Table 2 above)
Number of Representative AUs in the Dairy Operation	199.000	This is the number of representative AU's on the farm (calculated by dividing total farm weight by 453.597)

Hope Phetteplace = Information from Dr. Hope Phetteplace, Colorado State University, Personal Contact, Feb 2002

The performance standard calculates carbon sequestered for harvested cropland for the dairy operation as 16.338 Mg/year or 16,338 kg/year. This value is reported in the first row of Table E.31 with input values below it.

Summing the values for each type of gas provides the performance standard for the dairy operation for that gas. The performance standard is 25,859.154 kg/year for methane, 976.477 kg/year for nitrous oxide, and -22,404 kg/year for carbon since this is the rate at which carbon is sequestered. These numbers are then divided by the number of representative AUs, 199, to find the amount of each GHG emitted per animal. These values are 129.945 kg/year for methane, 4.907 kg/year for nitrous oxide, and -112.583 kg/year for carbon. To find the amount of each GHG emitted per metric ton of milk, the emissions per representative AU must be divided by 9.072, which is the number of metric tons of milk produced. This gives values of 14.323 kg/year for methane, 0.541 kg/year for nitrous oxide, and -12.410 kg/year for carbon. To find the net GHG emissions per metric ton of milk per animal, the values for each GHG per hundred weight of milk must be converted to their carbon equivalents. This is done for methane and nitrous oxide using the formula [metric tons of the gas · its global warming potential · (12/44)][39]. Carbon sequestered does not need to be converted since it is already in carbon equivalent form. The carbon equivalents per hundred weight of milk for methane, nitrous oxide, and carbon are 82.032 kg, 45.739 kg, and -12.410 kg, respectively. The total performance standard carbon equivalent per metric ton of milk is the sum of these values, 115.361 kg.

[39] One metric ton = one megagram (Mg) = 1000 kg

APPENDIX F: COMPLETE CASE STUDY FARM BUDGETS

Appendix F presents the complete budgets used to calculate the revenues and costs of the case study farms used in this study. The budgets are based on Virginia Cooperative Extension Farm Management Budgets and the Economics Section of the Virginia Forage and Grassland Council Grazing Handbook. The budgets are for the farm enterprise for a single year.

Budgets for each case study farm are presented in the following order: herd summary, revenues, non-forage variable costs, rations, forage costs, and costs associated with capital changes resulting from conversion to rotational grazing. There are three reference conditions for each case study farm. The first of these is *before rotational grazing*. This reference condition is based on the level of operation the case study farm operated at before converting to rotational grazing. The second reference condition is *without rotational grazing*. This condition presents an estimation of how the farm would operate if all present improvements less the rotational grazing system were in place. The final reference condition is *with rotational grazing*. This condition presents the current level of operation for the case study farm under rotational grazing. A summary of the revenues and costs for each of the conditions appears at the end of each section.

F.1 Cow-Calf Case Study Farm

A summary of the differences between each reference condition for the cow-calf case study farm is presented in Table 3.1.

Table F.1: Herd Summaries of Each Reference Condition for the Cow-Calf Case Study Farm (Areas in Gray are Inputs)

Cow-Calf Herd Statistics			
	Before Rotational Grazing	**Without Rotational Grazing**	**With Rotational Grazing**
Number of Cows	23	23	35
% Calf Crop	85	85	85
% Replacements Kept as a % of Cow Herd	15	15	15
% Annual Culling Rate	15	15	15
% Annual Cow Death Loss	1	1	1

It is assumed in all of the reference conditions that half of the calf crop is female and half is male. In the before reference condition, it is assumed the calf crop is born in February and March. In the *without* and *with* reference conditions, it is assumed that half of the calf crop is born in November and December, with the other half born in February and March.

Table F.2: Revenues for the Cow-Calf Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Revenues Before Rotational Grazing							
Item	No. of Animals Sold		Weight	Unit	Price[a]	Quantity	Total
Steers	9.78	@	4.73	CWT	$ 98.01	46.24	$ 4,531.57
Heifers	6.33	@	4.27	CWT	$ 98.01	27.01	$ 2,647.03
Cull Cows	3.22	@	11.50	CWT	$ 35.00	37.03	$ 1,296.05
Cull Bulls	0.23	@	17.00	CWT	$ 45.00	3.91	$ 175.95
			Gross Revenue Without Rotational Grazing				$ 8,650.60

[a] The prices for steers and heifers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. The prices for cull animals are presented in the Virginia Cooperative Extension Farm Management Budgets.

The animals are all assumed to be sold in early September in this reference condition.

Table F.3: Revenues for the Cow-Calf Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Revenues Without Rotational Grazing							
Item	No. of Animals Sold		Weight	Unit	Price[a]	Quantity	Total
Steers: Fall Calving	4.89	@	6.00	CWT	$ 101.09	29.33	$ 2,964.46
Heifers: Fall Calving	3.16	@	5.50	CWT	$ 101.29	17.39	$ 1,761.81
Steers: Spring Calving	4.89	@	5.00	CWT	$ 106.06	24.44	$ 2,591.84
Heifers: Spring Calving	3.16	@	4.50	CWT	$ 97.45	14.23	$ 1,386.84
Cull Cows	3.22	@	11.50	CWT	$ 35.00	37.03	$ 1,296.05
Cull Bulls	0.23	@	17.00	CWT	$ 45.00	3.91	$ 175.95
			Gross Revenue Without Rotational Grazing				$10,176.95

[a] The prices for steers and heifers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. The prices for cull animals are presented in the Virginia Cooperative Extension Farm Management Budgets.

The animals are all assumed to be sold in early September in this reference condition.

Table F.4: Revenues for the Cow-Calf Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Revenues Without Rotational Grazing							
Item	No. of Animals Sold		Weight	Unit	Price[a]	Quantity	Total
Steers: Fall Calving	7.44	@	7.35	CWT	$ 101.09	54.67	$ 5,526.15
Heifers: Fall Calving	4.81	@	6.65	CWT	$ 101.29	32.00	$ 3,241.60
Steers: Spring Calving	7.44	@	5.25	CWT	$ 106.06	39.05	$ 4,141.31
Heifers: Spring Calving	4.81	@	4.75	CWT	$ 97.45	22.86	$ 2,227.65
Cull Cows	4.90	@	11.50	CWT	$ 35.00	56.35	$ 1,972.25
Cull Bulls	0.35	@	17.00	CWT	$ 45.00	5.95	$ 267.75
			Gross Revenue Without Rotational Grazing				$17,376.70

[a] The prices for steers and heifers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. The prices for cull animals are presented in the Virginia Cooperative Extension Farm Management Budgets.

The animals are all assumed to be sold in early September in this reference condition.

Table F.5: Non-Forage Variable Costs for the Cow-Calf Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Non-Forage Variable Costs Before Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Salt & Mineral	CWT	$ 22.00	15.64	$ 344.08
Vet & Medicine	Head	$ 17.49	23	$ 402.27
Replacement Bull	Head	$ 1,600.00	0.23	$ 368.00
Haul Cull Cattle	Head	$ 5.20	3.45	$ 17.94
Market Cull Cattle	Head	$ -	3.45	$ 39.79
Haul Calves	Head	$ 3.75	16.10	$ 60.38
Market Calves	Head	$ -	16.10	$ 199.92
Building & Fence Repair	Foot	$ 0.01	1475.8	$ 14.76
	Total Variable Costs Without Rotational Grazing			$ 1,447.13

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

The quantity for building and fence repair is based on the number of feet of fencing needed to fence in a 50-acre square.

Table F.6: Non-Forage Variable Costs for the Cow-Calf Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Non-Forage Variable Costs Without Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Salt & Mineral	CWT	$ 22.00	15.64	$ 344.08
Vet & Medicine	Head	$ 17.49	23	$ 402.27
Replacement Bull	Head	$ 1,600.00	0.23	$ 368.00
Haul Cull Cattle	Head	$ 5.20	3.45	$ 17.94
Market Cull Cattle	Head	$ -	3.45	$ 39.79
Haul Calves	Head	$ 3.75	16.10	$ 60.38
Market Calves	Head	$ -	16.10	$ 230.45
Building & Fence Repair	Foot	$ 0.01	1475.8	$ 14.76
	Total Variable Costs Without Rotational Grazing			$ 1,477.66

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

The quantity for building and fence repair is based on the number of feet of fencing needed to fence in a 50-acre square.

Table F.7: Non-Forage Variable Costs for the Cow-Calf Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Non-Forage Variable Costs With Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Salt & Mineral	CWT	$ 22.00	23.80	$ 523.60
Vet & Medicine	Head	$ 11.75	35	$ 411.25
Replacement Bull	Head	$ 1,600.00	0.35	$ 560.00
Haul Cull Cattle	Head	$ 5.20	5.25	$ 27.30
Market Cull Cattle	Head	$ -	5.25	$ 60.55
Haul Calves	Head	$ 3.75	24.50	$ 91.88

Table F.7 (Cont.)				
Item	Unit	Price[a]	Quantity	Total
Market Calves	Head	$ -	24.50	$ 388.48
Building & Fence Repair	Foot	$ 0.01	1475.8	$ 14.76
	Total Variable Costs Without Rotational Grazing			$ 2,077.82

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

The quantity for building and fence repair is based on the number of feet of fencing needed to fence in a 50-acre square.

Table F.8: Rations for the Cow-Calf Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Rations Before Rotational Grazing							
Rations		Cows	Bulls	Calves	Yr. Repl. Heifers	1st Calf Heifers	
	No. Head=	19.55	0.92	19.55	3.45	3.45	Total
	Days Fed=	135	135	0	135	135	Tons
Grass Hay	#/head/day	27.50	27.50	0.00	12.00	20.00	49.99
Corn Grain	#/head/day	0.00	2.75	0.00	3.50	13.00	4.09
Other Feed	#/head/day	0.00	0.00	0.00	0.00	0.00	0

Table F.9: Rations for the Cow-Calf Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Rations Without Rotational Grazing							
Rations		Cows	Bulls	Calves	Yr. Repl. Heifers	1st Calf Heifers	
	No. Head=	19.55	0.92	19.55	3.45	3.45	Total
	Days Fed=	135	135	0	135	135	Tons
Grass Hay	#/head/day	29.00	29.00	0.00	12.00	20.00	52.27
Corn Grain	#/head/day	0.00	2.75	0.00	3.50	13.00	4.09
Other Feed	#/head/day	0.00	0.00	0.00	0.00	0.00	0

Table F.10: Rations for the Cow-Calf Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Rations With Rotational Grazing							
Rations		Cows	Bulls	Calves	Yr. Repl. Heifers	1st Calf Heifers	
	No. Head=	29.75	1.40	29.75	5.25	5.25	Total
	Days Fed=	59	59	0	59	59	Tons
Grass Hay	#/head/day	29.00	29.00	0.00	12.00	20.00	34.77
Corn Grain	#/head/day	0.00	2.75	0.00	3.50	13.00	2.72
Other Feed	#/head/day	0.00	0.00	0.00	0.00	0.00	0

Table F.11: Pasture Maintenance Costs for the Cow-Calf Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Pasture Maintenance Costs Per Acre Before Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Nitrogen	Lbs/Ac	$ 0.27	40	$ 10.80
Phosphorus	Lbs/Ac	$ 0.24	40	$ 9.60
Potash	Lbs/Ac	$ 0.15	40	$ 6.00
Fuel	Gal/Ac	$ 1.45	0.06	$ 0.09
	Total Pasture Maintenance Costs			**$ 26.49**

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

Table F.12: Pasture Maintenance Costs for the Cow-Calf Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Pasture Maintenance Costs Per Acre Without Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Nitrogen	Lbs/Ac	$ 0.27	40	$ 10.80
Phosphorus	Lbs/Ac	$ 0.24	40	$ 9.60
Potash	Lbs/Ac	$ 0.15	40	$ 6.00
Fuel	Gal/Ac	$ 1.45	0.06	$ 0.09
	Total Pasture Maintenance Costs			**$ 26.49**

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

Table F.13: Pasture Maintenance Costs for the Cow-Calf Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Pasture Maintenance Costs Per Acre With Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Red Clover/Inoculant	Lbs./Ac	$ 1.32	6.67	$ 8.80
Nitrogen	Lbs./Ac	$ 0.27	4.89	$ 1.32
Phosphorus	Lbs./Ac	$ 0.24	12.49	$ 3.00
Fuel	Gal./Ac	$ 1.45	0.06	$ 0.09
	Total Pasture Maintenance Costs			**$ 13.21**

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

Table F.14: Forage Costs for the Cow-Calf Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Forage Costs Before Rotational Grazing					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	10.0%	Ton	$ 50.00	49.99	$ 2,499.72
Corn Grain	2.0%	Bu	$ 2.25	146.20	$ 328.94
Other Feed	5.0%	Ton	$ -	0.00	$ -
Stockpiled Fescue		Acre	$ 30.00	0.00	$ -
Pasture Maintenance		Acre	$ 26.49	50.00	$ 1,324.28
	Total Forage Costs Without Rotational Grazing				$ 4,152.94

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.

Table F.15: Forage Costs for the Cow-Calf Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Forage Costs Without Rotational Grazing					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	10.0%	Ton	$ 50.00	52.27	$ 2,613.71
Corn Grain	2.0%	Bu	$ 2.25	146.20	$ 328.94
Other Feed	5.0%	Ton	$ -	0.00	$ -
Stockpiled Fescue		Acre	$ 30.00	0.00	$ -
Pasture Maintenance		Acre	$ 26.49	50.00	$ 1,324.28
	Total Forage Costs Without Rotational Grazing				$ 4,266.93

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.

Table F.16: Forage Costs for the Cow-Calf Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Cow-Calf Forage Costs Without Rotational Grazing					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	10.0%	Ton	$ 50.00	34.77	$ 1,738.27
Corn Grain	2.0%	Bu	$ 2.25	97.23	$ 218.76
Other Feed	5.0%	Ton	$ -	0.00	$ -
Stockpiled Fescue		Acre	$ 30.00	0.00	$ -
Pasture Maintenance		Acre	$ 13.21	50.00	$ 660.39
	Total Forage Costs Without Rotational Grazing				$ 2,617.42

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.

Table F.17: Capital Change Costs for the Cow-Calf Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Loan Length (Years)	30							
Annual Percentage Rate	6%							
Item	Unit	Price	Quantity	Total	Avg. Annual Cost Without Cost Share	Cost Share Rate	Net Cost To Farmer With Cost Share	Avg Annual Cost With Cost Share
Precast Concrete Watering Troughs		$969.00	2	$1,938.00	$140.79	60%	$775.20	$56.32
Annual O&M of Watering Troughs (Including 2 Hrs Labor)	Hours	$13.68	2	$27.36	$27.36	0%	$27.36	$27.36

Table F.17 (Cont.)								
Item	Unit	Price	Quantity	Total	Avg. Annual Cost Without Cost Share	Cost Share Rate	Net Cost To Farmer With Cost Share	Avg Annual Cost With Cost Share
	Total Added Capital Costs			**$27.36**	**$168.15**	**n/a**	**$802.56**	**$83.68**

Table F.18: Capital Change Costs for the Cow-Calf Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Loan Length (Years)	30							
Annual Percentage Rate	6%							
Item	Unit	Price	Quantity	Total	Avg. Annual Cost Without Cost Share	Cost Share Rate	Net Cost To Farmer With Cost Share	Avg Annual Cost With Cost Share
Portable Electric Fence	Feet	$0.14	1320	$184.80	$13.43	75%	$46.20	$3.36
Annual O&M of Portable Electric Fence	Feet	$0.01	1320	$9.24	$0.67	0%	$9.24	$0.67
Permanent Electric Fence	Feet	$0.29	3000	$855.00	$62.11	75%	$213.75	$15.53
Annual O&M of Permanent Electric Fence	Feet	$0.01	3000	$ 42.75	$42.75	0%	$42.75	$42.75
Electric Fence Charger (10 Yr Lifespan)		$399.00	1	$399.00	$28.99	0%	$399.00	$28.99
Replacement Electric Fence Charger (yr 10)		$222.80	1	$222.80	$16.19	0%	$222.80	$16.19
Replacement Electric Fence Charger (yr 20)		$124.41	1	$124.41	$9.04	0%	$124.41	$9.04
Annual O&M of Electric Fence Charger	$/KWH	$0.09	1500	$135.00	$135.00	0%	$135.00	$135.00
Added Owner Labor Required for Fence Installation	Hours	$5.70	200	$1,140.00	$82.82	0%	$1,140.00	$82.82

Table F.18 (Cont.)								
Item	Unit	Price	Quantity	Total	Avg. Annual Cost Without Cost Share	Cost Share Rate	Net Cost To Farmer With Cost Share	Avg Annual Cost With Cost Share
	Fencing Subtotal			$3,113.00	$390.99	n/a	$2,333.15	$334.34
Precast Concrete Watering Troughs		$969.00	2	$1,938.00	$140.79	60%	$775.20	$56.32
Annual O&M of Watering Troughs (Including 2 Hrs Labor)	Hours	$13.68	2	$27.36	$27.36	0%	$27.36	$27.36
	Watering Subtotal			$1,965.36	$168.15	n/a	$802.56	$83.68
	Total Added Capital Costs			**$5,078.36**	**$559.15**	**n/a**	**$3,135.71**	**$418.01**

Table F.19: Summary of Estimated Costs and Revenues for the Cow-Calf Case Study Farm under the Three Reference Conditions

Estimated Costs and Revenues for the Cow-Calf Case Study Farm			
	Before Rotational Grazing	**Without Rotational Grazing**	**With Rotational Grazing**
Gross Revenues[a]	**$ 8,680.04**	**$ 10,352.32**	**$ 17,840.75**
Costs			
Total Non-Forage Variable Costs	$ 1,445.98	$ 1,479.42	$ 2,084.44
Total Forage Costs	$ 3,954.23	$ 4,078.47	$ 2,492.08
Added Capital Costs	n/a	$ 83.68	$ 418.01
Total Costs	**$ 5,400.20**	**$ 5,641.57**	**$ 4,994.54**
Net Revenues	**$ 3,279.84**	**$ 4,710.76**	**$ 12,846.22**

[a] The *with rotational grazing* reference condition does not include the one-time sale of haying equipment.

F.2 Stocker Case Study Farm

The stocker case study farm holds two different herds throughout the year. One of these herds is bought in the early fall and sold in the early winter. This herd will be known as the "fall herd". The other is bought in the early spring and sold in the late summer. This will be known as the "spring herd". A summary of the differences between each reference condition is for the stocker case study farm is presented in Tables 3.2 and 3.3.

Table F.20: Fall Herd Summaries of Each Reference Condition for the Stocker Case Study Farm (Areas in Gray are Inputs)

Stocker Case Study Farm Herd Statistics – Fall Herd			
	Before Rotational Grazing	**Without Rotational Grazing**	**With Rotational Grazing**
Number of Steers	n/a	250	250
Days on Feed	n/a	76	30
Average Daily Gain on Feed	n/a	1.25	2
Days on Pasture/Hay	n/a	14	60
Average Daily Gain on Pasture/Hay	n/a	0.25	2
Purchase Weight	n/a	350	300
End Weight	n/a	448.5	480
% Death Loss	n/a	3	1
% Shrink	n/a	2	2
Selling Weight	n/a	439.53	470.4

Before converting to a rotational grazing system, the stocker case study farm did not have a fall stocker herd. The farm instead had a cow-calf herd. This herd is not examined since a more complete cow-calf case study farm is presented above

Table F.21: Spring Herd Summaries of Each Reference Condition for the Stocker Case Study Farm (Areas in Gray are Inputs)

Stocker Case Study Farm Herd Statistics -- Spring Herd			
	Before Rotational Grazing	**Without Rotational Grazing**	**With Rotational Grazing**
Number of Steers	79	120	120
Days on Feed	45	45	30
Average Daily Gain on Feed	1.11	1.11	2
Days on Pasture/Hay	123	123	138
Average Daily Gain on Pasture/Hay	1.5	1.5	2
Purchase Weight	400	425	425
End Weight	634.45	659.45	761
% Death Loss	2	2	1
% Shrink	2	2	2
Selling Weight	621.76	646.26	745.78

Table F.22: Fall Revenues for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Revenues Without Rotational Grazing -- Fall Herd							
Item	No. of Animals Sold		Weight	Unit	Price[a]	Quantity	Total
Steers	242.50	@	4.40	CWT	$ 92.06	1,065.86	$ 98,123.09

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University.

Animals are bought at the beginning of September and sold at the beginning of December.

Table F.23: Fall Revenues for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Revenues With Rotational Grazing -- Fall Herd							
Item	No. of Animals Sold		Weight	Unit	Price[a]	Quantity	Total
Steers	247.50	@	4.70	CWT	$ 92.06	1,164.24	$ 107,179.93

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University.

Animals are bought at the beginning of September and sold at the beginning of December.

Table F.24: Spring Revenues for the Stocker Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Revenues Before Rotational Grazing -- Spring Herd							
Item	No. of Animals Sold		Weight	Unit	Price	Quantity	Total
Steers	77.42	@	6.22	CWT	$ 99.08	481.37	$ 47,693.88

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University.

Animals are bought in early April and sold in mid August.

Table F.25: Spring Revenues for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Revenues Without Rotational Grazing -- Spring Herd							
Item	No. of Animals Sold		Weight	Unit	Price[a]	Quantity	Total
Steers	117.60	@	6.46	CWT	$ 106.06	760.00	$ 80,605.91

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University.

Animals are bought in early April and sold in mid August.

Table F.26: Spring Revenues for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Revenues With Rotational Grazing -- Spring Herd							
Item	No. of Animals Sold		Weight	Unit	Price[a]	Quantity	Total
Steers	118.80	@	7.46	CWT	$ 102.08	885.99	$ 90,441.52

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University.

Animals are bought in early April and sold in mid August.

Table F.27: Fall Acquirement Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Acquirement Costs Without Rotational Grazing -- Fall Herd					
Item	Head	Unit	Price[a]	Quantity	Total
Steers	250	CWT	$ 98.01	875	$ 85,758.75
Interest on Steers		APR	9.25%	85,758.75	$ 1,956.00
Procurement		Head	$ 3.75	250	$ 937.50
				Fall Total	$ 88,652.25

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. Interest on steers and procurement are from Virginia Cooperative Extension Farm Management Budgets.

Table F.28: Fall Acquirement Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Acquirement Costs With Rotational Grazing -- Fall Herd					
Item	Head	Unit	Price[a]	Quantity	Total
Steers	250	CWT	$ 98.01	750	$ 73,507.50
Interest on Steers		APR	9.25%	73,507.5	$ 1,676.58
Procurement		Head	$ 3.75	250	$ 937.50
				Fall Total	$ 76,121.58

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. Interest on steers and procurement are from Virginia Cooperative Extension Farm Management Budgets.

Table F.29: Spring Acquirement Costs for the Stocker Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Acquirement Costs Before Rotational Grazing -- Spring Herd					
Item	Head	Unit	Price[a]	Quantity	Total
Steers	79	CWT	$ 107.48	316	$ 33,963.68
Interest on Steers		APR	9.25%	33,963.68	$ 1,446.02
Procurement		Head	$ 3.75	79	$ 296.25
				Spring Total	$ 35,705.95

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. Interest on steers and procurement are from Virginia Cooperative Extension Farm Management Budgets.

Table F.30: Spring Acquirement Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Acquirement Costs Without Rotational Grazing -- Spring Herd					
Item	Head	Unit	Price[a]	Quantity	Total
Steers	120	CWT	$ 107.48	510	$ 54,814.80
Interest on Steers		APR	9.25%	54814.8	$ 2,333.76
Procurement		Head	$ 3.75	120	$ 450.00
				Spring Total	$ 57,598.56

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. Interest on steers and procurement are from Virginia Cooperative Extension Farm Management Budgets.

Table F.31: Spring Acquirement Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Acquirement Costs With Rotational Grazing -- Spring Herd					
Item	Head	Unit	Price[a]	Quantity	Total
Steers	120	CWT	$ 107.48	510	$ 54,814.80
Interest on Steers		APR	9.25%	54814.8	$ 2,333.76
Procurement		Head	$ 3.75	120	$ 450.00
				Spring Total	$ 57,598.56

[a] The prices for steers are from a table of seasonal price indexes supplied by Dr. Gordon Groover, Virginia Polytechnic Institute and State University. Interest on steers and procurement are from Virginia Cooperative Extension Farm Management Budgets.

Table F.32: Fall Non-Forage Variable Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Variable Costs Without Rotational Grazing -- Fall Herd				
Item	Unit	Price[a]	Quantity	Total
Mineral w/ BOV or RUM	CWT	$ 25.00	28.125	$ 703.13
Vet & Medicine	Head	$ 6.75	250	$ 1,687.50
Supplies	Head	$ 2.00	250	$ 500.00
Haul Calves	Head	$ 4.50	242.50	$ 1,091.25
Market Calves	Head	$ -	242.50	$ 3,302.79
Building & Fence Repair				$ 250.00
			Fall Total	$ 7,534.66

[a] Source: Virginia Cooperative Extension Farm Management Budgets

Table F.33: Fall Non-Forage Variable Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Variable Costs With Rotational Grazing -- Fall Herd				
Item	Unit	Price[a]	Quantity	Total
Mineral w/ BOV or RUM	CWT	$ 25.00	28.125	$ 703.13
Vet & Medicine	Head	$ 6.75	250	$ 1,012.50
Supplies	Head	$ 2.00	250	$ 500.00
Haul Calves	Head	$ 4.50	242.50	$ 1,091.25
Market Calves	Head	$ -	242.50	$ 3,302.79
Building & Fence Repair				$ 250.00
			Fall Total	$ 6,859.66

[a] Source: Virginia Cooperative Extension Farm Management Budgets

Table F.34: Spring Non-Forage Variable Costs for the Stocker Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Variable Costs Before Rotational Grazing -- Spring Herd				
Item	Unit	Price[a]	Quantity	Total
Mineral w/ BOV or RUM	CWT	$ 25.00	16.59	$ 414.75
Vet & Medicine	Head	$ 6.75	79	$ 533.25
Supplies	Head	$ 2.00	79	$ 158.00
Haul Calves	Head	$ 4.50	77.42	$ 348.39
Market Calves	Head	$ -	77.42	$ 1,224.85
Building & Fence Repair				$ 79.00
			Spring Total	$ 2,758.24

[a] Source: Virginia Cooperative Extension Farm Management Budgets

Table F.35: Spring Non-Forage Variable Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Variable Costs Without Rotational Grazing -- Spring Herd				
Item	Unit	Price[a]	Quantity	Total
Mineral w/ BOV or RUM	CWT	$ 25.00	25.20	$ 630.00
Vet & Medicine	Head	$ 6.75	120	$ 810.00
Supplies	Head	$ 2.00	120	$ 240.00
Haul Calves	Head	$ 4.50	117.60	$ 529.20
Market Calves	Head	$ -	117.60	$ 2,023.72
Building & Fence Repair				$ 120.00
			Spring Total	$ 4,352.92

[a] Source: Virginia Cooperative Extension Farm Management Budgets

Table F.36: Spring Non-Forage Variable Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Variable Costs With Rotational Grazing -- Spring Herd				
Item	Unit	Price[a]	Quantity	Total
Mineral w/ BOV or RUM	CWT	$ 25.00	25.20	$ 630.00
Vet & Medicine	Head	$ 6.75	120	$ 485.00
Supplies	Head	$ 2.00	120	$ 240.00
Haul Calves	Head	$ 4.50	118.80	$ 534.60
Market Calves	Head	$ -	118.80	$ 2,224.63
Building & Fence Repair				$ 120.00
			Spring Total	$ 4,234.23

[a] Source: Virginia Cooperative Extension Farm Management Budgets

Table F.37: Fall Rations for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Rations Without Rotational Grazing -- Fall Herd							
Rations		Stocker Steers					
	No. Head=	246.25	246.25	246.25	246.25	246.25	Total
	Days Fed=	14	77	80	9	0	Tons
Grass Hay	#/head/day	10.65	9.75	10.50	17.00	0.00	244.71
Corn Grain	#/head/day	0.00	3.30	4.75	1.75	0.00	81.61
Other Feed	#/head/day	0.00	0.00	0.00	0.00	0.00	0

Table F.38: Fall Rations for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Rations With Rotational Grazing -- Fall Herd							
Rations		Stocker Steers					
	No. Head=	246.25	246.25	246.25	246.25	246.25	Total
	Days Fed=	14	76	0	0	0	Tons
Grass Hay	#/head/day	0.00	0.00	0.00	0.00	0.00	0
Corn Grain	#/head/day	0.00	0.00	0.00	0.00	0.00	0
Other Feed	#/head/day	3.00	6.00	0.00	0.00	0.00	65.04

Table F.39: Spring Rations for the Stocker Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Rations Before Rotational Grazing -- Spring Herd							
Rations		Stocker Steers					
	No. Head=	78.21	78.21	78.21	78.21	78.21	Total
	Days Fed=	14	31	0	0	0	Tons
Grass Hay	#/head/day	12.25	9.50	0.00	0.00	0.00	19.13
Corn Grain	#/head/day	1.00	4.50	0.00	0.00	0.00	6.12
Other Feed	#/head/day	0.00	0.00	0.00	0.00	0.00	0

Table F.40: Spring Rations for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Rations Without Rotational Grazing -- Spring Herd							
Rations		Stocker Steers					
	No. Head=	118.8	118.8	118.8	118.8	118.8	Total
	Days Fed=	14	31	0	0	0	Tons
Grass Hay	#/head/day	12.25	9.50	0.00	0.00	0.00	29.06
Corn Grain	#/head/day	1.00	4.50	0.00	0.00	0.00	9.30
Other Feed	#/head/day	0.00	0.00	0.00	0.00	0.00	0

Table F.41: Spring Rations for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Case Study Farm Rations With Rotational Grazing -- Spring Herd							
Rations		Stocker Steers					
	No. Head=	119.4	119.4	119.4	119.4	119.4	Total
	Days Fed=	30.00	0	0	0	0	Tons
Grass Hay	#/head/day	0.00	0.00	0.00	0.00	0.00	0.00
Corn Grain	#/head/day	0.00	0.00	0.00	0.00	0.00	0.00
Other Feed	#/head/day	3.00	0.00	0.00	0.00	0.00	5.64

Table F.42: Pasture Maintenance Costs for the Stocker Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)[40]

Pasture Maintenance Costs Before Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Red Clover/Innoculant	Lbs./Ac	$ 1.32	1	$ 1.32
Potash	Lbs./Ac	$ 0.15	14.29	$ 2.14
Phosphorus	Lbs./Ac	$ 0.24	14.29	$ 3.43
Fuel	Gal./Ac	$ 1.45	0.08	$ 0.12
	Total Pasture Maintenance Costs			**$ 6.89**

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

Table F.43: Pasture Maintenance Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)[39]

Pasture Maintenance Costs Without Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Red Clover/Innoculant	Lbs./Ac	$ 1.32	1	$ 1.32
Nitrogen	Lbs./Ac	$ 0.27	40	$ 10.80
Potash	Lbs./Ac	$ 0.15	40	$ 6.00
Phosphorus	Lbs./Ac	$ 0.24	40	$ 9.60
Fuel	Gal./Ac	$ 1.45	0.08	$ 0.12
	Total Pasture Maintenance Costs			**$ 27.84**

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

Table F.44: Pasture Maintenance Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)[39]

Pasture Maintenance Costs With Rotational Grazing				
Item	Unit	Price[a]	Quantity	Total
Red Clover/Innoculant	Lbs./Ac	$ 1.32	0.6	$ 0.79
Potash	Lbs./Ac	$ 0.15	14.29	$ 2.14
Phosphorus	Lbs./Ac	$ 0.24	14.29	$ 3.43
Fuel	Gal./Ac	$ 1.45	0.08	$ 0.12
	Total Pasture Maintenance Costs			**$ 6.48**

[a] All prices are from Virginia Cooperative Extension Farm Management Budgets.

[40] Because pasture maintenance costs are annual and independent of the herds, they are not broken down into fall and spring.

Table F.45: Fall Forage Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Forage Costs Without Rotational Grazing – Fall Herd					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	5.0%	Ton	$ 50.00	256.95	$ 12,847.28
Corn Grain	2.0%	Bu	$ 2.25	2,973.05	$ 6,689.35
Other Feed	5.0%	Ton	$ -	0.00	$ -
Pasture Maintenance[b]		Acre	$ 6.89	0.00	$ -
	Total Forage Costs Without Rotational Grazing				$ 19,536.63

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.
[b] Pasture maintenance costs here are zero because the pasture maintenance costs are included in the spring herd budgets.

Table F.46: Fall Forage Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Forage Costs With Rotational Grazing – Fall Herd					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	5.0%	Ton	$ 50.00	0.00	$ -
Corn Grain	2.0%	Bu	$ 2.25	0.00	$ -
Other Feed	5.0%	Ton	$ 102.00	68.29	$ 6,965.32
Pasture Maintenance[b]		Acre	$ 6.48	0.00	$ -
	Total Forage Costs Without Rotational Grazing				$ 6,965.32

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.
[b] Pasture maintenance costs here are zero because the pasture maintenance costs are included in the spring herd budgets.

Table F.47: Spring Forage Costs for the Stocker Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Forage Costs Before Rotational Grazing – Spring Herd					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	5.0%	Ton	$ 50.00	20.09	$ 1,004.54
Corn Grain	2.0%	Bu	$ 2.25	223.04	$ 501.84
Other Feed	5.0%	Ton	$ -	0.00	$ -
Pasture Maintenance		Acre	$ 6.89	77.00	$ 530.77
	Total Forage Costs Without Rotational Grazing				$ 2,037.15

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.

Table F.48: Spring Forage Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Forage Costs Without Rotational Grazing – Spring Herd					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	5.0%	Ton	$ 50.00	30.52	$ 1,525.88
Corn Grain	2.0%	Bu	$ 2.25	338.80	$ 762.29
Other Feed	5.0%	Ton	$ -	0.00	$ -
Pasture Maintenance		Acre	$ 27.84	77.00	$ 2,143.68
	Total Forage Costs Without Rotational Grazing				$ 4,431.85

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.

Table F.49: Spring Forage Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Stocker Forage Costs With Rotational Grazing – Spring Herd					
Item	Feed Waste[a]	Unit	Price[a]	Quantity	Total
Grass Hay	5.0%	Ton	$ 50.00	0.00	$ -
Corn Grain	2.0%	Bu	$ 2.25	0.00	$ -
Other Feed	5.0%	Ton	$ 102.00	5.92	$ 604.22
Pasture Maintenance		Acre	$ 6.48	77.00	$ 499.04
	Total Forage Costs Without Rotational Grazing				$ 1,103.27

[a] All values are from Virginia Cooperative Extension Farm Management Budgets.

Table F.50: Capital Change Costs for the Stocker Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Loan Length (Years)	30							
Annual Percentage Rate	6%							
Item	Unit	Price	Quantity	Total	Avg. Annual Cost Without Cost Share	Cost Share Rate	Net Cost To Farmer With Cost Share	Avg Annual Cost With Cost Share
Concrete Watering Troughs		$555.00	4	$2,220.00	$161.28	60%	$888.00	$64.51
RAM Pump		$610.50	1	$610.50	$610.50	60%	$244.20	$17.74
Pump Installation/Modifications: Initial Installation		$2,220.00	1	$2,220.00	$161.28	60%	$888.00	$64.51
Pump Installation/Modifications: Move		$1,665.00	1	$1,665.00	$120.96	60%	$666.00	$48.38
O&M of RAM Pump during 1st 2 yrs	Hours	$7.77	208	$1,616.16	$117.41	0%	$1,616.16	$117.41
Spring-fed Concrete Watering Troughs		$888.00	2	$1,776.00	$129.02	60%	$710.40	$51.61
O&M for 6 Watering Troughs and the RAM Pump	Hours	$7.77	12	$93.24	$93.24	0%	$93.24	$93.24
	Total Added Capital Costs			**$10,200.90**	**$1,393.70**	**n/a**	**$5,106.00**	**$457.41**

Table F.51: Capital Change Costs for the Stocker Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Loan Length (Years)	30							
Annual Percentage Rate	6%							

Table F.50 (Cont.)									
Item	Unit	Price	Quantity	Total	Avg. Annual Cost Without Cost Share	Cost Share Rate	Net Cost To Farmer With Cost Share	Avg Annual Cost With Cost Share
Permanent Electric Fence	Feet	$0.07	16500	$1,190.48	$86.49	0%	$1,190.48	$86.49
Gates		$27.75	38	$1,054.50	$76.61	0%	$1,054.50	$76.61
Annual O&M of Permanent Electric Fence and Gates		$89.80	n/a	$89.80	$89.80	0%	$89.80	$89.80
Electric Fence Charger (3 Yr Lifespan)		$116.55	2	$233.10	$16.93	0%	$233.10	$16.93
Replacement Electric Fence Charger (yr 3)		$97.86	2	$195.72	$14.22	0%	$195.72	$14.22
Replacement Electric Fence Charger (yr 6)		$82.16	2	$164.33	$11.94	0%	$164.33	$11.94
Annual Cost for Charger Operation	KWH	$0.06	149	$8.64	$8.64	0%	$8.64	$8.64
Annual Charger Maintenance Cost		$44.40	1	$44.40	$44.40	0%	$44.40	$44.40
Added Owner Labor Required for Fence Installation	Hours	$11.10	60	$666.00	$48.38	0%	$666.00	$48.38
	Fencing Subtotal			$3,646.96	$397.41	n/a	$3,646.96	$397.41
Concrete Watering Troughs		$555.00	4	$2,220.00	$161.28	60%	$888.00	$64.51
RAM Pump		$610.50	1	$610.50	$610.50	60%	$244.20	$17.74
Pump Installation/Modifications: Initial Installation		$2,220.00	1	$2,220.00	$161.28	60%	$888.00	$64.51
Pump Installation/Modifications: Move		$1,665.00	1	$1,665.00	$120.96	60%	$666.00	$48.38
O&M of RAM Pump during 1st 2 yrs	Hours	$7.77	208	$1,616.16	$117.41	0%	$1,616.16	$117.41
Spring-fed Concrete Watering Troughs		$888.00	2	$1,776.00	$129.02	60%	$710.40	$51.61
O&M for 6 Watering Troughs and the RAM Pump	Hours	$7.77	12	$93.24	$93.24	0%	$93.24	$93.24
	Watering Subtotal			$10,200.90	$771.78	n/a	$1,132.20	$457.41
	Total Added Capital Costs			**$13,847.86**	**$1,169.19**	**n/a**	**$4,779.16**	**$854.82**

Table F.52: Summary of Estimated Costs and Revenues for the Stocker Case Study Farm under the Three Reference Conditions

Estimated Costs and Revenues for the Stocker Case Study Farm			
	Before Rotational Grazing	**Without Rotational Grazing**	**With Rotational Grazing**
Gross Revenues	**$ 47,693.88**	**$ 203,307.74**	**$ 197,621.45**
Costs			
Acquirement Costs	$ 35,705.95	$ 146,250.81	$ 133,720.13
Total Non-Forage Variable Costs	$ 2,758.24	$ 11,887.58	$ 11,823.45
Total Forage Costs	$ 2,037.15	$ 15,112.57	$ 8,068.59
Added Capital Costs	n/a	$ 457.41	$ 479.66
Total Costs	**$ 40,501.33**	**$ 173,708.38**	**$ 154,091.84**
Net Revenues	**$ 7,192.55**	**$ 29,599.37**	**$ 43,529.61**

F.3 Dairy Case Study Farm

A summary of the differences between each reference condition for the dairy case study farm is presented in Table 3.4.

Table F.53: Herd Summaries of Each Reference Condition for the Dairy Case Study Farm (Areas in Gray are Inputs)

Dairy Case Study Farm Herd Statistics			
	Before Rotational Grazing	**Without Rotational Grazing**	**With Rotational Grazing**
Number of Cows	54	70	70
Annual milk production per cow	17666	21000	19500
% cows leaving herd annually	14	14	14
% annual death loss	4	4	2

Table F.54: Revenues for the Dairy Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Revenues Before Rotational Grazing							
				Unit	Price	Quantity	Total
Milk				CWT	$ 14.50	9539.64	$ 138,324.78
Cull cows	5.4	@	13	CWT	$ 35.00	70.2	$ 2,457.00
Bull calves				Head	$ 75.00	25.65	$ 1,923.75
Heifers[a]				Head	$ 1,100.00	7.71	$ 8,481.00
Patronage Dividends							$ 1,921.18
			Gross Revenue Before Rotational Grazing				**$ 153,107.71**

[a] The dairy case study farm gets 6-8 lactations per cow (before & after rotational grazing). Here it is assumed that 1/7 of herd is culled per year.

Table F.55: Revenues for the Dairy Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Revenues Without Rotational Grazing							
				Unit	Price	Quantity	Total
Milk				CWT	$ 14.50	14700	$ 213,150.00
Cull cows	7	@	13	CWT	$ 35.00	91	$ 3,185.00
Bull calves				Head	$ 75.00	33.25	$ 2,493.75
Heifers[a]				Head	$ 1,100.00	10	$ 11,000.00
Patronage Dividends							$ 2,960.42
			Gross Revenue Without Rotational Grazing				**$ 232,789.17**

[a] The dairy case study farm gets 6-8 lactations per cow (before & after rotational grazing). Here it is assumed that 1/7 of herd is culled per year.

Table F.56: Revenues for the Dairy Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Revenues With Rotational Grazing							
				Unit	Price	Quantity	Total
Milk				CWT	$ 14.50	13650	$ 197,925.00
Cull cows	8.4	@	13	CWT	$ 35.00	109.2	$ 3,822.00
Bull calves				Head	$ 75.00	33.25	$ 2,493.75
Heifers[a]				Head	$ 1,100.00	10	$ 11,000.00
Patronage Dividends							$ 2,748.96
			Gross Revenue Without Rotational Grazing				**$ 217,989.71**

[a] The dairy case study farm gets 6-8 lactations per cow (before & after rotational grazing). Here it is assumed that 1/7 of herd is culled per year.

Table F.57: Non-Forage Variable Costs for the Dairy Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Variable Costs Before Rotational Grazing				
Item	Unit	Price	Quantity	Total
Summer ration (12% protein)[a]	ton	$ 165.00	82.35	$ 13,587.75
Winter ration (24% protein)[a]	ton	$ 196.00	82.35	$ 16,140.60
minerals	head	$ 47.50	54	$ 2,565.00
milk replacer	cwt	$ 81.00	14.58	$ 1,180.98
calf grower	cwt	$ 13.00	126.9	$ 1,649.70
breeding (up to 2 services/cow)	head	$ 40.00	54	$ 2,160.00
Bull (cleanup)	bull	$ 1,600.00	1	$ 1,600.00
vet&med	head	$ 80.00	54	$ 4,320.00
supplies	head	$ 155.00	54	$ 8,370.00
bST	injection	$ 5.25	0	$ -
DHIA	head	$ 22.00	0	$ -
milk haul	cwt	$ 0.80	9539.64	$ 7,631.71
assessmt & advert.	cwt	$ 0.26	9539.64	$ 2,480.31
haul & mkt culls				$ 356.84
bldg & fence repair	head	$ 90.00	54	$ 4,860.00
machinery	head	$ 60.00	54	$ 3,240.00
utilities	head	$ 65.00	54	$ 3,510.00
custom hire	head	$ 32.00	54	$ 1,728.00

Table F.57 (Cont.)				
Item	Unit	Price	Quantity	Total
Hired labor[b]	hrs.	$ 7.50	832	$ 6,240.00
	Total Variable Costs Without Rotational Grazing			$ 81,620.89

[a] Lactating animals are fed 20 lbs of supplement per day. Assume lactation period (305 days) is spread equally over summer and winter.
[b] Assume 8 hrs per day for 2 days each week (weekend milking).

Table F.58: Non-Forage Variable Costs for the Dairy Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Variable Costs Without Rotational Grazing				
Item	Unit	Price	Quantity	Total
Summer ration (12% protein)[a]	ton	$ 165.00	106.75	$ 17,613.75
Winter ration (24% protein)[a]	ton	$ 196.00	106.75	$ 20,923.00
minerals	head	$ 47.50	70	$ 3,325.00
milk replacer	cwt	$ 81.00	18.9	$ 1,530.90
calf grower	cwt	$ 13.00	164.5	$ 2,138.50
breeding (up to 2 services/cow)	head	$ 40.00	70	$ 2,800.00
Bull (cleanup)	bull	$ 1,600.00	1	$ 1,600.00
vet&med	head	$ 23.73	70	$ 1,661.10
supplies	head	$ 155.00	70	$ 10,850.00
bST	injection	$ 5.25	1143	$ 6,000.75
DHIA	head	$ 22.00	70	$ 1,540.00
milk haul	cwt	$ 0.80	14700	$ 11,760.00
assessmt & advert.	cwt	$ 0.26	14700	$ 3,822.00
haul & mkt culls				$ 406.78
bldg & fence repair	head	$ 90.00	70	$ 6,300.00
machinery	head	$ 60.00	70	$ 4,200.00
utilities	head	$ 65.00	70	$ 4,550.00
custom hire	head	$ 32.00	70	$ 2,240.00
Hired labor[b]	hrs.	$ 7.50	832	$ 6,240.00
	Total Variable Costs Without Rotational Grazing			$109,501.78

[a] Lactating animals are fed 20 lbs of supplement per day. Assume lactation period (305 days) is spread equally over summer and winter.
[b] Assume 8 hrs per day for 2 days each week (weekend milking).

Table F.59: Non-Forage Variable Costs for the Dairy Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Variable Costs With Rotational Grazing				
Item	Unit	Price	Quantity	Total
Summer ration (12% protein)[a]	ton	$ 165.00	106.75	$ 17,613.75
Winter ration (24% protein)[a]	ton	$ 196.00	106.75	$ 20,923.00
minerals	head	$ 47.50	70	$ 3,325.00
milk replacer	cwt	$ 81.00	18.9	$ 1,530.90
calf grower	cwt	$ 13.00	164.5	$ 2,138.50
breeding (up to 2 services/cow)	head	$ 40.00	70	$ 2,800.00
Bull (cleanup)	bull	$ 1,600.00	1	$ 1,600.00
vet&med	head	$ 23.42	70	$ 1,639.40
supplies	head	$ 155.00	70	$ 10,850.00

Table F.59 (Cont.)				
Item	Unit	Price	Quantity	Total
bST	injection	$ 5.25	1143	$ 6,000.75
DHIA	head	$ 22.00	70	$ 1,540.00
milk haul	cwt	$ 0.80	13650	$ 10,920.00
assessmt & advert.	cwt	$ 0.26	13650	$ 3,549.00
haul & mkt culls				$ 418.09
bldg & fence repair	head	$ 90.00	70	$ 6,300.00
machinery	head	$ 60.00	70	$ 4,200.00
utilities	head	$ 65.00	70	$ 4,550.00
custom hire	head	$ 32.00	70	$ 2,240.00
Hired labor[b]	hrs.	$ 7.50	832	$ 6,240.00
	Total Variable Costs Without Rotational Grazing			$108,378.39

[a] Lactating animals are fed 20 lbs of supplement per day. Assume lactation period (305 days) is spread equally over summer and winter.
[b] Assume 8 hrs per day for 2 days each week (weekend milking).

Table F.60: Rations for the Dairy Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Rations Before Rotational Grazing							
Rations		lact cows	dry cows	bred heif	open heif (500-800)	heifers (300-500)	
	no head=	54	54	7.56	8.0892	8.6184	
	days fed=	305	60	365	365	365	
							Total Tons
corn silage	#/head/day	60	25	37	19	18	642.010
fescue/clover hay	#/head/day	9	14	5	7.5	3	119.484
SBOM 48%	#/head/day	3	0	3	1.7	1	32.927

Table F.61: Rations for the Dairy Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Rations Without Rotational Grazing							
Rations		lact cows	dry cows	bred heif	open heif (500-800)	heifers (300-500)	
	no head=	70	70	9.8	10.486	11.172	
	days fed=	305	60	365	365	365	
							Total Tons
corn silage	#/head/day	60	25	37	19	18	832.235
fescue/clover hay	#/head/day	9	14	5	7.5	3	154.887
SBOM 48%	#/head/day	3	0	3	1.7	1	42.683

Table F.62: Rations for the Dairy Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Rations With Rotational Grazing							
Rations		lact cows	dry cows	bred heif	open heif (500-800)	heifers (300-500)	
	no head=	70	70	9.8	10.486	11.172	
	days fed=	305	60	365	365	365	
							Total Tons
corn silage	#/head/day	38	12.5	23.5	12	11.5	520.341
fescue/clover hay	#/head/day	2.5	8	1.5	2	1	52.037
SBOM 48%	#/head/day	3	0	3	1.7	1	42.683

Table F.63: Pasture Maintenance Costs for the Dairy Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Pasture Maintenance Costs for the Dairy Case Study Farm Before Rotational Grazing				
Item	Unit	Price	Quantity	Total
red clover/innoculant	lbs/ac	$ 1.32	6	$ 7.92
Nitrogen	lbs/ac	$ 0.27	0.9	$ 0.24
phosphorus	lbs/ac	$ 0.24	2.7	$ 0.65
potash	lbs/ac	$ 0.15	5.4	$ 0.81
fuel	gal/ac	$ 1.45	1.56	$ 2.26
	Total pasture maintenance costs			$ 11.88

Table F.64: Pasture Maintenance Costs for the Dairy Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Pasture Maintenance Costs for the Dairy Case Study Farm Without Rotational Grazing				
Item	Unit	Price	Quantity	Total
red clover/innoculant	lbs/ac	$ 1.32	6	$ 7.92
Nitrogen	lbs/ac	$ 0.27	0.9	$ 0.24
phosphorus	lbs/ac	$ 0.24	2.7	$ 0.65
potash	lbs/ac	$ 0.15	5.4	$ 0.81
fuel	gal/ac	$ 1.45	1.56	$ 2.26
	Total pasture maintenance costs			$ 11.88

Table F.65: Pasture Maintenance Costs for the Dairy Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Pasture Maintenance Costs for the Dairy Case Study Farm With Rotational Grazing				
Item	Unit	Price	Quantity	Total
red clover/innoculant	lbs/ac	$ 1.32	6	$ 7.92
Nitrogen	lbs/ac	$ 0.27	0.9	$ 0.24
phosphorus	lbs/ac	$ 0.24	2.7	$ 0.65
potash	lbs/ac	$ 0.15	5.4	$ 0.81
fuel	gal/ac	$ 1.45	1.56	$ 2.26
	Total pasture maintenance costs			$ 11.88

Table F.66: Forage Costs for the Dairy Case Study Farm under the *Before Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Forage Costs Before Rotational Grazing					
Item	Feed waste	Unit	Price	Quantity	Total
corn silage[a]	8%	ton	$ 27.50	128.37	$ 3,530.19
fescue/clover hay	5%	ton	$ 101.00	125.46	$12,671.30
SBOM 48%	2%	ton	$ 225.00	33.59	$ 7,556.66
Pasture maintenance		ac	$ 11.88	40	$ 475.32
	Total forage costs before rotational grazing				$24,233.46

[a] It is assumed that the thirty acres of corn land produces 565 tons of corn silage. This amount is subtracted from the total amount of silage used to get how much corn silage is purchased.

Table F.67: Forage Costs for the Dairy Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Forage Costs Without Rotational Grazing					
Item	Feed waste	Unit	Price	Quantity	Total
corn silage[a]	8%	ton	$ 27.50	333.81	$ 9,179.87
fescue/clover hay	5%	ton	$ 101.00	162.63	$16,425.75
SBOM 48%	2%	ton	$ 225.00	43.54	$ 9,795.67
Pasture maintenance		ac	$ 11.88	40	$ 475.32
	Total forage costs without rotational grazing				$35,876.62

[a] It is assumed that the thirty acres of corn land produces 565 tons of corn silage. This amount is subtracted from the total amount of silage used to get how much corn silage is purchased.

Table F.68: Forage Costs for the Dairy Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Dairy Case Study Farm Forage Costs With Rotational Grazing					
Item	Feed waste	Unit	Price	Quantity	Total
corn silage[a]	8%	ton	$ 27.50	-3.03	$ (83.36)
fescue/clover hay	5%	ton	$ 101.00	54.64	$ 5,518.47
SBOM 48%	2%	ton	$ 225.00	43.54	$ 9,795.67
Pasture maintenance		ac	$ 11.88	40	$ 475.32
	Total forage costs with rotational grazing				$15,706.10

[a] It is assumed that the thirty acres of corn land produces 565 tons of corn silage. This amount is subtracted from the total amount of silage used to get how much corn silage is purchased. The quantity is negative here because there is more grown than used. It is assumed that this extra is sold.

Table F.69: Capital Change Costs for the Dairy Case Study Farm under the *Without Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Loan Length (years)	30							
Annual percentage rate	7%							

Table F.69 (Cont.)								
Item	Unit	Price	Quantity	Total	Avg annual cost without cost share	Cost share rate	Net cost with cost share	Avg annual cost with cost share
Travel lane grading	hours	$45.90	25.66	$1,177.79	$94.91	50%	$588.90	$47.46
geotextile, 64' x 12.5'	feet	$1.63	64	$104.32	$8.41	50%	$52.16	$4.20
geotextile, 378' x 15'	feet	$1.94	378	$733.32	$59.10	50%	$366.66	$29.55
Mixed large and small stone	tons	$7.08	273	$1,932.84	$155.76	50%	$966.42	$77.88
limestone	tons	$12.79	42	$537.18	$43.29	50%	$268.59	$21.64
2 strand HT electric fence	feet	$0.41	850	$348.50	$28.08	50%	$174.25	$14.04
annual permanent fence O & M	percent	$0.02	850	$17.43	$17.43	0%	$17.43	$17.43
Lime application in spring	tons	$8.29	16	$132.64	$132.64	0%	$132.64	$132.64
front end loader to spread	hours	$30.60	2	$61.20	$61.20	0%	$61.20	$61.20
lime application in fall	tons	$8.29	16	$132.64	$132.64	0%	$132.64	$132.64
front end loader to spread	hours	$30.60	2	$61.20	$61.20	0%	$61.20	$61.20
	Travel lane subtotal			$5,239.06	$794.66	n/a	$2,822.08	$599.88
drilled well	feet	$8.16	200	$1,632.00	$131.52	50%	$816.00	$65.76
well casing	feet	$7.14	90	$642.60	$51.78	50%	$321.30	$25.89
pump, pressure tank, and building	each	$1,836.00	1	$1,836.00	$147.96	50%	$918.00	$73.98
	New well subtotal			$4,110.60	$331.26	n/a	$2,055.30	$165.63
	Total added capital costs			**$9,349.66**	**$1,125.91**	**n/a**	**$4,877.38**	**$765.51**

Table F.70: Capital Change Costs for the Dairy Case Study Farm under the *With Rotational Grazing* Reference Condition (Areas in Gray are Inputs)

Loan Length (years)	30							
Annual percentage rate	7%							
Item	Unit	Price	Quantity	Total	Avg annual cost without cost share	Cost share rate	Net cost with cost share	Avg annual cost with cost share
Travel lane grading	hours	$45.90	25.66	$1,177.79	$94.91	50%	$588.90	$47.46
geotextile, 64' x 12.5'	feet	$1.63	64	$104.32	$8.41	50%	$52.16	$4.20
geotextile, 378' x 15'	feet	$1.94	378	$733.32	$59.10	50%	$366.66	$29.55
Mixed large and small stone	tons	$7.08	273	$1,932.84	$155.76	50%	$966.42	$77.88
limestone	tons	$12.79	42	$537.18	$43.29	50%	$268.59	$21.64
2 strand HT electric fence	feet	$0.41	850	$348.50	$28.08	50%	$174.25	$14.04
annual permanent fence O & M	percent	$0.02	850	$17.43	$17.43	0%	$17.43	$17.43
Lime application in spring	tons	$8.29	16	$132.64	$132.64	0%	$132.64	$132.64
front end loader to spread	hours	$30.60	2	$61.20	$61.20	0%	$61.20	$61.20
lime application in fall	tons	$8.29	16	$132.64	$132.64	0%	$132.64	$132.64
front end loader to spread	hours	$30.60	2	$61.20	$61.20	0%	$61.20	$61.20
	Travel lane subtotal			$5,239.06	$794.66	n/a	$2,822.08	$599.88
2 strand HT electric fence	feet	$0.78	6000	$4,680.00	$377.14	45%	$2,574.00	$207.43
14 ft steel gates	each	$56.10	25	$1,402.50	$113.02	50%	$701.25	$56.51
gate installation	hours	$10.20	25	$255.00	$20.55	50%	$127.50	$10.27
1320 ft polywire	rolls	$67.32	2	$134.64	$10.85	50%	$67.32	$5.43
fiberglass posts	each	$2.05	30	$61.50	$4.96	50%	$30.75	$2.48

Table F.70 (Cont.)								
electric charger	each	$280.50	1	$280.50	$22.60	50%	$140.25	$11.30
annual permanent fence O & M	percent	$0.04	6000	$234.00	$234.00	0%	$234.00	$234.00
steel gate O&M	percent	$1.12	25	$28.05	$28.05	0%	$28.05	$28.05
Polywire (movement)	hours	$10.20	30	$306.00	$306.00	0%	$306.00	$306.00
Polywire maintenance	percent	$3.37	2	$6.73	$6.73	0%	$6.73	$6.73
Electric charger O&M	percent	$14.03	1	$14.03	$14.03	0%	$14.03	$14.03
	Added fencing subtotal			$7,402.95	$1,137.93	n/a	$4,229.88	$882.23
drilled well	feet	$8.16	200	$1,632.00	$131.52	50%	$816.00	$65.76
well casing	feet	$7.14	90	$642.60	$51.78	50%	$321.30	$25.89
pump, pressure tank, and building	each	$1,836.00	1	$1,836.00	$147.96	50%	$918.00	$73.98
four hole freeze proof richie	each	$604.86	1	$604.86	$48.74	50%	$302.43	$24.37
two hole freeze proof richie	each	$472.26	4	$1,889.04	$152.23	50%	$944.52	$76.12
40 gal portable polytubs	each	$131.58	2	$263.16	$21.21	50%	$131.58	$10.60
1 1/2 inch pvc pipe	feet	$0.30	4800	$1,440.00	$116.04	50%	$720.00	$58.02
pvc pipe installation	feet	$1.54	4800	$7,392.00	$595.69	50%	$3,696.00	$297.85
quick couplings	each	$15.30	15	$229.50	$18.49	50%	$114.75	$9.25
installation of quick couplings	each	$15.30	15	$229.50	$18.49	50%	$114.75	$9.25
Watering system O&M	percent			$187.88	$187.88	0%	$187.88	$187.88
	added watering subtotal			$16,346.54	$1,490.05	n/a	$8,267.21	$838.96
	Total added capital costs			**$28,988.54**	**$3,422.64**	**n/a**	**$15,319.17**	**$2,321.07**

Table F.71: Summary of Estimated Costs and Revenues for the Stocker Case Study Farm under the Three Reference Conditions

Estimated Costs and Revenues for the Dairy Case Study Farm						
	Before Rotational Grazing		**Without Rotational Grazing**		**With Rotational Grazing**	
Gross Revenues	**$**	**155,626.71**	**$**	**232,789.17**	**$**	**217,989.71**
Costs						
Total Non-Forage Variable Costs	$	90,429.29	$	113,440.68	$	112,338.99
Total Forage Costs	$	24,233.46	$	35,876.62	$	15,706.10
Added Capital Costs		n/a	$	765.51	$	2,321.07
Total Costs	**$**	**114,662.75**	**$**	**150,082.81**	**$**	**130,366.17**
Net Revenues	**$**	**40,963.96**	**$**	**82,706.36**	**$**	**87,623.54**

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