Charting the Course for Sustainability at Aurora Organic Dairy

Phase II: Energy, Greenhouse Gas, Nutrient Use, Water Use and Solid Waste Generation Life Cycle Assessment

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Abstract

This study is the second phase of a three-phase sustainability assessment of milk production by Aurora Organic Dairy (AOD). AOD is a leading provider of private-label organic milk to retailers throughout the U.S., and operates five farms in Colorado and Texas as well as a processing plant in Colorado. This study extended Phase I results to include a second year of data on energy use and greenhouse gas (GHG) emissions throughout the milk production life cycle. It also added three new categories of environmental impact—nutrient use, water use, and solid waste generation—based on their relevance to agricultural production systems. Primary data from AOD were collected over the period of April 2008 to March 2009, supplemented by existing literature, and used to benchmark impacts in each of the five categories across the full milk production life cycle, from feed and bedding production to final disposal. The functional unit of analysis was one gallon of packaged fluid milk. In addition to these life-cycle results, simplified environmental performance indicators (EPIs) were developed to aid management in understanding the environmental effects of operational decisions. Life-cycle results per functional unit were: 68 MJ (energy consumption), 7.8 kg CO_2 eq. (greenhouse gas emissions), 4.6 moles H+ eq. (acidification potential), 2.5 g N eq. (eutrophication potential), 810 gallons (water consumption), 12 gallons (water utilization), 160 g (direct municipal solid waste), and 160 g (indirect solid waste). The feed and bedding production life cycle stage was both a major contributor to most impacts, and the stage with the highest data uncertainty. A set of strategies for improvement were identified for each impact area.

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Executive Summary

Objectives

This study is the second phase of a life cycle assessment (LCA) of milk production at Aurora Organic Dairy (AOD). The first phase examined the life-cycle primary energy consumption and greenhouse gas (GHG) emissions of AOD milk production, while this phase has added three more categories — nutrient use, water use and solid waste (SW) generation — for measuring the environmental impacts associated with the production of one gallon of AOD milk. Impacts were also assessed using environmental performance indicators (EPIs). Nutrient use, water use and solid waste were chosen as assessment categories due to their importance in agricultural systems and their value in measuring AOD progress towards environmental sustainability. Results are summarized in Table 1.

Table 1. Summary of results for assessment categories over the full life cycle

Category	Result per gallon of packaged fluid milk (functional unit)	Equivalent to…
Energy Use	67.7 MJ	1.54 gallons of gasoline (LHV)
Global Warming Potential	7.79 kg CO_2eq	17 miles driven in a car
Acidification Potential	4.62 moles H+ eq	17 kWh of electricity (US grid avg.)
Eutrophication Potential	2.5 grams N eq	3 pounds of urea fertilizer
Water Consumption	808 gallons	16 (50 gal.) bathtubs
Water Utilization	12 gallons	7.5 low-flow toilet flushes
DMSW	160 grams	About 5 ½ ounces
IMSW	156 grams	About 5 ½ ounces

Energy Use and Greenhouse Gas Emissions

Phase I results for energy and GHG emissions were updated for the Phase II time period (April 2008 to March 2009) using a similar methodology. Results comparing energy use between the two time periods are shown in Figure 1.

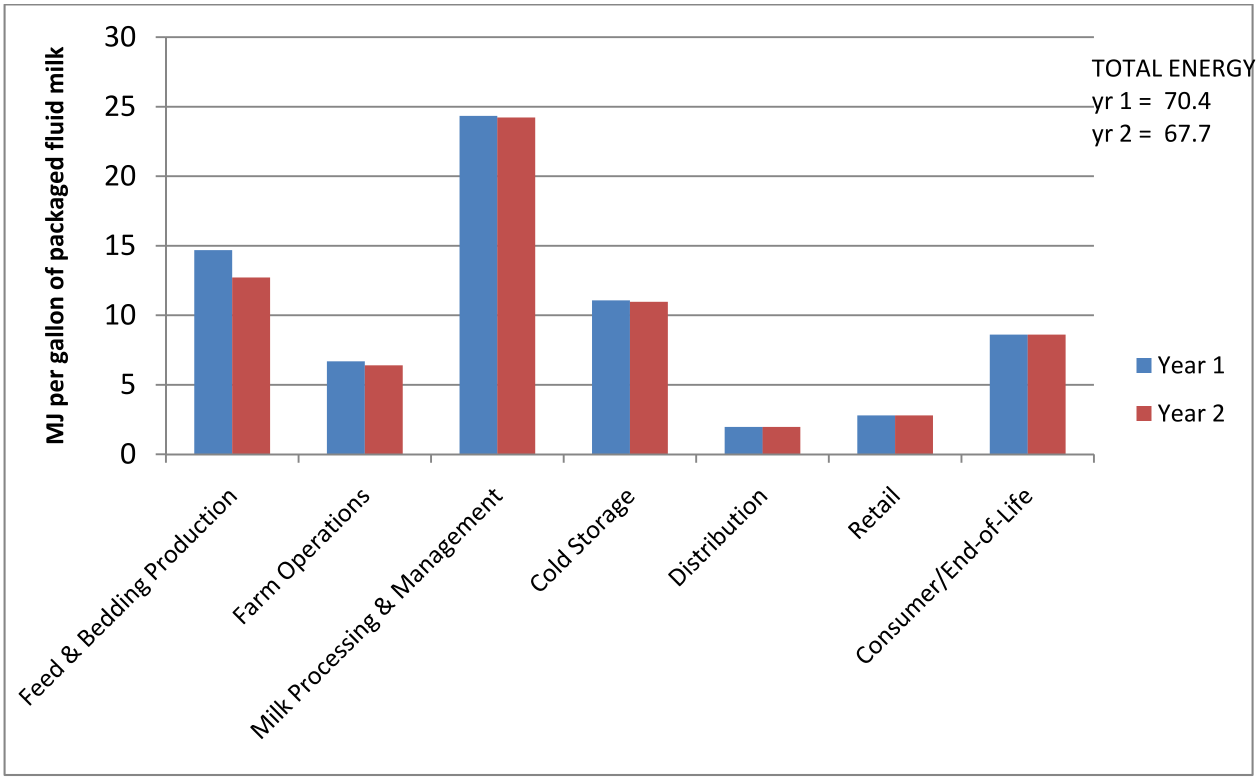

Figure 1. Energy use for all modeled processes on a per gallon packaged fluid milk basis

Total energy use per gallon of packaged milk decreased between the study periods from 70.4 MJ/gallon in year 1 to 67.7 MJ/gallon in year 2, for an overall reduction of 3.8%. The slight decrease in energy consumption per gallon of milk may be due to a smaller proportion of dry animals to total animals in the total herd and, possibly, increases in general operational efficiency. However, given the level of uncertainty in the analysis, this may not reflect a significant change in AOD operational efficiency.

Greenhouse gas emissions impacts are shown in Figure 2.

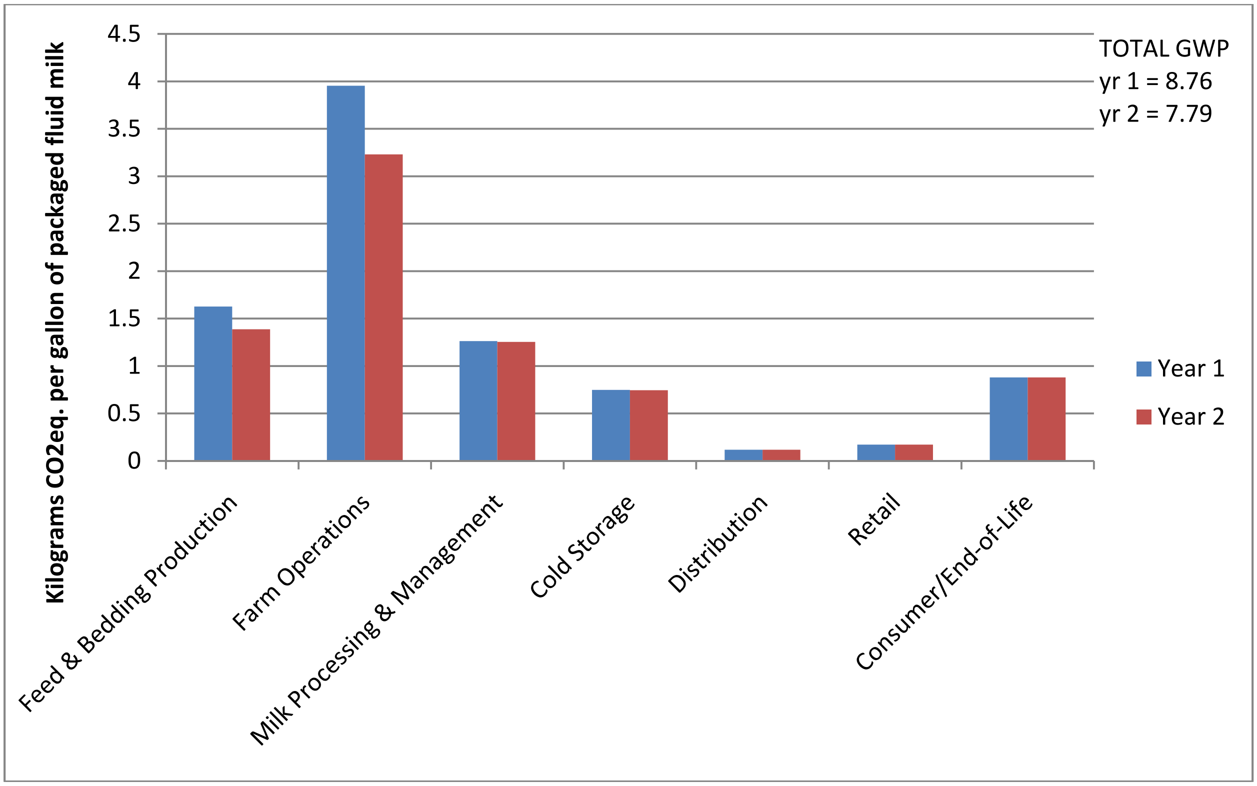

Figure 2. Greenhouse gas emissions expressed on a Global Warming Potential per gallon packaged fluid milk basis for all modeled processes

Greenhouse gas emissions decreased from 8.76 kg CO_2eq per gallon packaged milk in year 1 to 7.79 kg CO_2eq per gallon in year 2 for an overall reduction of 11%. Most of the improvements are due to reductions from impacts in the upstream stages, especially from feed production, enteric fermentation, and manure management.

Nutrient Use Introduction and Methodology

Agricultural productivity depends on the availability of nitrogen (N), phosphorus (P), and other elemental nutrients in farm systems. In order to meet the nutrient demands required for milk production, AOD imports large quantities of N and P nutrients embodied in feed, which then is converted into milk and manure in the farm systems. The nutrients contained within manures can then be released to the environment and lead to a variety of impacts. These impacts were quantified using eutrophication and acidification impact categories in LCA; nutrient use efficiency and surplus environmental performance indicators for operational management were also calculated.

The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) 2 v3.0 (Bare, 2003; Norris, 2003) was used to quantify eutrophication and acidification impacts over the life cycle and SimaPro software datasets were relied upon for emissions outside of the Farm Operations stage. Within the Farm Operations stage, nitrous oxide (N_2O), ammonia (NH_3), nitrate (NO_3^-), and phosphate (PO_4^{3-}) releases were calculated. AOD records and expert opinion were used for direct data inputs and to configure models of the farm system. IPCC guidelines for reporting greenhouse gas emission were used for N_2O releases and adapted to calculate NH_3 emissions at the Farm Operations stage (IPCC, 2006). Nutrient content flows in feeds, manure, milk, pasture leaching, and all other flows were calculated along with full farm-gate, soil-surface, and herd utilization balances for each farm system and nutrient. Nutrient surplus and use efficiency at the Farm Operations stage were also quantified per farm for each nutrient and represented as environmental performance indicators for operational management. Nutrient surplus measures the amount of nutrient imported to farm systems that is not exported as products and nutrient use efficiency is the ratio of nutrients exported in products to total imported nutrients.

Nutrient Use Results and Conclusions

Acidification Impact

Figure 3 describes the acidification impacts from the production of one gallon of packaged fluid milk throughout the life cycle.

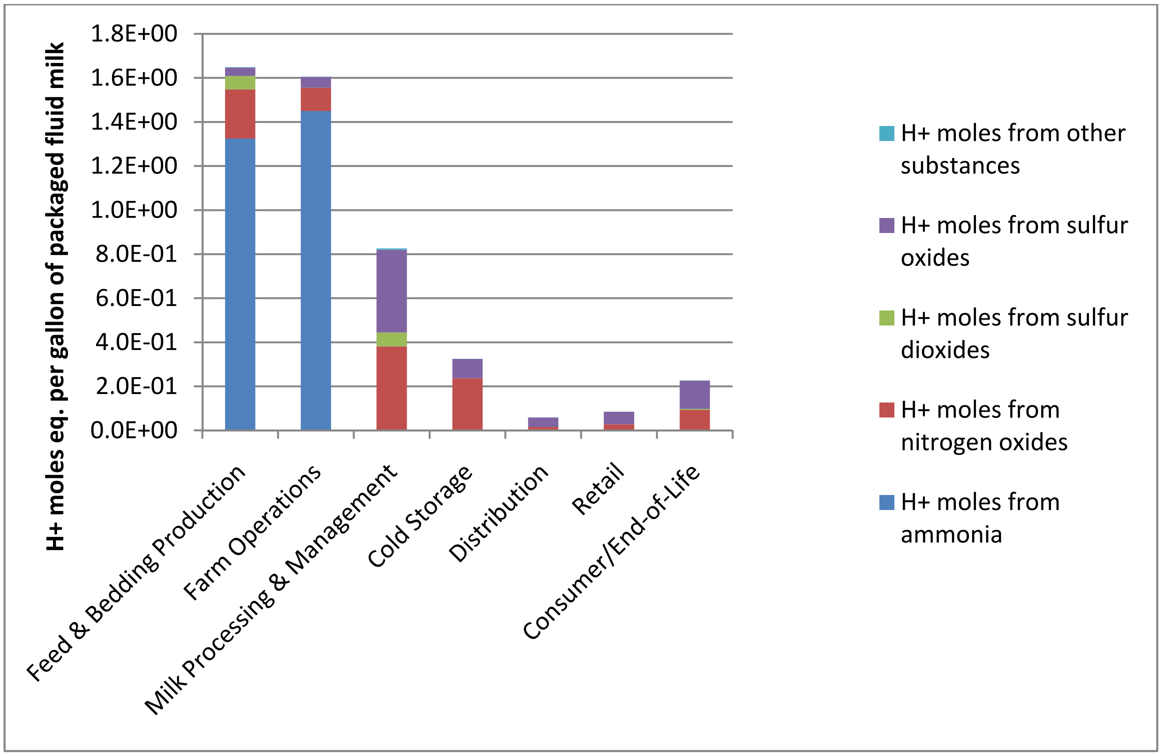

Figure 3. Acidification potential contributions from stages of the full life cycle on a per one gallon of packaged fluid milk basis

Eutrophication Impact

Eutrophication impacts from the production of one gallon of packaged fluid milk can be seen in Figure 4.

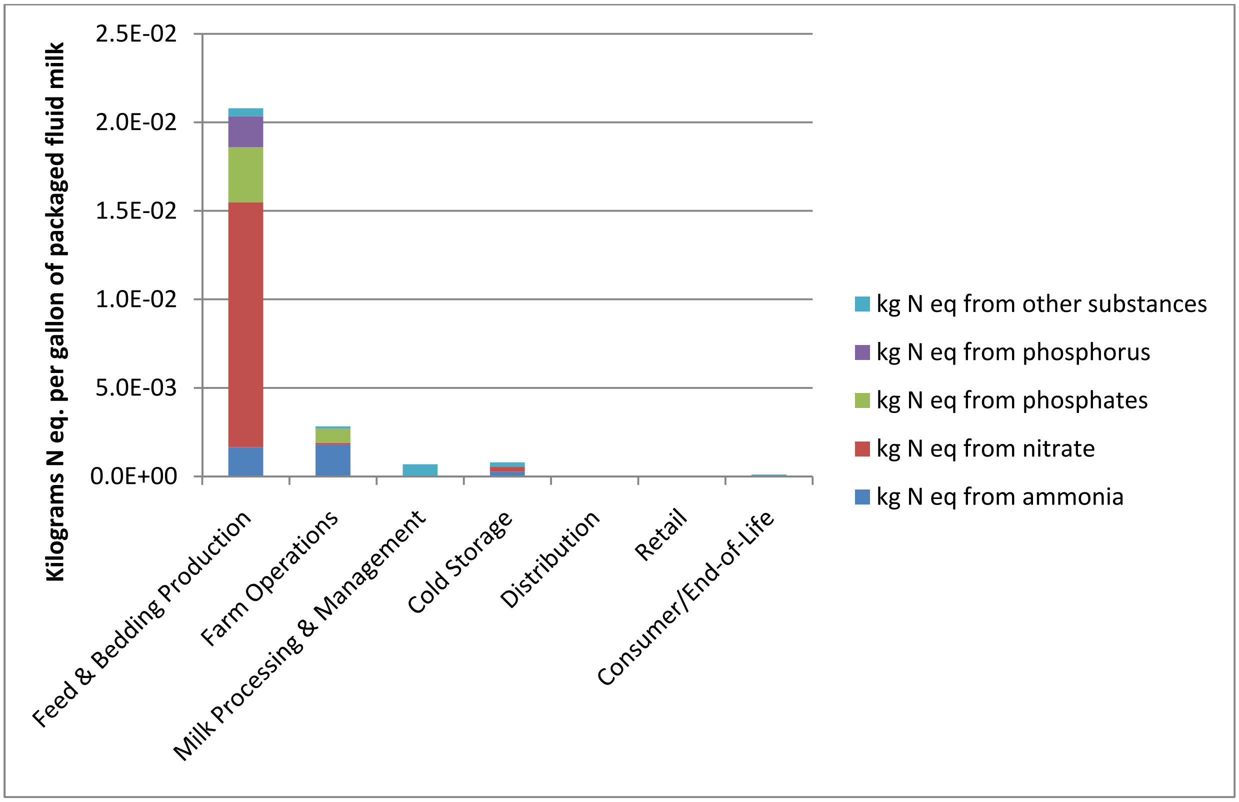

Figure 4. Eutrophication potential from major contributing nutrient species across all stages of the full life cycle on a one gallon of packaged fluid milk basis

Nutrient surplus and use efficiency results are summarized in Tables 2 and 3.

Table 2. Annual nutrient surplus by farm

Nutrient Surplus (pounds)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Nitrogen	142,000	349,000	547,000	630,000	107,000	796,000	979,000	1,780,000
Phosphorus	18,200	44,900	70,400	97,000	13,500	102,000	14,200	244,000

Table 3. Annual nutrient use efficiency by farm

Nutrient Use Efficiency

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Nitrogen	0.26	0.20	0.27	0.28	0.25	0.27	0.25	0.26
Phosphorus	0.37	0.29	0.38	0.34	0.37	0.37	0.32	0.35

Key Findings

- The acidification impact for the full life cycle of one gallon of packaged milk was 4.62 moles H+ equivalents.
- The Feed and Bedding Production and Farm Operations stages contributed most to acidification impacts over the life cycle.
- Of all emissions throughout the life cycle, ammonia contributed most to acidification, of which, most emissions came from the Farm Operations stage due mostly to manure management.
- Downstream from the Farm Operations stage, most acidification impacts are due to emissions from energy use and electricity generation.
- The eutrophication impact for the full life cycle of one gallon of packaged milk was 0.0025 kg N equivalents.
- The Feed and Bedding Production stage was the largest contributor to eutrophication.
- Most eutrophication impacts were from nitrate leaching from fertilizer application in crop production, but phosphates and ammonia were also significant.
- Impacts from the Feed and Bedding Production stage are uncertain and likely overestimate impacts due to the reliance on conventional crop production datasets and lack of organic crop production data.
- Over all farms during the study period, there was a total surplus of 1.78 million kg of N and 244,000 kg of P.
- There were significant differences in nutrient surpluses and use efficiencies between AOD farms.
- Nutrient use efficiencies at AOD (0.20-0.28 for N; 0.29-0.38 for P) fell within the published range in the literature and compare relatively well given the large quantity of inputs to the farm systems.

Key Recommendations

- Experiment with reducing dietary nutrient content while monitoring milk production, milk quality and manure nutrient content to confirm that manure nutrients can be decreased without affecting milk production.

- Develop assessment techniques for measuring nutrient contents and primary productivity of pasture forage, and identify the percentage of total dry matter intake derived from pasture.
- Favor pastures with low risk P and N leaching indexes over those with high leaching indexes.
- Engage with feed suppliers to encourage efficient nutrient use and gather data on AOD feed supplier management practices.

Water Use Introduction and Methodology

Clean freshwater is becoming an increasingly scarce resource globally, especially in arid regions such as the Western United States. As human demand for water expands in the future, competition over freshwater resources will intensify and water itself will continue to become more expensive. AOD facilities, and major AOD suppliers, are located in water-stressed areas and are, therefore, exposed to the financial risk of higher water prices and the operational risk of limited water availability. It is critical that the company quantify water use throughout the milk production life cycle and assess the impacts associated with this water use.

Many previous studies measure water use in terms of the water inputs to an industrial system, but because it is more important to understand the fate of water when it leaves the system, this study focused on water outputs from the milk production life cycle. Two types of water outputs are distinguished: 1) water consumption—water that is evaporated, transferred to a different watershed, or incorporated into the final product; and 2) water utilization—water that is returned to the watershed from which it is withdrawn. As an example, water consumption at the milk processing plant consists of water that is evaporated for cooling purposes, while water utilization consists of water that is used in the plant and then pretreated before being returned to the local sanitation district.

This study quantifies water consumption and utilization in each stage of the milk life cycle. In the Feed and Bedding Production stage, irrigation water that is evapotranspired by crops is counted as water consumption. The specific irrigation practices of the feed growers were not known, so the U.N. Food and Agriculture Organization's CROPWAT 8.0 and CLIMWAT 2.0 programs were used to determine the amount of irrigation water required to produce AOD's feed and bedding, taking growing locations into consideration. The specific locations of feed growers were not known and therefore major crop-growing regions located close to the feed consolidators were used. CROPWAT 8.0 provides theoretical estimates of crop water needs and tends to overestimate the amount of irrigation water used. Actual irrigation numbers are likely to be lower.

In the Farm Operations and Milk Processing and Management stages, water consumption and utilization at AOD facilities were quantified based on AOD records, consultation with AOD experts, and literature sources. Additionally, the water consumption and utilization associated with electricity generation and transport fuel production were quantified using the most recent data available. In the later life-cycle stages (cold storage, Distribution, Retail and Consumer/End-of-Life) only water use associated with electricity and fuel was included.

This inventory of water consumption and utilization throughout the milk life cycle was supplemented with a LCA impact category called "water deprivation," which measures the extent to which AOD water consumption limits the amount of water available to other users in the same watershed. This analysis is based on a water stress index (WSI) value, which compares water withdrawn to total water available in each watershed. Essentially, WSI values measure competition over water resources, and a higher WSI value indicates greater competition; where there is greater competition, AOD water consumption has a correspondingly larger impact on the amount of water available to other users in the same watershed.

Water Use Results and Conclusions

Figure 5 shows results for water consumption and utilization throughout the milk production life cycle.

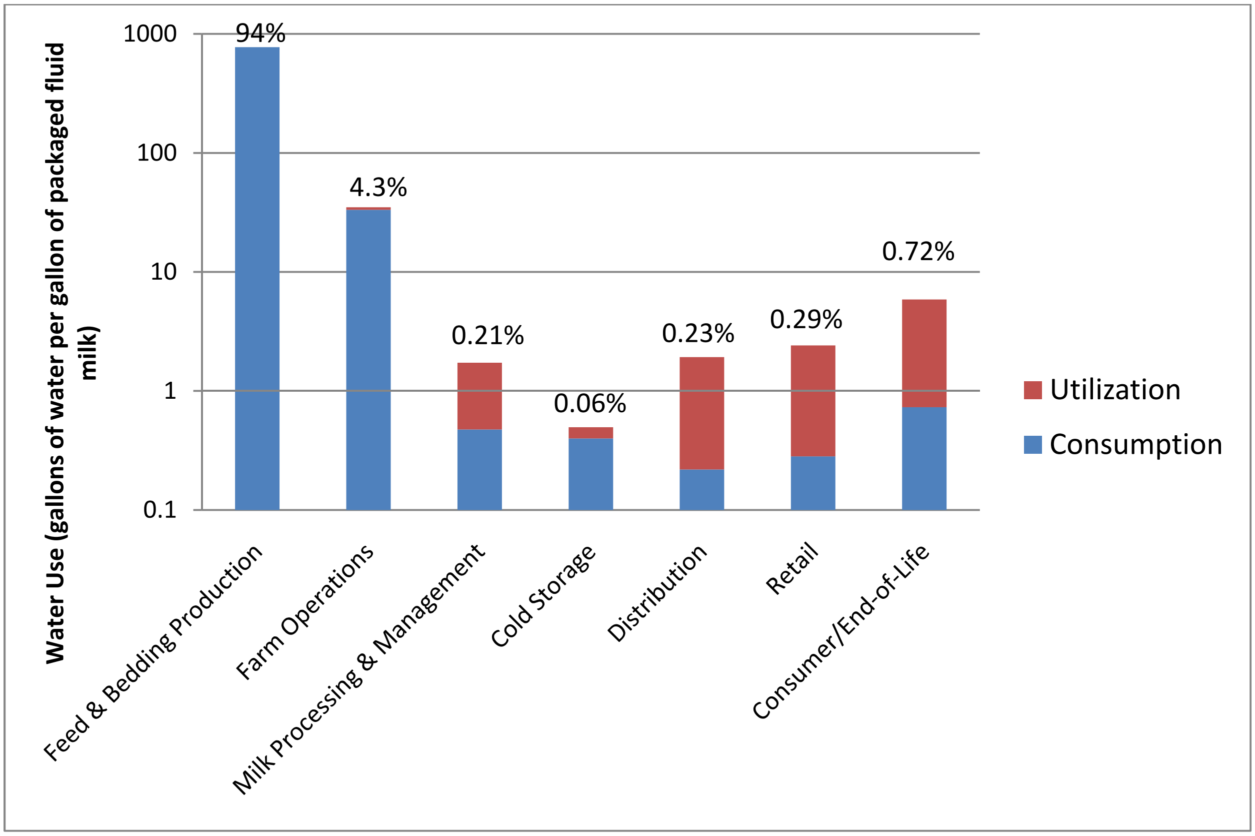

Figure 5. Water use (gallons of water per gallon of packaged fluid milk) over the full life cycle.

Key Findings

- Total life-cycle water consumption is 808 gallons per gallon of packaged fluid milk, and total life-cycle water utilization is 12.3 gallons per gallon of packaged fluid milk.
- The Water Footprint Network found that the global average is about 1000 gallons of water per gallon of milk produced, and the U.S. average is 700 gallons of water per gallon of milk. However, these results are not directly comparable because are based on a different methodology and are not specific to U.S. organic milk production.
- Irrigation for organic feed and organic bedding production accounts for 94% of total life-cycle water use (this number is likely to be an upper estimate). When including pasture irrigation at AOD farms, irrigation water accounts for 97% of all water use in the milk production life cycle.

- Alfalfa hay accounts for 55% of all water consumption in the Feed and Bedding Production stage.
- Water use at AOD facilities (and for electricity and fuel used at AOD facilities) accounts for 4.6% of total life-cycle water use.
- Among AOD farms, High Plains and Ray-Glo show the highest water use per gallon of raw milk produced, due to greater use of irrigation water.
- On average, about 35% of water use for organic feed and organic bedding production leads to water deprivation, and 87% of water use at AOD farms and at the processing plant leads to water deprivation.
- AOD farms are located in areas of high water stress, except Coldwater (however, 88% of water use at Coldwater contributes to permanent depletion of the Ogallala Aquifer).
- WSI in feed/bedding growing locations varies from very low to very high; alfalfa grower in Idaho has very low water stress.
- Table 4 summarizes the results of the EPIs associated with water use.

Table 4. Water Use EPI Summary

EPI Name	Total Annual Result for All AOD Facilities
Total water inputs by source	1.22 billion gallons (58% surface water, 42% groundwater, 0.37% rainwater)
Total volume and percentage of water inputs recycled or reused	70 million gallons reused, or 5.7% of water inputs
Water intensity	54 gallons of water used per gallon of finished milk
Water use associated with electricity and fuel	66 million gallons

Key Recommendations

- Install water meters in strategic locations on all AOD farms in order to gather more accurate information on water use; in particular, it would be helpful to install meters at the milking parlors, the lagoons, the irrigation systems, and also on the wells at High Plains and Dipple.
- Use this information to target efforts to increase water intensity on the farms.

- Work with organic feed/bedding suppliers and growers to obtain more precise information about irrigation practices, and encourage growers to increase irrigation efficiency.
- Source feed/bedding from locations that irrigate more efficiently, and from regions of lower water stress.
- Conserving electricity and fuel, and using renewable energy sources, reduces life-cycle water use.

Solid Waste Generation Introduction and Methodology

Solid Waste (SW), is generated at every stage of the milk production life cycle, and can cause significant environmental impacts if it is landfilled or incinerated. Recycling of municipal solid waste (MSW) commonly referred to as garbage or trash, is one solution for reducing these impacts, but the U.S. Environmental Protection Agency states that "source reduction" of waste is the best strategy for reducing SW impacts. (EPA, 2010)

This study quantifies three different flows of SW in the milk life cycle: direct MSW (DMSW), indirect solid waste (ISW), and the portion of DMSW that is diverted from the waste stream through recycling (RMSW). DMSW encompasses all solid waste generated as a direct result of AOD operations; major components include disposable udder wipes, filter socks, nitrile milking gloves, various types of packaging, and milk containers. ISW encompasses all solid waste generated during the generation of electricity and processing of fuels. One example of ISW would be sludge and ash from coal-fired electricity generation. RMSW encompasses a variety of waste flows; major components include cardboard and plastic. During the study period there was no recycling at AOD farms, however udder wipes are currently being composted at High Plains and Platteville and Cold Water's west parlor has switched to microfiber cloth reusable udder wipes. There is significant recycling of MSW from the AOD processing plant and also for certain materials in later life cycle stages.

Data on DMSW and RMSW were gathered from AOD purchase records, from AOD experts, and from literature sources referencing national average recycling rates. This study did not include DMSW generated during Feed and Bedding Production, but did include DMSW from all other life cycle stages. ISW was calculated using the SimaPro modeling software's processes for various designated regions' energy mixes and fuels as well as the nation's energy mix average.

EPIs were used to analyze DMSW and RMSW generation within individual stages as well. The three EPIs for SW generation were: 1) quantity of MSW, 2) characterization of MSW, and 3) a recycling ration (DMSW:RMSW). Table 5 below explains these EPIs in more depth as well as which life-cycle stages were assessed by each of the three.

Table 5. MSW EPIs

Environmental Performance Indicator	Description	Stages Assessed
Quantity of MSW	weight produced annually in grams & weight (g) per finished gallon fluid milk	Farm Operations, Milk Processing and Management, Distribution, and Consumer/End-of-Life
Characterization of MSW	Material composition of MSW	Farm Operations, Milk Processing and Management (Gabletop carton waste and RMSW only), Distribution (MSW associated with AOD product packaging), Consumer/End-of-Life (MSW associated with AOD product packaging),
Recycling Ratio	Amount RMSW/Amount DMSW	Farm Operations, Milk Processing and Management, Distribution (MSW associated with AOD product packaging), Consumer/End-of-Life (MSW associated with AOD product packaging),

Solid Waste Generation Results and Conclusions

Figure 6 shows the results for all three types of MSW throughout the milk production life cycle.

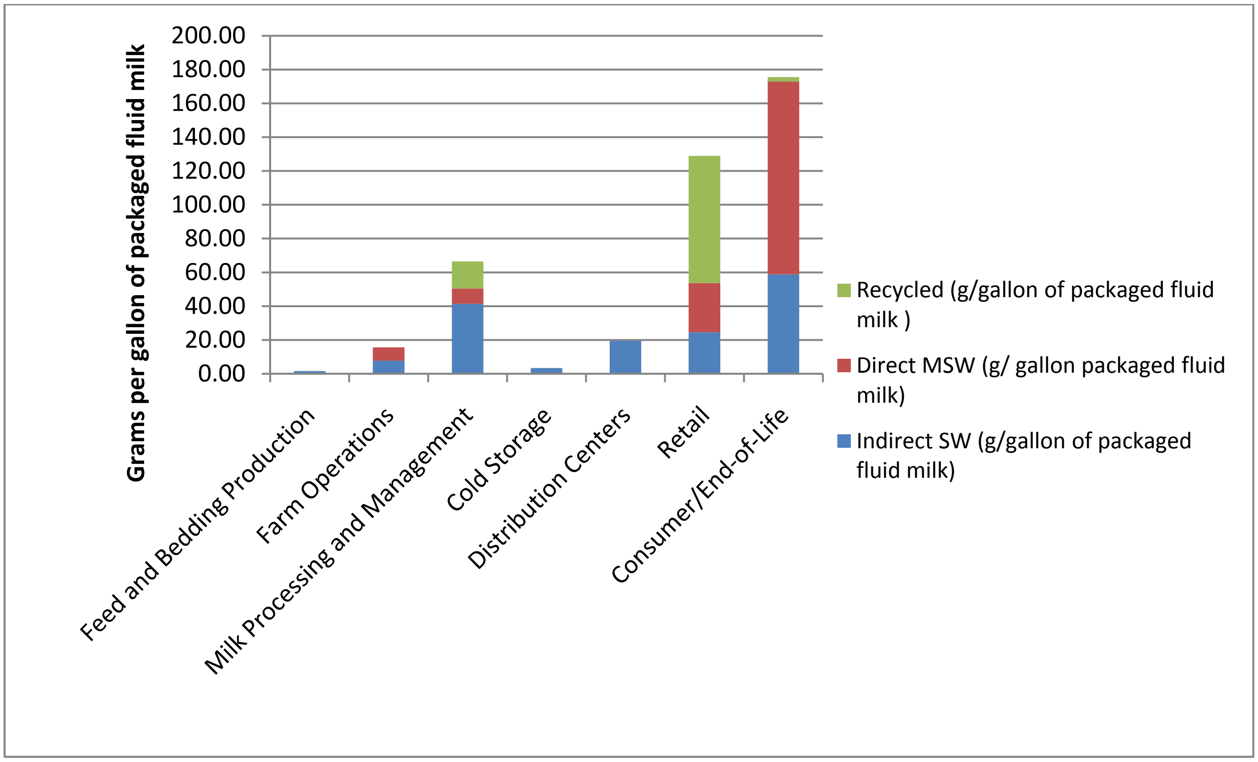

Figure 6. Results for ISW, DMSW, and RMSW for each life-cycle stage in grams per one gallon of packaged fluid milk

Key Findings

- One gallon of packaged fluid milk results in 156g of ISW, 160 g of DMSW, and 93.91g of DMSW is diverted from the waste stream through recycling (RMSW).
- The Consumer/End-of-Life stage contributes most to the life-cycle ISW and DMSW; it contributes 38% of ISW, and 71% of DMSW.
- The Retail stage performs the best with regard to recycling, contributing 80% of all recycling throughout the milk life cycle.
- Udder wipes were the largest contributor to DMSW in the Farm Operations stage, at 73% of DMSW in this stage.
- Gabletop containers contributed most (65%) to DMSW at the processing plant.
- 97% of Retail stage MSW is cardboard.

- 93% of Consumer/End-of-Life DMSW is gabletop containers.

Key Recommendations

- Investigate potential for implementing recycling at Farm Operations.
- Conduct waste sort study for Farm Operations and Milk Processing and Management to develop more detailed understanding of other DMSW components.
- Conserve electricity and fuel, and use renewable energy sources, to reduce life-cycle ISW.

Introduction

Background

This study is the second phase of a life cycle assessment (LCA) of milk production at Aurora Organic Dairy (AOD), a large vertically integrated organic dairy company in the United States. The first phase examined the life-cycle primary energy consumption and greenhouse gas (GHG) emissions of AOD milk production. (For a detailed description of AOD's operations, the life cycle of a milking cow, and the LCA framework, see the report from Phase I of this study—Heller et al., 2009). This second phase added three more categories — nutrient use, water use and Solid Waste (SW) generation — for measuring the environmental impacts associated with AOD milk production. In addition to quantifying these impacts using a LCA framework, AOD operations were assessed using environmental performance indicators (EPIs). Together, both phases represent the first comprehensive LCA of large-scale, vertically integrated organic milk production in the United States. In combination, all five categories included in these studies (energy use, GHG emissions, nutrient use, water use, and solid waste generation) aim to broadly assess AOD operations and guide future management decisions at the company. Nutrient use, water use and solid waste were chosen as assessment categories due to their importance in agricultural systems and their value in measuring AOD progress towards environmental sustainability.

Nutrient Use

Elemental nutrients are essential to the health of all living organisms and entire ecosystems. Nutrients partially determine organism growth rates, seasonal growth trends, species composition, biodiversity and many other factors that affect life and even define particular ecosystem types. Changes to nutrient cycling within these systems have somewhat predictable and often deleterious impacts throughout the many unique ecosystems around the world. The disruption of nutrient cycling can ultimately decrease ecosystem health by removing limiting nutrients, changing the relative abundance of nutrients in the environment, and creation of nutrient surpluses, which may lead to a variety of environmental, human health, and economic impacts as indicated in Table 6.

Table 6. Selected environmental, economic and human health impacts from nutrient releases

Impact	Description
Blue baby syndrome	Potentially fatal human syndrome caused by high nitrate concentration in drinking water
Acid rain	Widespread but regional damage to buildings and ecosystems
Increased soil toxicity	Release of toxic compounds as soil pH changes
Hypoxia	Widespread death of many forms of marine life due to nutrient enrichment and oxygen depletion
Loss of soil biodiversity	Enriched systems favor few rich site species

Under natural conditions, nutrients tend to cycle internally within ecosystems due to competition between organisms for limited nutrient resources. However, human activity can break the cycle by adding nutrients from other areas or removing nutrients in products that have economic value. Agriculture can have a very strong impact on nutrient cycles because addition and removal of nutrients in fertilizers, animals, and crops are fundamental to operations. Furthermore, in conventional agriculture, the application of nutrients may be managed to secure profit rather than for nutrient efficiency, which can have the effect of incentivizing surpluses when fertilizers aren't prohibitively expensive.

There is an ever-increasing awareness that the impacts of nutrient disruptions from agricultural production is leading to large-scale environmental consequences. The effects of nutrient releases from farm systems throughout the US have been shown to affect local freshwater ecosystems and have been implicated as the primary cause of a periodic 4 million acre dead zone in the Gulf of Mexico (Nassauer et al., 2007.) In Europe, ammonia emissions have resulted in widespread damage to ecosystems, with an estimated 90% originating from farm systems – most of which is due to dairy (Meisinger and Jokela, 2000).

By taking a proactive stance in understanding and mitigating its nutrient use impacts, AOD can maintain industry leadership in an increasingly important area of environmental stewardship. Additionally, by adding nutrient use impacts to the first large-scale US organic LCA, this study sets the stage for comparing differences between nutrient impacts from organic and conventional large-scale US production.

Water Use

Water is the most basic of all natural resources, essential to all life on the planet and to sustaining human society. Though there is no shortage of water itself, clean freshwater is becoming increasingly scarce around the world as more sources are appropriated by humans for use in agriculture, industry and municipal water supply systems. This scarcity is especially acute in certain areas, including the American West, where AOD's farms are located. In particular, Coldwater and the Colorado farms are all situated in semi-arid to arid regions where annual precipitation is less than 20 inches per year. In northeastern Colorado, artificial reservoirs are required to store and release available runoff in useful quantities. In addition, significant population growth is creating more competition between traditional agricultural water users and the burgeoning municipalities north of Denver, which can afford to pay much higher prices for the water. In addition, climate change impacts may reduce total water availability in Colorado by the middle of the century (Colorado Water Conservation Board, 2008). In the Texas Panhandle (where the Coldwater farm is located) nearly all water comes from deep wells that tap into the Ogallala Aquifer. At the Dipple, groundwater is the major source as well. Though population growth is not a major concern for the Texas farms, they face increasingly stringent regulations on groundwater withdrawals.

In short, water is already a scarce resource in the vicinity of AOD's facilities, and it will only become scarcer—and therefore more expensive—in the future. Thus, it is vital that AOD quantify its water use and estimate the impact that this water use creates within the context of regional water resources. Freshwater use is now commonly accepted as an important measure of a company's environmental performance in any region, but it is an especially critical indicator for AOD because its facilities are located in water-limited areas. And while climate change and greenhouse gas emissions are perhaps the dominant environmental issue in the public's mind today, freshwater scarcity (which will almost certainly be exacerbated by climate change) is likely to arouse similar concern in the coming decades. By proactively addressing concerns about water scarcity, AOD can help to maintain its position as an industry leader on sustainability issues, and potentially address water scarcity issues related to its decision to locate its farms in the arid West.

Waste Generation

According to the EPA, Americans generated an estimated 250 million tons of trash, and recycled and composted 83 million tons of this material in 2008 (EPA, 2008). 81 percent of all municipal solid waste (MSW) was disposed of in a landfill and 19 percent was combusted in an incinerator with energy recovery (EPA, 2008). Both incineration and landfill disposal result in the release of greenhouse gas emissions, which contribute to climate change. In addition to influencing climate change, the disposal of SW can impact human health and the environment. Therefore, it is important to consider waste management and reduction strategies when assessing a company's overall sustainability performance.

Description of LCA Framework

The LCA process begins with the definition of system boundaries and scope, as well as the selection of a functional unit and statement of objectives. The system boundaries, scope, functional unit, and objectives for this study are described in the following sections. The next step in the process is the life cycle inventory. In this stage, the inputs and outputs for the system in question are quantified. Inputs include natural resources and industrial products; outputs include the products and the associated releases to land, air and water. In this study, a full life cycle inventory was carried out and the inventory results were used (nutrient use, water use and Solid Waste generation). Next, the impact assessment stage translates inputs and outputs into specific environmental impact categories. Pertinent impact categories were selected for energy use, greenhouse gas emissions, nutrient use and water use. It is important to note that the analysis of SW was based solely in the life cycle inventory, and not on any impact category.

Impact results from this study adhere to International Organization for Standardization guidelines (ISO, 1997) for LCA (Figure 7), Intergovernmental Panel on Climate Change (IPCC, 2006) methodology for greenhouse gas emissions and a variety of peer-reviewed resources for water use, nutrient use, energy use and waste generation. The interpretation of each impact category is described below.

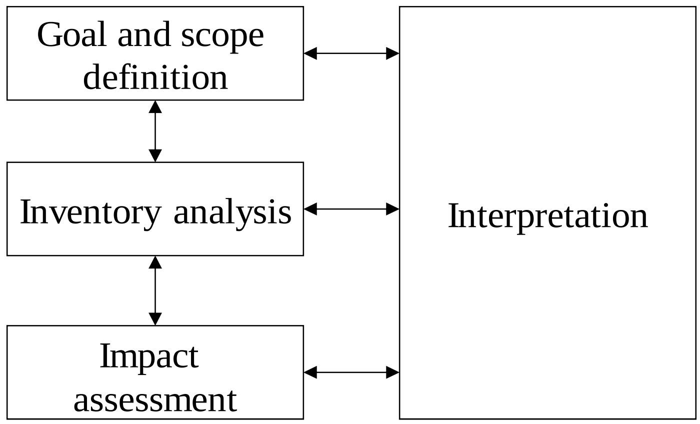

Figure 7. Phases of a LCA (ISO, 1997)

System Boundaries and Scope

Phase I considered the AOD milk production life cycle over one year, from April 2007 to March 2008. Because it was important to provide the most up-to-date results possible, Phase II considered the following year, from April 2008 to March 2009. In order to make reliable comparisons between all five environmental impact categories, it was necessary to update the Phase I results for energy use and GHG emissions to reflect AOD operations in the Phase II time period. This allowed results to be reported across all five categories from April 2008 to March 2009.

The milk life cycle, as considered in this study, encompasses seven main stages:

1) **Feed and Bedding Production**: includes all organic feed and organic bedding of all types purchased by AOD, as well as the transport to bring such feed and bedding to AOD farms.

2) **Farm Operations**: encompasses all activities on the farm, including fuel and electricity used; there are three AOD farms in Colorado (Platteville, High Plains and Ray-Glo) and two in Texas (Coldwater and Dipple).

3) **Milk Processing and Management:** includes the AOD milk processing plant in Colorado, fuel and electricity used at the plant, the transport of raw milk from AOD farms to the AOD processing plant, and the corporate office.

4) **Cold storage:** includes electricity use for refrigeration at the cold storage facility where AOD milk is housed before it is shipped to customers and the transport of finished milk from the AOD processing plant to the cold storage facility.

5) **Distribution:** includes electricity use for refrigeration at the regional distribution centers where AOD milk is stored before it is shipped to retail stores, and the transport of milk from the cold storage facility to the distribution centers.

6) **Retail:** includes electricity use for refrigeration at the retail stores where AOD milk is sold, and the transport of milk from distribution centers to retail stores.

7) **Consumer/End-of-Life:** includes electricity use for refrigeration in consumer households, transport of milk from retail store to consumer households, and burdens associated with disposal of milk packaging in landfills.

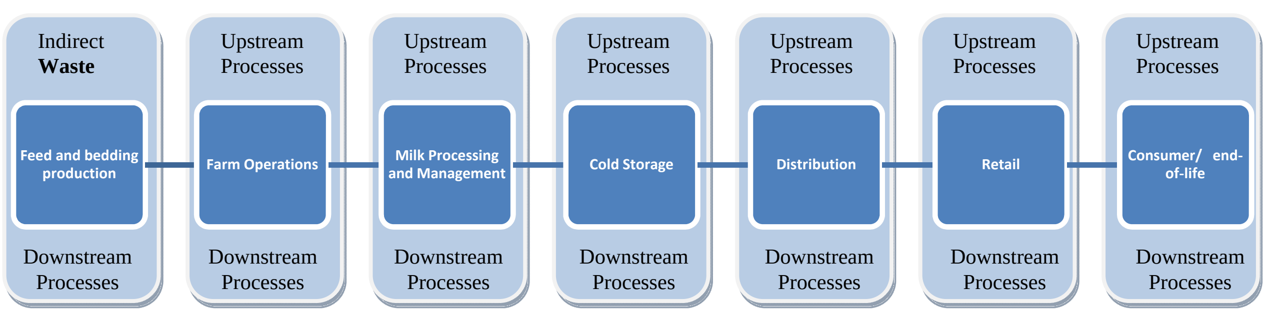

Figure 8. Seven stages of the milk life cycle as considered in this study

Figure 9. Location of AOD's 5 dairy farms; due to their close proximity, Ray-Glo and High Plains are represented by one push pin.

Table 7. Characteristics of the five AOD farms during the study period (March 2008 – April 2009)

<table>
<tr><th></th><th>Coldwater</th><th>Dipple</th><th>High Plains</th><th>Platteville</th><th>Ray-Glo</th></tr>
<tr><td>Location</td><td>Stratford, Texas</td><td>Dublin, Texas</td><td>Kersey, Colorado</td><td>Platteville, Colorado</td><td>Kersey, Colorado</td></tr>
<tr><td>Climate description</td><td>Semi-arid</td><td>Humid Sub-tropical</td><td>Semi-arid</td><td>Semi-arid</td><td>Semi-arid</td></tr>
<tr><td>Average milking herd size*</td><td>4,864</td><td>1,831</td><td>3,672</td><td>892</td><td>614</td></tr>
<tr><td>Pasture area for milking cows*</td><td>930 acres</td><td rowspan="2">1,540 acres of organic pasture used for either milking or dry cows</td><td>660 acres</td><td>270 acres</td><td>130 acres</td></tr>
<tr><td>Pasture area for dry cows*</td><td>150 acres</td><td>450 acres</td><td>120 acres</td><td>100 acres</td></tr>
<tr><td>Barn type</td><td>West – freestall
East – open lot</td><td>Freestall</td><td>Freestall</td><td>Open lot</td><td>Open lot</td></tr>
</table>

*This data is based on historical operations for year 2008 and does not reflect the current facilities.

Figures 8 and 9 and Table 7 provide an overview of the AOD farm system. Figure 10 below shows which co-products in the life cycle were allocated away from milk production—namely, powder, butter, culled cows and bull calves.

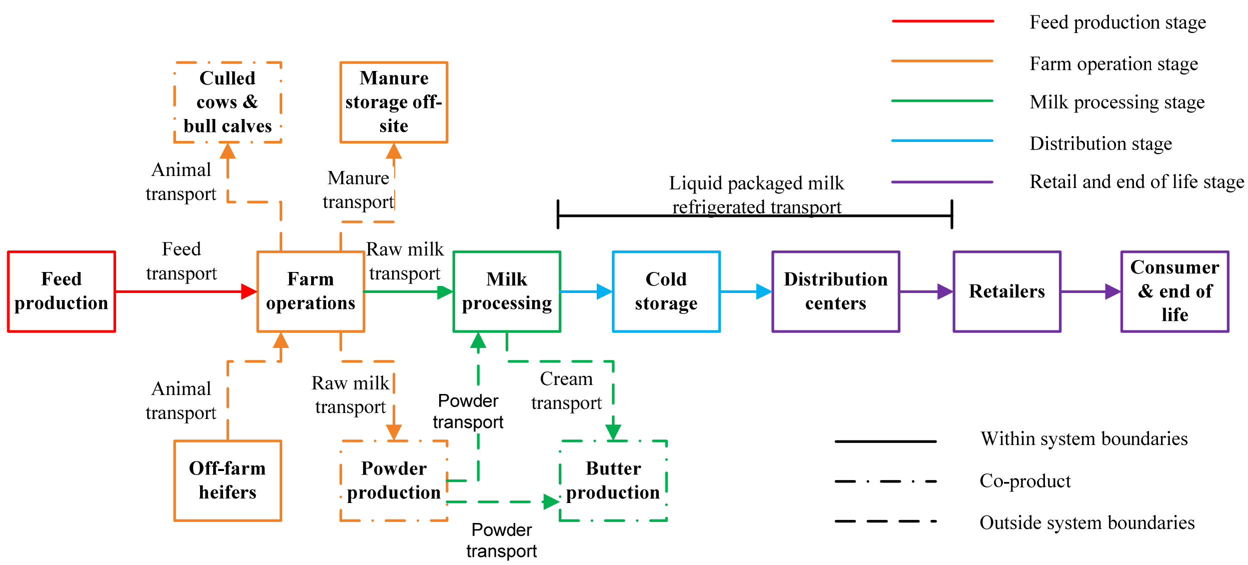

Figure 10. Allocations of co-products throughout the milk life cycle. (from Heller et al., 2009)

System Changes from Phase I

There were several significant changes in AOD operations between the Phase I and Phase II time periods:

- High Plains switched from a dry manure management system to a composting system; the resulting compost is then provided to local farmers.
- Multiple farms switched to artificial insemination, which decreased bull populations.
- During the last two months of the Phase II time period, milking was ramped down at Ray-Glo, so that by the end of March there were no milking cows left at that farm.
- The number of cows at Dipple decreased during this period.
- On average, the overall herd was older than during Phase I.

Functional Unit

This study quantifies the full life-cycle environmental impacts associated with the production of one gallon of packaged fluid milk. "Packaged fluid milk" was defined as all sold products, employee samples, sales samples and donations to the community.

Focus of Analysis

This study employed two different approaches: 1) to assess the life-cycle environmental impacts of AOD milk production using LCA methodology, and 2) to benchmark the environmental performance of AOD operations and measure progress in the future. LCA methodology provides a comprehensive analysis of environmental impacts throughout a product's life cycle. It enables a company to understand which life cycle stages contribute most to environmental impacts, as well as allowing for comparisons between different companies. However, from a management perspective the performance of an LCA can be costly and time-intensive. Therefore, this study complements the LCA analysis with a set of simplified metrics called environmental performance indicators (EPIs).

EPIs Defined

EPIs serve as in-house tools to measure and report how well a company is taking care of the environment. These tools can systematically measure the performance of the company's environmental policies and improvement programs. They help managers prioritize which policies and programs to implement for environmental improvement and further measure that improvement. Indicators are measurable with current technology at a reasonable cost, scientifically defensible, and easy to interpret and understand (New Zealand Ministry for the Environment, 1998). EPI and LCA results fall at the opposite ends of various trade-offs regarding assessment criteria as indicated in Figure 11.

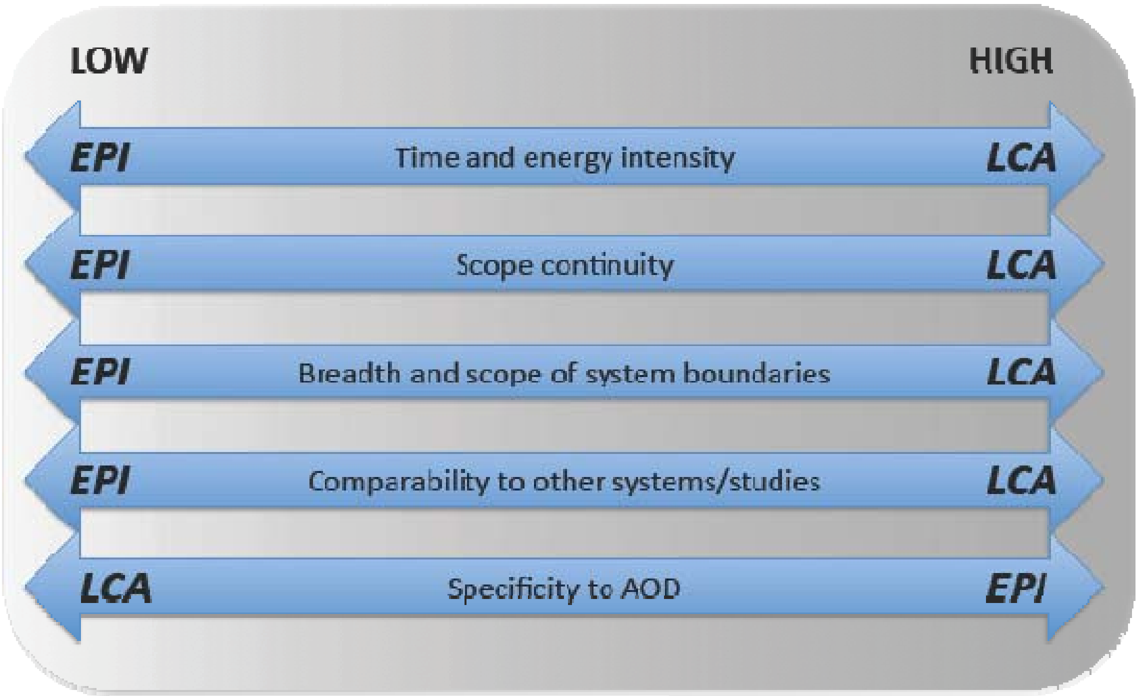

Figure 11. Selected trade-offs between the use of LCA and EPIs for measuring environmental performance as visualized on a low to high basis

There are a number of important differences between the LCA and EPI approaches, which are listed below:

1) EPI results are not normalized like LCA results and, therefore, do not relate to an environmental end result. For example, EPI results would not quantify the contribution of a company's operations to global warming (in LCA all GHG emissions are characterized into a combined global warming impact) across the entire product life cycle. Instead, they might measure total energy use at a company's facilities.

2) LCA methodology adheres to a rigidly defined system boundary and scope, whereas EPI scope and boundaries can be defined differently for each indicator—the same data can be used multiple times, boundaries can overlap, etc.

3) Because of the rigid boundaries and scope in LCA, results are more readily comparable across studies than EPI results. EPI results are often tailored specifically for in-house decision-making.

Using EPIs for Operational Management at AOD

Initial EPI results can be used as performance benchmarks, and aid management in setting goals for improvement. EPIs are also highly useful for estimating the effect of a particular operational change. Improvements tracked in EPIs over time should correspond to improvements in LCA results, but may provide feedback to AOD operations over a shorter time horizon, as indicated in Figure 12. However, the limited scope of EPIs means that they are not a substitute for full LCA results.

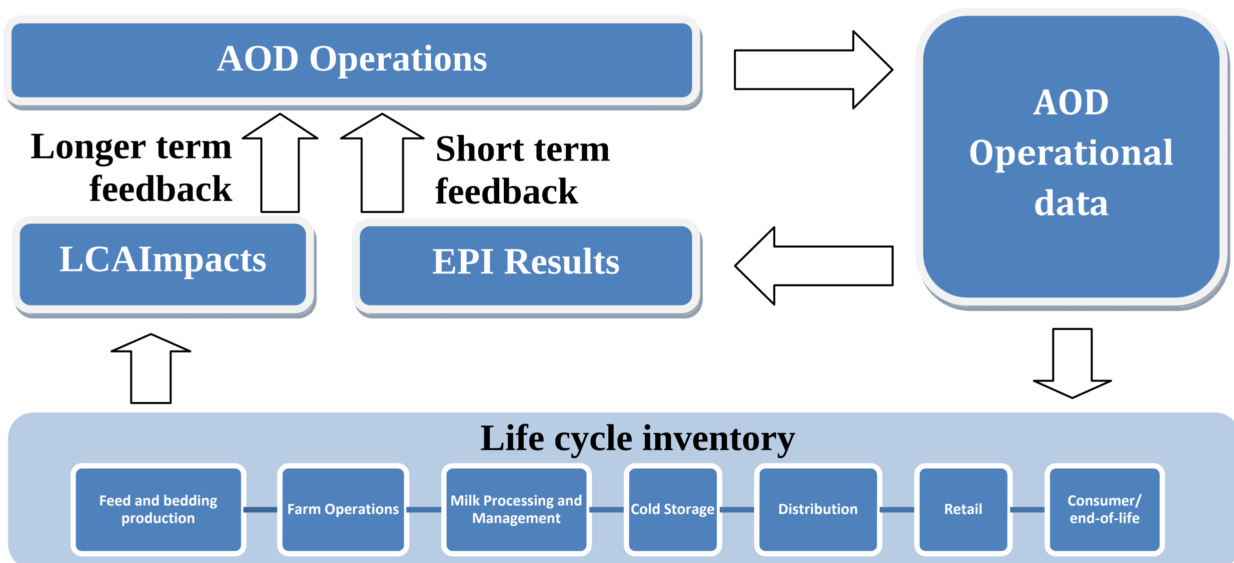

Figure 12. Feedback between AOD operations, data from operations relevant to environmental performance, and LCA and EPI results as indicated by arrows.

Objectives

The primary objectives of this study are the following:

- Update the results for energy use and GHG emissions through the Phase II time period
- Investigate and select LCA methodology for quantifying nutrient use, water use and solid waste generation in the milk life cycle

- Apply the LCA methodology to model the environmental impacts of AOD milk production over one year
- Highlight which processes within the milk life cycle contribute most to nutrient use, water use and solid waste generation
- Provide a benchmark for future improvement of AOD operations
- Identify strategies for improvement based on the interpretation of LCA and EPI results

Energy Use and Greenhouse Gas Emissions

Overview

The focus of this report is to extend an existing LCA to include impacts from water use, nutrient use and waste generation. The existing energy use and greenhouse gas emission impacts are discussed thoroughly in the previous report (Heller et al., 2009) and will not be described in detail here. However, the full set of energy use and greenhouse gas impacts were quantified using the methodologies developed by Phase I; refinements made for modeling these impacts will be highlighted.

Methodological Changes from Phase I

All methods used were identical to Phase I with the following exceptions:

- An emission factor related to N_2O releases from manure management and managed soils using IPCC methodology (IPCC, 2006) was corrected from a per day emission factor to a per year emission factor as required by the formula. This resulted in the increase of N_2O emissions by a factor of 365 where relevant.
- The allocation of impacts away from the production of milk by treating sold animals as a product has changed from Phase I to Phase II. The new allocation procedure is based on an energy allocation model that is described explicitly in appendix XXX.
- The manure management system modeling at High Plains was changed to reflect the conversion to manure composting.
- Data that was shown to be insignificant in Phase I was not updated in the second year. Year two data were not gathered for employee transport, consumer transport, and building embodied energy.

Results and Discussion

Energy Use

Total energy use per gallon of packaged milk decreased between the study periods from 70.4 MJ/gallon in year 1 to 67.7 MJ/gallon in year 2, for an overall reduction of 3.8%. Most of the decreases are the result of improvements in the upstream stages of milk production, where gains were made in the Feed and Bedding Production stage and throughout Farm Operations. As expected, energy use in the downstream stages did not change much as the modeling remained constant between both years. Life cycle results are shown in Figure 13.

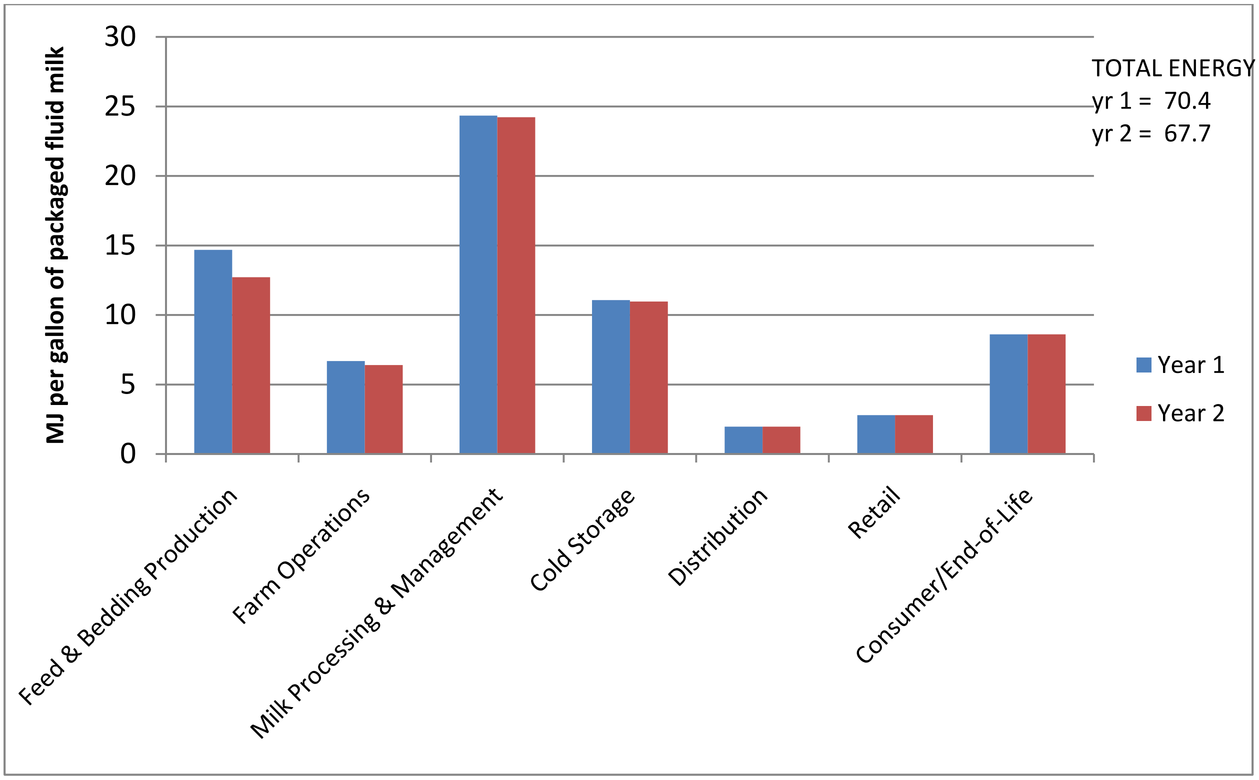

Figure 13. Energy use on a per gallon packaged fluid milk basis for all modeled processes

The drivers behind the decrease in energy consumption per gallon of milk were not obvious, but are believed to be due to a smaller proportion of dry animals to total animals in the total herd and, possibly, increases in general operational efficiency. A decrease in the relative proportion of dry animals was observed with cows and also with bulls due to increased adoption of artificial insemination in year 2. Another interesting result was the plant utilities energy use increased in year 2, but it is unclear why. Processing less milk per run due to reduced supply adjustments and increased plant refrigeration due to increases in inventory increases due to lagging demand market conditions were all considered as possible drivers for this energy use increase, but no results from this study indicate the underlying cause. However, the decrease in energy use between the first and second year may be due to uncertainty in the analysis; in general, the year-to-year differences are not large enough to draw definitive conclusions about changes in operational efficiency. One possible strategy for reducing life-cycle energy use is the implementation of reusable udder wipe systems at AOD farms (see Appendix A).

Greenhouse Gas Emissions

Greenhouse gas emissions decreased from 8.76 kg CO_2eq per gallon packaged milk in year 1 to 7.79 kg CO_2eq per gallon in year 2 for an overall reduction of 11%. Most of the improvements are due to reductions from impacts in the upstream stages, especially from feed production, enteric fermentation, and manure management. Most other impacts stayed roughly similar between years. Life cycle results are shown in Figure 14.

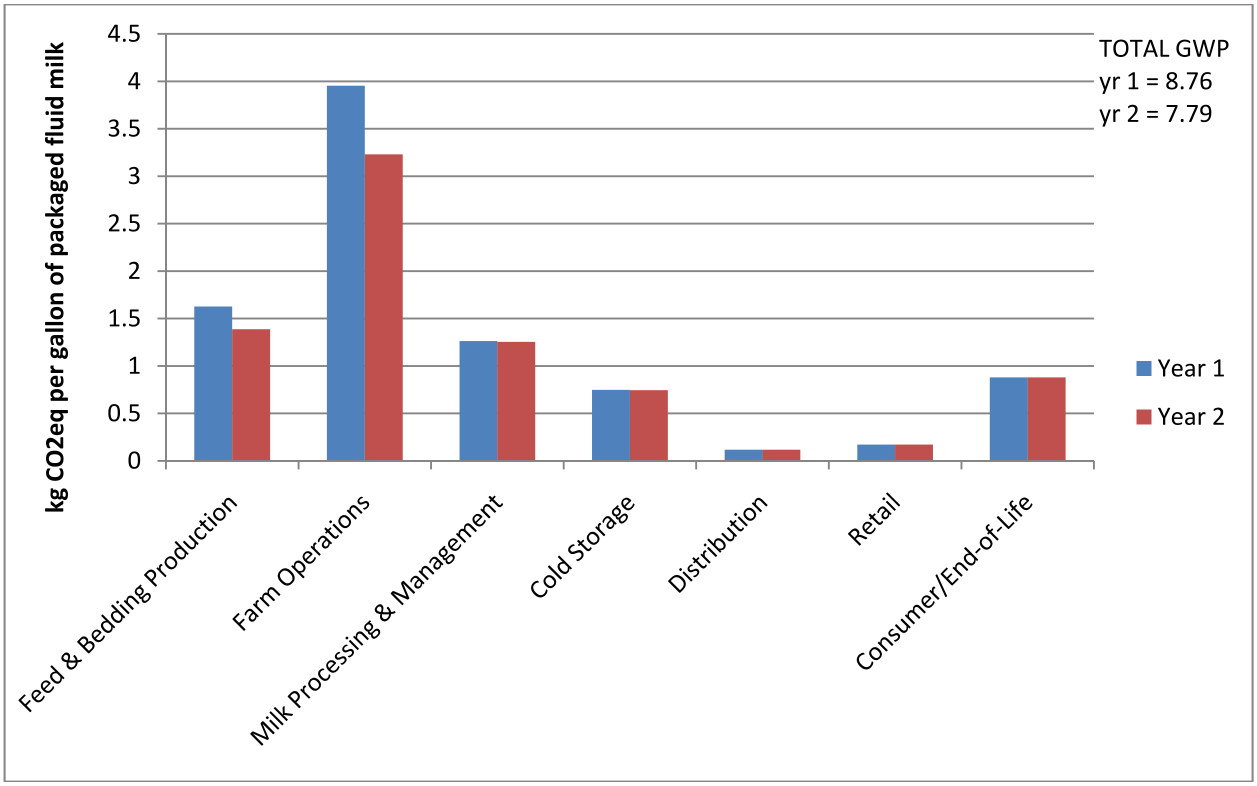

Figure 14. Greenhouse gas emissions expressed as Global Warming Potential on a per gallon of packaged fluid milk basis, for all modeled processes.

The drivers behind the decreases in greenhouse gas emissions were probably due to the same factors that drove down energy use between years. As with energy use, the lower herd sizes relative to milk production contribute to reducing GHG emissions per gallon of packaged fluid milk, because a smaller herd produces less manure and causes less enteric fermentation. Given the high GWP of methane and the direct relationship between herd size and methane emissions from manure and enteric fermentation, the impact due to changes in herd size is more apparent in the GHG emissions results than the energy use results. This explains why the year-to-year decrease in GHG emissions was greater than the decrease in energy use. As with energy use, life-cycle GHG emissions could be reduced through the implementation of reusable udder wipe systems at AOD farms (see Appendix A).

Nutrient Use

Introduction

Nutrient cycling through Aurora's agricultural systems involve a number of interactions between natural ecological systems and nutrient flows through the supply chain. Large quantities of nitrogen and phosphorus are continuously imported to farm systems from organic feed, organic bedding, and other inputs while milk, manure, and compost are exported. While some nutrient releases are environmentally benign (e.g. N_2 releases from a lagoon to the atmosphere), others can contribute to environmental burdens in varying capacities (e.g. NH_3 and N_2O releases from the same lagoon). Impacts of nutrient releases due to AOD production were modeled by combining a complete mass balance for nutrient flows through the Farm Operations stage with a full life cycle inventory to characterize impacts using acidification and eutrophication impact categories.

Plants, animals, microbes and other life are specifically adapted to their environments, which are often characterized by a very particular pH. Decreasing this pH (increasing acidity) can have drastic impacts on ecosystems by limiting important nutrients and releasing toxins. Impacts from acidification received public attention during the eighties when releases of SO_x from coal powered power plants were implicated in the damaging and killing large tracts of forests, acidifying streams and soils, damaging buildings, and freeing large quantities of toxic soil-bound aluminum into terrestrial ecosystems. In response, Title IV of the Clean Air Act was established to cap SOx emissions from electricity generation. Though the "Acid Rain Program" as it is now commonly known was very successful at reducing the impacts of acidification from electricity, most industries – including agriculture – remain basically unregulated on the basis of acidification. In Europe, 80-90% of all ammonia releases (a powerful acidifying agent) were due to agriculture (EMEP/CORINAIR, 2002) and dairy farming in particular has been found to be the largest animal husbandry source of ammonia emissions (Asman, 1992).

Results related to acidification are quantified in units of moles of H+ equivalents, which is a measurement of the number of protons added to the environment. Since acidity is often defined by the number of free protons in solution (e.g. pH measures free protons in a solution on a concentration basis), moles of H+ eq give a good indication of the potential impact of releases on acidity. The impacts from all substances were converted into moles of H+ equivalents and reported on this basis throughout.

Eutrophication

Some ecosystems are very sensitive to changes in concentration of certain elemental nutrients in the environment. This is because certain elements that are crucial to life are only available in limited quantities based on the climatic or other biophysical characteristics of the particular ecosystem. Therefore, competition for limiting nutrients can be very strong among species in an ecosystem. Since organisms evolve to use limiting nutrients very efficiently due to this competition, nutrients are highly conserved and recycled. The total stock of limiting nutrients then tends to remain relatively stable and nutrients become available to organisms at a relatively constant rate for a particular ecosystem type over long time horizons (nutrient availability fluctuates considerably in the short-term under natural conditions.) Agricultural productivity is similarly limited by nutrients, so they are often imported into farm systems to ensure consistent yields. However, agricultural systems are not perfectly efficient; nutrient imports in fertilizers and feeds invariably make their way into natural systems through various pathways, a process called eutrophication. Since the nutrients that limit farm systems are often the same nutrients that limit the productivity of aquatic ecosystems (e.g. nitrogen and phosphorus), nutrient losses from farm systems can significantly impact ecosystems.

Suffocation due to oxygen depletion (hypoxia) is one such environmental end result due to eutrophication. In aquatic ecosystems, certain organisms like algae have evolved to utilize limiting nutrients very efficiently. Therefore, eutrophication can lead to their aggressive growth. These growth spikes lead to an increase in biomass, which is then decomposed within the ecosystem after the short-lived organisms die. While decomposers harvest energy from the dead biomass they respire aerobically, which has the end result of drawing down the concentration of oxygen below levels required for survival for many species. These anoxic areas are referred to as "dead zones" because many organisms that enter the areas simply cannot survive in such conditions and perish soon after. Agriculture has contributed to a large periodic dead zone in the Gulf of Mexico that, in 2002, was almost as large as the state of New Jersey (Nassauer et al., 2007.) Smaller freshwater water bodies are also affected by eutrophication, though the limiting nutrients are often different that in saltwater. In addition to hypoxia, eutrophication leads to other environmental end results that are not discussed in this report. This is because eutrophication is a mid-point impact, so its results are not reported in reference to any ultimate environmental fate.

Eutrophication results are expressed in terms of kg N equivalents in this report. This unit is used in the Tool for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), which provides US-specific weighting factors for environmental emissions (Bare, 2003; Norris, 2003.)

System Description and Scope

Eutrophication and acidification impacts from the life cycle inventory include emissions from all seven stages of the milk life cycle. In the Feed and Bedding Production stage, nutrients applied to fields to increase crop production may contribute to eutrophication and acidification impacts when they are not incorporated into plant tissues. At the Farm Operations stage, nutrients are released during manure management, grazing, and pasture management that also contribute to eutrophication and acidification. After the Farm Operations stage, there is little interaction between the nutrients embodied in milk, and therefore, nutrient releases are insignificant. However, other processes – such as electricity generation – result in environmental releases that are relevant to the acidification and eutrophication impact categories and are thus quantified in this report.

Methodology

Though the eutrophication and acidification impact categories quantify different types of impacts to the environment, most of the direct nutrient releases from the Farm Operations and other stages quantified in this report affect both AP and EP results. Due to this overlap, methodologies for quantifying nutrient flows relating to eutrophication and acidification are described together in this section along with the methods used to complete full nutrient mass balances within the Farm Operations stage. The nutrient emissions from farm systems quantified for the life cycle inventory (LCI) at the Farm Operations stage in this report were nitrous oxide (N_2O), ammonia (NH_3), nitrate (NO_3^-), and phosphate (PO_4^{3-}). Contributions to the LCI from the rest of the life cycle inventory included HCl, NO, sulfur oxides and dioxides, and other minor emissions. Nutrient flows that did not contribute to EP or AP were also quantified within the Farm Operations stage to complete mass balances (Figures 23- 24 and Tables 11-12.) Mass balances were used at the Farm Operations stage to confirm flows relevant to EP and AP, to provide a full nutrient pathway overview for the farm systems, and to quantify the environmental performance indicators in the improvement strategies section of this report.

Datasets and Impact Categories

Processes included in SimaPro databases were relied upon for various emissions related to acidification and eutrophication throughout the milk life cycle. Characterization and impact assessment of acidification and eutrophication impacts due to nutrient releases were quantified using "The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts" (TRACI) 2 v3.0 (Bare, 2003; Norris, 2003). Because the impacts of eutrophication and acidification vary regionally, the North America specific factors used in TRACI were most appropriate for this system. Eutrophication and acidification describe impacts in reference to a midpoint, which means that they are designed to estimate the potential for a certain type of environmental damage rather than estimate the extent of the damage itself. For example, the potential to enrich a freshwater ecosystem is seen as a midpoint, while the number of deaths of aquatic animals due to the enrichment is considered an endpoint. Though midpoints describe impacts in less tangible terms, they lead to more certain conclusions because they minimize forecasting and assumption (Bare, 2003). Eutrophication impacts are expressed as kg N equivalents; Acidification impacts are expressed as moles H+ equivalents per kilogram of emission.

Feed and Bedding Production stage

Emissions from organic feed and organic bedding production

All emissions from the production of crops for feed and bedding were from inventories included within SimaPro datasets. All datasets were consistent with Phase I of this project. U.S. conventional agriculture datasets were used for corn, soybeans and soybean meal while Swiss organic agriculture datasets were used for alfalfa hay, flax meal, corn silage, grass silage, wheat midds, and millet hulls. No datasets were available for organic production in the US for AOD feedstuffs. Refer to the Phase I report for a full description of feed production datasets (Heller et al., 2009).

Organic feed and organic bedding amounts and types

Feed amounts and types were obtained from AOD records of purchased organic feed by month by facility. AOD feed purchase records quantified both individual organic feeds, e.g. alfalfa, and mixed feeds that included many feed types. To break down mixed organic feeds into the individual feed components for grain premix and calf rations, purchase orders ("tickets") indicating feed composition from a grain supplier were used. An average organic feed composition was calculated from a one-year sample of purchase orders at the High Plains facility and used for grain premix and calf rations at all farms. Grain premix as purchased from the grain consolidator includes feeds like corn, barley, wheat, soy hulls, soy meal, and minerals in various ratios. The makeup of grain premix varies over time and was different for Phase I and Phase II of this project, which is reflected in the model.

Farm Operations Stage

A variety of methods quantifying individual N and P flows through the farm systems were combined to establish farm gate, soil surface, and herd utilization mass balances. An overview of the most important pathways for nutrient movement throughout the farm systems is illustrated in Figure 15.

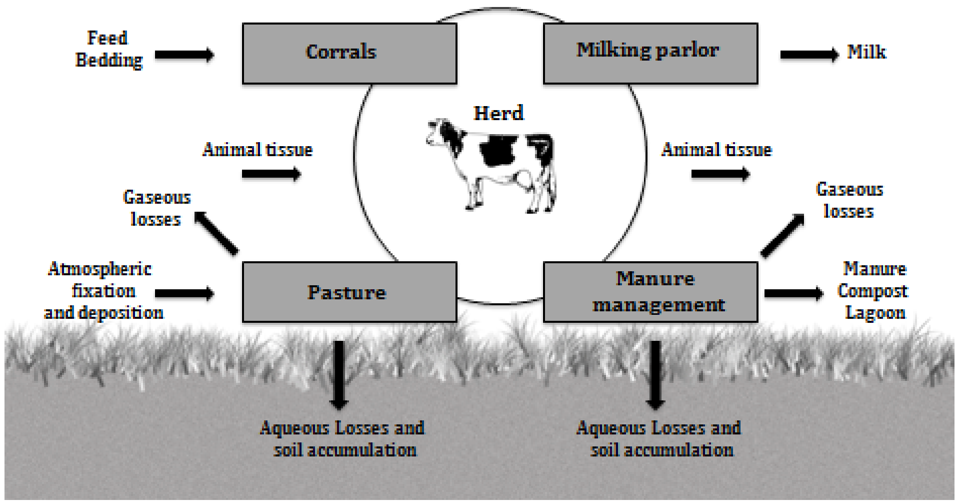

Figure 15. Overview of major nutrient pathways through AOD farm systems

Mass balances report elemental P or N mass while the LCI reports on the masses of released compounds. For instance, since N_20 contains both nitrogen and oxygen, one kilogram of N_20 contains about 0.64 kilograms of elemental nitrogen (kg N_20-N) and 0.36 kg of elemental oxygen (kg N_20-O). Mass balances always report elemental masses - as indicated by the "-N" and "-P" suffixes - while LCI emissions are reported using the masses of whole compounds (0.36 kg N_20-N compared to 1 kg N_20 in this example). Conversions between elemental masses and compound masses are reported in Table 8 below.

Table 8. Conversions between elemental mass and compound mass for select nutrient flows

Multiply elemental nutrient mass	By this conversion factor	To yield compound mass
N_20-N	1.57	N_20
N_2 -N	2	N_2
NH_3-N	1.21	NH_3
NO_3^--N	4.43	NO_3^-
PO_4^{3-}-P	3.06	PO_4^{3-}

Mass balance formulas and conventions

Quantifying farm flows required integrating a variety of available methodologies as appropriate for the AOD system. IPCC guidelines for GHG reporting were adhered to for N_2O to ensure consistent reporting with LCA greenhouse gas and energy impacts. IPCC methodology was also adapted to quantify nutrient releases other than greenhouse gases, such as ammonia. Colorado State University's "Best Management Practices for Manure Utilization" and the "Agricultural Waste Management Field Handbook" from the USDA were relied upon extensively for manure nutrient composition, manure management systems, and other factors (Waskom and Davis, 2008; USDA, 1992). General mass balance calculations, literature sources, and AOD data input sources can be found in Tables 9 and 10 and are described in more detail below.

Table 9. Methodology for quantifying nitrogen mass balance flows for all farm systems

Nitrogen Farm Gate Balance

Flow (I = input, O = output)	**Calculation formula**	**Source**
Herd I/O	# cows * N content/cow	AOD records; Dou et al., 1996
Purchased feed I	Feed mass * N content/feed	AOD records; NRCS, 2009
Bedding I	Bedding mass * N content/feed	AOD records; NRCS, 2009
Pasture forage seed I	Seed mass * N content/seed	AOD records; NRCS, 2009
Atmospheric N fixation I	Ha legume forage * N fixation/Ha	AOD records; Ledgard & Steele, 1992
Milk O	Milk mass * N content/mass	AOD records; Powell et al., 2008; confirmed with Barbano and Lynch, 1999
N_2 from manure management O	Sum over all cow populations and management systems (total gaseous N * fraction of N_2 in gaseous N)	Adapted from tables 10.32, 10.22 and 10.24 IPCC (2006)
N_2 from managed soils O	Total N to pasture * 10% Emission factor	Adapted from Brentrup, 2000; IPCC, 2006
N_2O total O	Direct N_2O from manure management + Indirect N_2O from manure management + Direct N_2O from managed soils + Indirect N_2O from manages soils	AOD records; IPCC, 2006; Heller et al., 2009
NH_3 from manure management O	Sum over all cow populations and management systems (total N volatilized as $NH_3$and NO_x - total N volatilized as N_2O from manure management)	AOD records; IPCC, 2006; confirmed with Pinder et al., 2004; assumed N_2O to total NO_x ratio of 1:3
NH_3 from pastures O	Sum over all cow populations and management systems (N deposited on pastures * 30% volatilization rate)	AOD records; IPCC, 2006; Davis, 2009
NO3- to pastures O/I	Sum over all cow populations and	AOD records; IPCC, 2006; Davis,

	management systems (total organic N applied to pastures * 30% mineralization rate * 100% denitrification factor)	2009; assumed denitrification rate
NO3- leached from pastures O	Total mineralized N to pasture (NH_4, NO_3^-) during growing season * emission factor (based on effective root zone, field capacity, and water exchange frequency	Brentrup, 2000; NRCS, 2009 (soil type); NOAA, 2009 (precipitation records)
Exported manure O	Farm gate inputs (feed N + bedding N +Herd N + seed N + atmospheric deposition N + fixation N) – farm gate outputs (milk N + gaseous loss N + herd N)	
Soil pool I/O (only I/O, not stock)	0	Assumed equal to zero based on AOD records - N application at agronomic rate of crop removal

Table 10. Methodology for quantifying phosphorus mass balance flows for all farm systems

Phosphorus Farm Gate Balance		
Flow (I = input, O = output)	**Calculation formula**	**Source**
Herd I/O; Purchased feed I; Bedding I; Pasture forage seed I; Milk O; Exported manure O	See Table XXX	See Table XXX
PO_4^{3-} leached from pastures	Water soluble P applied to pastures * leaching rate	Kleinmann, 2003; Sharkoff, 2008; IPCC, 2006
Exported manure O	Farm-gate inputs (feed P + bedding P +Herd P + seed P) – farm gate outputs (milk P + pasture applied P + herd P)	AOD records; NRCS, 2009
Soil pool I/O	Total P inputs to pasture – total P losses from pasture	Assumed to be a dynamic soil pool; consistent with deBoer, 2003 & Cederberg, 2000.

Nutrient inputs from purchased organic feed and organic bedding

Total amounts of feed by facility were multiplied by average percent N and P percentage values on a dry matter basis from the Crop Nutrient Tool from the USDA Natural Resources Conservation Service (NRCS, 2009) to yield total pounds N and P for all feeds. Protein and phosphorus content from similar commercially available products (Poulin Grain, 2010) were used for "bagged calf grain", "calf starter", and "calf rations with molasses" nutrients, and protein was converted to nitrogen based on Barbano and Lynch methodology (1999). Organic wheat straw, oat straw, and cottonburrs used for bedding were calculated from the same AOD data using the same methodology as feed nutrients. For a complete breakdown of feed and bedding nutrient contents, refer to Appendix B.

Nutrients from milk product output from farms

Raw milk shipped to the processing facility from each individual farm was considered the milk product for farm mass balances since it gives the most accurate view of N and P leaving the farm systems. Pounds of milk, butterfat percentage and protein percentage data were available in plant utilization summaries by farm by month. Amounts of N and P were calculated using Powell et al. methodology for N and P content per pound of milk (Powell et al., 2008). N percentages were checked against another methodology based on the protein content of milk and Kjeldhal nitrogen analysis as described in Barbano and Lynch (1999) and were found to be consistent between methodologies. Nutrients from AOD milk fed to AOD cattle on farms were quantified using the same techniques.

Changes to animal embodied nutrients

Movement of animals into and out of the herd from culls and cattle purchases was compiled from AOD dairy-to-date and heifer-to-date records by month and facility. Nutrient content of animals was calculated using methodology originally developed in the Cornell Net Carbohydrate and Protein System (CNCPS) as used in the Maryland Nutrient Balancer on a per pound and animal age class basis (Dou et al., 1996; Spears et al., 2003). Adult animals were assumed to be 1150 pounds per head at time of purchase and 1450 pounds per head as adult culls from the herd. These weights are consistent with energy and greenhouse gas emission methodology from Phase I of this report and are used for other nutrient flows relevant to the LCA based on an average 1,400 pound weight per lactating cow in the rolling herd. Calves culled from the herd were assumed to be 250 pounds. Animal weight assumptions were not based on actual AOD herd weight samples. Total weights of exported and imported animals were multiplied by percentage nutrient content (calves - 2.5% N, 0.72%P; mature animals - 2.9% N, 0.83% P) per age class and summed to find herd nutrient flux.

Nutrients flows from pasture seeding, N fixation, and atmospheric deposition

To find the nutrient content of forage seeds applied to pastures, organic certification records from AOD were used to find seed species, number of seedings per year, number of individual pastures, and acres per pasture for all farms. An AOD expert provided an application rate for major seed varieties and the total mass of seeds to the pastures was found by multiplying the application rate by the total acres seeded. During our study period ryegrass, triticale, wheat, clover, perennial grass mix, and millet were planted on pastures at rates determined by AOD experts. Nutrient content of the seeds was determined using the Crop Nutrient Tool (NRDC, 2010) in a manner consistent with feed and bedding nutrient content methodology.

Atmospheric deposition of nitrogen to the farm system was quantified by applying a deposition rate of 8 kg/ha-yr to the total number of pasture hectares at all AOD farms (Nadelhoffer et al., 1999.) Only pasture areas were assessed since they make up the vast majority of the total area of AOD operations.

Nitrogen fixation by leguminous pasture forages was calculated using fixation rates by crop based on the planted area of each type of legume forage (Ledgard & Steele, 1992). According to AOD records, just one species of leguminous crop was planted on pastures during our study period – clover (unspecified species) at the Dipple farm. Other leguminous crops such as clover and alfalfa were grown in areas of perennial pasture at several farms, but were not accounted for in this study. Therefore nitrogen fixation is underestimated in this study.

Accumulation of N in soils was assumed to be zero for all farm systems since nutrients were professionally applied to pastures at recommended agronomic rates based on pasture forage uptake estimates and soil tests that estimate N saturation. Since soil releases of nitrogen tend to be highly water soluble, releases are prone to leaching rather than accumulation. This is a long-term assumption because it may take pastures a few years to accumulate enough N for soil tests to indicate that soils are near N saturation. However, once soil pool N is near the N saturation threshold, it was assumed to stay relatively constant because AOD nutrient management plans do not allow for fertilization on fields where soils tests indicate N saturation and recommend fertilization when soil N is lower than pasture forage needs.

Nutrients flows from exported manure and compost

Nutrients in exported manures and compost was quantified by difference from farm gate balances for both nitrogen and phosphorus. All phosphate, nitrate, dinitrogen (N_2), and ammonia losses from the system were thus quantified using various methodologies before exported manure nutrients were calculated by difference.

N_2O releases from managed soils and manure management

Since N_2O is a potent greenhouse gas, tier 2 IPCC methodologies for greenhouse gas reporting based on AOD-specific manure management practices, feed characteristics, and cow populations were used, as reported in Phase I of this report (Heller et al., 2009; IPCC, 2006). Though all methodology has remained consistent between phases, one major correction was applied in this report that significantly increased N_2O emissions across all manure management systems. This error was due to the use of a daily rather than annual emission factor used to calculate excreted nitrogen from all cows that resulted in under-reported N_2O emissions by a factor 365. Updated greenhouse gas results for Phase I and two can be found in the results section of this report. Refer to the Phase I report of this project for specific methodological details for IPCC methodology N_20 releases (Heller et al., 2009). Specific N2O pathways calculations can be found in Figure 23 and Table 11.

Ammonia releases from manure management and pastures

Ammonia emissions from manure management were calculated by adapting IPCC methodology for N_2O as described in Phase I of this project. The IPCC methodology includes a factor for estimating the total N volatilized as NH_3 and NO_x from manure management and a separate factor that describes the portion of this volatilized N that is made up of N_2O. To adapt this methodology, the 1% N_2O emission factor from IPCC was used to find NO_x and NH_3 emission factors. It was assumed that the ratio of N_2O to total NO_x in volatilized N was 1:2, so that the emission factor for NO_x not including N_2O was 2%. Therefore, 97% of total volatilized N was in the form of NH_3, so an emission factor (EF_4) of 0.97 was substituted for an emission factor of 0.01 in IPCC methodology to yield NH_3 losses rather than N_20 losses. This formula is used across all animal populations and manure management systems to yield total ammonia emissions from all manure management systems on all farms per month.

Ammonia emissions from grazing animal manure to pastures was found by multiplying total N deposited to pasture from grazing animals by a 30% emission factor recommended by Jessica Davis (Davis, 2009). Total N to pasture from grazing animals was found by using nitrogen excretion rates (N_{ex}) described in the IPCC methodology (2006) and the nitrate releases section below for all animal populations on all farms.

Though there are many sources for ammonia emission factors for dairy production, adapted IPCC methodology was preferred because of the inclusion of dietary characteristics, population categories, and other AOD specific parameters. However, one extensive study has quantified ammonia emissions factors from dairy production to the county level for all CO pastures as seen in Figure 16 (Pinder et al., 2004). The Pinder et al. study has been recommended for use by others (Faulkner and Shaw, 2008) but was only used indirectly to confirm the adapted IPCC methodology. Over all farms total ammonia emissions from IPCC methodology were found to be only 4% larger than calculated by Pinder et al. methodology (2004).

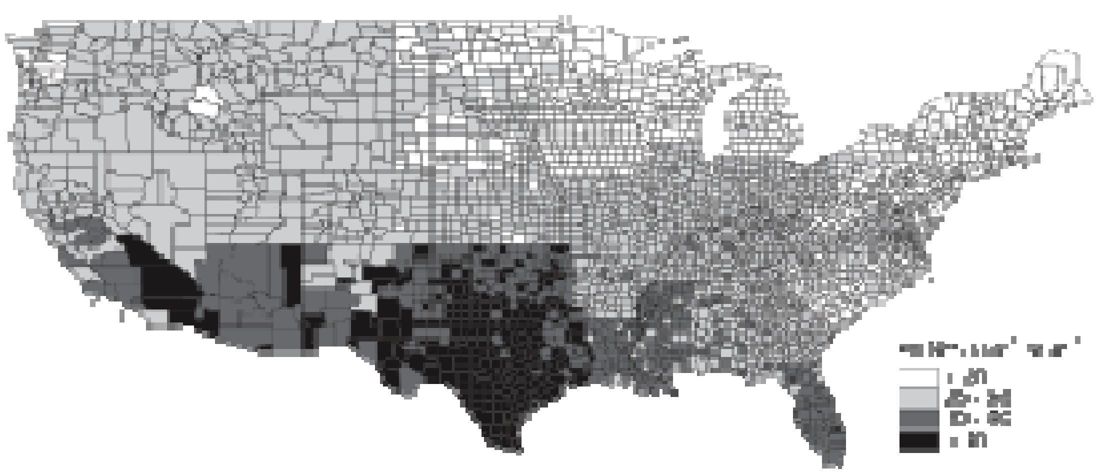

Figure 16. Regional NH_3 emission factors on a per cow basis by county from Pinder et al., 2004.

Nitrate releases from pastures

Final nitrate releases from pastures were calculated in accordance with Brentrup (2000) from the total amount of water-soluble N (NH_4-N and NO_3-N) added to pastures from three sources: N from grazing animals, N from manure spread, and N from lagoon irrigation water to pastures. Soil water drainage class, field capacity of pastures, effective root zone, annual precipitation, summer precipitation, and winter precipitation were then used to find exchange frequencies for pastures by farm (Brentrup, 2000). Soil water drainage class was found using National Resource Conservation Service aerial soil maps of pasture areas and drainages classes from Brentrup (2000). Platteville and Ray-Glo were assumed to have sandy loam (sL) pastures; Dipple and Coldwater assumed to have clayey loam (tL) pastures; High Plains was assumed to have loamy sand pastures (lS). Precipitation averages were obtained from the National Oceanic and Atmospheric Administration from 1971-2000 using Greely, CO for all CO farms, Amarillo, TX for Coldwater, and Dublin, TX for Dipple (NOAA, 2009). Pasture forage N uptake during the growing season was then subtracted from the total water-soluble N additions to pastures (as described below) to yield total water-soluble N available for leaching. Water-soluble N available for leaching was then multiplied by exchange frequencies calculated using the above variables to yield total nitrate leached per month during the period with active water drainage from pastures, assumed from March to November.

Water-soluble N from grazing animals was found by multiplying the total N excretion rates per cow per month by the proportion of cow manure per cow population that is deposited on pasture by month from IPCC methodology (2006) by the proportion of manure that is water-soluble based on Griffin (2005) methodology (71.7% organic N) to yield total organic and total water-soluble N to pasture for all animals per month. Organic-N mineralized into water-soluble forms was assumed to occur at a rate of 30% per year based on estimates from Jessica Davis and pasture management documents from AOD experts (Davis, 2009; AOD records). Mineralized organic-N and direct water soluble N combined are the total water soluble N to pastures from grazing animals.

Total N to pastures from manure spread was found by multiplying total tons of manure spread per farm by the total manure N content per ton of manure spread (1.2 kg/ton) from AOD records (AOD, 2009). N loss due to volatilization was assumed to be 30% based on AOD records (AOD, 2009). After volatilization losses were accounted for, total water-soluble N was calculated as described in the preceding paragraph for grazing animals, using a 38.5% water-soluble N to organic-N ratio. Total water soluble N from lagoon application to pastures was found using the same methodology as manure spread, but with a 0.00027 g/gallon N content, a 45% volatilization rate, and a 50% water-soluble N to organic-N ratio from AOD records and BMPMU (AOD records; Waskom and Davis, 1999).

Phosphate releases from pastures

Phosphate leaching from pastures was estimated by multiplying the total amount of P available for leaching on pastures by a leaching rate that was assumed based on phosphate leaching risk class indexes. Phosphate losses from soil erosion were not measured directly, but are a factor in P risk index calculations.

P to pastures from grazing animals was found using the same technique outlined in the nitrate leaching section above, but with a P manure content factor of 18.5 pounds P per 1,000 pounds of animal from BMPMU (Waskom and Davis, 1999). Methodology for P to pastures from lagoon water was also consistent with the nitrate techniques above, but with a 0.4 pounds P per 1,000 gallon P content from AOD records (2009). P from daily spread was found by multiplying the amount of daily spread by the percentage of P in daily spread manure, both found in AOD records (2009). The sum of these three sources was multiplied by the proportion of total P assumed to be water soluble (33%) based on Kleimann (2003) to yield total water soluble P available for leaching.

The Colorado Phosphorus Index Risk Assessment was used to classify CO pastures based on their potential to release P into the Environment (Sharkoff, 2008). Individual pastures were assessed based on runoff class, soil P tests, P application rate, P application rate, and best management practices, then aggregated to the farm level. Some parameters – such as the runoff class and the P application rate per pasture – were not known, so best estimates were made. TX farms had already been classified by risk class by third party nutrient management consultants, so the Sharkoff methodology was not used (2008). Very high, high, medium, and low risk pastures were assumed to leach water soluble-P available for leaching at rates of 100%, 80%, 50%, 30%, and 10% respectively. No literature could be found to corroborate this assumption. All farms were found to be in the medium risk class except for Coldwater, which was classified by a third party consultant as being at low risk.

Milk Processing and Management Through Consumer/End-of-Life Stages

All nutrient flows downstream of the Farm Operation stage were quantified using SimaPro datasets. All processes used are consistent processes used in Phase I of this project, and contain inventories that were examined to ensure the inclusion of EP and AP sensitive emissions. See Heller et al. (2009) for more specific modeling details regarding SimaPro datasets used.

Results and discussion

Life Cycle Acidification and Eutrophication Impacts

Acidification impacts

All farms. It was found that 4.62 moles of H+ equivalents are released over the full life-cycle of one gallon of packaged milk. As shown in Figure 17, the feed production and Farm Operations stages contributed most of the burdens, but there were significant contributions from other life cycle stages related to energy use. Results confirmed the expectation that stages involving agricultural production contributed most to the acidification impact of packaged milk since many nutrient transformations and releases occur in soil surfaces and manure management systems. Ammonia was responsible for most of the impact burden overall, and almost all ammonia release was due to the upstream feed production and Farm Operations stages. In downstream stages, nitrogen and sulfur oxides were important contributors from processes involving energy use and, especially, electricity generation. Although the Feed and Bedding Production stage had the highest overall acidification impacts, the modeled emissions from this stage are uncertain and likely overestimated due to the use of conventional agriculture production datasets.

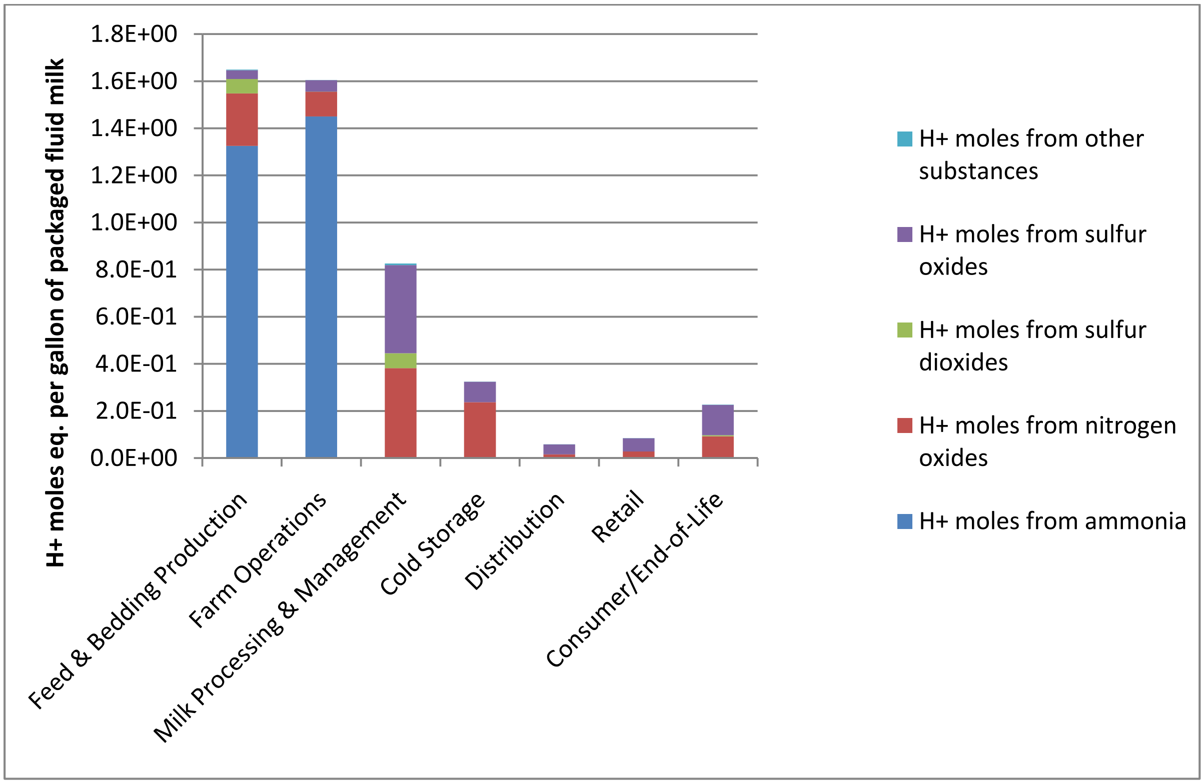

Figure 17. Acidification contributions from all stages of the life cycle on a one gallon of packaged fluid milk basis

When acidification impacts are disaggregated from life cycle stages into individual processes, contributions from managed soils, farm utilities and other processes can be seen. The eight largest process contributions to acidification over the entire life cycle are characterized in Figure 18.

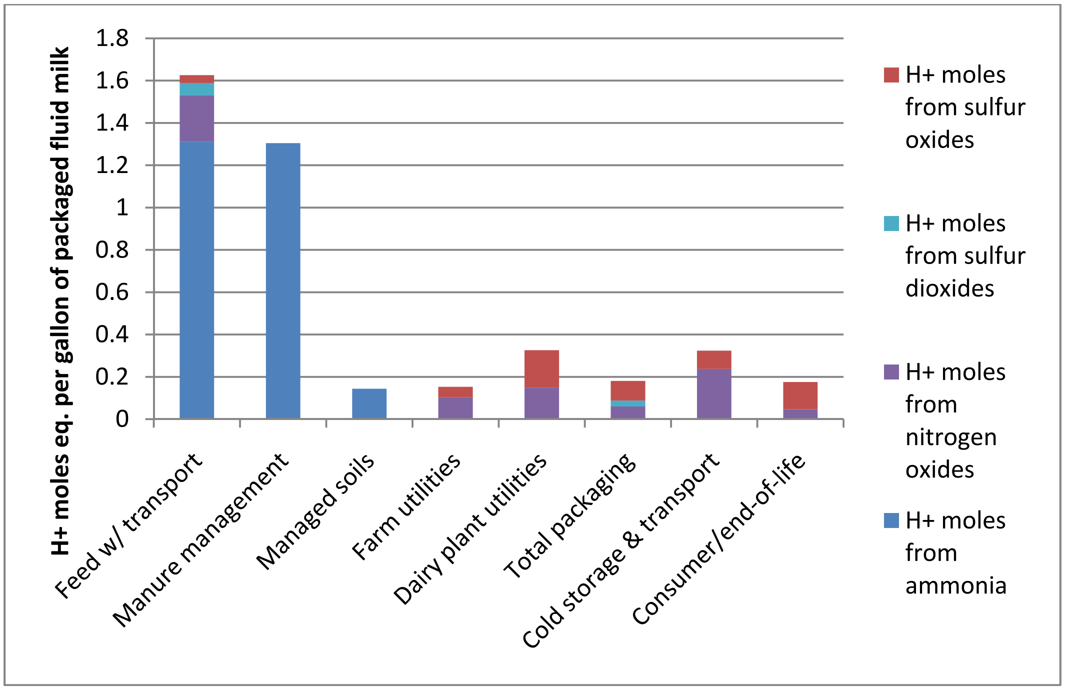

Figure 18. Acidification impacts from major contributing nutrient species across relevant processes in the life cycle on a one gallon of packaged fluid milk basis

Individual farm acidification results. There were significant differences between farms when acidification impacts were expressed per functional unit. Relatively lower farm performance could be attributed to low milk production, high emissions, or both. Figure 19 demonstrates the differences between in acidification impacts across different farms in terms of the functional unit. Gallons of raw milk production from each farm were used for these results.

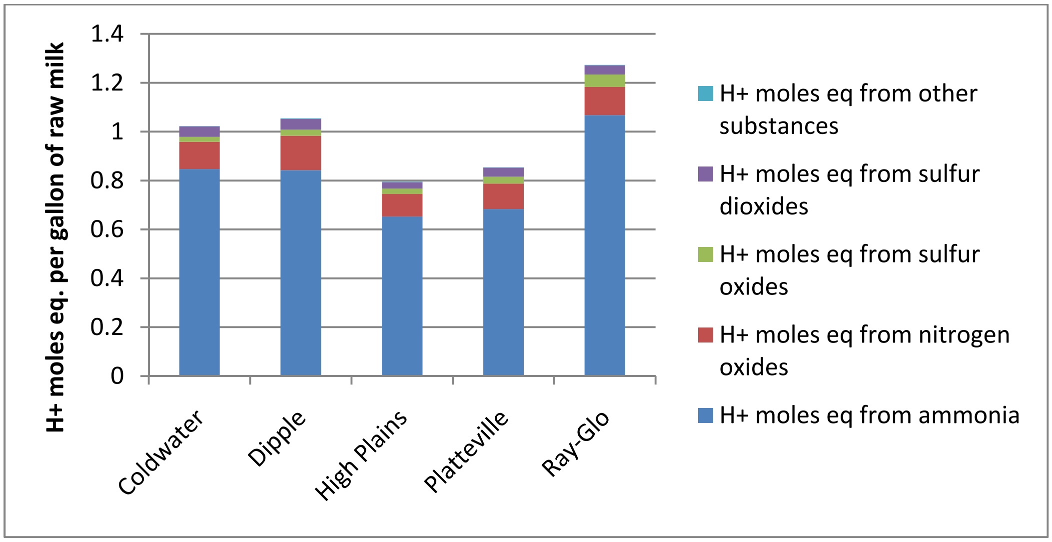

Figure 19. Acidification impacts by farm for major contributing species on a one gallon per raw milk basis

Ray-Glo contributes the most to acidification while High Plains and Platteville contribute the least. High Plains' low impact could partially be explained by its high milk production per cow, which is marginally higher than all other farms.

Eutrophication impacts

All farms. Over the entire life cycle 0.0025 kg N eq are released from the production of one gallon of packaged milk. Most impacts occurred in the upstream Feed and Bedding Production stage but the Farm Operations stages was also significant. All other downstream stages contributed very little to eutrophication, as indicated in Figures 20 and 21. Nitrate (NO_3^-) was the largest nutrient species contribution and was emitted mostly in the Feed and Bedding Production stage. Releases in this stage are uncertain and likely overstated because of the reliance on conventional agriculture production datasets that include inorganic fertilization of fields. By contrast, nitrate releases from organic production are largely the result of microbial decomposition of organic N into water soluble NH_4^+ and NO_3^- that are only leached in the presence of adequate soil water to carry nitrates away from the rooting zone of plants that readily absorb the nutrients. Manure fertilizers generally release about 30% of total nitrogen content as water-soluble forms of

N per year, while inorganic ammonium nitrogen fertilizer N is water-soluble at the time of application and can be quickly leached from farm systems. Due to low average annual rainfall in CO and TX - and the use of organic fertilizers at the recommended agronomic rate - AOD pastures released only 0.28% of the total nitrate release over the life cycle. Phosphates (16%) contributed about 2% more to EP than ammonia (14%), but most releases were in the Feed Production and Bedding Stage. By contrast, about half of ammonia was released at the Farm Operation stage where releases were much more certain.

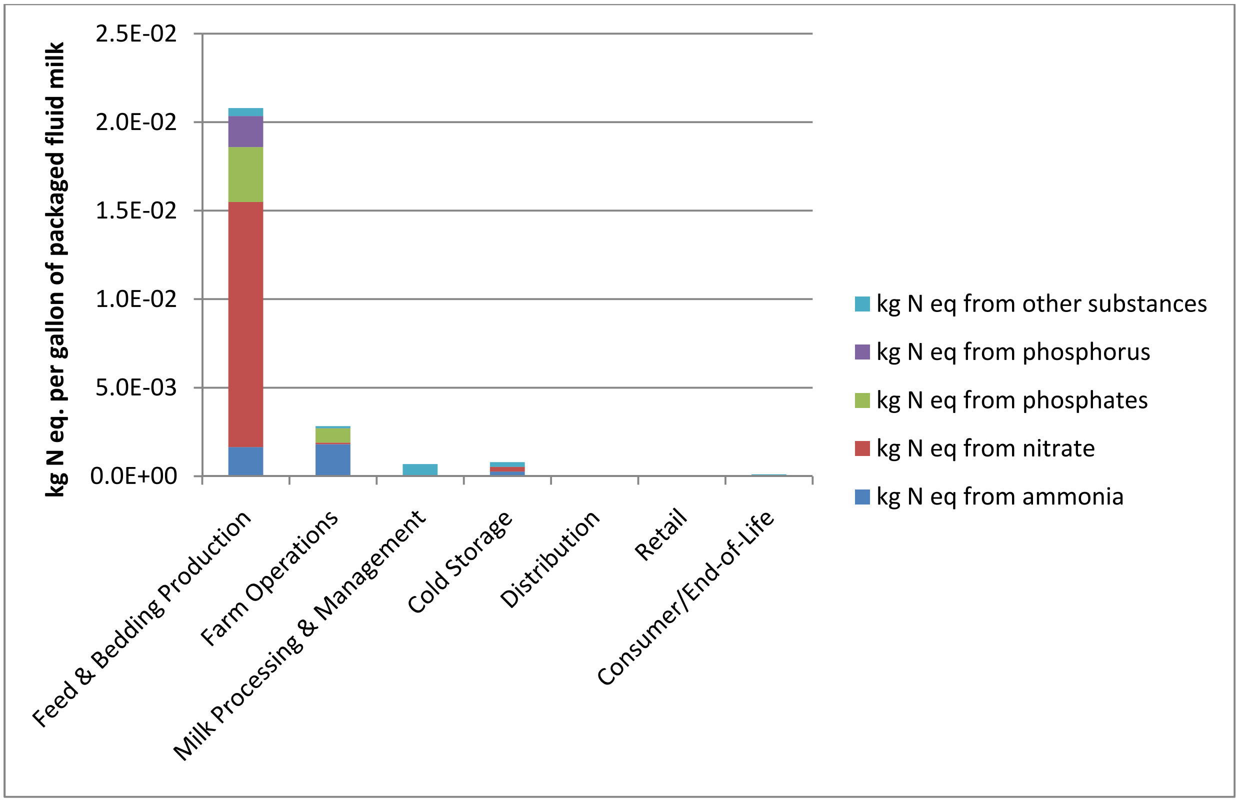

Figure 20. Eutrophication impacts from major contributing nutrient species across all stages of the life cycle on a one gallon of packaged fluid milk basis

Bedding was shown to contribute relatively little to eutrophication in the upstream and at the Farm Operations stage, while manure management had more impact than managed soils due solely to ammonia releases. Since organic fertilizer has a higher P:N ratio than plants require, P accumulates in soils and increases the likelihood of leaching in the water-soluble phosphate form. Though the datasets used for Feed and Bedding Production don't accurately describe organic agricultural production, the comparison between Feed Production and Managed soils do provide some insight into the impacts of conventional and organic production. Since N availability is often the limiting nutrient for plant growth, conventional producers often employ a high N:P ratio synthetic fertilizer in a water-soluble (and, therefore, plant available) form. By contrast, organic producers apply a lower N:P ratio organic fertilizer in a less water-soluble form that leads to P accumulation in soils. Due to these fertilization techniques, we would expect that organic production to lead to higher phosphate emissions and lower nitrate emissions compared to conventional production, which is what was found between the feed production and Managed soils at AOD. Pastures management and field crop production are not directly comparable, but the relative releases of EP relevant nutrients seem to be consistent with general nutrient management trends in conventional and organic agriculture.

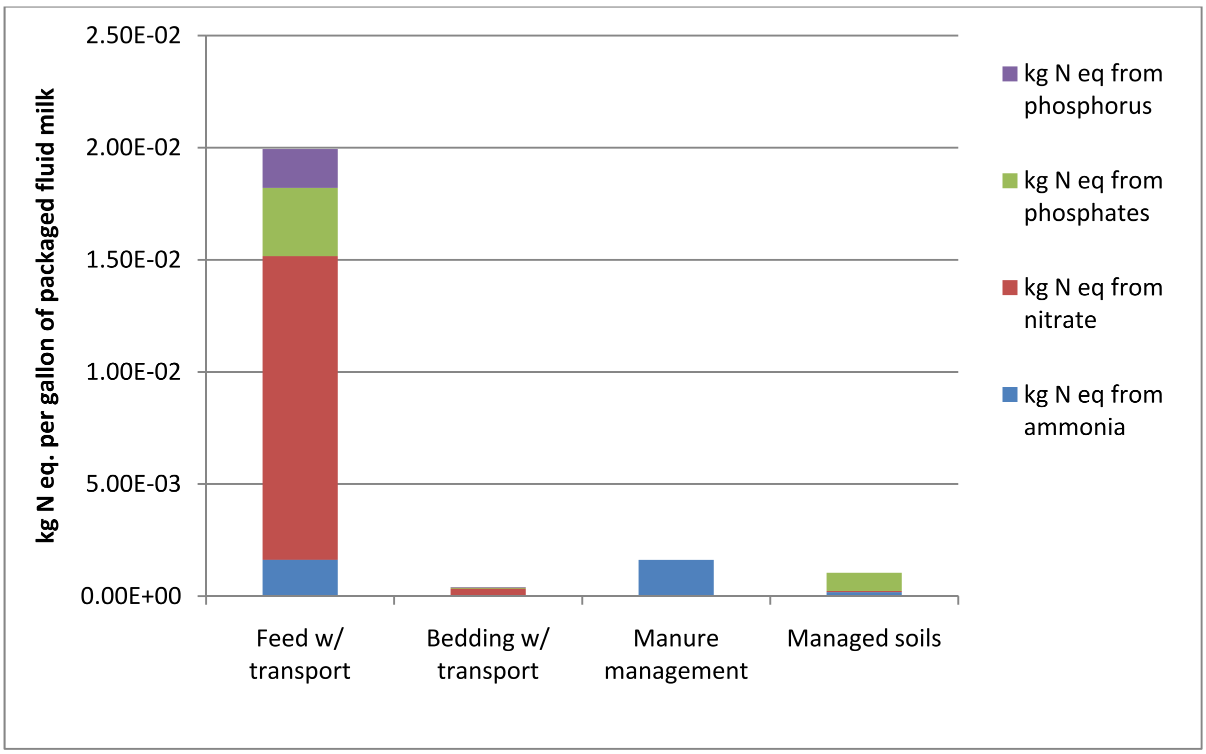

Figure 21. Eutrophication impacts from major contributing nutrient species from relevant processes within the life cycle on a one gallon of packaged fluid milk basis

Individual farm eutrophication results. There was slight variability between eutrophication from farms, mostly due to the phosphate emissions that are related to pasture management. Dipple had the most phosphate releases during the Phase II time period because more total phosphorus was applied to pastures at Dipple than for any other farm according to the pasture management data collected by the research. Nitrate was the largest contributor for each farm due to feed production. Ammonia impacts varied by farm in manner consistent with acificidification impacts, with Ray-Glo, Coldwater and Dipple emitting more per gallon of milk than the High Plains and Platteveille. Differences between emissions of phosphorus and other substances were negligable between farms. Results by farm are displayed in Figure 22. Note that while AOD kept comlpete records for lagoon irrigation water, compost, and manure application to pastures, the data set obtained by the research team may be incomplete. This was because data was gathered from various sources and not compiled by AOD staff. Therefore, these results are slightly uncertain.

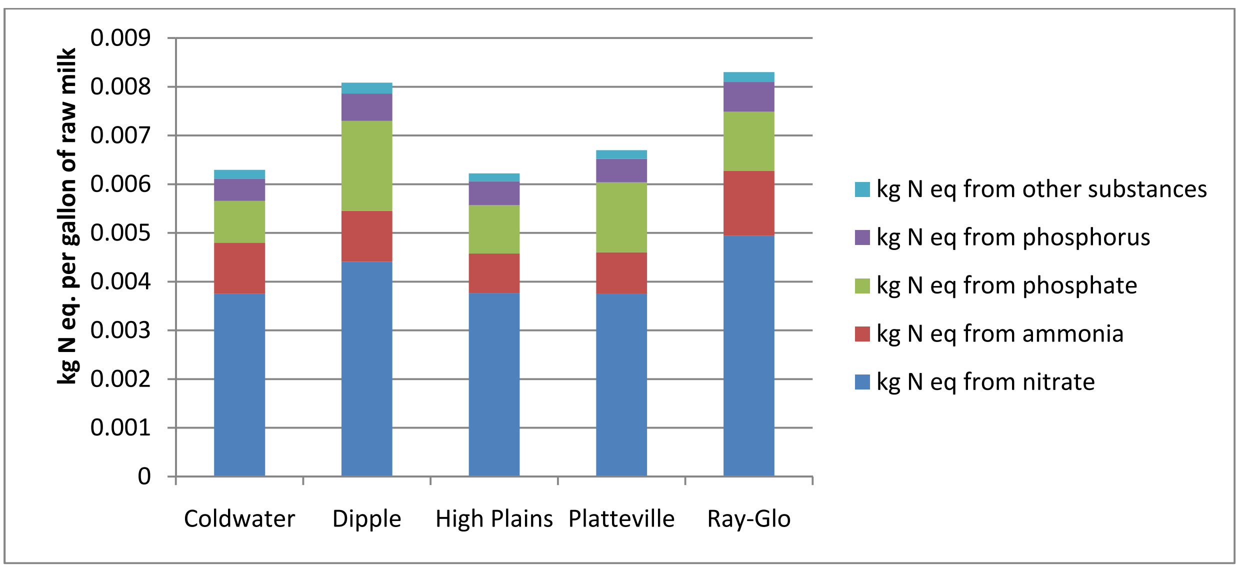

Figure 22. Eutrophication impacts by farm for major contributing species over the life cycle on a one gallon of raw milk basis

Feed and Bedding Production Stage

Acidification impacts

Ammonia, nitrogen oxides and sulfur dioxide were responsible for most impacts in the Feed and Bedding Production stage as seen in Figures 20 and 21. However, these impacts cannot be relied upon as an accurate assessment of AOD feed production burdens. This is because feed production datasets were based on U.S. conventional agricultural production, whereas suitable information on US production of organic feeds was unavailable. Therefore, these impacts better reflect the upstream impacts of conventional feed or bedding production and include the use of ammonium fertilizers that readily volatilize into ammonia and nitrogen oxides when applied to fields.

Eutrophication impacts

Though nitrate losses were the single largest contributor to eutrophication potential (57%) over the life cycle, releases were only significant in the Feed and Bedding Production stage. As discussed above, the emissions from this stage are uncertain and likely overestimated. Any effort to improve the availability of LCI data from organic feed producers would greatly improve the accuracy of this study.

Farm Operations Stage

As discussed in the methodology section, complete mass balances for N and P were completed at the Farm Operations stage and discussed here independently of acidification and eutrophication impacts.

Acidification impacts

Changes to on-farm management systems have the potential to significantly affect overall acidification potential since the Farm Operations stage impacts are relatively high and much more certain than Feed and Bedding Production stage impacts. All acidification impacts over the seven stages of the entire milk life cycle are reported in Figure 20. Almost all of the ammonia released in the Farm Operations stage was due to manure management as seen in Figure 21. Therefore, changes to manure management systems have the potential to significantly alter life cycle acidification impacts.

Eutrophication impacts

For managed soils, phosphates contributed most to eutrophication, which is consistent with AOD pasture management practices that routinely apply P to pastures at a rate higher than the estimated pasture forage P uptake. This is because organic fertilizer that contains a higher P:N ratio of nutrients than plants require is applied at the recommended agronomic rate for N forage crop uptake rather than P. Ultimately this results in accumulation of soil pool P, which may be available for leaching. Though only a small fraction of total P in soils is leached (3-9% in this study based on Kleinmann (2003) and the Colorado Phosphorus Index Risk Assessment version 4 (Sharkoff, 2008), there is usually soil pool P available, unlike N. Among fertilization techniques used on AOD farms, the P:N ratio was lowest in lagoon water, highest in manure spread, and intermediate for lagoon solids. Therefore, switching from manure spread fertilization to lagoon water irrigation (at Dipple) could decrease the amount of phosphates released.

Nitrogen farm gate balance

The whole farm nitrogen budget including various important internal nutrient flows is shown in Table 11 and Figure 23 below. Complete mass balances for the soil surfaces (pasture), herd utilization and whole farm can be found in Appendices C, D and E.

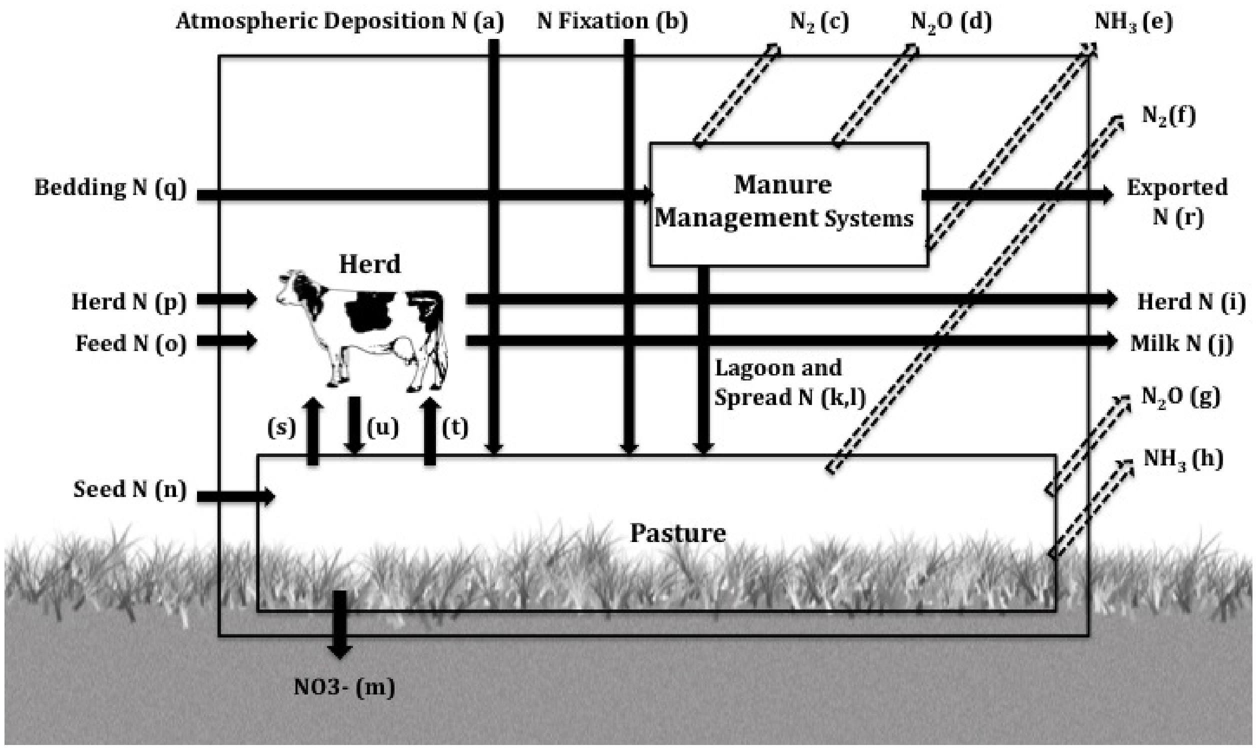

Figure 23. Overview of nitrogen flows through the farm system, herd, and pasture indicating major pathways as quantified in Table 11

Table 11. Farm system mass balance nitrogen flows expressed by mass of nitrogen as illustrated in Figure 23. Inputs and outputs may not balance due to rounding

Nitrogen flow	Label	Input/Output	Chemical species	Kg N, all farms
Atmospheric deposition to pastures	a	Input	Various N species	12,100
Fixation from leguminous pasture forages	b	Input	N_2 converted to Organic-N	17,200
N_2 emissions due to denitrification in manure management systems	c	Output	N_2-N	218,000
N_2O emissions due to denitrification in manure management systems	d	Output	N_2O-N	58,660
NH_3 emissions due to nitrification/volatilization in manure management systems	e	Output	NH_3-N	408,000
N_2 emissions from managed soils	f	Output	N_2-N	20,000
N_2O emissions from managed soils	g	Output	N_2O-N	9,360
NH_3 emissions due to nitrification/volatilization	h	Output	NH_3-N	47,100

in managed soils				
Herd animal tissue	i	Output	Organic-N	143,000
Milk nutrient	j	Output	Organic-N	484,00
Lagoon irrigation to pastures	k	Internal farm flow	Various N species	19,100
Manure spread to pastures	l	Internal farm flow	Various N species	39,400
Nitrate leached to groundwater from pastures	m	Output	NO_3^--N	1,970
Pasture seed nutrients	n	Input	Organic-N	6,520
Feed nutrient content	o	Input	Organic-N	2,360,000
Herd animal tissue	p	Input	Organic-N	33,300
Bedding nutrient content	q	Input	Organic-N	19,100
Exported manure nutrient	r	Output	Various N species	1,040,000
Pasture forage to herd	s	Internal farm flow	Organic-N	207,000
Unaccounted feed nutrient	t	?	Organic-N	253,000
Manure and urine to pasture from grazing animals	u	Internal farm flow	Various N species	191,000

Phosphorus farm gate balance

The whole farm phosphorus budget including various important internal nutrient flows are shown in Table 12 and Figure 24 below. Complete mass balances for the soil surfaces (pasture), herd utilization and whole farm can be found in Appendices F, G and H.

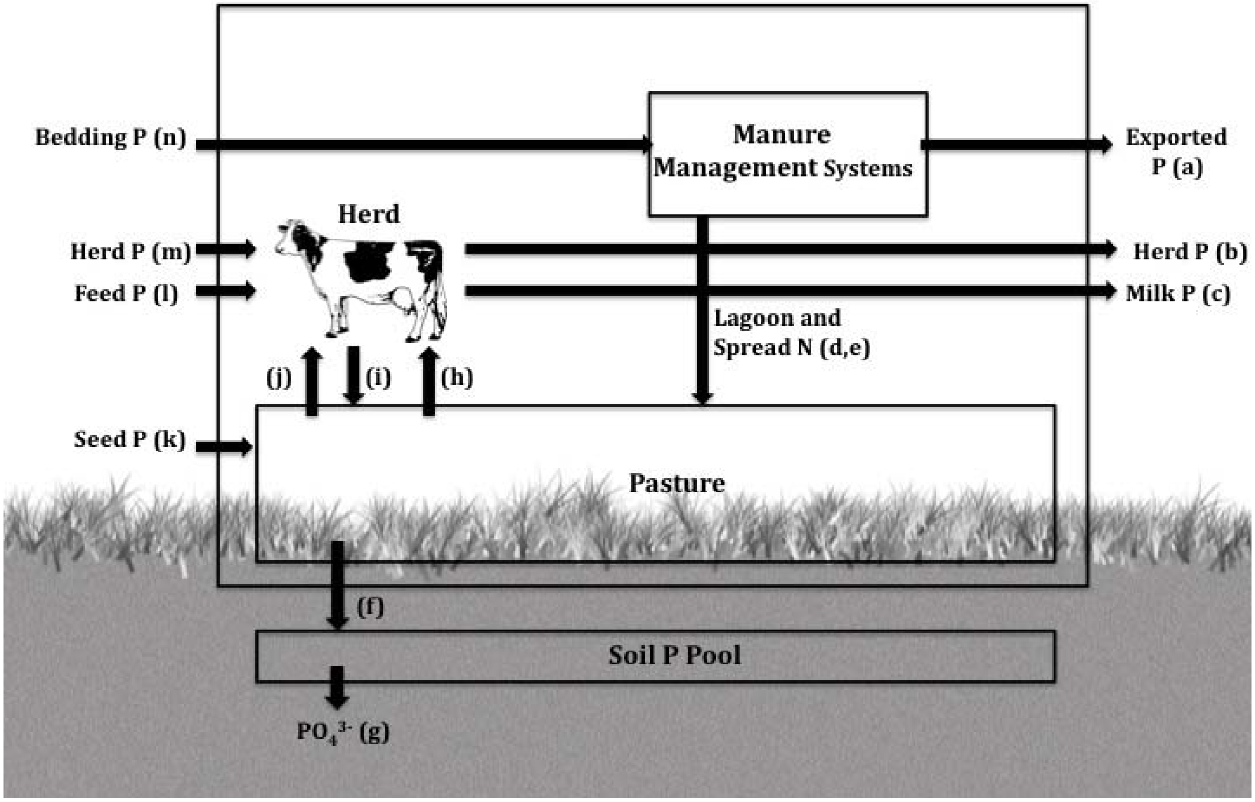

Figure 24. Overview of phosphorus flows through the farm system, herd, and pasture indicating major pathways as quantified in Table 12

Table 12. Farm system mass balance nitrogen flows expressed by mass of nitrogen as illustrated in Figure 24

Phosphorus flow	Label	Input/Output	Chemical species	Kg P, all farms
Exported manures	a	Output	Various P species	242,000
Herd animal tissue	b	Output	Organic-P	41,100
Milk nutrients	c	Output	Organic-P	89,000
Lagoon irrigation to pastures	d	Internal farm flow	Primarily PO_4^{3-}-P and Organic-P	5,560
Manure spread to pastures	e	Internal farm flow	Various P species	23,100
Additions to soil pool	f	Internal farm flow	Various P species	18,400
Phosphate losses from soil pool	g	Output	PO_4^{3-}-P	4,130
Pasture forage to herd	h	Internal farm flow	Organic-P	25,100
Manure and urine to pasture from grazing animals	i	Internal farm flow	Various P species	17,900
Unaccounted for pasture forage inputs	j	Internal farm flow	Various P species	0
Pasture seed nutrients	k	Input	Organic-P	1,070
Feed nutrient content	l	Input	Organic-P	363,000

Herd animal tissue	m	Input	Organic-P	9,590
Bedding nutrient content	n	Input	Organic-P	2,260

Interpretation of mass balances

Since a significant proportion of life cycle acidification and eutrophication impacts were found to occur within AOD farms, a thorough understanding of nutrient cycling within the farm system is necessary to assess the impacts of operational changes. The mass balances provided within this section serve the purpose of putting all nutrient flows into context on the basis of the same unit (kg elemental mass of P or N) so that the relative contributions from each flow are known. For instance, to reduce acidification impacts over the life cycle, mangers can refer to the N farm gate balance to quickly find where the highest releases of NH_3 - a powerful contributor to acidification potential - are born and NH_3's relative abundance compared to other gaseous N releases (in this case there is about a ten-fold higher release of NH_3 from manure management than from managed soils as seen in Figure 23 and Table 11). Used in this way, mass balances provide an important compliment to LCA – farm mass balances inform mechanisms of nutrient releases in the farm systems and LCA impact results provide a comprehensive assessment of the effects of emissions after their release. Mass balances can also be used to interpret possible trade-offs from management decisions by providing a full context for comparison of nutrient flows through the system. For instance, Figure 24 and Table 12 demonstrate that much more P was applied to pastures through daily spread than lagoon water irrigation, even though Dipple was the only farm that consistently spread manures to pastures during the study. Therefore, a management change to divert spread manure to the lagoon management systems at Dipple would significantly reduce P flows to soils even though Dipple already treats most manure in lagoon-based systems. Additionally, mass balances form a basis for comparison between other systems since mass balances are a common environmental assessment methodology. Flows from the mass balances will also be used in the environmental performance indicators section of the improvement strategies section of this report.

Milk Processing and Management Through Consumer/End-of-Life

Acidification potential

There were significant AP impacts in the stages downstream from the Farm Operations, but these impacts are of little concern in this product system because the magnitude of the impacts per process are small and these stages are less directly influenced by AOD operational changes. Additionally, no on-site data collection was available for downstream stages so more of the impacts results are based on modeling assumptions – such as the average distance consumers drive to pick up milk – which increases uncertainty. About 33% of total acidification impacts occurred after the farm operation stage, most of which was due to sulfur and nitrogen oxide emissions. Since these emissions are highly related to energy use, AOD could potentially reduce these impacts by working with more efficient or renewably powered distributers and retailers. Decreasing the energy use at the AOD processing plant and farm utilities or reducing the energy intensity of packing materials could also help to reduce AP. Though reductions in energy use may be difficult to achieve due to health and safety regulations and other operational requirements, reduced energy use would likely result in lower acidification, greenhouse gas emissions, water use and waste generation throughout the life cycle.

Eutrophication

Only 4.5% of total life cycle eutrophication was from stages downstream of Farm Operations. 47% of this downstream impact occurred in the Milk Processing and Management stage, which was dominated by impacts from dairy plant utilities and packaging. Overall, the impacts of these stages were found to be negligible, so efforts to decrease life cycle EP should not focus on these stages at this time. EP impacts were highly correlated with agricultural production rather than the processing side of the industrial supply chain.

Water Use

Before describing this study's approach to quantifying water use, it is important to clarify the definitions of a few key terms: "water use," "water consumption" and "water utilization."

Definitions

Water Use: The total water inputs to an industrial system; in the case of an AOD farm, water use equals the total amount of water withdrawn from the natural hydrological cycle and brought to the farm by artificial means (including municipal water, irrigation water, collected rainwater and well water); this does not include natural precipitation on fields.

Water Consumption: Beginning from the perspective of a specific watershed, consumption is the total amount of water removed from the watershed and not immediately available for other users in the watershed (Koehler, 2008). Water consumption consists of three components: water lost to the atmosphere through evaporation, water transferred to a different watershed, or water incorporated into the company's product (in this case, milk). For example, at the AOD processing plant, "consumption" equals the water lost through evaporation and the water contained in the milk that leaves the plant. An example of "water transferred to a different watershed" would be water that is taken in by a power plant from one river system and returned to a different river system after use.

Water Utilization: Water which is used in a system but is then returned to the same watershed and is available for other users (Koehler, 2008); e.g. at the AOD processing plant, "utilization" is the water which is used in the plant but then treated and returned to the local sanitation district for other users.

"Water use" can be thought of as the amount of water entering a system, while "consumption" and "utilization" are the two different ways that water can leave a system; in other words, "water use" is the total input, and "consumption" and "utilization" added together are the total output. A visual representation of this relationship is depicted in Figure 25; in equation form, this can be written as:

(Water Use) = (Consumption) + (Utilization)

Figure 25. Visual representation of water definitions, using the AOD processing plant as an example

Quantifying Water Use

The most basic, and most common, way to quantify a company's demand for water is to measure "water use" as defined above, i.e. the water inputs to the company's operations. For example, the U.S. Geological Survey takes a national survey of demand for water every five years, and focuses solely on "water use," defined as water inputs to human systems (Kenny et al., 2009). "Water use" is also the indicator selected by the Global Reporting Initiative in its most recent G3 guidelines for corporate sustainability reporting (GRI, 2006). However, this level of analysis can do little to help a business understand where and how it can lessen the impact of its use of freshwater. (Saltwater is not used at any of AOD's operations or its major suppliers, and so only freshwater is considered in this study.) The gross amount of water that a company takes in as an input to production matters less than the fate of that water once it leaves the company's system.

"Consumption" of water decreases the amount of water that is available for natural ecosystems and for other human users, while "utilization" does not diminish availability for others and is therefore much less of a concern. Thus, it was decided that "consumption" and "utilization" would both be measures within the Water Use category. When evaluating strategies for environmental improvement, a company such as AOD will be able to make use of the greater detail these indicators provide (as compared with a simple "water use" indicator) by focusing primarily on reducing "consumption" where possible and secondarily on "utilization," which entails fewer impacts. As described above, the fact that AOD operates in dry regions means that its "consumption" has a larger relative impact than another dairy company operating in a wetter region where water scarcity and competition over water resources may not be as significant.

System Description

The water use indicator includes all seven stages of the milk life cycle, excluding any water use within consumer households. It includes water use for organic feed and organic bedding production, on AOD farms, at the AOD processing plant, at the AOD corporate office, as well as for the generation of electricity used in AOD operations, and for the production of fossil-based fuels (gasoline, diesel, natural gas and propane) used in AOD operations. Finally, the indicator includes water use associated with electricity for refrigeration throughout the distribution chain, and associated with fuel used to transport AOD milk from farm gate to final consumer.

In the first of the seven life cycle stages, large amounts of water are used in the irrigation of organic crops that become AOD feed and bedding. Depending on the timing of irrigation, most or all of this water is consumed by the organic crops through the simultaneous processes of evaporation and transpiration, together called “evapotranspiration.”

Within the scope of AOD operations, the large majority of water use takes place on AOD farms. Water comes to each farm in four possible ways (though only one farm obtains water in all four ways): as municipal water purchased from a local water utility, as irrigation water purchased from a “ditch” company, as free rainwater collected from the roofs of buildings, or as on-site well water from groundwater sources. In general, the Colorado farms use both municipal water and “ditchwater,” while the Texas farms use mostly well water. Once it is brought to the farm, water is used for the following purposes: maintaining proper sanitation in the milking parlor, washing vehicles and equipment, domestic use (i.e. restrooms and kitchens for farm employees), cow water intake, and irrigation of pastures. On each farm, all water used in the milking parlor flows to a lagoon, and this “dirty” lagoon water is then used for irrigation in combination with “clean” irrigation water—which comes from either a ditch company or a well. Water then leaves the farm system through evaporation from the lagoon surface, evapotranspiration from pastures, losses due to cow bodily functions, and also within the raw milk itself.

Raw milk is transported to the AOD processing plant, where it is converted into finished milk; this conversion includes pasteurization and subsequent cooling of the milk, and this cooling process results in some evaporation from the plant. However, the majority of water used in the processing plant is not evaporated and is pretreated in an aerobic wastewater treatment facility, before being returned to the local sanitation district. AOD is legally obligated to return this water to the sanitation district, because other users have rights to it after AOD is finished with it. AOD’s corporate office uses a small amount of water, and then returns it to the municipal supply from which it came.

Water is also used in large quantities to generate electricity for AOD operations, either at thermoelectric power plants or at hydroelectric power plants. In thermoelectric plants, water is withdrawn from the local watershed for cooling purposes, as well as for a number of other miscellaneous purposes. At hydroelectric plants, water is not withdrawn from its natural watershed, but a greater portion is evaporated due to the large surface area of reservoirs behind dams (Torcellini et al., 2003). In addition, water is used in significant amounts to produce fossil-based fuels, from the extraction stage through the refinement stage, although more water is used in extraction than refinement (Wu et al., 2009).

In the latter four stages of the life cycle, electricity is used for refrigeration purposes throughout the distribution chain. Milk leaving AOD's processing plant is shipped to a centralized cold storage facility in Colorado, and from there to regional distribution centers around the country. It is then shipped from each distribution center to multiple retail stores, and from there consumers bring it home and store it in their refrigerators. Electricity use for refrigeration is accounted for at each step in this process, along with the associated water use. Likewise, transportation fuel used in each of these steps in the distribution chain is accounted for, along with the associated water use.

Methodology

Data-Gathering

Assessment of the life-cycle water use of AOD's operations began with primary data-gathering during site visits to all of the AOD farms in Colorado and Texas, the processing plant in Colorado, and the corporate office in Colorado. In many cases, the company provided written records such as bills for water purchases and internal datasheets. Where specific records of water use were not appropriate for the study context, AOD experts were consulted and estimates were made based on their knowledge of company operations. Where the desired information was not known by AOD employees, articles in the literature were used. Data were gathered on a monthly basis (results are reported on an annual basis, because variation between months is small for most data categories).

The team also toured the operations of the Northern Colorado Water Conservancy District, which is the independent agency that ultimately supplies irrigation and municipal water to all of AOD's Colorado farms and the processing plant. This provided a more detailed understanding of the complicated system by which precipitation in the Rocky Mountains is collected and transported to the agricultural lands and cities of Colorado's Front Range.

The life cycle inventory for water use is divided into seven portions, which match the seven main stages of the milk life cycle: Feed and Bedding Production, Farm Operations, Milk Processing and Management, Cold Storage, Distribution, Retail, and Consumer/End-of-Life. Within each of these seven stages, the life cycle inventory includes upstream water use associated with the generation of electricity, and the production of fossil-based fuels, used in that stage. Though there is upstream water use associated with the production of nearly every item that AOD purchases or uses, it was assumed that in most cases this quantity would be negligible relative to direct water use inputs in farming and milk processing. Therefore, efforts were focused on quantifying the upstream water use for electricity and fossil-based fuels. The next two sections describe how the water use associated with electricity and fuels was calculated, and the subsequent four sections detail how water use was quantified in each of the seven life-cycle stages.

Electricity

Studies of water use for electricity generation tend to be inconsistent in how they report water use and in their terminology. Some studies focus only on water inputs to power plants, some studies focus only water consumption in power plants, and some studies include both utilization and consumption. Moreover, most of these studies do not account for full life-cycle water use, i.e. they do not include upstream water use for coal or uranium mining and processing, natural gas extraction and refinement, etc. Available life-cycle data was not considered reliable, so it was decided that a non-life-cycle study would be used, with the caution that the resulting water use numbers would be low estimates, since they only account for water use at the power plant itself. However, studies indicate (U.S. DOE, 2006) that the majority of water use for electricity generation occurs at the power plant, rather than in upstream processes.

Every five years, the U.S. Geological Survey (USGS) performs a nationwide survey of all water use, including water use in thermoelectric power plants; the most recent report provides data for the year 2005 (Kenny et al., 2009). Thermoelectric plants account for virtually all water withdrawals in the electricity system, and they result in both "utilization" and "consumption" of water; conventional hydroelectric facilities do not withdraw water from its natural stream and, thus, do not contribute to "utilization," but they do create "consumption" by increasing evaporation above what it would be in a natural stream. The USGS 2005 survey estimates only water inputs to power plants, and does not monitor outputs, so a study from the National Renewable Energy Laboratory (Torcellini et al., 2003) was used to estimate consumption in both thermoelectric and hydroelectric plants. In thermoelectric plants, "utilization" was found by subtracting "consumption" from total water inputs; in hydroelectric plants, "utilization" was assumed to be zero.

In order to determine the proportion of each generation type in the electricity grid, data were collected from the U.S. Energy Information Administration (U.S. EIA, 2009) on the "grid mix" in Colorado, Texas and Oklahoma for the most recent year available—2007. The Colorado grid mix was used for the three Colorado farms, and the Texas grid mix was used for Dipple. The Oklahoma grid mix was used for Coldwater, because the farm is located in a region in which the grid is interconnected with Oklahoma rather than the rest of Texas. A weighted value for consumption and utilization per kilowatt-hour were calculated for each grid mix. The kilowatt-hours used were then multiplied by the corresponding value, in order to compute the total water consumption and utilization associated with electricity use throughout the milk life cycle. These numbers were then corrected to account for losses in the electricity transmission and distribution system, which are estimated at 7% of gross electricity generation (U.S. EIA, 2009).

Fossil-based Fuels

There is water consumption and utilization associated with the production of fossil-based fuels, but because these fuels represent a small contribution to total water use within the milk life cycle, it was decided that only the water consumption associated with their production would be estimated. A recent study (Wu et al., 2009) estimated that approximately 4.27 gallons of water are consumed for every gallon of gasoline produced, and this number was used to quantify total water consumption associated with gasoline used in AOD's operations. It was assumed that water consumption for diesel fuel production is roughly equivalent to that for gasoline, thus the same number was used—4.27 gallons of water consumed for each gallon of diesel produced. The production of natural gas is far less water-intensive, consuming only 3.0×10^{-6} gallons of water per BTU of natural gas (Younos et al., 2009). Propane fuel is produced as a byproduct of natural gas refining and petroleum refining, with approximately equal amounts of propane originating from each source. Water consumption associated with propane production was calculated as the mathematical mean of water consumption for gasoline/diesel production and water consumption for natural gas production, or approximately 1.83 gallons of water consumed per gallon of propane produced. The amount of each fuel used was multiplied by the water intensity of that fuel in order to find the total water consumption associated with the use of each fuel type in each stage of the milk life cycle.

Feed and Bedding Production

In order to calculate the water use associated with the production of organic feed and organic bedding at AOD's farms, software from the United Nations Food and Agriculture Organization (FAO) was utilized—specifically, the CROPWAT 8.0 and CLIMWAT 2.0 programs—to determine water needs for various types of crops. The CROPWAT 8.0 computer program requires climatic data in order to calculate evapotranspiration for specific crop types that are stored in its database. Crop evapotranspiration consists of transpiration of water from plant tissues plus evaporation from the soil and plant surfaces, which occur simultaneously as crops grow. The evapotranspiration value indicates the total water a crop needs in order to grow, and this water need can be met by rainfall and/or irrigation. Therefore, crop evapotranspiration (as calculated by CROPWAT 8.0) minus effective rainfall yields the amount of irrigation water necessary to maintain the crop without any water stress. Because irrigation is a human-induced water input to the system, it is considered water use, and the amount of irrigation water, which is then evapotranspired by the crop, is considered water consumption. CROPWAT provides evapotranspiration in "mm per growing season," which is a volume of water measured by the depth of water in millimeters over the whole area in which the crop is grown (FAO, 1986).

Crop evapotranspiration varies greatly depending on climate. CROPWAT requires the input of climatic data on minimum and maximum temperatures, morning humidity, afternoon humidity, windspeed in km/day, solar radiation, and precipitation in order to determine the evapotranspiration for a particular crop in a specific location. These climatic data were imported to CROPWAT 8.0 from CLIMWAT 2.0, which contains the data reported by weather stations located throughout the United States. CROPWAT also contains datasets on particular crops that include crop characteristics, such as length of growth stages, crop factors (coefficients that compare crop evapotranspiration to a standard reference crop evapotranspiration), rooting depth, allowable depletion levels, and yield response factors (FAO, 2009). CROPWAT calculates crop irrigation requirement per growing season by using the corresponding climate and crop datasets for a particular crop in a particular location. It also requires the entry of the corresponding planting date for a particular crop in a particular location. This data was found on a state-by-state basis from the USDA dataset from the document "Usual Planting and Harvesting Dates for U.S. Field Crops" (USDA, 1997).

Once all of this information is put into CROPWAT 8.0, the program calculates the crop irrigation requirements per growing season in mm per hectare by subtracting effective rainfall from the evapotranspiration for the respective crop. Effective rainfall is the amount of total rainfall that is efficient. This number decreases with increasing rainfall. CROPWAT calculates this number through a standard method created by the USDA Soil Conservation Service (FAO, 2009). The irrigation needs in mm/hectare were converted into m^3 per hectare.

Since irrigation requirements are based on evapotranspiration, and evapotranspiration is classified as water consumption in this study, irrigation requirements for each crop in each location were assumed to be entirely "consumption." More specific information on irrigation techniques of Aurora's feed growers was unavailable and, therefore, irrigation efficiency was unknown. However, any over-irrigation by any of the feed suppliers would not be considered consumption—it would instead be classified as water utilization.

AOD purchases organic feed and organic bedding from multiple organic suppliers located throughout the Rocky Mountain and Great Plains regions of the U.S. Feed growers and consolidators were not contacted directly; this study uses the feed growing location information obtained by Phase I. For some of the feed types, the locations of feed growers were known. In this case, crop irrigation requirements were determined for specific crops in those particular locations using climatic data from CLIMWAT 2.0 and crop data from CROPWAT 8.0. When CLIMWAT did not have data for a particular location, the closest weather stations in CLIMWAT were used, and an average of crop irrigation requirements between these locations was calculated. Some feeds came from several different locations. When this was the case, irrigation requirements for that particular feed for each location were found in CROPWAT and a weighted average was taken based on the percentage of feed coming from each location.

In some cases, only the feed consolidator was known, and not the location of the growers. This was the case with the pre-mix. Therefore, crop irrigation requirements for each component of the feed were determined for several different locations close to the consolidator that also had weather data available in CLIMWAT 2.0. An average between these locations was then calculated. The same method was applied to the major alfalfa consolidator.

Once the irrigation requirements (in m^3 per hectare) for each particular type of organic feed and organic bedding were calculated, the yields for each feed (in kg/ha) were used to determine the water consumption for feed in m^3 per kg of feed. The respective crop yields in kg/ha were obtained from the U.S. conventional agriculture datasets in the SimaPro database. When specific yields were not available for particular feed and bedding types, they were obtained from USDA national averages (USDA, 2010). The irrigation requirements in m^3/ha were then divided by kg/ha to determine the water consumption in m^3/kg for each type of feed and bedding in each growing location. However, not all of the irrigation water required to grow the crops for each type of feed was allocated to AOD. The water requirements for a particular crop contribute to growth of all of the parts of the plant, and particular types of feed do not consist of the entire plant. Therefore, a general rule of 50% for the grain and 50% for the shaft was used to determine water allocations for the feed and bedding. In the case of soybeans, 50% of water is allocated to the bean, while 74% of the bean is soy meal (37% of the total plant) and 8-10% (4.5% of the plant on average) is soy hull (Johnson & Smith, 2003). The allocations were then used to determine the final water consumption for feed and bedding in m^3/kg. These numbers were then entered into SimaPro to determine total water consumption for the Feed and Bedding Production stage.

Farm Operations

In order to quantify water use on AOD's farms, it was necessary to gather data on three levels: water inputs, intermediate uses and water outputs. "Water inputs" quantifies how much water enters the farm from each type of source, "intermediate uses" quantifies how much water is used for each purpose while it is on the farm, and "water outputs" quantifies how much water leaves the farm system through each possible pathway. Within each pathway, water can leave the farm as consumption or utilization; thus, the water consumption and utilization from the Farm Operations stage are simply sums of the consumption and utilization within each pathway.

Water Inputs to AOD Farms

Water inputs to AOD farms come in four main forms: municipal water, ditchwater, well water, and rainwater collected from building roofs.

Municipal water is purchased from local water utilities, and is metered. Bills for municipal water purchases with exact quantities were obtained for all AOD farms.

Ditchwater is purchased from local ditch companies for irrigation purposes at the Colorado farms. This water ultimately comes from the large reservoirs maintained by the Northern Colorado Water Conservancy District, which store runoff from the Rocky

Mountains. Bills for ditchwater purchases were obtained for all of the Colorado farms, but the quantities listed on these bills may not exactly match the quantities of water actually delivered to the farms. This is because local reservoirs may not always have the capacity to meet all orders from the farms that they supply, and also because some evaporation always takes place as the water moves from the reservoir through a series of ditches to the farm and as the water sits on the farm waiting to be used.

Well water is metered only at Coldwater, because of strict regulations in that area on reporting of groundwater withdrawals. At the other farms with wells (High Plains and Dipple), it is not metered and no specific records on well water use are kept. AOD experts provided estimates of the volumetric flow rates of the well pumps at High Plains and Dipple, as well as estimates of how frequently the well pumps run. These were used to estimate the total quantity per month drawn from wells at each farm.

Rainwater is collected from building roofs at High Plains and Coldwater and directed into the lagoons, but it is not measured. AOD experts could not provide specific estimates, so estimates were based on simple calculations using total roof area and monthly precipitation.

Intermediate Uses of Water on the Farm

On the farm, water is used in six significant ways: for cleaning purposes in the milking parlor, for washing heavy equipment such as trucks, for domestic use by employees, for cows to drink, for irrigation with clean water, and for irrigation with dirty lagoon water.

In the milking parlor, proper sanitation standards are maintained by the use of significant volumes of water. Water is used to flush the floor where the cows stand during milking, to rinse milking equipment and milk tanks, to spray down cows, and in various other ways to keep the parlor clean and ensure that the milking process is sanitary. This is not metered and records are not kept, so estimates were based on consultation with AOD experts.

For equipment washing, high pressure hoses are used, but no records were kept. The flow rates of the hoses were measured directly, and AOD experts provided rough approximations of how often equipment was washed and for how long. These numbers were used to estimate total quantities of water used for equipment washing per month.

For domestic use, no records were kept. AOD experts provided an estimate that 25 gallons of water are used per employee per day, which was obtained from studies by the St. Vrain Sanitation District in Colorado.

Cow water intake accounts for a large portion of water use on the farm. This includes water that cows drink from water troughs and also water that is mixed with their feed. No records are kept and AOD experts could not provide specific estimates, so recent academic studies were used to estimate the daily "free water intake" of a lactating cow (Cardot et al., 2008) and a non-lactating cow (NAS Board on Agriculture and Natural Resources, 2001). The first study derived a formula to predict free water intake based on dry matter intake, amount of water mixed with dry matter intake, milk yield, minimum temperature and rainfall. The second study predicted free water intake based on dry matter intake, amount of water mixed with dry matter, and crude protein content of diet. For all cows on all farms, AOD experts estimated that a cow's dry feed was mixed with an equal mass of water. Calculations of total cow drinking water per month were made by adding lactating cow water intake (based on Cardot et al., 2008) and dry cow water intake (based on NAS, 2001), using feed data from AOD records and local weather data for each farm. The water contained in the grass that cows eat while out on pasture was not included in these calculations.

Irrigation with clean water is quantified based on written records. Specifically, it is assumed that all ditchwater purchased (and quantified under "water inputs") for the Colorado farms is applied to those pastures, i.e. none is wasted. At Coldwater, there are specific records for how much clean well water was used for irrigation. Dipple does not irrigate with any clean water.

Irrigation with dirty lagoon water occurs at all farms, and records are kept in order to monitor the levels of nutrients applied to pastures. However, these internal datasheets were not suitable for this study, so this quantity was estimated. First, it was assumed that all wastewater from the milking parlor entered the lagoon. Second, evaporation from the lagoon was estimated as described below. Third, it was assumed that any lagoon that did not evaporate was used for irrigation, so evaporation from the lagoon was subtracted from wastewater entering the lagoon to calculate the amount of lagoon water used for irrigation.

Water Outputs

Water leaves AOD farms in four ways: through normal evaporation, through evapotranspiration from pastures, through losses from the cow bodily functions, and through water contained in the milk.

Evaporation takes place on the farms (primarily from the lagoons), but it is not directly measured anywhere. AOD experts could not provide an estimate of evaporation from the lagoons, so it was estimated using a common method called pan evaporation. Throughout the country, records are kept of how much water evaporates each day from a standardized cylindrical water tank four feet in diameter. This number can be adjusted for large bodies like lagoons by a factor of 0.75 (Hobbins et al., 2004), and this adjusted number was then used to estimate total evaporation from lagoons each month. All of this evaporation is considered water consumption, so the water utilization for this output pathway is zero.

Evapotranspiration from pastures is not measured directly, and AOD experts could not provide specific estimates. As with evapotranspiration for the Feed and Bedding Production stage, CROPWAT 8.0 and CLIMWAT 2.0 were used to calculate evapotranspiration on AOD pastures. For each AOD farm, CLIMWAT 2.0 data from close weather stations were imported into the CROPWAT 8.0 computer program. CROPWAT then provided total evapotranspiration in mm for each of these locations for the months in which the pastures were irrigated. The dataset for pastures was chosen from the CROPWAT 8.0 database. CROPWAT provides total crop water needs in terms of mm, which was then converted into m^3/hectare. This number was then multiplied by the total area of hectares of pasture to determine the total crop water needs for each pasture at each AOD farm. Because these estimates of evapotranspiration from pastures exceeded the amount of irrigation water applied, it was assumed that all irrigation water applied to AOD pastures could be considered water consumption, since presumably all of the water made available by irrigation would be evapotranspired. Therefore, water consumption in this output pathway is equal to the total irrigation water (clean and dirty) applied, and water utilization is zero.

Cow water losses consist of urine losses (18% of total water intake), fecal losses (33% of total intake), losses through saliva and respiration (18% of total intake), and milk produced (accounted for below). These are not measured, and AOD experts could not provide estimates, so they were estimated using information in a recent national study (NAS Board on Agriculture and Natural Resources, 2001). For this output pathway, it was assumed that all of these losses were consumption except for urine losses, which were assumed to return to the watershed and were thus counted as utilization. (It was assumed that all water contained in manure is evaporated eventually; however, there may be a small amount of water that percolates back into the soil where the manure is deposited.)

Water contained in milk is much more accurately known than the other types of water outputs. AOD keeps careful records of all raw milk produced at the farms. AOD records indicate that milk contains 3.6% butterfat, 3.1% protein, 5.7% other solids, and 87.6% water by weight. Using standard densities for each of the milk components (Goff, 1995), it was calculated that milk is 81.4% water by volume. Thus, gallons of raw milk leaving AOD farms are multiplied by 0.814 to find the amount of water contained in that milk.

Milk Processing and Management

AOD's milk processing plant in Colorado purchases municipal water, so there are exact records of how much water it takes in. AOD personnel also keep high-quality records of how water is used within the plant, and how it leaves the plant. They estimated that approximately 27% of all water inputs to the plant are evaporated, while the other 73% are pretreated and returned to the local sanitation district. The portion that is evaporated is counted as water consumption, and the rest is counted as utilization.

AOD's corporate office also purchases municipal water. Water bills were available only for the entire office building in which the office is located, so a fraction of the total building water use was allocated to AOD's office based on the proportion of the building's floor space occupied by the office. Because this water was used and then returned to the municipal supply system from which it came, all of the office water use was counted as water utilization.

Cold Storage, Distribution, Retail and Consumer/End-of-Life

Water use associated with electricity and fuel consumption in the distribution chain was calculated according to the methodology described above.

Results and discussion

Life-cycle water use results were calculated using SimaPro software. This yielded results of 808 gallons of water consumed per gallon of packaged fluid milk, and 12.3 gallons of water utilized per gallon of packaged fluid milk. This number appears very large, but it should be emphasized again that it is likely a high estimate because of how CROPWAT calculates crop water needs. The Water Footprint Network (WFN) has performed an analysis of the "water footprint" of milk production, finding that the global average is 1000 gallons of water use per gallon of milk produced; WFN also provides a result that is specific to milk production in the United States: 700 gallons of water per gallon of milk (Hoekstra and Chapagain, 2008). At present, this is the only published analysis of water use in the milk production life cycle that accounts for feed and bedding production, where most water use occurs. Thus, it is the only other study that is at all comparable to this one (results are compared in Table 13 below). However, there are two reasons why it is not possible to directly compare the WFN result to the results obtained by this study:

1) WFN employs a different methodology, which includes rainfall on crops as part of the water inputs to the milk production system. This study does not include rainfall on crops. Because WFN does not reveal what proportion of its result is due to rainfall, it is not possible to make a fair comparison.

2) WFN's result of 700 gallons is specific to the United States, but it is not specific to organic milk production. Again, this means that a direct comparison is not possible.

Table 13. Comparison of This Study to WFN Results

This Study	WFN Global Average Water Footprint for Milk Production	WFN United States Average Water Footprint for Milk Production
820 gallons of water use per gallon of packaged fluid milk	1000 gallons of water use per gallon of milk	700 gallons of water use per gallon of milk

Life-Cycle Water Consumption and Utilization

Total water consumption and utilization, broken down by milk life-cycle stage, are shown in the following graph (Figure 26). Feed and Bedding Production dominates life-cycle water use at 94%, while Farm Operations account for 4.3% and all other stages amount to less than 1% each. When including pasture irrigation at AOD farms, irrigation makes up 97% of total life-cycle water use, confirming expectations that crop irrigation is the most water-intensive portion of the milk life cycle. AOD cows need large quantities of feed and bedding, as well as large pastures on which to graze, requiring the use of significant amounts of irrigation water.

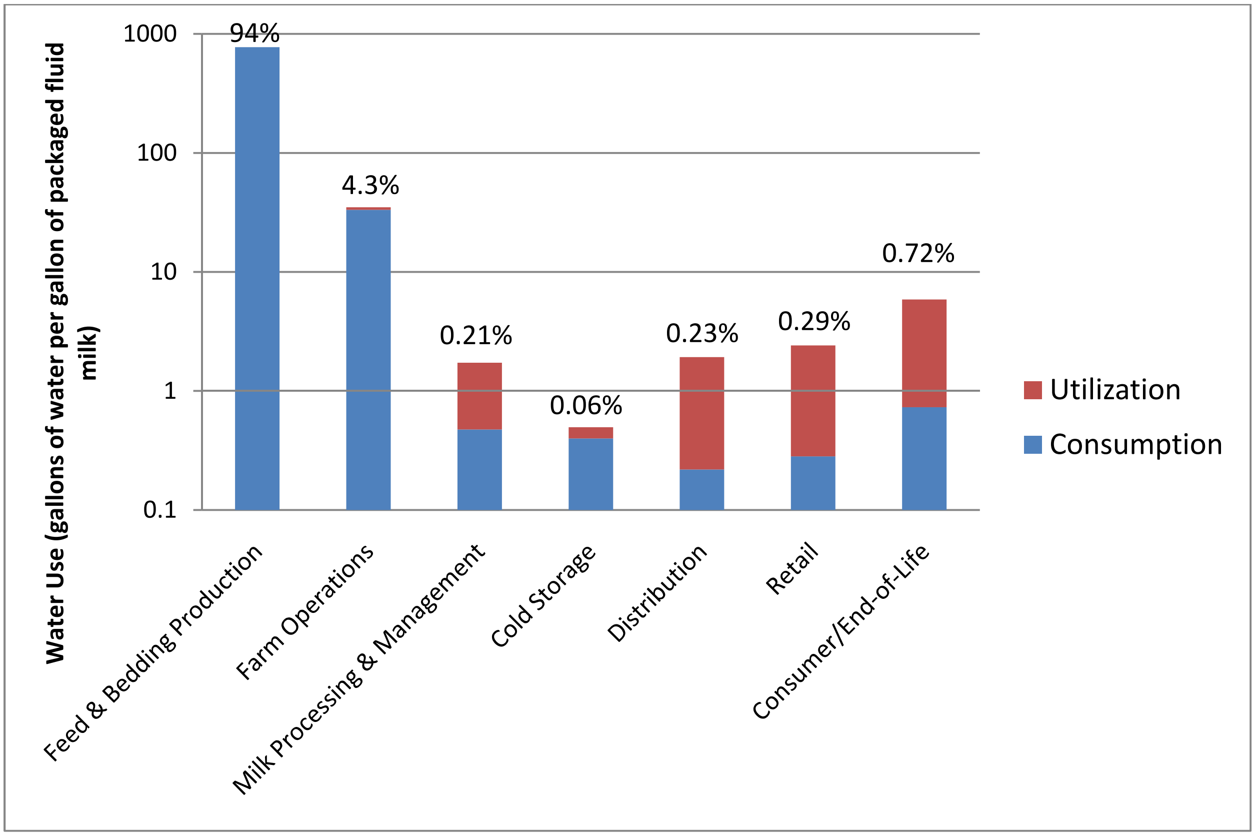

Figure 26. Water consumption and utilization broken down by milk life-cycle stage on a per gallon packaged fluid milk basis

Feed and Bedding Production Stage

As described above, the Feed and Bedding Production stage is by far the largest contributor to life-cycle water use—overall, water consumption for feed and bedding production accounts for 94% of total life-cycle water use. Water use associated with organic feed and organic bedding is highest at the High Plains facility, making up 39% of the total water associated with feed and bedding at all facilities. It is also substantial at Coldwater, which accounts for 28% (Figure 27). Feed and bedding usage across all AOD farms accounts for 772 gallons of consumption per gallon of packaged fluid milk. Most of the water consumption for feed and bedding at each farm comes from organic alfalfa hay, which accounts for 55% of total water for feed production or 424 gallons per gallon of packaged fluid milk. Grass hay accounts for 19% of total water for feed or 146 gallons per gallon of packaged fluid milk, and grain premix accounts 18% or 140 gallons per gallon of packaged fluid milk (Figure 27).

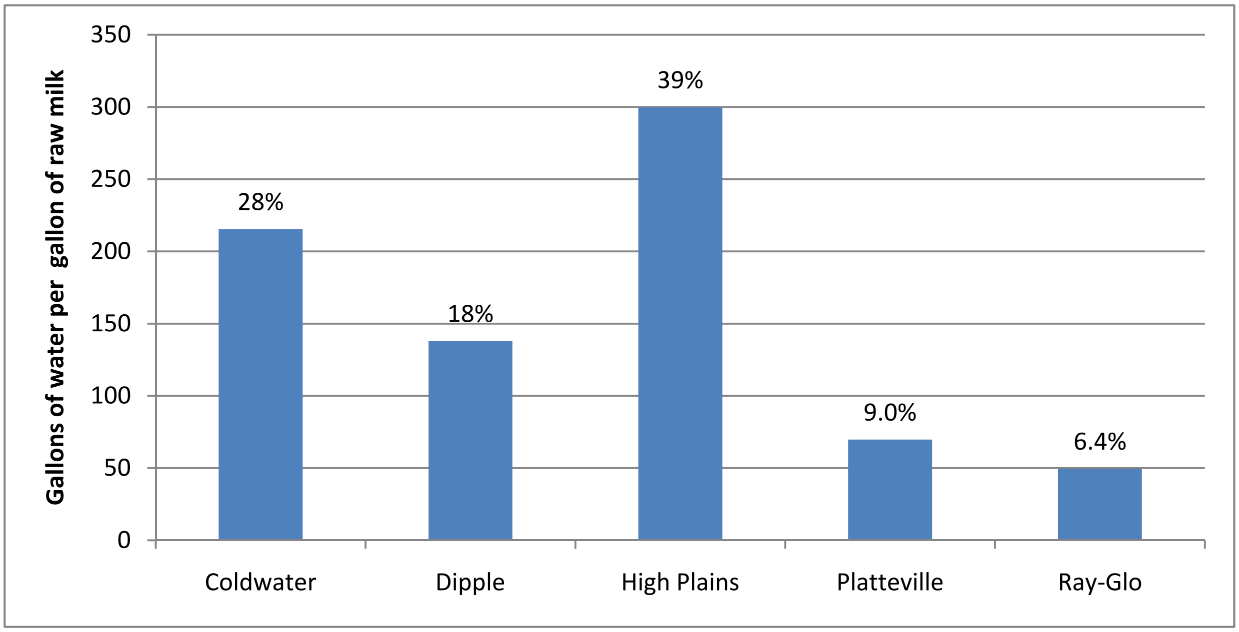

Figure 27. Break-down of water consumption associated with feed for each farm on a per gallon raw milk basis

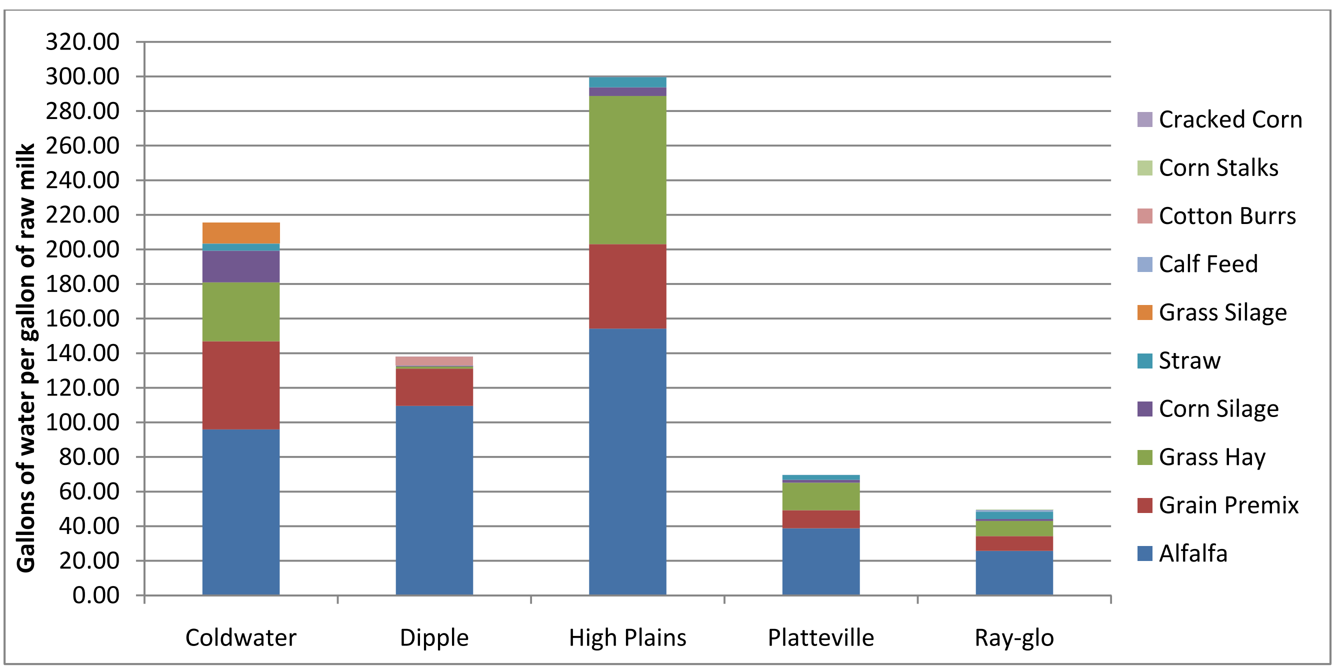

Figure 28. Break-down of water included in each type of feed on a per gallon raw milk basis

Figure 28 shows the amount of water required to grow each feed rather than the percentage breakdown of what is being fed to AOD cow. Alfalfa, grass hay, and grain premix account for most of the water associated with organic feed and organic bedding at the farms. This is in large part due to the fact that these feeds are commonly used and ordered in high quantities. Corn silage is also ordered in high quantities yet only accounts for 3.5% of the total water for feed production. This is due in large part to the fact that silage yields are often much higher than those of other feed types. For instance, corn silage yields about 49,166 kg/ha versus 2,702 kg/ha for grass hay. (However, this comparison may be misleading, because corn silage is usually harvested while it still contains a large amount of water weight, whereas grass hay is usually harvested in a relatively dry state.)

The overall water consumption results for the production of organic feed and organic bedding are high, especially compared to the rest of the life cycle. However, it is important to note that the CROPWAT method for calculating crop irrigation requirements is theoretical and tends to provide an overestimate of crop water needs for many organic crops (Pfister et al., 2009). Because of the lack of more specific information on the particular irrigation methods, yields, and specific locations of AOD's feed growers, the CROPWAT program was utilized to provide consistent estimates for a broad range of crops grown in various locations throughout the Great Plains and Rocky Mountain regions. It is very possible that many of the crops were either irrigated less or more than the crop water requirements calculated by CROPWAT. There is also a possibility that a select number of growers are not irrigating crops at all, especially in wetter, more northern climates. However, more specific records on the actual feed growers, rather than the feed consolidators, would need to be obtained in order to provide more accurate results. Again, it must be emphasized that the Feed and Bedding Production results are highly uncertain.

Farm Operations and Milk Processing and Management Stages

Figure 29 shows the breakdown of direct water consumption and utilization per functional unit at all AOD-operated facilities. Pasture Irrigation dominates water use at AOD facilities with 75% of the total. Farm Operations—which includes all water outputs from farms except evapotranspiration from pasture—is much smaller at 20%. Water use at the processing plant is smaller still at 4.9%, and water use at the corporate office is practically negligible in comparison to the other categories. As explained above, all pasture irrigation is assumed to be "consumption," as is the water used directly on the farms (except for a small portion of cow water losses, which return to the soil). Most water used in the processing plant is returned to the local sanitation district after on-site pretreatment, but about 27% is evaporated. All water used in the corporate office is immediately returned to the local municipal supply system from which it came.

As noted above, wastewater from AOD milking parlors is captured in lagoons and then reused for irrigation of pastures. It was calculated that 5.7% of all water inputs to AOD operations are reused for irrigation on the farms, or approximately 2.16 gallons of water per gallon of packaged milk.

Farm Utilities includes the water use associated with the generation of electricity for AOD facilities and fuel used on AOD farms (not including fuel for trucks transporting milk). This category contributes a small portion of total water use, mostly because fuel production is not very water-intensive and because the electricity generation plants that supply most of the farms are relatively water-efficient.

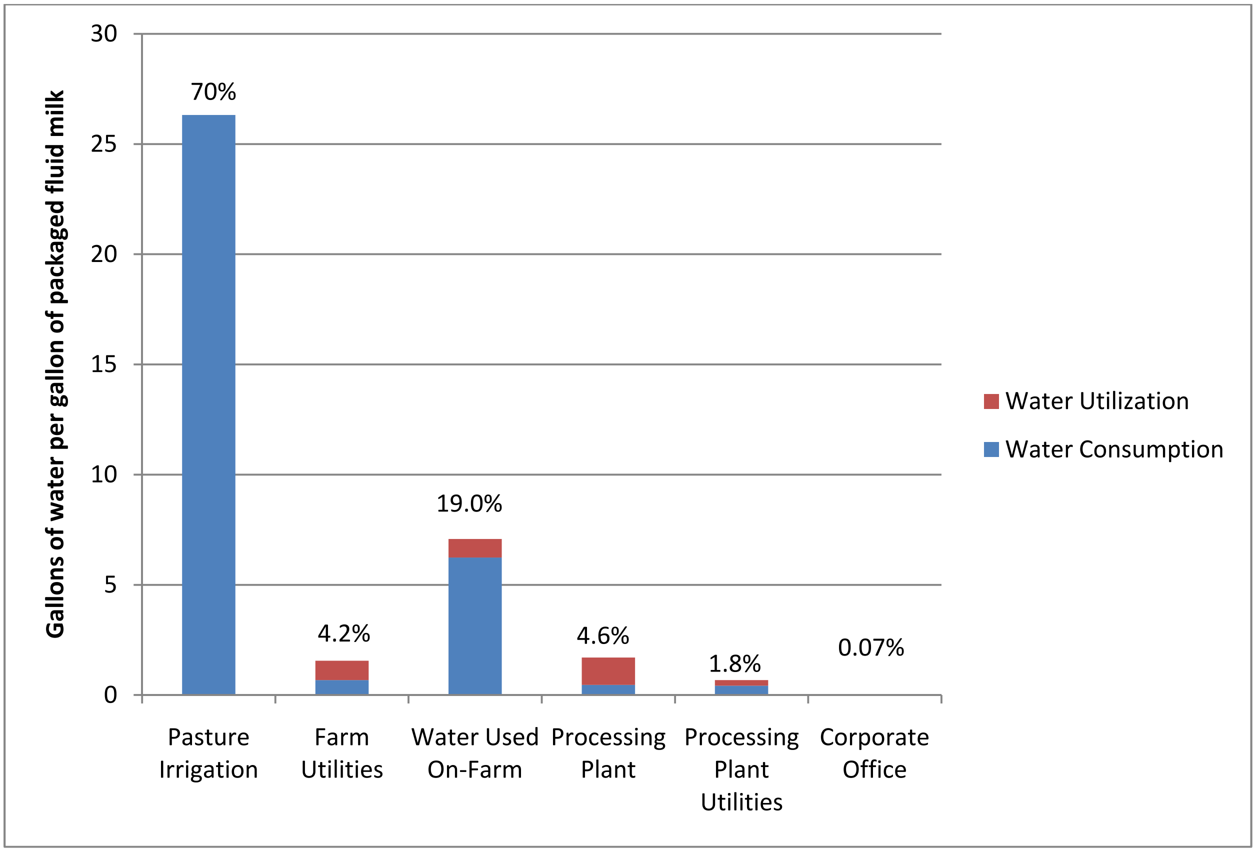

Figure 29. Distribution of water consumption and utilization within Farm Operations and milking processing and management stages on a per gallon packaged fluid milk basis

Results by AOD Farm

Figure 30 compares the water consumption and utilization at each AOD farm, including water use associated with electricity and fuel used on the farm, but excluding water for the Feed and Bedding Production stage and Transport stages. High Plains and Ray-Glo show significantly higher water consumption because at those two farms more water is used for pasture irrigation per functional unit than at the others. Dipple shows much lower water consumption because it has no supply of clean water for irrigation, and can use only lagoon water, limiting the volume it has available to apply on pastures. Also, Dipple's pastures require less irrigation because annual precipitation in the area is somewhat higher than at the other AOD farms. Dipple also shows significantly higher water utilization than the other farms, because the plants from which it receives electricity generally utilize more water than plants in Colorado.

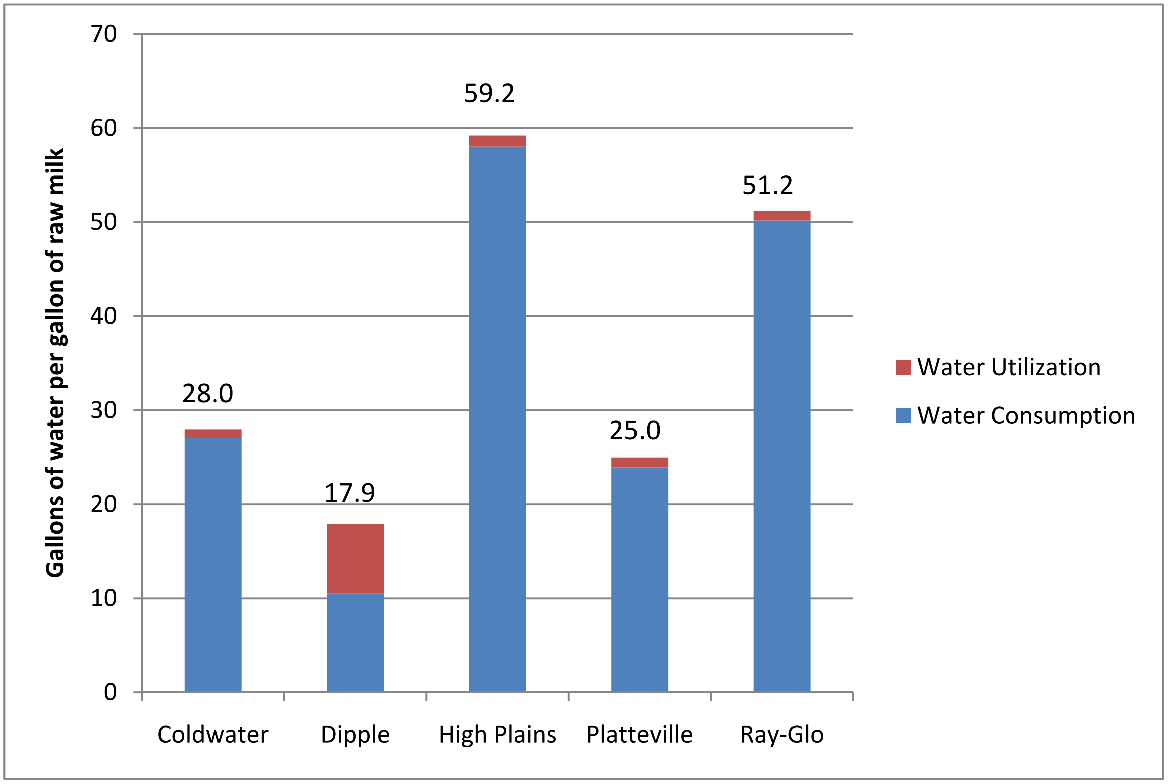

Figure 30. Water consumption and utilization at each AOD farm on a per gall raw milk basis

Cold Storage, Distribution, Retail and Consumer/End-of-Life Stages

Figure 31 shows the breakdown of water consumption and utilization per functional unit for all life-cycle stages after milk is shipped from the processing plant. Transport stages are classified as "consumption" and are small contributors, because only consumption was considered in quantifying water use associated with fuel production and because fuel production is not very water-intensive. Refrigeration stages involve large amounts of electricity, and the average electricity generation mix in the U.S. includes many plants with high water utilization and low water consumption. Thus, these stages show high utilization and relatively low consumption. Consumer refrigeration accounts for the largest portion of downstream water use at 54%, while Retail and distribution center refrigeration account for 22% and 18%, respectively.

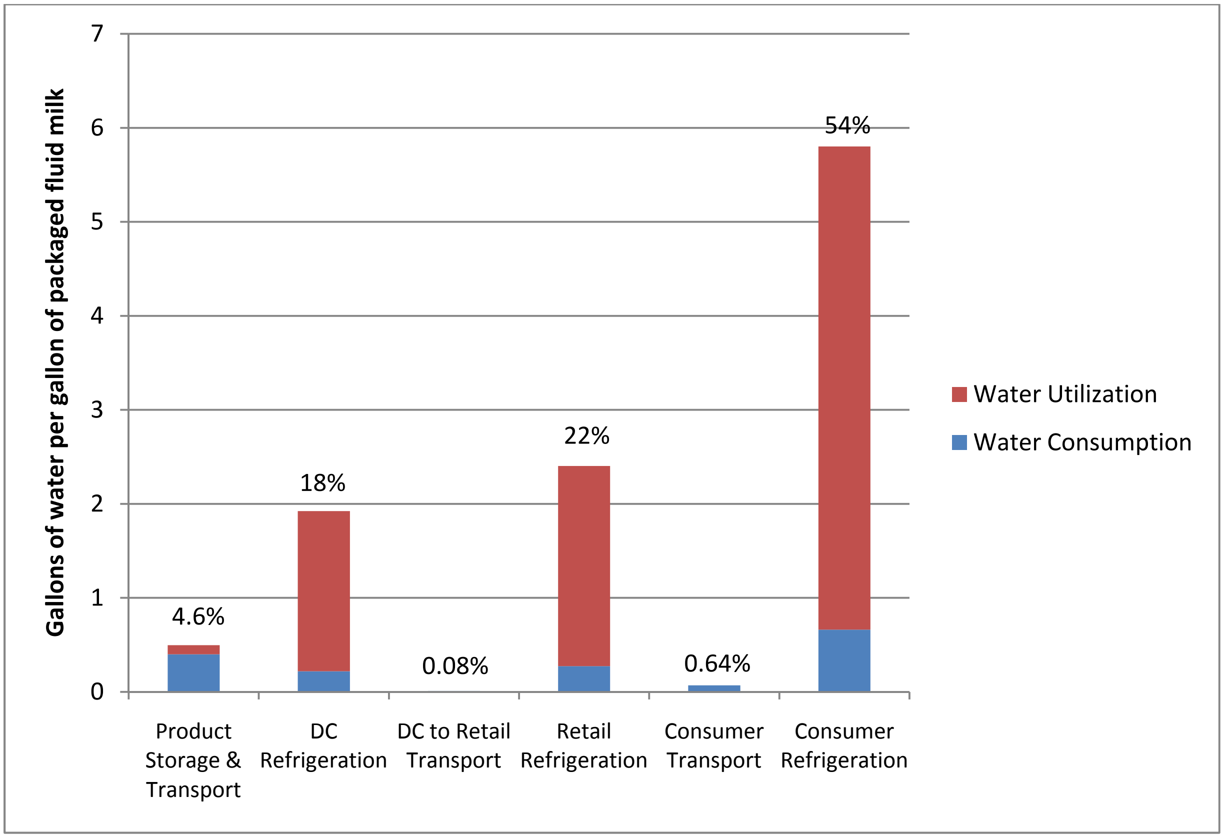

Figure 31. Distribution of water consumption and utilization in Cold Storage, Distribution, Retail and Consumer/End-of-Life stages on a per finished gallon of packaged fluid milk basis

Methodological Issues

Throughout the milk life cycle, and within AOD operations, water use is an indicator which is often difficult to quantify. While AOD does have good records for the water it purchases (municipal water and ditchwater in Colorado), it does not meter the well water used at High Plains or Dipple, so these numbers were estimated. Beyond water purchases and irrigation logs, there are few AOD records about how water is used on the farms. Thus, estimates were made for every other water quantity on the farm, including water use in the parlor, the amount of cow water intake, water evaporated from the lagoons, etc. The information used to make these estimates was based on many different sources of varying quality, although every effort was made to obtain the best information possible.

In addition, there is no widely-accepted methodology for quantifying water use within the life cycle assessment (LCA) literature, although in the last few years multiple articles have been published on the topic. Where possible, this study attempts to use terminology (e.g. "consumption" and "utilization") and methodology (e.g. the impact assessment methodology discussed below) from these recent articles. One well-defined methodology for measuring life-cycle water use is the "water footprint" concept, developed primarily by Arjen Hoekstra (Hoekstra and Chapagain, 2008). It is closely connected to the effort to measure "virtual water," or the amount of water embodied in internationally traded goods. When dealing with agricultural products, it accounts for both rainfall and irrigation for crop production. Because AOD has no control over weather patterns and the amount of rainfall that occurs, and because rainfall is relatively low in the regions where AOD operates, it was decided that the "water footprint" methodology was not appropriate to use in this study.

As mentioned above, it is critical to investigate the ultimate sources of the water used in AOD operations, because its facilities are located in semi-arid to arid areas with limited water resources. Clearly, when possible, it is preferable to use water that comes from sources that are not being over-used.

In northeastern Colorado along the Front Range (the easternmost peaks of the Rocky Mountains, which also form part of the Continental Divide), water comes ultimately from precipitation in the mountains, which feed streams and rivers. A large portion of the flow of these streams and rivers is diverted and captured in large reservoirs at high elevations. In this area, over 80% of the rain- and snowfall occurs on the Western slope of the Front Range, while the majority of human users (municipalities, industry, or farms such as those operated by AOD) are located on the Eastern slope. The public agency tasked with managing and delivering water within the region, known as the Northern Colorado Water Conservancy District (NCWCD), transports water from the Western to the Eastern slope via a tunnel that passes under the Continental Divide. Thus, a large amount of water from the Colorado River watershed (Western slope) is transferred to the South Platte River watershed (Eastern slope). According to a strict interpretation of the definition of water "consumption" given above, any water that is transferred in this way from one watershed to another would be considered consumption. However, such an interpretation is not useful, because any water transported from the Western to the Eastern slope and then purchased by AOD would automatically be counted as consumption—whether or not it was actually "consumed" by AOD operations. It is important to note this fact, especially because the Colorado River watershed is significantly over-used, but this study does not count all water stemming from the Western slope as "consumption."

In 2008, about 41% of this water from the Western slope was used for industry and municipal water supplies, which are the source of AOD's "municipal water." The other 59% was stored in a series of smaller reservoirs before it was delivered through an extensive ditch system to agricultural lands—including AOD farms—as "ditchwater" (Figure 32.) Rainwater collected from building roofs and corrals and in lagoons, and well water from underground formations are the only water inputs to AOD operations in Colorado that do not ultimately come from mountain precipitation on the Western slope.

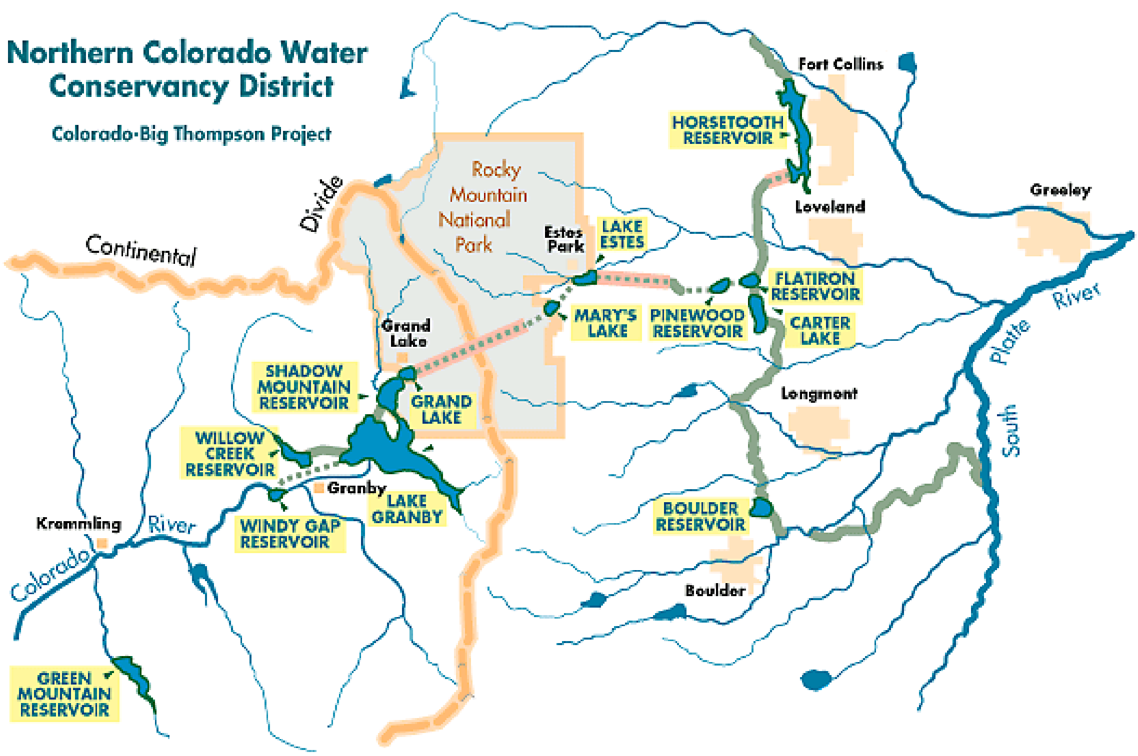

Figure 32. Northern Colorado Water Conservancy District Service Area (NCWCD, 2009)

At the Texas farms, issues arise not with surface water withdrawals, but more often with groundwater withdrawals. Deep groundwater wells are the primary means of providing freshwater to farms in the regions surrounding both Coldwater and Dipple, and they draw from finite aquifers. Local organizations called Groundwater Conservation Districts have been established by the State of Texas in both regions, which monitor groundwater withdrawals and enforce limits on these withdrawals in order to ensure that a particular aquifer is not depleted too quickly. Depletion of aquifers is especially problematic in the northern panhandle area of Texas where Coldwater is located, because this area overlies portions of the Ogallala Aquifer, a well-known formation which is essentially "fossil groundwater." Fossil groundwater sources like the Ogallala Aquifer are underground formations which hold water but are not naturally replenished. They can be thought of as similar to fossil fuel deposits—they are one-time stocks and once used up they cannot be replaced. This means that every gallon of groundwater extracted by the wells at Coldwater permanently reduces the amount available for future users. However, because of the lack of surface water resources in the area, any farm operating in this region must use this fossil groundwater. Moreover, it is important to note that water from the Ogallala Aquifer is heavily used for agriculture, municipalities, and industry in every state that overlies the Aquifer—Texas, Oklahoma, Kansas, Nebraska, South Dakota, Wyoming, Colorado and New Mexico.

Water Deprivation

Methodology

The life cycle impact assessment (LCIA) method used here is based on the article "Assessing the Environmental Impacts of Freshwater Consumption in LCA" (Pfister et al., 2009). This study aims to assess the environmental impacts of water use in a quantitative form, and uses a regional characterization of water use and impacts to take into account varying hydrological conditions.

The first component of this framework is the hydrological water availability, abbreviated WTA, which is calculated by dividing the total withdrawals from a watershed by the total annual freshwater availability in that watershed. This annual freshwater availability is based on the availability in both surface water and aquifers, but does not take into account fossil groundwater. The WTA numbers were provided by Pfister et al., and originated from a hydrological model called WaterGAP2. WTA ratios were obtained for each of the watersheds in which AOD's facilities are located, as well as each of the locations from which AOD sources its feed. The WTA ratios are then inserted into a logarithmic function to determine the water stress index (WSI) (Pfister et al., 2009). The WSI has a potential range of values between 0.01 and 1. A WSI of 0.5 is the critical point that separates moderate from severe water stress. This WSI is an indicator of the proportion of water consumption that deprives other users of freshwater (Pfister et al., 2009). It can be used as a general characterization factor for water consumption in LCIA by multiplying the amount of water consumption by the WSI for the particular watershed from which the water was withdrawn.

In order to calculate water deprivation in the Feed and Bedding Production stage, WSI values were obtained for each of the watersheds in which AOD's feed is grown, from Pfister et al. For feed types such as alfalfa, grass hay and straw, which are grown in multiple locations and therefore come from multiple watersheds, the WSI for each watershed was obtained. The total water consumption in each watershed was obtained by applying the percentage of total feed type that came from each location. The WSI value for each location was then multiplied by the respective water consumption in order to calculate water deprivation for each feed type in each location. These numbers were then added together to find the total water deprivation for each feed or bedding type for each farm. A similar method is applied to find the water deprivation due to water consumption in the Farm Operations and in the Milk Processing and Management stages; i.e., the WSI for each farm's watershed was obtained and then this WSI value was multiplied by the water consumption to find water deprivation. Because water use is concentrated in the first three stages of the milk life cycle (see Results for water use indicator above), it was decided that water deprivation would not be quantified in the Cold Storage, Distribution, Retail and Consumer/End-of-Life stages. Water deprivation from upstream water consumption associated with electricity and fuels was also not quantified, because reliable information was not available on the locations of the numerous power plants which feed into the electric grid in each region, nor on the location of fuel production.

Results and Discussion

Feed and Bedding Production

A greater difference between water consumption and water deprivation indicates that a smaller proportion of water consumption deprives other users of freshwater. The difference is greatest at Dipple and smallest at Coldwater (Figure 33). At Dipple, water deprivation for Feed and Bedding Production is 28% of water consumption. At Coldwater, water deprivation is 44% of water consumption.

According to the feed location estimates employed here, a majority of the straw, grain premix, and calf feed is likely being produced in watersheds that have a WSI ranging from .99 to 1, which indicate very severe levels of water stress. However, a majority of the feeds, such as alfalfa, , corn silage are produced in watersheds with a level of stress ranging from 0.026 to 0.18, which indicate low levels of water stress and result in a much lower amount of water deprivation relative to the water consumption for those feed types.

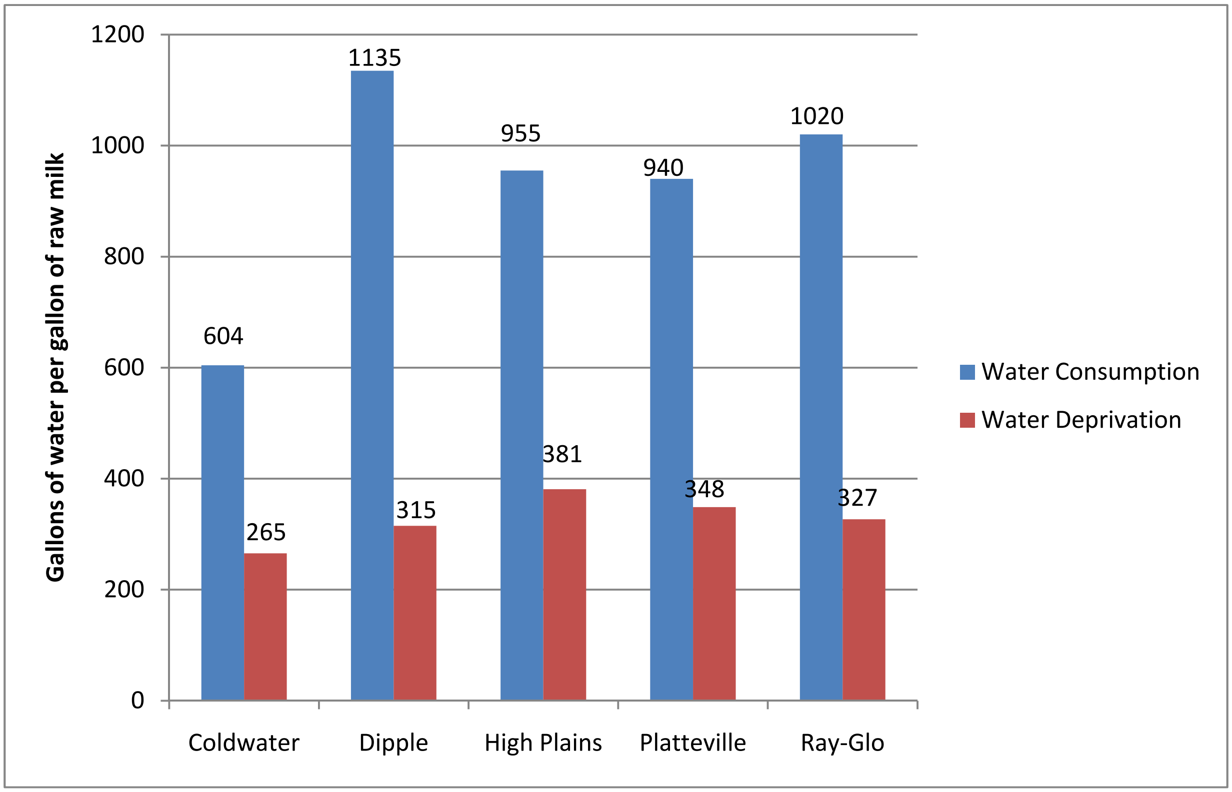

Figure 33. Break-down of water consumption vs. water deprivation for feed/bedding production by farm, on the basis of raw milk produced at each farm

Water consumption and water deprivation associated with feed and bedding production at each farm are significantly different because alfalfa production makes up 84% of the total water consumption associated with growing organic feed and organic bedding across all farms, and a majority of the alfalfa is sourced from the greater Idaho region, which is a region of low water stress (WSI = 0.026). For example, at Dipple, where water deprivation is relatively low, alfalfa accounts for 79% of the total water for feed and bedding, and it sources 87% of its alfalfa from Idaho. In other words, Idaho-grown alfalfa has a low water deprivation value, which significantly reduces the overall water deprivation value for each farm.

There is a vast range in water stress indicators for the regions in which AOD's feed is grown. All of the locations appear to be either very highly stressed with WSI values between 0.99 and 1, or under very low stress with WSI values ranging from 0.01 to 0.18.

65% of the consumptive water for the Feed and Bedding Production stage comes from areas of low water stress and 35% comes from areas of high stress, while no feed or bedding comes from areas of moderate stress.

Although it appears that a majority of AOD's feed is sourced from areas of low water stress, there are several factors that could affect this condition. More specific information on the location of feed producers is needed, and could change these results. In addition, the water stress index was not developed to take fossil groundwater into account, due to the level of complexity that this would add to the analysis. Thus, in regions where fossil groundwater is being depleted, the WSI value may be low but there may still be environmental problems associated with water use. Taking the depletion of aquifers into account could alter the picture. However, this would not change the value for water deprivation from the Feed and Bedding Production stage.

Farm Operations and Milk Processing and Management

Figure 34 compares water consumption and water deprivation at each AOD farm. At Coldwater, WSI is 0.18 and therefore water deprivation is only about 18% of water consumption. However, all of the other farms are located in watersheds with a WSI of 1, so water consumption and water deprivation are equal. As the processing plant is located in the same watershed as the other Colorado farms, water consumption equals water deprivation at that stage as well.

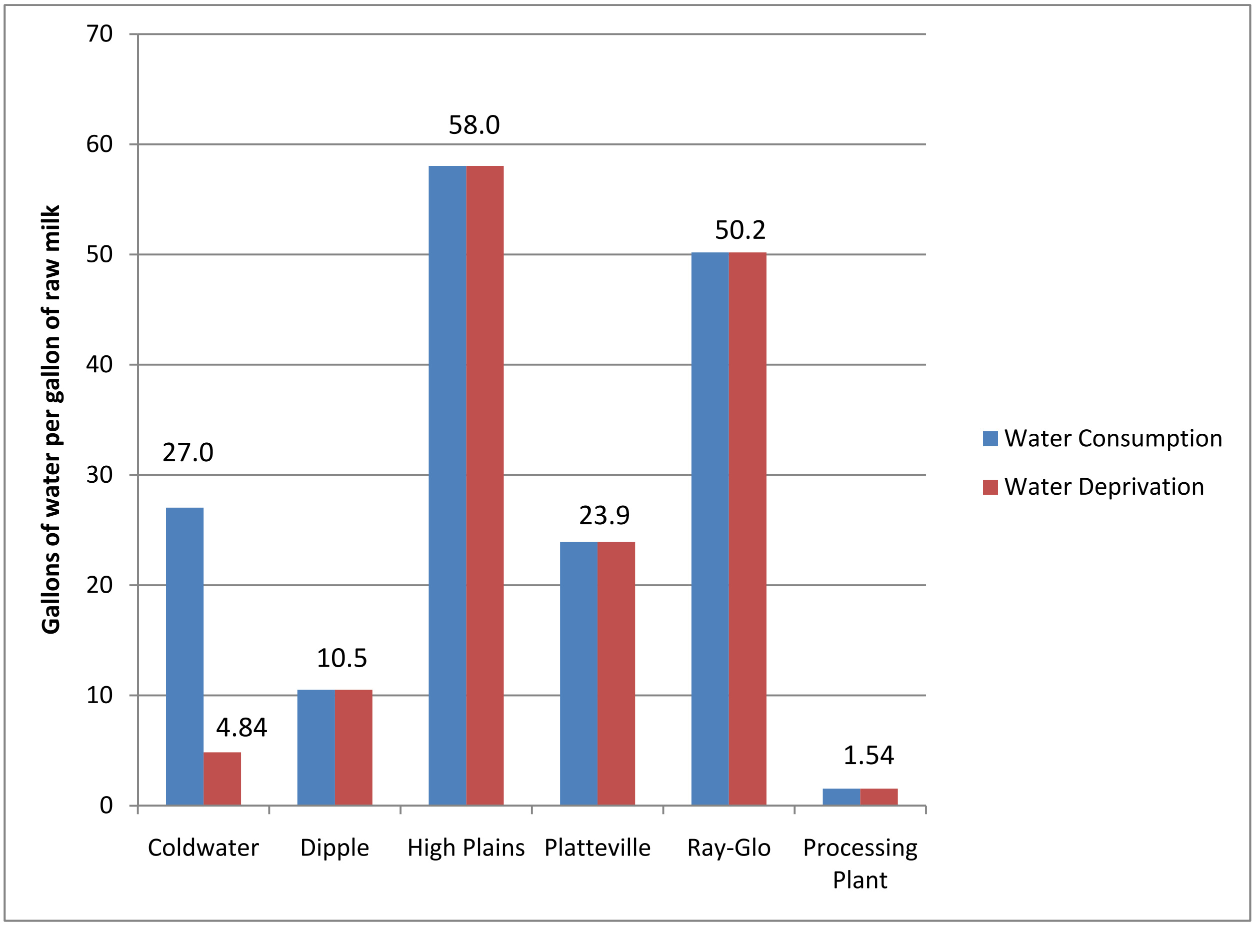

Figure 34. Comparison of water consumption and water deprivation at each farm and at the processing plant on a gallon of raw milk basis

The water deprivation result for Coldwater is misleading, because the WSI value does not account for the use of fossil groundwater. According to records from the North Plains Groundwater Conservation District (the District in which Coldwater is located), annual extraction of fossil groundwater from the Ogallala Aquifer in 2007 was 1,245,074 acre-feet, of which 150,991 was replenished (North Plains Groundwater Conservation District, 2008). Thus, there was an annual depletion of 1,094,083 acre-feet within the entire District. This means that, on average, 88% of groundwater extraction in the District causes depletion of the aquifer. So while extraction of fossil groundwater does not cause water deprivation, insofar as it does not reduce the water available to other current users, it does cause aquifer depletion and reduce the water available to future users. It should be noted that Dipple also relies on groundwater, but the aquifer it draws from is not fossil water. Records from the Middle Trinity Groundwater Conservation District show that aquifer depletion in the area is negligible (Middle Trinity Groundwater Conservation District, 2009).

Water deprivation results for all of the farms (except Coldwater) and the processing plant show that they are located in highly water-stressed areas where competition over water resources is significant. Thus, AOD's water consumption at these farms has a measurable impact in terms of reduced availability for other current users. And at Coldwater, water consumption has a measurable impact in terms of reduced availability for future users.

Solid Waste Generation

Introduction

"EPA defines solid waste as any garbage refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining and agricultural operations, and from community activities" (EPA, 2008). This study focuses on municipal solid waste (MSW), commonly referred to as trash or garbage as well as the indirect solid wastes (ISW) associated with electricity generation and fuel processing. According to the EPA, the best management option for waste is source reduction. They claim waste management, "greatly outweighs benefits from recycling, incineration, and landfilling in terms of energy use, greenhouse gas emissions, and other environmental impacts."(EPA, 1999)

"Throughout the life cycle of a product from extraction of raw materials to transportation to processing and manufacturing facilities to manufacture and use waste is generated" (EPA, 2008). Therefore, while a specific life cycle assessment impact category was not used to analyze AOD SW in this study, a full life cycle inventory was compiled for SW results.

System Description

The MSW associated with AOD operations from the Farm Operations, Milk Processing and Management, Cold Storage, Distribution, Retail, and Consumer/End-of-Life stages was quantified. Two types of SW were assessed: Indirect Solid Waste (ISW) and Direct Municipal Solid Waste (DMSW). ISW represents the SW burdens associated with the material fabrication and production of goods, for example wastes from paper and plastic processing. Additionally ISW included the upstream SW associated with fuels and electricity used throughout the AOD life cycle. Examples of solid waste associated with electricity production include "waste treatment sludge from coal and uranium mining and processing operations, as well as from fuel combustion residues (ashes, etc.) and combustion pollution control devices (solids and sludge)" (SimaPro, 2008). (Refer to Appendix X for kg ISW/MJ energy for fuel types.) DMSW is the waste generated directly at AOD facilities, namely the garbage. Examples of this include udder wipes, paperboard gabletop cartons and HDPE gallon jugs. The term "Primary packaging" refers to paperboard gabletop cartons and HDPE gallon jugs and the term "secondary packaging" refers to pallet packaging material (e.g. cardboard, shrink wrap, and tape). DMSW diverted from the waste stream through recycling was reported as a third flow, recycled municipal solid waste (RMSW).

Methodology

A variety of methodologies for characterizing SW streams exist in the literature today. (Finnveden et al., 1996; E.P.A., 1998; Newenhouse and Schmit, 2000; Gay, et al., 2009) These methods include quantitative techniques such as waste sorts and the conversion of economic sales data into waste quantities in addition to qualitative methods like interviews, and field observations. This study employed a combination of qualitative methods and some quantitative techniques to characterize the solid waste stream over the entire life cycle of AOD milk. Specifically, waste characterizations of the DMSW stream were completed for the Farm Operations, Milk Processing and Management, Distribution, and Consumer/End-of-Life stages. This information then allowed for educated estimations of the overall quantity (kg) of DMSW throughout the product life cycle. The quantity (kg) of ISW was obtained from databases contained within the software program Sima Pro. It should be noted that using the Sima Pro databases to calculate ISW introduces a degree of uncertainty. This is because Sima Pro databases are inconsistent in the way they aggregate and report waste, leading to inconsistencies regarding waste accounting. Specifically it should be noted that no waste is accounted for with regard to electricity generated by hydro-power and natural gas (see Appendix X, for kg/MJ information). Therefore the ISW results may underestimate overall ISW.

The Phase I LCA showed that the corporate office contributed less than one percent to GHG and energy. Due to these findings the corporate office stage was omitted from the DMSW characterization. However, the corporate office's energy and natural gas usages were included in the SimaPro model and, therefore, ISW components were calculated. Similarly, Phase I categories for the AOD "building embodied energy" stage, "employee transport" and employee housing impacts were not included in the DMSW characterization component.

Farm

To quantify and characterize DMSW at the farm level, field observations, consultation with AOD staff, and information from the farm waste haulers were used. This enabled educated assumptions regarding the major composition of farm level solid waste to be made. After determining what the major contributors were, the individual components' usage rates, disposal rates, and individual component weights were used to estimate total farm DMSW. These key components include udder wipes, nitrile milking gloves, filter socks, bags formerly containing calf feed and minerals, and twine used to bale hay and straw. Purchase records, feed usage records, and usage rates based on AOD experts' knowledge were obtained. The weights of the aforementioned solid waste components were combined with these usage estimates to obtain the weight of waste for the farm level during the period of study (see appendix XX for individual component methodologies). The products' material compositions were then utilized to characterize the composition of the farm's DMSW.

The SimaPro model included processes for farm electricity, natural gas usage, diesel usage, gasoline usage, and purchased farm supplies. The model's output for solid waste for these processes was utilized to report Farm Operations ISW.

Processing Plant

The weight of DMSW for the milk processing stage was calculated by summing the individual weights of the plant's 34-yard roll-away dumpster at each collection during the time period of the study. Additionally, AOD's recycler provided weights for all recycled materials collected. These were utilized to quantify the overall amount of MSW produced.

Purchase records for gabletop containers and the HDPE resin utilized for the fabrication of gallon containers were obtained for the period of study. The number of gabletop containers disposed at the plant was estimated by subtracting the amount of packaging purchased from the number of finished half gallon cartons of fluid milk. Finished half gallon cartons of fluid milk refers to the milk which is packaged and sold in gabletop carton containers that is distributed to retailers, employees, sales samples, or donated. Gallon container resin that is not contaminated is reground and reincorporated in additional containers. Recycling figures account for gallon container waste contaminated with milk product that could not be reincorporated into new containers as regrind.

The SimaPro model included processes for the milk processing plant's utility usage, the gabletop and gallon packaging components, as well as purchased supplies. The ISW for these processes was used to characterize ISW.

Distribution and Consumer/End-of-Life

Secondary packaging (shrink-wrap and cardboard boxes) and primary packaging (gabletops cartons and HDPE gallon containers) associated with AOD milk were calculated and characterized. These wastes were attributed to the Retail stage (secondary packaging) and the Consumer/End-of-Life stages (primary packaging).

The total primary and secondary packaging was extrapolated using AOD records of half gallon and gallon orders filled. Paperboard gabletop half gallon cartons are packaged to be sold in one of two ways - individually or in packs of three (three half gallons/unit). HDPE gallon jugs are sold individually.

Paperboard gabletop half gallons are shipped in one of two ways. The half gallon cartons sold individually are packed on pallets in groups of six. The half gallon cartons sold as three-packs are packed on pallets in groups of three. HDPE gallon jugs are packed on pallets in groups of four. Overall pallet sales were separated into the three aforementioned categories. Individual weights of the carton or jug and the associated packaging material components (divided by percentage of individual component) were used to determine the overall material makeup of all finished product packaging.

National Recycling averages were used to calculate the recycled quantities diverted from the DMSW stream. These rates were 1 percent for the paperboard gabletop cartons, 28 percent for the HDPE gallon jugs, and 72 percent for cardboard. (Franklin Associates, 2007; E.P.A., 2010; CSS, 2010) An EPA recycling rate for polyvinyl chloride (PVC), the plastic in shrink wrap, was not found, however, Consumer Reports Greener Choices website indicated a recycling rate of less than 1 percent in 2006 (CRGC, 2010). Therefore, recycling of shrink wrap was assumed negligible and not included.

Results and Discussion

Results show that one gallon of AOD finished milk results in 156 g of ISW, 160 g of DMSW, and that 93.9 g of DMSW is diverted from the waste stream through recycling. Overall results broken down by life cycle stage are reported in Table 14 and Figure 35.

The Consumer/End-of-Life stage accounts for 38% of the overall ISW and 71 % of the overall DMSW throughout the life cycle. The ISW generated in this stage results predominantly from wastes associated with electricity generation. This stage's electricity is modeled using national averages for electricity grid mix. 48 percent of this electricity comes from coal-fired plants. SimaPro databases indicate that .000327 kg of solid waste are generated per MJ of energy created, which is higher than all other electricity sources. For the Farm Operations and Milk Processing and Management stages electricity was modeled on the Colorado, Texas, and Oklahoma grids which have relatively lower contributions from coal-fired plants and greater contributions from hydro-electric and natural gas plants. Recall from the methodology section that wastes associated from electricity generation from natural gas or hydro-electric were not represented in the SimaPro databases which may underestimate the ISW from electricity generation. As expected, the Consumer/End-of-Life stage was the largest contributor to overall DMSW. This is the stage where the paperboard gabletop cartons and HDPE gallon jugs are disposed. The environmental performance indicator section discusses this finding in more depth.

Table 14. MSW results on a grams per gallon of packaged fluid milk basis

	Indirect SW (g/ gallon of packaged fluid milk)	Direct MSW (g/ gallon of packaged fluid milk)	Recycled (g/ gallon of packaged fluid milk)
Feed and Bedding Production	1.57	0.00	0.00
Farm Operations	7.74	7.91	0.00
Milk Processing and Management	41.4	9.15	16.0
Cold Storage	3.35	0.00	0.00
Distribution	19.5	0.00	0.00
Retail	24.5	29.2	75.2
Consumer/End-of-Life	58.8	114	2.67
Total	157	160	93.9

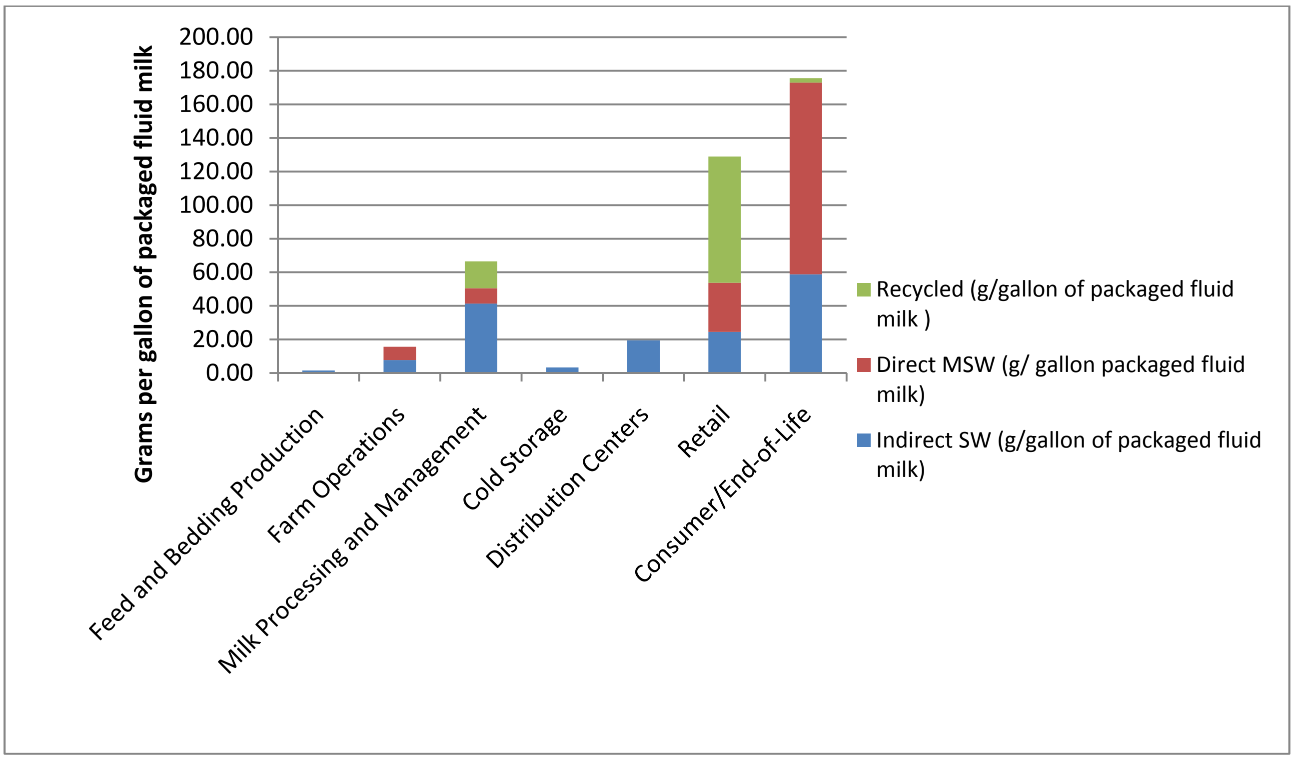

Figure 35. Full life cycle distribution of SW. Results are reported in grams per gallon of packaged fluid milk basis

The ISW results calculated by the different processes created in the SimaPro model are reported below in Figure 36. Processes that require electricity, such as refrigeration and milk processing components, have high ISW because of the solid waste burdens associated with the production of electricity.

Figure 36 also highlights the large contribution packaging contributes to ISW. This process includes ISW associated with the processing of primary packaging for gabletops and gallons, as well as secondary packaging products: cardboard, shrink wrap and tape. In the overall analysis these contributions were included in the Milk Processing and Management stage. The inclusion of these packaging components in addition to the Milk Processing and Management electricity demands explain why this overall stage is second largest contributor to ISW.

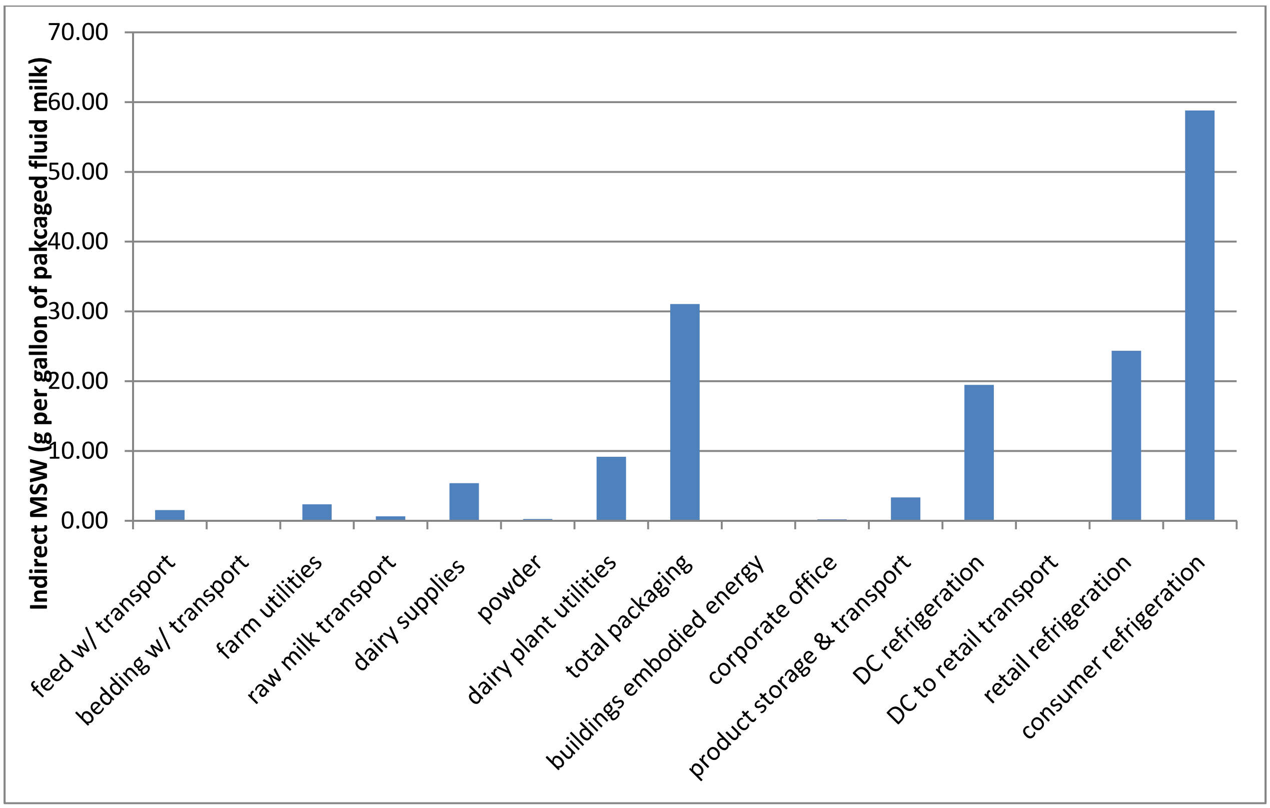

Figure 36. ISW results from individual processes within the lifecycle reported in grams per gallon packaged fluid milk basis

Farm Operations

Farm Operations contributed a total of 7.91 g/gallon of finished fluid milk to overall DMSW. Of the stages in which DMSW was calculated, Farm Operations produced the lowest amounts. For AOD to understand and manage waste, however, it is still important to understand the components and characteristics of DMSW at the farm level. During the period of the study, AOD farms did not recycle.

DMSW produced by individual farms was also analyzed by dividing the DMSW (kg) by individual raw milk production (lbs. raw milk) produced by each farm annually (Figure 37). These results indicate that Ray-Glo contributes the most to overall DMSW when analyzing DMSW on a raw milk production basis. Note that the farms with larger herd sizes tend to perform better with regard to DMSW per pound of raw milk.

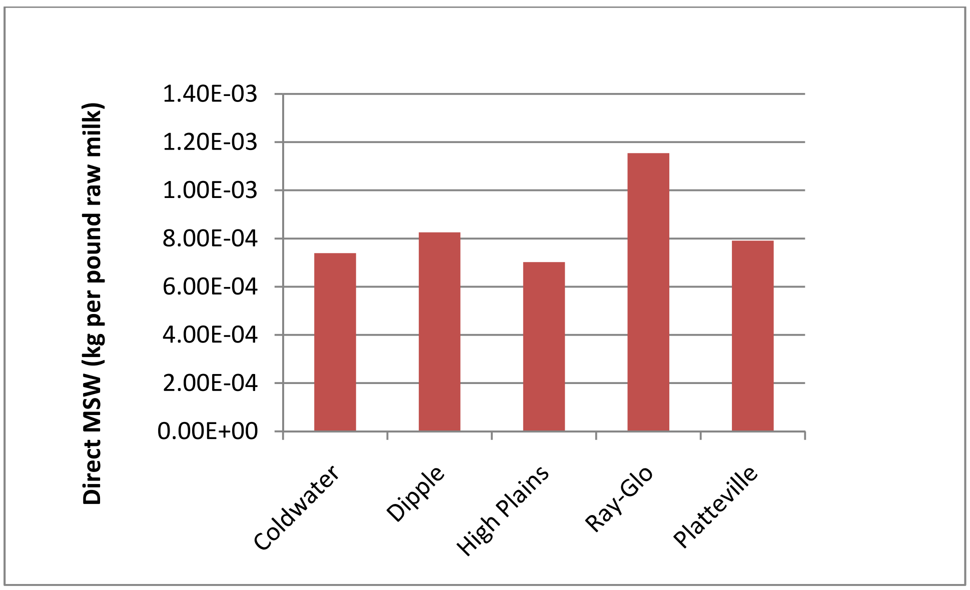

Figure 37. DMSW produced at individual AOD farms reported on a kilograms per pound raw milk basis

DMSW differences observed between the five farms (illustrated in Figure 38) exist due to operational differences. The silage plastic only occurs at High Plains and Coldwater because these farms are the only ones with on-site silage piles. The high amount of disposed bags at Ray-Glo can be attributed to the larger numbers of on-site calves raised there during the period of the study. Calf-feed is purchased and transported in bags while most other adult cow feed is not.

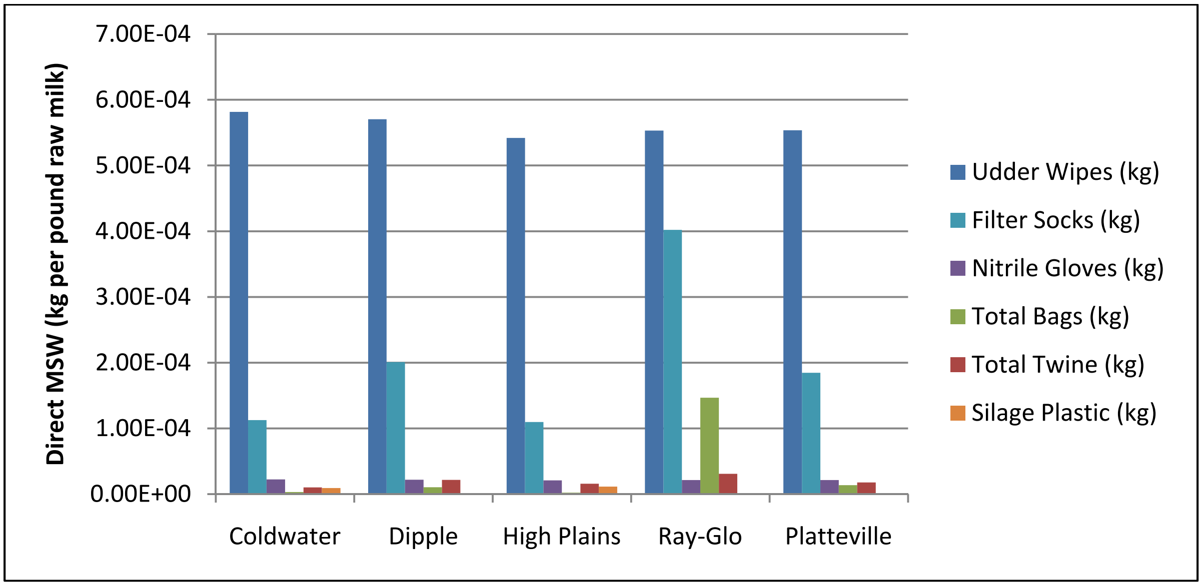

Figure 38. Farm Operations DMSW by farm and waste type on a kg per pound raw milk produced basis

Milk Processing and Management

The overall weight of DMSW for the milk processing plant was 228 tons and the total amount recycled was 339.43 tons. These numbers were used in the comparisons of this stage to other life cycle stages reported above. The DMSW and recycling amounts are the most accurate calculations for an individual stage because these measurements were taken from the waste and recycling hauler's direct records.

Environmental Performance Indicators (EPIs) for Operational Management

Selected EPIs

- Nutrient Use
  - N surplus
  - N use efficiency
  - P surplus
  - P use efficiency
- Water Use
  - Total water inputs by source
  - Total volume and percentage of water inputs recycled or reused
  - Water intensity
  - Water use associated with electricity and fuel
- Solid Waste Generation
  - Quantity of DMSW
  - Characterization of MSW
  - Recycling Ratio

Nutrient Use EPIs

Even within a single farm system, nutrient releases are dependent on a variety of physical properties such as soil pH, temperature, manure management systems and other variables that require complicated modeling for environmental impact assessment. EPIs for nutrient use are provided to avoid the more complicated calculations in LCA that include these variables. Rather than quantify each individual nutrient transformation throughout the farm systems, the nutrient use EPIs take a higher-level approach and quantify the *potential* for environmental impacts from a farm system. Since environmental impacts are the result of nutrient releases to ecosystems, nutrient EPIs quantify the amount of nutrients that are potentially available to be released into ecosystems without specifying the particular form of environmental release. To quantify this potential, nutrient use EPIs simply measure the amount of elemental nitrogen and phosphorus that enter the farm system as imports but do not leave through farm products or exports. Every gram of nitrogen or phosphorus that enters a farm system and is not exported has the potential to affect natural ecosystems and is thus measured with the nutrient use EPIs. EPIs have been shown to be effective environmental assessment techniques on many farm systems (Thomassen and de Boer, 2005). Four EPIs related to nutrient use were selected:

- N surplus
- N use efficiency
- P surplus
- P use efficiency

Since significant nutrient releases to ecosystems from AOD milk production occur on farms, EPIs for nutrient use are focused on the Farm Operations stage rather than the entire milk life cycle (Figure 39). Though there are nutrient emissions throughout the milk value chain, EPIs focused at the farm level provide managers with feedback on farm systems directly within their control. The nutrient use EPIs do not directly account for the manure in the farm system (only the inputs and milk products), and so do not provide any information on the fate of manure nutrients. Since farm gate balances are typically applied to single farms, balances were quantified at each farm per month and aggregated into annual totals for reporting. It is important to note that nutrient surpluses were not expressed on an area basis (e.g. kg per hectare) for AOD since some of the manure is exported to farms of unknown area. For instance, any manure sent to a third-party composting service from the Platteville farm and some manure shipments from the Dipple farm had unknown application per area rate. Therefore it was most accurate to describe results on a per farm basis. In the literature, surplus is commonly expressed on a per farm (as in this study), per cow, or per area basis.

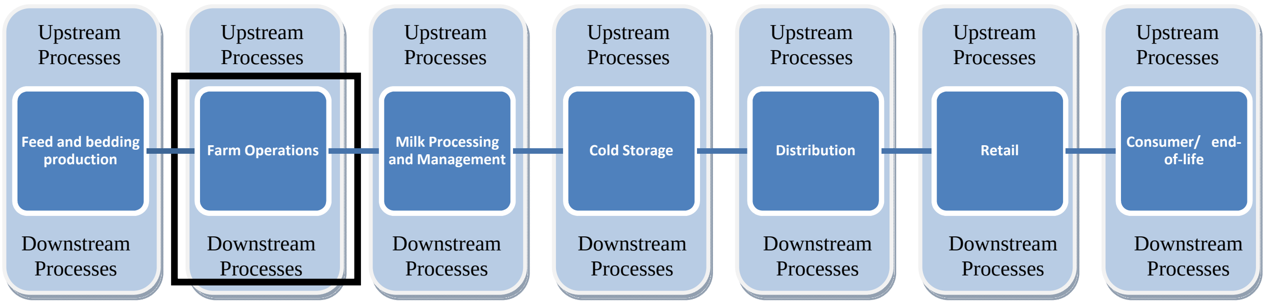

Figure 39. Scope of the Nutrient use EPI calculations in reference to the life cycle of milk production as quantified in the LCA component of this study

Nutrient use EPI methodology is based on commonly accepted mass balance approaches documented by Spears et al. (2003), Thomassen and de Boer (2003) and others. Farm gate, soil surface, and herd mass balances for nitrogen and phosphorus were quantified using the best available methodologies and cross-referenced with other methodologies for accuracy, as explained in the Farm Operations stage in the nutrient use methodology section above.

Surplus and Use Efficiency EPI Formulas

Nutrient surplus and use efficiency formulas are described in Table 15.

Table 15. Nutrient surplus and nutrient use efficiency formulas for N and P, partially adopted from Spears et al., 2003a,b and others

EPI	Calculation
N or P nutrient surplus, pounds	**Total nutrient inputs** [imported feed + imported bedding + imported animals + imported fertilizer + legume fixation (N only) + atmospheric deposition (N only)] — **Product nutrients**[milk products + sold animals]
N or P nutrient use efficiency, unitless	**Product nutrients** [milk products + sold animals] **/ Total nutrient inputs** [imported feed + imported bedding + imported animals + imported fertilizer + legume fixation (N only) + atmospheric deposition (N only)]

Nutrient Use EPI Results and Discussion

It was found that over all farms during the study period, there was a surplus of 1.78 million kilograms of N and 244,000 kilograms of P that had the potential to accumulate in farm systems and the environment. These surpluses correspond to nutrient use efficiencies of

0.26 for N and 0.35 for P. Detailed summaries of surplus and use efficiency can be found in Tables 16 and 17.

Table 16. Annual nutrient surplus by farm

Nutrient Surplus (pounds)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Nitrogen	142,000	349,000	547,000	630,000	107,000	796,000	979,000	1,780,000
Phosphorus	18,200	44,900	70,400	97,000	13,500	102,000	14,200	244,000

Table 17. Annual nutrient use efficiency by farm

Nutrient Use Efficiency

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Nitrogen	0.26	0.20	0.27	0.28	0.25	0.27	0.25	0.26
Phosphorus	0.37	0.29	0.38	0.34	0.37	0.37	0.32	0.35

The largest farms – Coldwater and High Plains – had the largest nutrient surpluses in both nitrogen and phosphorus, as expected. For all calculations, Dipple reports high nutrient surplus for its small size, corresponding to low nutrient use efficiencies. For instance, though the herd size at Platteville was roughly half that of Dipple during the study period, every calculated surplus was over twice as large for Dipple than Platteville. This is consistent with findings that Dipple had the highest P applied to pasture per cow (0.71 kg/cow compared to 0.26 kg /cow for all farms) and lowest milk P output per cow (0.37kg/cow compared to 0.50kg/cow for all farms) of all farms. As noted previously, this finding is slightly uncertain because the data for lagoon irrigation water, compost, and manure application to pastures was compiled from a variety of AOD records by the research team. Though AOD keeps complete records of nutrient applications to pastures, this information may not have been obtained in full by the research team.

In general, N use efficiency was lower than P use efficiency for all farm systems, which is consistent with literature sources.   However, P use efficiency was more variable than N use efficiency despite the relatively simple on-farm P transformations and flows.

Inputs and outputs to all farm systems by month by nutrient for major flows are shown in Figures 40 and 41. Growth in both inputs and outputs corresponds to a growth in overall herd size and milk production, but there may also be some moderate seasonality in purchased feed inputs due to pasture forage uptake and temperature affects on cow metabolism. Exported manure nutrients (calculated by difference) were shown to be highly variable in Figure 40, which is consistent with EPI results. Imported feed, milk output, herd movement, and manure management were found to contain the largest nutrient flows.

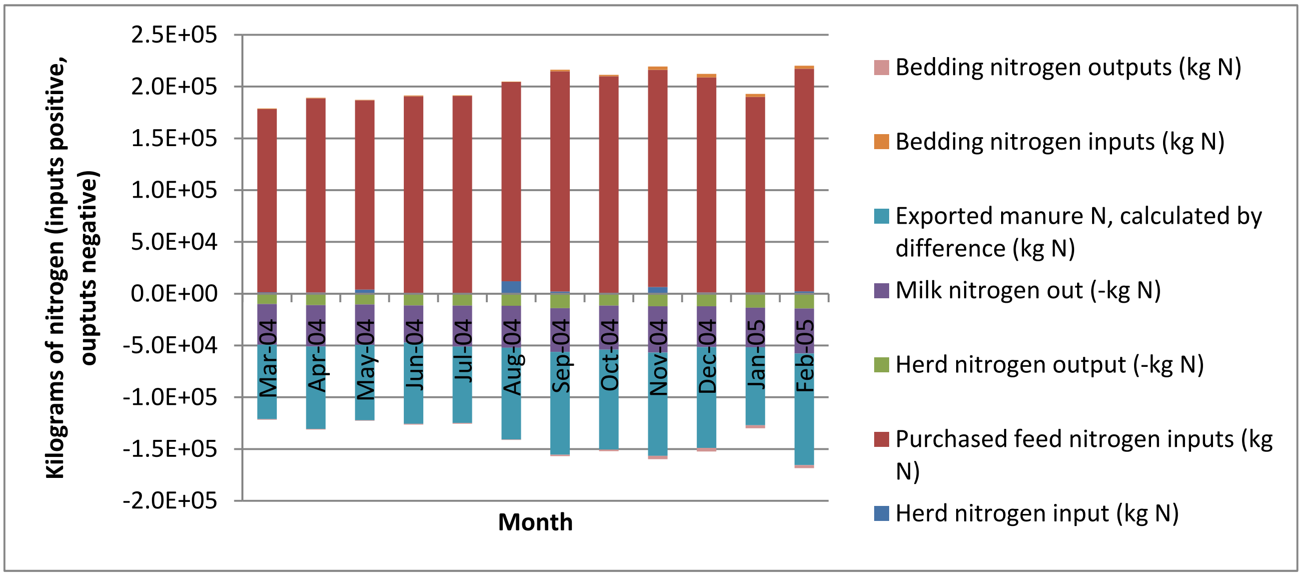

Figure 40. Monthly nitrogen inputs and outputs to all farm systems

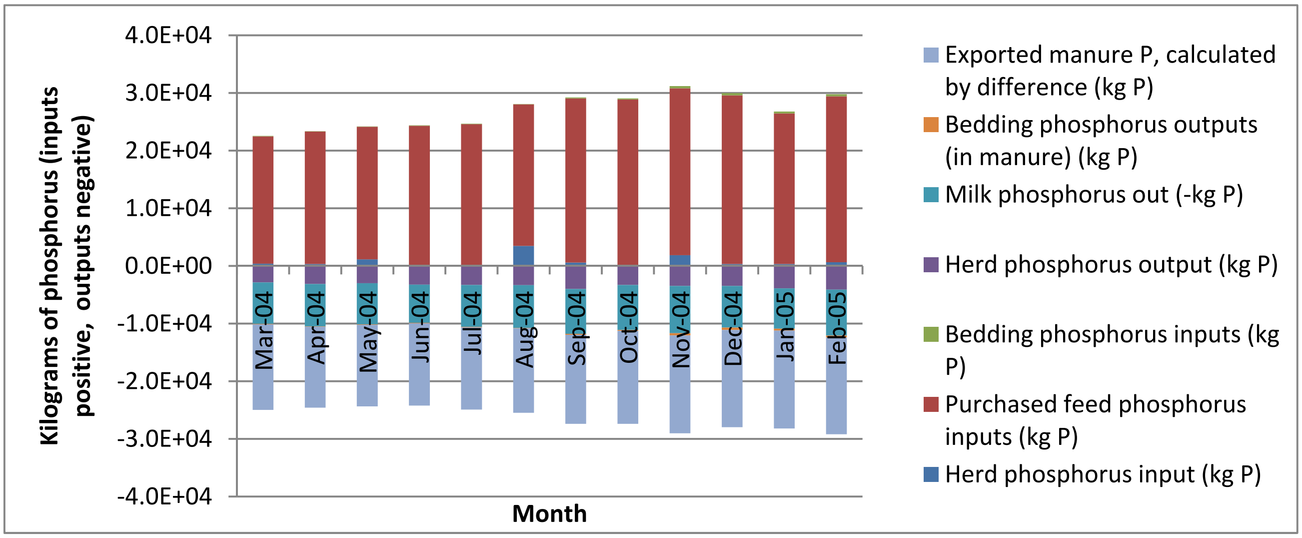

Figure 41. Monthly phosphorus inputs and outputs to all farm systems

Nutrient surplus and use efficiency calculations are useful both for comparing across farm systems and for measuring incremental improvements to farm systems due to management changes. Nutrient surpluses – especially when expressed on a per cow or per area basis – can provide tangible emission factors that can be used to calculate the impacts of operational change. For instance, moving 100 cows from a farm with high nutrient surplus per cow (Dipple with 132 pounds N surplus cow^{-1} $year^{-1}$) to a farm with a low nutrient surplus per cow (High Plains with 108 pounds N surplus cow^{-1} $year^{-1}$) could theoretically prevent the release of ~24,900 total pounds of N into the environment, assuming surpluses/cow are independent of herd size and all management systems remain unchanged (and all gathered data was representative of actual operations.) On the other hand, nutrient use efficiencies are best utilized to benchmark performance over time and to compare the efficiency across different farm systems. Efficiencies are easier to compare between studies because they are dimensionless, so no unit conversions are necessary. Additionally, efficiencies scale with farm size because inputs are divided by total product output unlike surpluses that always grow with increasing farm size. This means that farms of different sizes can be compared accurately, so that any differences in milk production per cow due to farm size will be found.

EPIs for Water Use

In the water use category, the following four EPIs have been selected for their relevance to AOD, and because they are relatively simple indicators that can be used to track operational performance. The four EPIs selected were:

- Total water inputs by source
- Total volume and percentage of water inputs recycled or reused
- Water intensity
- Water use associated with electricity and fuel

Total water inputs by source. This EPI has been proposed by the Global Reporting Initiative (GRI) as a metric for water use in its G3 Guidelines (GRI, 2006). GRI's guidelines are currently the most widely used standards for corporate sustainability reporting, and cover a broad range of areas related to sustainability. They include not only environmental indicators, but social and economic indicators as well.

This particular EPI quantifies water withdrawals, i.e. the total direct water inputs to AOD facilities. As described above, water inputs to AOD facilities consist of municipal water, ditchwater, well water and rainwater. Water withdrawals from municipal supply systems and from ditch companies were easy to track because they involve purchases, and therefore, AOD records contain bills showing the exact amount of municipal water and ditchwater purchased in each month. Well water is more difficult to track, since it is unmetered at AOD farms (except Coldwater). These inputs were estimated using the methodology described above in the Water Use Methodology section.

All water inputs can be classified by source into three categories: rainwater, surface water or groundwater. Almost all water used at Coldwater and Dipple is groundwater, except for the small amount of rainwater collected from building roofs at Coldwater. In Colorado, municipal water and ditchwater ultimately come from surface water runoff in the Rocky Mountains; well water used at High Plains is counted as groundwater; and collected rainwater at High Plains is counted as rainwater. (More detail on AOD's ultimate water sources is given in the Water Use Results and Discussion section above.) It is important to look not only at total AOD water use, but also at each AOD facility separately, because each facility employs a different mix of sources.

Total volume and percentage of water inputs recycled or reused. This EPI is also included in the GRI G3 Guidelines as a measure of how well a company is managing its water inputs (GRI, 2006). A company that is recycling or reusing a larger portion of its water inputs requires fewer water inputs overall, and is, therefore, reducing its burden on local water resources. At AOD farms, a significant amount of water is reused because all water used to flush the milking parlor drains into the lagoon and is then used for irrigation of pastures. At the AOD processing plant, wastewater is pretreated and returned to the local sanitation district so that it can be used again by other parties, but plant wastewater is not included here because that water is not reused within AOD's operations. Employing the methods described above in the Water Use Methodology section, the total volume of lagoon water used for pasture irrigation was estimated, and this was then divided by total water inputs to find the percentage of total withdrawals recycled or reused.

Water intensity. This EPI is not part of the GRI G3 Guidelines, but it is used in a number of studies, including a study of environmental indicators for dairy farms (Meul et al., 2008). It calculates the amount of water used on a farm per gallon of raw milk produced, following the "eco-efficiency" indicator concept—i.e. that companies should measure their environmental impacts per unit of product, and then endeavor to reduce this number by increasing the efficiency of their production processes. The water intensity EPI provides important information not covered by the "total withdrawals" EPI, because a farm with large total withdrawals may be more water-efficient per gallon of milk than a smaller farm. To calculate this ratio, the total water withdrawals at each farm were divided by the total gallons of raw milk produced at each farm.

Water use associated with electricity and fuel. In addition to direct water use at AOD facilities, it is important to account for the indirect water use associated with AOD's consumption of electricity and fuel, because the production of both requires significant amounts of water inputs. This study quantifies this water use according to the sources described above in the Water Use Methodology section, which estimate that:

- 4.27 gallons of water are used per gallon of gasoline and diesel
- 1.83 gallons of water are used per gallon of propane
- 3.0×10^{-6} gallons of water are used per BTU of natural gas
- In Colorado, 1.68 gallons of water are used per kilowatt-hour generated; at Dipple, 13.8 gallons of water are used per kilowatt-hour generated; at Coldwater, 6.89 gallons of water are used per kilowatt-hour generated

It will be important to update these numbers as more accurate and more current data become available in the future. Because of growing interest in the “energy-water nexus” (a term for the fact that energy and water are tightly interconnected, because energy production requires significant water use, and the provision of clean water requires significant energy use), it is likely that better data on the water use associated with energy production will soon be published.

Water Use EPI Formulas

Table 18 summarizes the formulas used to calculate each water use EPI.

Table 18. Water Use EPI Summary

EPI Name	Formula
Total water inputs by source	(Inputs from surface water) + (inputs from groundwater) + (inputs from rainwater)
Total volume and percentage of water inputs recycled or reused	(Lagoon water for pasture irrigation)/(total water inputs)
Water intensity	All AOD facilities: (Total water inputs)/(total gallons of finished milk produced) AOD farms: (Total water inputs)/(total gallons of raw milk produced)
Water use associated with electricity and fuel	(Total water use for gasoline) + (total water use for diesel) + (total water use for propane) + (total water use for natural gas) + (total water use for electricity)

Water Use EPI Results and Discussion

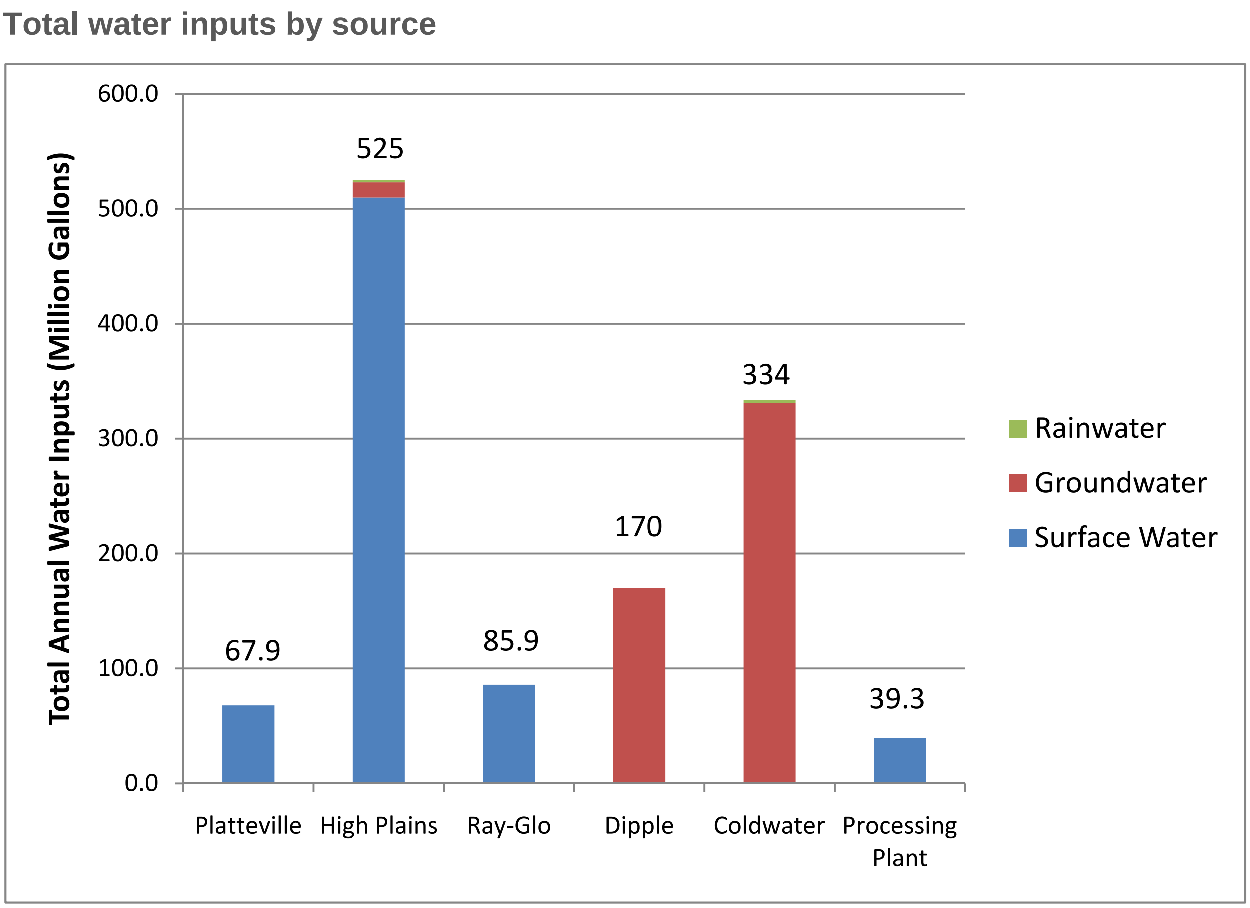

Figure 42. Total annual water inputs by source at each AOD facility

Figure 42 shows the results for this EPI. Total annual water inputs to all AOD facilities during the Phase II time period amount to 1.22 billion gallons of water. High Plains contributes 43% of this total, Coldwater contributes 27%, Dipple contributes 14%, and the other facilities each account for less than 10%. High Plains and Ray-Glo show high water inputs (relative to the amount of milk they produce) because they purchase larger amounts of ditchwater for irrigation purposes. Across all facilities, 58% of water inputs come from surface water sources, 42% come from groundwater, and 0.37% come from rainwater. These results demonstrate that AOD is a large water user and that different water sources are important in different regions. In Texas, groundwater is the major source, while in

Colorado surface water is the major source. Rainwater is an insignificant source, and though it would be preferable to use more rainwater at AOD facilities (in order to decrease pressure on surface and groundwater resources) this is legally risky because the State of Colorado restricts the amount of rainwater that can be collected by property owners.

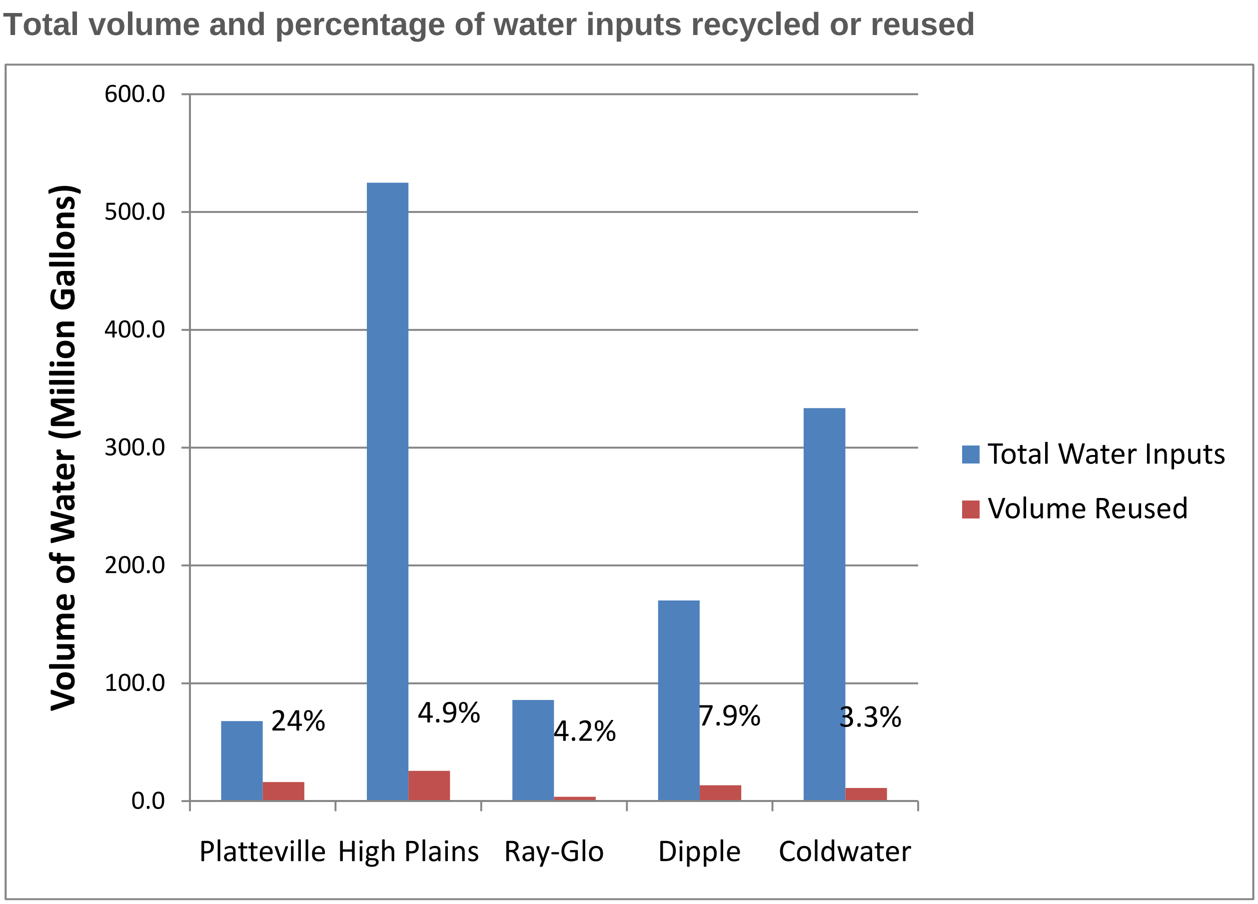

Figure 43. Total water inputs, volume of water reused, and percentage of inputs reused at each AOD farm

Figure 43 compares reuse rates at all five AOD farms. Approximately 70 million gallons of water were reused at all AOD farms during the Phase II time period, which was calculated as 5.7% of total water inputs. The reuse rate at Platteville was significantly higher than at the other farms (24%), probably due to the fact that Platteville uses less irrigation water per gallon of milk produced, so that the lagoon water makes up a larger portion of total irrigation water used. At all locations, 100% of the lagoon water is used for irrigation.

While AOD does maintain pasture irrigation records, these records were not compatible with the data required for this study. Monitoring designed with this EPIs data needs in mind could improve the accuracy of this EPI and may reveal that the actual reuse rate is higher than this estimate. AOD farms may be able to find ways to reuse and recycle more water, such as by capturing more of the water used for domestic purposes or for the washing of farm vehicles.

Water intensity

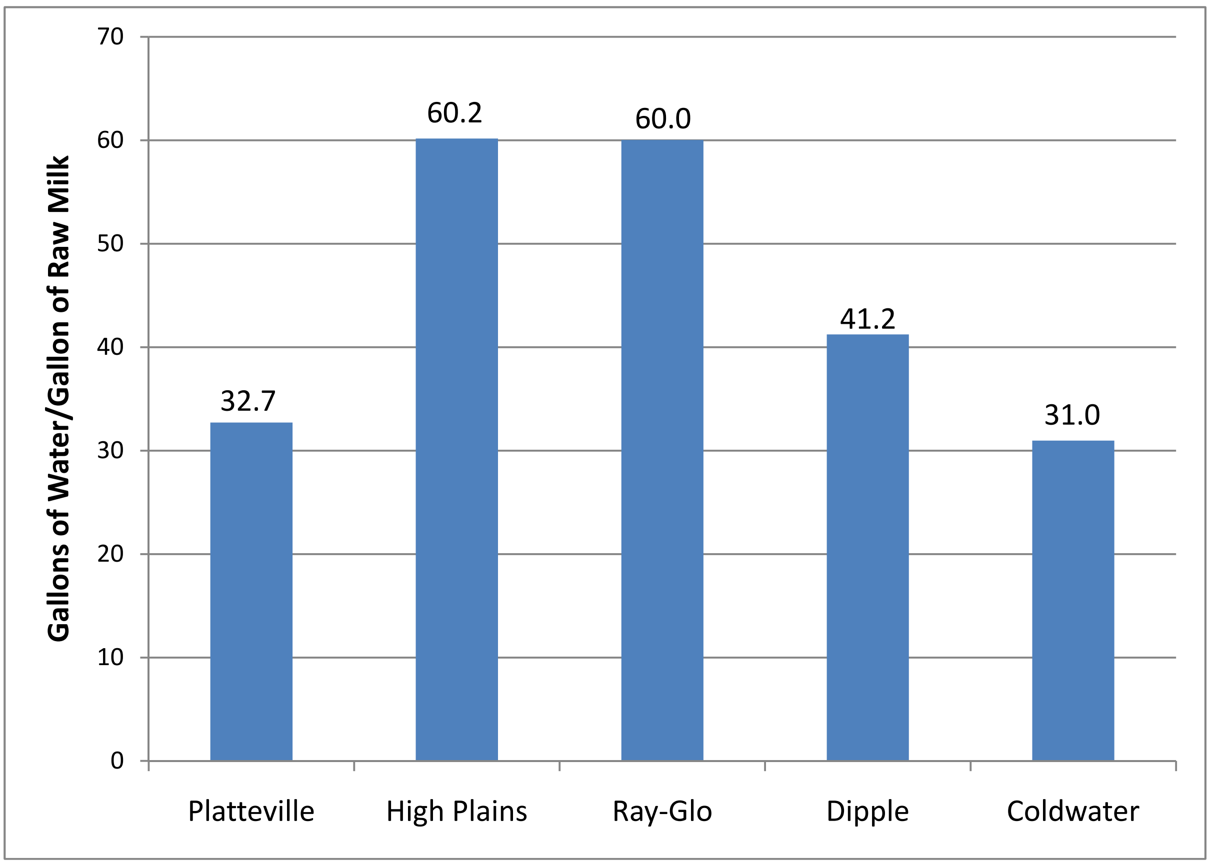

Figure 44. Water intensity at each AOD farm

Figure 44 shows that High Plains and Ray-Glo require the most water inputs per gallon of raw milk produced. Again, this is due to the relatively larger amount of irrigation water applied at these farms. For all AOD facilities, including the processing plant, the result was

54 gallons of water used per gallon of finished milk produced. While the full life cycle results given above in the Water Use Results and Discussion section indicate that water use for the Feed and Bedding Production stage is much greater than water use at the AOD Farm Operations stage, these EPI results demonstrate that there is substantial water use that is under the direct control of AOD operations, and therefore, opportunities for management to reduce this direct water use.

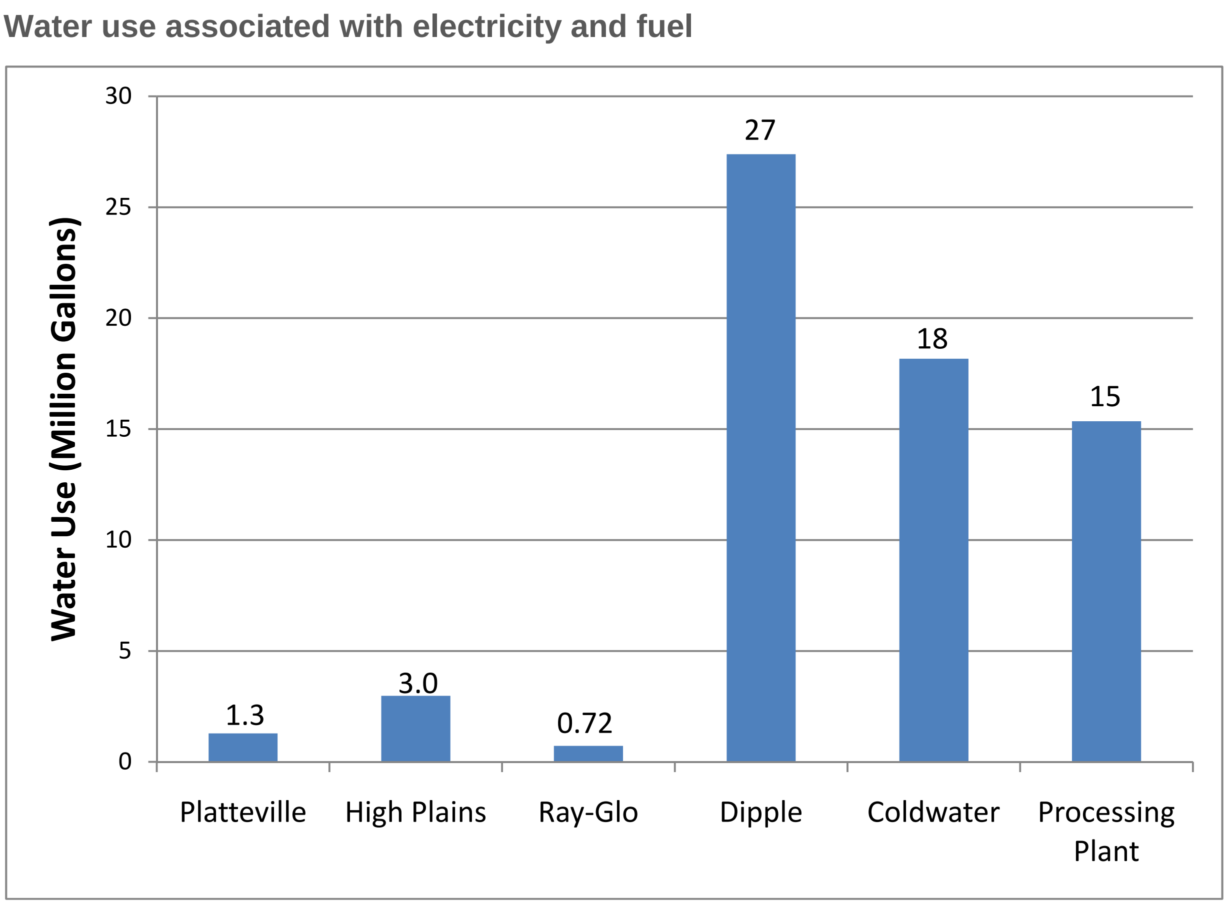

Figure 45. Water use associated with electricity and fuel consumption at each AOD facility

Figure 45 shows that Dipple's indirect water use associated with electricity and fuel is significantly higher than the other AOD farm, because the regional electric grid in which it is located is more water-intensive than at the other farms. Coldwater's grid is also significantly more water-intensive than the Colorado grid, which serves the other farms and the plant. The fact that the processing plant value is much higher than the Colorado farms simply indicates that the plant uses much more electricity than the farms. The total indirect water use at all AOD facilities was approximately 66 million gallons.

Solid Waste EPIs

The U.S. EPA promotes a three prong strategy with regard to SW management in the U.S.: source reduction first, recycling second, and finally disposal (EPA, 2008). This study attempts to lay the groundwork for future AOD waste management strategies in line with EPA philosophy by developing a solid waste environmental performance indicator (SW EPI). The indicator will be used in the evaluation of waste generation and implementation of reduction strategies best suited for AOD.

The three EPIs selected for assessing Solid Waste Generation are:

- Quantity of DMSW
- Characterization of MSW
- Recycling Ratio

New Zealand's Ministry for the environment utilized similar EPIs to assess the state of solid waste in New Zealand (New Zealand Ministry for the Environment, 1998).

The Quantity of DMSW measures DMSW and RMSW generated in kilograms, occurring at AOD farms, the AOD milk processing plant, distribution, as well as end of life consumer packaging waste. The Characterization of SW EPI, characterized the composition of AOD DMSW for these same stages as well as RMSW for the milk processing plant, Distribution, and the Consumer/End-of-Life stages. The Recycling Ratio EPI, was calculated for the Farm Operations, Milk Processing and Management, Distribution, and the Consumer/End-of-Life stages. By benchmarking AOD's SW with these performance indicators AOD can implement a strategic waste management plan successfully.

Solid Waste Generation EPI formulas

Formulas for quantifying SW EPIs are summarized in Table 19.

Table 19. MSW EPI formulas

Environmental Performance Indicator	Description	Stages Assessed
Quantity of DMSW	weight produced annually in grams & weight (g) per finished gallon fluid milk	Farm Operations, Milk Processing and Management, Distribution, and Consumer/End-of-Life
Characterization of MSW	Material composition of MSW	Farm Operations, Milk Processing and Management (Gabletop carton waste and RMSW only), Distribution (MSW associated with AOD product packaging), Consumer/End-of-Life (MSW associated with AOD product packaging),
Recycling Ratio	Amount RMSW/Amount DMSW	Farm Operations, Milk Processing and Management, Distribution (MSW associated with AOD product packaging), Consumer/End-of-Life (MSW associated with AOD product packaging),

Solid Waste Generation EPI Results and Discussion

Quantity of DMSW

Using the Farm Operations DMSW methodology calculations, the total annual weight (kg) of DMSW for Farm Operations was calculated. AOD farms did not recycle during the time of the study, therefore, RMSW is not reported here. Results are reported below in Table 20 by individual farm totals, component totals. The overall DMSW total is179,154. kg per year. It should be noted that these calculations only account for the largest MSW contributors to farm operation waste, therefore, this number underestimates total DMSW weight. Conducting a full waste sort study of AOD Farm Operations DMSW could improve the level of accuracy of this EPI.

To consider DMSW associated with milk production occurring at the Farm Operations stage, as well as each farm individually, DMSW results were divided by the amount of raw milk each farm produced during the study period. Results are shown in Figure 20 below. These results seem to illustrate that farms which produced greater quantities of raw milk during the study period (a result of herd size) are more efficient because the level of DMSW produced begins to be distributed over a larger quantity of milk product.

Table 20. Annual DMSW (kg). Reported by main component categories and individual farms

	Udder Wipes	Total Twine	Total Bags	Nitrile Gloves	Filter Socks	Silage Plastic	Farm Totals
Coldwater	54,000	954	293	2,080	10,500	864	68,600
Dipple	20,300	773	375	782	7,150	0.00	29,400
High Plains	40,700	1,190	175	1,570	8,250	864	52,800
Ray-Glo	6,820	382	1,810	264	4,950	0.00	14,200
Platteville	9,900	318	246	382	3,300	0.00	14,100
Total:	132,000	3,620	2,900	5,080	34,100	1,730	**179,000**

The overall quantity of the DMSW (kg) produced annually by the Milk Processing and Management stage was calculated using the methodology discussed above in the MSW generation section. However, individual component contributions to this total were not calculated. It was possible to calculate the amount (kg) of total processing plant waste resulting from the gabletop cartons (e.g. leakers whose packaging is disposed at the processing plant) using the methods described earlier. Additionally, the recycling contractor provided detailed information regarding overall RMSW amounts (kg) and individual components.

The gabletop cartons contributed 135,734kg to (166,379 kg DMSW – 30,663.62kg RMSW) or 65% of total AOD DMSW at the processing plant. These results are shown in Table 21 below in terms of annual weight (kg) and DMSW (g) per finished gallon of fluid milk. This table also reports this information in terms of raw material composition. This figure does not account for amounts of this DMSW diverted through recycling at the processing plant. Other processing plant DMSW components include cardboard that becomes wet preventing recyclability, waste bags delivering milk powder, Styrofoam packaging peanuts, employee garbage (e.g. trash from lunches), etc.

Table 21. Annual Weight (kg) of waste associated with gabletop cartons disposed at plant due to defect

Component	Paperboard	LDPE	EVA	HDPE	Total
Annual Weight DMSW (kg)	148,000	14,200	2,300	1,880	166,000

The RMSW quantities are shown in Table 22 below. This table reports weights (kg) in annual total as well as amount (g) per finished gallon of fluid milk. Recycling efforts diverted 363,121 kg of waste from landfills and incineration.

Table 22. Milk Processing and Management Recycling (kg) for the study period.

Material	Cardboard	Gabletop Cartons	Labels	Plastic Stretch Wrap	Office Paper	Pallets and Wood Scrap	Plastic from Blow Mold	Plastic from Barrels	Metal	Total
Annual RMSW (kg)	175,000	30,700	2,560	814	1,120	73,500	41,100	16,500	21,900	363,000

During the Retail stage of the lifecycle bundled pallets of AOD milk are separated and prepared for individual unit sale. This means that the secondary packaging is disposed at this stage. Methods for calculating this secondary packaging were described above in the MSW waste methodology section. This DMSW included cardboard, shrink wrap and tape.

Table 23 below reports the quantity of DMSW and RMSW produced annually. Cardboard comprises the largest portion of this DMSW. Cardboard was the only component at this stage with a national recycling rate greater than one percent (72% national recycling average for cardboard), therefore, it was the waste for which recycling was considered.

Table 23. Amount of Retail RMSW and DMSW produced annually (kg) and in terms of grams per finished gallon of fluid milk

	Cardboard	Plastic Wrap	Tape	Total
Annual RMSW (kg)	1,700,000	0	0	1,700,000
Annual DMSW (kg)	662,000	28,300	43,100	733,000

As was shown earlier the Consumer/End-of-Life stage is responsible for a 71% of AOD DMSW. The results in Table 24 below show the compositional makeup of this stage's DMSW as well as the total annual overall (kg) DMSW and RMSW weights. Results are also reported in terms of grams produced per finished gallon of fluid milk.

While gallon containers of AOD milk are composed of HDPE, which has a national recycling rate of 28%, the majority of AOD milk is sold in the paperboard gabletop containers whose national recycling rate is much lower (1%) (Franklin, 2007). Paperboard, the main component in gabletop packaging, contributes the most waste (kg) to DMSW. The HDPE gallons, recycled at a national rate of 28%, divert the most MSW as RMSW (kg). The majority of AOD product is packaged in the gabletop cartons (roughly 93%), therefore, this has a much more significant impact on overall recycling at this stage.

Table 24. Amount of Consumer/End-of-Life RMSW and DMSW produced annually (kg) and in terms of grams per finished gallon of milk

	Paperboard	LDPE	EVA	HDPE from Gabletops	HDPE from Gallon containers	Totals
Annual RMSW (kg)	22,700	2,170	352	288	27,100	52,600
Annual DMSW (kg)	2,270,000	217,000	35,000	28,800	96,900	2,640,000

Characterization of MSW

Considering the individual components comprising AOD DMSW at various operational stages can help AOD better understand areas where waste reduction strategies can be best implemented. Therefore, the characterization of MSW EPI was created and utilized to assess DMSW and RMSW where enough information was available. For the farm stage, the portion of the main DMSW components was assessed and reported (Figure 46). The plant processing stage's DMSW lacked sufficient information to accurately assess overall DMSW, however, an assessment of overall RMSW waste was possible and results are shown above in Figure 22. The characterization of the Retail and the Consumer/End-of-Life stages only accounts for DMSW associated with AOD milk packaging (primary and secondary packaging).

Farm Operations DMSW is dominated by udder wipes as shown in Figure 46, which shows the individual contributions of the major waste pieces occurring at AOD farms. As the figure shows, udder wipes dominate the Farm Operations waste stream, accounting for 73%. The filter socks account for 19% of on-farm waste.

These results can guide waste management strategies. For example, switching from disposable wipes to reusable washable wipes would have an impact on total overall DMSW.

Additionally, they highlight the point that some DMSW generation can be challenging to reduce. Considering the second largest contributor, filter socks' functional purpose, milk filtration, it becomes clear that their purpose is critical to the overall quality of AOD's product and are probably an unlikely target for waste management strategies.

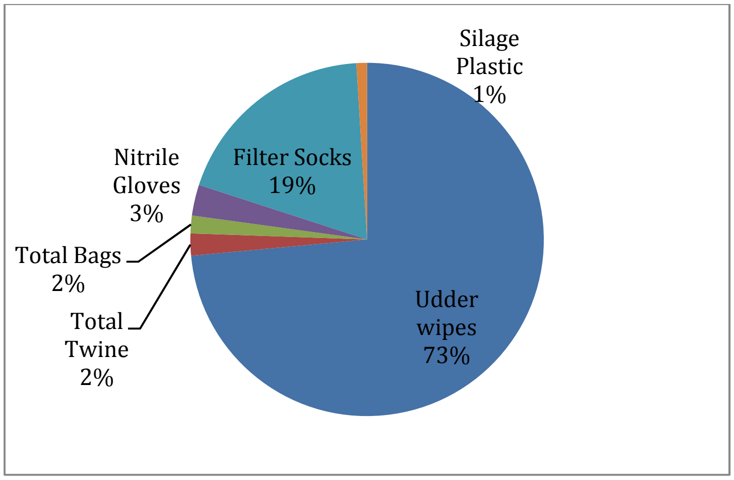

Figure 46. Farm Operations DMSW material composition by percent contribution to overall DMSW)

The characterization of RMSW from the processing plant illustrates what types of material are being diverted from the waste stream (Figure 47). By recycling these goods, AOD prevents further resource depletion of the given raw material comprising these goods, as well as avoids greenhouse gas emissions and environmental harms associated with these materials' decomposition in landfills or incineration.

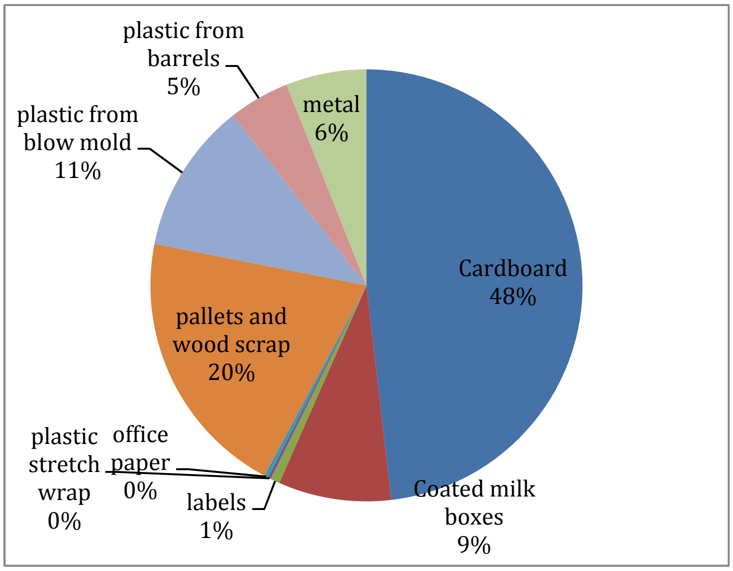

Figure 47. Milk Processing Stage DMSW diverted from landfill through recycling by percent contribution to total amount recycled

Figure 48 characterizes secondary packaging disposed at the Retail stage of the life cycle. Exterior cardboard packaging (removed, for individual product retail), dominates this stage. This highlights the potential for packaging reconfigurations which reduce the reliance on outer packaging during bulk shipping.

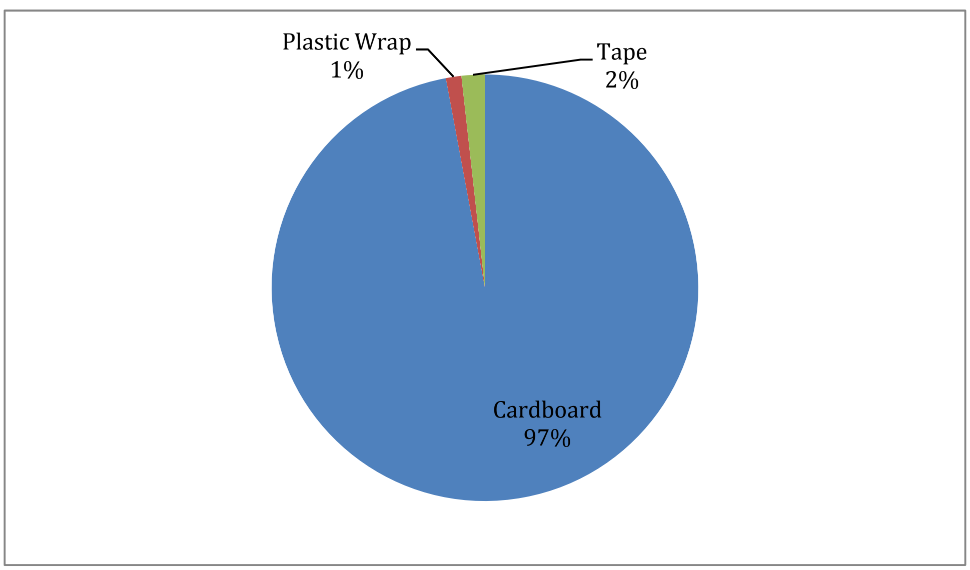

Figure 48. Overall composition of Retail DMSW (percentages do not exclude RMSW) by percent contribution to total amount of MSW (excludes ISW).

Figure 49 characterizes primary packaging disposed at the Consumer/End-of-Life stage. This figure includes both half gallon gabletop carton waste and high density polyethylene gallon waste. The paperboard which forms the exterior of the gabletop cartons (the primary packaging type) is the main component. The LDPE (low density polyethylene) component is the second largest contributor. It is used to waterproof the paperboard component of the gabletop carton. Finally, the third largest contributor is the "HDPE Gallon," which encompasses the entire packaging for the gallon carton. The remaining "HDPE gabletop" is from the gabletop's cap, and the EVA (ethylene-vinyl acetate) is used as an adhesive for the gabletop.

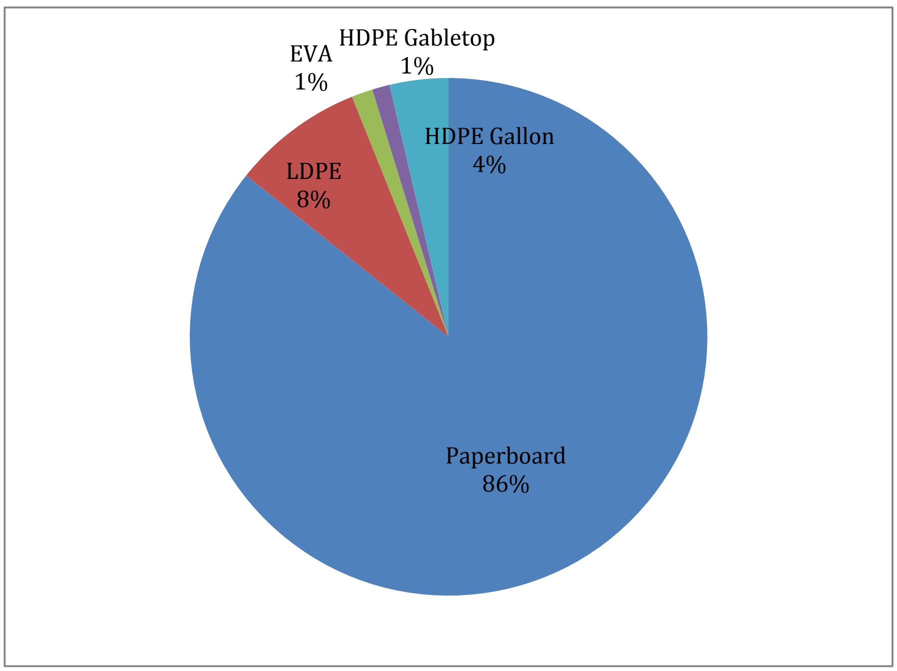

Figure 49. Overall composition of Consumer/End-of-Life DMSW (percentages do not exclude RMSW) by percent contribution to total amount of MSW (excludes ISW)

Ratio of Recycled MSW to Direct MSW

To determine or measure AOD's performance in an attempt to divert DMSW ratios of recycled MSW to DMSW at the Farm Operations stage, Milk Processing and Management stage, Retail stage, and Consumer/End-of-Life stage was calculated. The results of these calculations are illustrated in Table 25 and Appendix L. The totals used to calculate these ratios were derived from the RMSW and DMSW methodologies discussed above in the MSW generation section.

Overall, the Farm Operations stage presents the greatest opportunity in regard to this indicator due to the absence of any recycling efforts. The Milk Processing and Management stage performed well, recycling over 50% (64% or 339.48 tons) of total MSW generated on site. The performance of these two stages was assessed using information obtained directly.

The latter two stages, Distribution and Consumer/End-of-Life, relied upon national average recycling rates (referenced above) to estimate performance. The Retail stage, with regard to AOD secondary packaging waste, performs quite well, mainly due to the high national recycling rate of cardboard (72%), which is also the dominate waste component in this stage (97%)(CSS, 2010). The Consumer/End-of-Life stage performs poorly with regard to this performance indicator, only recycling 1% of overall waste. This small recycling ratio results from the fact that the gabletop carton (the dominant packaging type) has a low national recycling rate (1%) (Franklin, 2007).

In regard to this EPI, AOD has a direct impact on farm performance as well as the processing plant. While results suggest the processing plant is performing well, potential for management strategies at AOD farm operations exist. The first being a strategy aimed at implementing recycling efforts. It should be noted that the remote locations of some farm operations can make recycling efforts economically prohibitive and strategies should consider not only environmental improvement implications but financial components as well.

Table 25. Results for the recycling ratio EPI

Life Cycle Stage	Percent DMSW	Percent RMSW
Farm Operations	100%	0%
Milk Processing and Management	36%	64%
Retail	30%	70%
Consumer/End-of-Life	99%	1%

Conclusion

Key Findings

Key findings are summarized in Table 26 below.

Table 26. Key findings for all assessment categories

Category	Result per gallon of packaged fluid milk (functional unit)	Equivalent to…
Energy Use	67.7 MJ	1.54 gallons of gasoline (LHV)
Global Warming Potential	7.79 kg CO_2eq	17 miles driven in a car
Acidification Potential	4.62 moles H+ eq	17 kWh of electricity (US grid avg.)
Eutrophication Potential	2.5 grams N eq	3 pounds of urea fertilizer
Water Consumption	808 gallons	16 (50 gal.) bathtubs
Water Utilization	12 gallons	7.5 low-flow toilet flushes
DMSW	160 grams	About 5 ½ ounces
IMSW	156 grams	About 5 ½ ounces

Nutrient Use

Most of the eutrophication and acidification impacts from milk production were due to emissions from the Feed and Bedding Production and Farm Operations stages of the milk life cycle. The overall life cycle acidification impact of 4.62 moles H+ equivalents per gallon of packaged fluid milk was due mostly to releases of ammonia from crop fertilization and manure management, but energy related sulfur oxides, nitrogen oxides, and other releases contributed significantly in stages downstream of Farm Operations. The overall life cycle eutrophication impact of 2.5 grams N equivalents per gallon of packaged fluid milk was mostly due to nitrate releases from crop fertilization in the Feed and Bedding Production stage, though phosphates and ammonia were significant in both the Feed and Bedding

Production and the Farm Operations stage. There were very few eutrophication impacts downstream of the Farm Operations stage.

Nutrient use efficiencies varied between farms with a range of 0.20-0.28 for N and 0.29-0.38 for P. For all farms, overall N and P use efficiencies were 0.26 and 0.35, respectively, with an associated total surplus of 1.78 million pounds of N and 244,000 pounds of P over one year. Both nutrient use efficiencies fell within the published range of nutrient use efficiencies in the literature, but comparisons must be made cautiously because there are no studies of large-scale US organic dairies similar to AOD for comparison. Regardless, nutrient use efficiency at AOD farms compares favorably to many conventional and organic farm systems of various sizes, but room for improvement remains.

Nutrient releases from the Farm Operations stage were the most certain due to the availability of primary data, while the Feed and Bedding Production releases were the least certain due to a lack of supplier-specific management data. Because of this limitation, conventional production datasets were relied upon for certain crops, which probably led to an overestimation of nutrient releases and, therefore, eutrophication and acidification impacts. For nutrient surplus and use efficiency, uncertainty was mainly due to the use of average datasets for feed crop nutrient content and manure nutrient content.

Water Use

Freshwater is a vital resource for the milk production life cycle, and AOD can benefit greatly from knowing more about where its water comes from, how much water it uses and where, what the impacts of its water use are, and how it can improve its performance with regard to water use. This study found that, throughout the life cycle, there were 808 gallons of water consumption and 12.3 gallons of water utilization per gallon of packaged fluid milk. These numbers show that about 99% of water inputs end up as water consumption, meaning that any future reductions in water use in the milk life cycle will have a direct benefit in terms of increasing the amount of water available for other users in the same watersheds.

This very large result (820 gallons water used per gallon of packaged fluid milk produced) shows that more research into water use is necessary, in order to fully understand AOD's financial risks (increasing prices) and operational risks (adequate supply) related to water. Freshwater scarcity is a strategic issue for agricultural businesses in the American West, and developing a detailed picture of its water use in its own operations and throughout its supply chain will help AOD maintain its leadership position within the dairy industry. The effects of increasing demand for water may be exacerbated by climate change, which could reduce total water availability in the coming decades and thereby further heighten competition over water.

Crop production in the Great Plains and Rocky Mountain regions is a very water-intensive process, and the water use associated with feed and bedding production makes up 94% of total life-cycle water use. This consumptive use is highest at High Plains and Coldwater, accounting for 39% and 28%, respectively, of the total water consumption associated with feed and bedding across all farms. This is attributable to the fact that these are the two largest farms, and hence the largest purchasers of organic feed and organic bedding. Alfalfa production accounts for 55% of the total water consumption associated with feed and bedding across all farms, due to the fact that it is typically ordered in the largest quantities and has a lower yield compared to the other feeds that were ordered in large quantities.

However, there is a high level of uncertainty surrounding irrigation for crop production with regard to the exact locations of organic feed/bedding production, as well as the specific irrigation methods used by the growers. In place of such hard data, CROPWAT 8.0 provides a theoretical estimation of the water required to grow a particular crop in a particular climate. It is highly probable that many of the feed growers are using less irrigation water than was estimated or, perhaps, not irrigating at all. The irrigation numbers calculated in CROPWAT should be considered an upper bound, rather than an average.

Water use at AOD facilities accounts for 4.6% of total life-cycle water use. This is broken down as follows: 70% is for pasture irrigation (throughout the life cycle about 97% of all water use is for irrigation); 19% is for on-farm purposes besides irrigation, mainly drinking water for cows and water used for sanitation in the milking parlor; 4.6% is for the processing plant; and about 5% is associated with the generation of electricity and the production of fuel that AOD purchases for its facilities. As with feed and bedding production, there is uncertainty about the water use at AOD facilities. In particular, there are no exact records of how much lagoon water was applied for irrigation at the farms, nor are there records of the amount of well water used at High Plains or Dipple. In the rest of the milk life cycle from Cold Storage to end-of-life, only water use associated with electricity and fuel were included, and this accounted for 1.3% of total life-cycle water use.

Turning to the environmental impacts from water consumption, purchased feeds such as alfalfa, grass silage and corn silage are produced in watersheds with low levels of stress, resulting in lower levels of water deprivation relative to the water consumption for those feed types. Dipple had the lowest level of water deprivation for feed and bedding production at 28% of water consumption, indicating that it sources a majority of feed/bedding from areas of low water stress. Coldwater had the highest level at 44% of water consumption, indicating that it sources a greater percentage of its feed from areas of higher water stress. In the Farm Operations stage, Dipple and the Colorado farms are all located in areas of high water stress, and 100% of their water consumption leads to water deprivation. At Coldwater, only 18% of water consumption leads to water deprivation, but this is misleading because Coldwater draws from the Ogallala Aquifer, a nonrenewable water resource. 88% of water use at Coldwater contributes to permanent depletion of the Aquifer, and therefore reduces the amount of water available for future users in the area. Again, can we put this into perspective? But, as noted above, Coldwater is no different in this regard than the many other farms, municipalities, and industries throughout the region that rely on Ogallala water. Overall, about 35% of water consumption for organic feed and organic bedding production leads to water deprivation, while 87% of water consumption for Farm Operations and milk processing lead to water deprivation.

Overall, the watersheds where AOD's feed and bedding are grown tend to have very high or very low levels of water stress. However, more specific information on the location of growers is needed to pinpoint the exact watersheds in which the feed and bedding are grown. Nevertheless, sourcing a greater percentage of feed and bedding from areas of low water stress would reduce the water deprivation associated with feed production. These areas of low water stress include Fairfield, ID, Yates Center, KS, Elgin, OK, Stratford, TX, Holstein, NE, and Wisconsin. However, several of these locations draw from the Ogallala Aquifer, which is currently being depleted; the WSI does not account for this. Taking the depletion of this aquifer into account could substantially alter the picture of water stress in these regions, and make some regions with low WSI values look much worse in terms of water resources.

Table 27. Water Use EPI Summary

EPI Name	Total Annual Result for All AOD Facilities
Total water inputs by source	1.22 billion gallons (58% surface water, 42% groundwater, 0.37% rainwater); Colorado farms use mostly surface water, and Texas farms use mostly groundwater; individual farms range from 67.9 to 525 million gallons of water inputs
Total volume and percentage of water inputs recycled or reused	70 million gallons reused, or 5.7% of water inputs; individual farms range from 3.3% to 24% of water inputs reused
Water intensity	54 gallons of water used per gallon of finished milk; individual farms vary from 31 to 60 gallons of water used per gallon of raw milk produced
Water use associated with electricity and fuel	66 million gallons; individual farms range from 0.72 to 27 million gallons of indirect water use

EPI results, shown in Table 27, show that AOD operations require a substantial amount of water, and that the sources of this water differ by region. They also show that there are likely to be opportunities to reuse more water on AOD farms, and that there are significant differences between farms in terms of water intensity and the water intensity of the electric grid.

Solid Waste Generation

This study indicated that one gallon of finished fluid milk produced by AOD results in the generation of 156g of ISW and 160g DMSW. 93.9g of DMSW is diverted from landfills and incineration due to recycling efforts undertaken by AOD, retailers and consumers. Given the small difference between ISW and DMSW, the finding suggests that efforts to reduce overall MSW should focus both on lowering DMSW generated by AOD directly, as well as efforts to lower their overall energy consumption and fuel use, thereby reducing their overall ISW.

The Consumer/End-of-Life stage has the highest contribution for both ISW (38%) and DMSW (71%). With fewer than 3% of overall recycling efforts occurring here, it is clearly the area to focus reduction strategies. The electricity used for refrigeration is the main contributor to the ISW generation at this stage. Because the need for refrigeration cannot be easily avoided, it would be more feasible to focus efforts on reducing DMSW.

The Retail stage performed the best with regard to recycling. It was responsible for 80% of the overall amount recycled. This finding was not surprising given that this stage's dominant DMSW component is cardboard which has a very successful national recycling rate.

Milk processing was responsible for 26 percent of ISW, the second largest contributor. This is due to the large amount of energy required to process milk.

When considering farms individually, farms with smaller herd sizes contributed more DMSW than farms with larger herd sizes. It is believed this is an effect of waste production being distributed over larger milk production which occurs with larger herd sizes.

The udder wipes were the largest individual component of farm operation waste, contributing a total of 131,700 kg annually. Recycling did not occur at Farm Operations during the timeframe of the study. The milk processing stages DMSW was dominated by gabletop cartons, which contribute 148047 kg annually to AOD DMSW. The milk processing RMSW was dominated by cardboard with 174909 kg being diverted annually. The Retail stage was composed of predominately cardboard, with 1701180 kg being diverted from recycling and 661570 kg being disposed either in a landfill or through incineration. Finally the gabletop cartons were the predominant waste for the Consumer/End-of-Life stage. Gallon cartons contribution was found to be negligible given that they only make up 7 percent of overall product packaging.

It was found that the Farm Operations stage performs the worst with regards to recycling (0%), followed by the Consumer/End-of-Life stage (1%), then the processing plant with 64%, and retail performing the best with recycling 70% of total waste.

Methodology issues and future refinements

Nutrient Use

Feed and Bedding Production data uncertainty

Because most of the cycling of nutrient relevant to AP and EP occur on the soils where crops are raised, higher quality information is needed on the agricultural production impacts of AOD's organic feeds. SimaPro datasets provide an accurate inventory for conventional production, but the organic producers working with AOD do not use inorganic fertilizers and biocides and are likely to manage crops differently than the average conventional farm. Since AOD uses large quantities of feed for milk production, small differences in management practices could lead to big differences in LCA impacts. For these reasons, suppliers should be encouraged to disclose management practices or conduct LCI's that accurately portray organic production. If AOD was collecting management details from its feed suppliers, the life-cycle impacts due to nutrient use would be more certain, which would lead to more informed environmental solutions.

Organic Feed and Organic Bedding nutrient content

Because AOD farms require an overall large quantity of organic feed, small differences in nutrient contents for feed types could potentially have a large impact on farm mass balances and surpluses. Nutrient contents of feeds vary widely by source, and ultimately the NRCS Crop nutrient Tool (NRCS, 2009) was relied upon to increase reliability and consistency of data. However, it was not uncommon for the nutrient content of the same crop to differ by a factor of two between sources, so measured nutrient contents of actual AOD organic feed and organic bedding would improve data accuracy significantly.

Lagoon water, settling pond solids, and spread manure application logs

It was not possible to obtain a full set of records for any AOD farm that consistently tracked the application of manures, lagoon irrigation water, and settling pond solids to pastures. Though logs documenting these applications were kept, they were housed in various locations, managed by many staff members, accounted for with a variety of formats that required the agglomeration of data from various sources to arrive at a complete dataset. Platteville had the most accessible documentation of all application types. More accessible application logs would likely lead to a more consistent and accurate dataset for nutrient release inventories.

Water Use

Metering

For effective management and conservation of water, it is essential to have more exact, detailed measurements of water use at AOD's facilities. Metering can encourage decreased use of water as it draws more awareness to actual daily water use. It is highly recommended that AOD install flow meters in its facilities to give a more precise measurement of actual water use. Water flow meters measure the velocity of water moving through the pipes on which they are placed. Some meters specifically provide the total amount of water, while others only provide the speed and additional calculations are required (Mathews, 2000). For AOD's purposes, it would be most efficient to install meters that show both the flow rate and the total gallons. The most important places to install meters are at pipes entering and leaving the milking parlors, pipes entering and leaving the lagoons, and the pipes associated with irrigation water. In addition the installation of meters may reduce time and labor spent tracking water use. It is also important that meters be installed on the wells at High Plains and Dipple in order to know exactly how much groundwater is being extracted at those farms.

Since water for the irrigation of pastures is one of the most significant uses at AOD's farms, it would be important to strategically install meters on the pipes leaving the pumps that provide water to the pivots, sprinklers and water guns that are used for irrigation of AOD's pastures. Propeller meters can provide accurate and simple measurements for clean water, and would, therefore, be especially useful for measuring the fresh irrigation water. Propeller meters measure water through an actual propeller, which is inserted into a pipe. This propeller spins on bearings, and the speed of the spinning is used to measure the speed of the water flowing through the pipe. (Mathews, 2000) It is important to install the meter at a location before a valve, as valves can distort actual flow rates. This is one of the most widely used and least expensive types of water meter used for agricultural purposes.

Propeller meters could also be used for measuring the clean water entering the milking parlors or for measuring the amount of drinking water for the cows. Another important place where installing propeller-type meters would make measuring water more accurate is on the wells at High Plains and Dipple. Propeller meters can be installed on the well's discharge line to measure the amount of water flowing from the pumping well. They also have the advantage of monitoring the efficiency of the wells themselves.

It is also important to measure the effluent water entering and leaving the lagoons. Propeller meters, however, will not work for lagoon water (either the effluent water entering or leaving the lagoons), since the debris can easily clog these meters. However, both electromagnetic and flow meters are effective for measuring effluent water. Doppler meters attach to the outside of PVC or metal pipes and work by transmitting an acoustic signal and measuring the frequency of the signal transmitted back from particles in the water (Schwankl, 2006). Electromagnetic meters come in two different varieties—either an insertable tube or rod. Tube meters involve inserting a section of pipe equipped with electromagnets permanently into the existing pipeline, while the rod meters involve inserting a rod structure into existing pipeline that contains an electromagnet at its tip. Both of these electromagnetic meters work by inducing an electromagnetic field in the water passing by, which changes depending on the movement of water. These meters then determine the flow rate of the effluent (Schwankl, 2006). Doppler works better if it is often going to be moved to different locations.

According to Schwankl, accuracy should be within 10% for monitoring effluent water flow rates. Both of the electromagnetic flow meters are within 5%, while the Doppler ranges from 10 to 15%. Therefore, the Doppler meter would suffice and also has the advantage of being portable, so that it can be used in separate locations, which could reduce costs. The electromagnetic rod meter can also be moved, but with less ease. However, the Doppler meter is applied using a conductive gel, which can degrade in response to excessive heat or moisture, so it is best used when it is going to be moved daily or every few days, while the electromagnetic rod meter would be best for taking measurements over a week or more. Doppler meters have the other disadvantage of needing to be reinstalled every time manure water is released. Since this occurs daily on Aurora's AOD's farms, the constant movement and re-installment would be very labor intensive, and thus the electromagnetic rod meters would be the most desirable option since they do not require constant attention, can be moved if necessary, and provide a higher level of accuracy than the Doppler meters. Having accurate measurements of total effluent water flows is important not only for estimating total water use at AOD's facilities, but would also provide more accuracy for nutrient management plans.

Information on Organic Feed and Organic Bedding Production

In addition to more accurate metering of water use at AOD facilities, and efficiency and conservation measures, more accurate estimates of water use for the Feed and Bedding Production stage should be a high priority. This study estimates that Feed and Bedding Production accounts for over 94% of total water use across the entire life-cycle. Therefore, it is critical to obtain more specific information on this water use. With this information, AOD could either choose to source its feed and bedding from less water-intensive growers or engage with growers to reduce their water use. If these options are viable given the scarcity of organic feedstuffs, either strategy could have a major impact on AOD's life-cycle water use per gallon of milk produced.

First of all, more specific information on the locations of both feed consolidators and feed producers would greatly reduce the uncertainty associated with water use for feed production. Different geographic locations will have varying climatic conditions and, hence, varying evapotranspiration and crop water requirements for any given type of crop. Knowing these locations and the exact amount of feed obtained from each location would allow for more precise estimates of crop water needs through methods such as CROPWAT 8.0. However, direct communication and engagement with both suppliers and growers would provide a greater level of detail as to their actual irrigation schedule and water use than do the theoretical calculations from CROPWAT 8.0. Once the specific locations and water use numbers are obtained, the WSI developed by Pfister et al. can be more effectively applied to the water consumption for feed production. The WSI values can then be used as a sort of "risk map" of the long-term availability of water in the respective feed growing locations.

Solid Waste

This study set out to benchmark AOD's SW generation, categorizing SW into three types ISW, DMSW and RMSW. While methods employed for ISW calculations are founded in analysis tied into other operational measurements such as energy and fuel use, DMSW and RMSW methods were comprised of a number of different techniques ranging from the collection of purchase records to obtain usage rates, to consultation with AOD experts, to waste and recycling contractor records. These methods give AOD a preliminary and broad understanding of future potential management strategies, as well as highlight some key areas to focus efforts. However, the addition of more precise methods, such as waste sorts for Farm Operations and Milk Processing and Management stages, will enable AOD to achieve a much clearer and more accurate understanding of MSW generation. Additionally, utilizing the same methods across life-cycle stages will make life-cycle stage comparisons more relevant and meaningful.

A waste sort study would be one option that would enable accurate sampling of AOD DMSW. This type of study would ideally sample dumpsters several times throughout the year for both Farm Operations and the processing plant. It would entail the sorting and weighing of every waste component into defined categories or groups (e.g. plastics, paper, etc.). Thus this waste sort would provide AOD with higher clarity and understanding with regard to the overall composition of their operations' DMSW. The downside of this kind of study is that it can be cost-prohibitive and timely.

A more cost-effective alternate method to waste sorts is the utilization of economic data to derive associated waste estimates. This type of assessment analyzes a company's purchase and sales data and then converts figures into associated weights of waste (Gay et al., 1993). This technique is not without flaws, however, given the implications involved in disclosing confidential purchase and sales records to outside sources for analysis.

Whether AOD decides to undertake waste sorts, economic analysis, or even simply begin to track annual weight hauled by asking waste haulers to track this information, it is clear AOD has much to gain by taking a more in-depth direct approach to quantifying and characterizing their operational DMSW as they continue to pursue strategies to improve environmental performance. The article, Cost-Effective Solid-Waste Characterization Methodology, by Alan Gay and company offers further analysis on the benefits of economic analysis in contrast to waste sorts. Similarly Newenhouse and Schmit focus on the added benefits of qualitative methods in their article Qualitative methods add value to waste characterization studies.

While the nutrient and water use categories employed the life cycle impact assessment methodologies, this was not the case for the SW category. SW disposed of in a landfill may contribute to several environmental impacts (e.g. methane off-gassing, soil toxicity, nutrient leaching, etc.) but these impacts were not explicitly assessed in this study. Some researchers have highlighted this as a major limitation within LCA methodology (Finnveden et al. 1995)

Recommendations for Improving Performance

Nutrient Use

There are several strategies that can be utilized to increase nutrient use efficiency and decrease surpluses:

Ration manipulation

The efficient use of N is related to the efficiency of protein use in the diet, and can be improved by providing only enough N (protein) and P to ensure maximum milk production (Spears et al., 2003; Van Horn, 1994). The diet should also be balanced to ensure that more common amino acids are not overfed when attempting to provide limiting amino acids. AOD rations are carefully balanced to ensure optimal animal health and milk production based on these criteria. However, since manure nutrient reductions of around 30% have been found by limiting N and P in the diet, AOD should strive to feed as little nutrients as possible without affecting milk production (Cerosaletti, 2003). Specific data on manure nutrient contents was not found by the research team and therefore this is a general strategy recommendation rather than an interpretation of AOD manure nutrient sampling.

Decrease feed losses in storage and feeding

Decreasing feed losses from feed storage, transport, and feeding stations would all improve nutrient use efficiencies. However, since AOD experts generally assume that these losses only account for around 3% of total feed weight, the improvements could be minimal.

Increases in pasture forage productivity

Continuing to increase pasture productivity would reduce the demand for imported nutrients. This would have the effect of increasing nutrient use efficiency, assuming all else remains equal. Increases in productivity could come from an increase in forage production per unit area on existing pastures through precise pasture management or the addition of more pasture area per cow to farms. Addition of pasture to farm systems would also increase internal nutrient cycling that would coincide with the displacement of feed nutrient inputs. AOD has already taken steps to achieve greater internal nutrient recycling and should continue to do so to reduce nutrient use impacts. For instance, AOD supplies local crop producers and pasture owners with AOD manure to fertilize forage that is eventually consumed by AOD animals. Any strategy to increase the productivity per acre of pasture should also be explored (i.e. rotational grazing period, high-yielding or drought tolerant species, etc.), though there may be limited room for improvement since pastures are already expertly managed.

Increases in milk production

Increases in milk production per unit feed input would also increase nutrient use efficiency. However, there may be little potential for improvement in this area since there are also clear economic incentives to do so and we assume that AOD operations are already very economically efficient.

Water Use

Efficiency and Conservation

The milk life cycle involves large amounts of water use at physical locations dispersed throughout the United States, and a large portion of this water use, especially the 94% that associated with the production of organic feed and organic bedding, is not within the direct control of AOD management. However, the 4.6% of life-cycle water use that is under AOD control can be made more efficient. A more comprehensive metering system at AOD farms may highlight areas where water could be conserved or more water-efficient equipment could be installed. Although there may be an initial investment in new equipment, water savings will reduce future costs, and the cost reduction will only become more significant over time given increasing water demand and prices in the region. For instance, a recent study on a dairy farm found that the installation of meters provided several benefits: it was shown that water use for plate cooling could be cut in half without affecting milk temperature, hidden leaks could be detected right away, and the new information from the meters could be used to train employees on how to reduce water use (Brugger, 2008). In addition, the implementation of a reusable udder wipe system at AOD farms would significantly reduce life-cycle water use (see Appendix A).

Continued improvements of pasture maximization and quality will allow AOD more control over the water use associated with the production of feed, the largest component of water use across the life cycle. In addition, the generation of electricity and the production of fossil-based fuels entail large amounts of water use. Therefore, any instance in which energy can be saved—either through actual conservation, better energy efficiency, or the use of renewable energy sources which do not have large water burdens associated with them—represent an opportunity to save on life-cycle water use. Water use associated with electricity and fuels represents about 5% of water use in the Farm Operations and milk processing stages (the portions of the life cycle under AOD control). Therefore, a 20% reduction in AOD's electricity and fuel use would reduce water use under AOD's control by 1%, or 0.4 gallons per gallon of milk. Clearly, though, the main opportunities lie in reducing irrigation water use.

Engagement with Suppliers

Engagement with feed suppliers and growers can make them aware of the fact that AOD is interested in reducing the amount of water associated with the feed they purchase. It would be helpful to be aware of any practices they are currently undertaking or plan to implement to reduce water use for crop production. For instance, there is a potential to plant alternate strains of crops, such as barley and wheat, which require less water than conventional barley and wheat crops. Winter varieties of crops can conserve water because they can be planted in colder months and, therefore, ripen earlier. No-till or minimum farming techniques have also be shown to conserve water. Regardless, contacting growers, evaluating their current irrigation methods, and working with them on initiatives to reduce their water use could greatly reduce the amount of water consumption associated with feed production for AOD.

Sourcing from regions of low water stress

Sourcing from regions of lower water stress can help AOD to greatly reduce water consumption and the associated water deprivation. For instance, more northern, wetter climates with a greater number of natural bodies of water, such as those of Idaho and Wisconsin, tend to have both lower levels of water stress and crop water needs for any given crop. However, these locations tend to be farther away from AOD's farms than those in the Great Plains regions, especially the Texas farms. There are also individual watersheds within Kansas and Nebraska in which AOD currently sources a small percentage of its feed, such as hay and straw, which have a very low water stress level. For instance, Elgin, Oklahoma has a WSI of 0.012 and Holstein, Nebraska has a WSI of 0.0385. Sourcing a greater percentage of feed from these locations could greatly reduce the water deprivation from growing feed.

Solid Waste

Given the small difference between total amounts of ISW and DMSW generated (156g of ISW and 160.g DMSW), the finding suggests that efforts to reduce overall SW should focus both on lowering DMSW generated by AOD directly, as well as efforts to lower their overall energy consumption and fuel use, thereby reducing their overall ISW.

As mentioned, the Consumer/End-of-Life stage is responsible 114.g of DMSW generated in the production of one gallon of packaged fluid milk. This is not a surprising finding, given that this is the stage where primary packaging is disposed. In order to reduce environmental impacts resulting from the incineration and landfilling of packaging, efforts aimed at lowering the weight, volume, and impact of product packaging would be realized as environmental improvements with regard to DMSW generation. See Appendix L for a life cycle comparison of various milk packaging options.

Given the nature of AOD's business structure however, it is important for them to provide the packaging types requested by their customers. In other words, since AOD is a private label producer they must work not only with the manufacture of their packaging (TetraPak) to create alternatives, but they also have to educate their retailers and convince them that alternative packaging designs are effective and will not harm the bottom line or milk sales.

In addition to efforts aimed at light-weighting of packaging, continued efforts to raise the number of municipal recycling programs that accept gabletop cartons are necessary, as well as consumer education surrounding these recycling opportunities. Increases in recycling rates would divert cartons away from the waste stream and would improve AOD's overall waste generation performance.

Given the large contribution of overall DMSW from the Consumer/End-of-Life stage and the high recycling rate of DMSW at the Retail stage, no other stages are found to be significantly high contributors to DMSW. This is not true with ISW. The Cold Storage stage and the Retail stage contribute 12 and 16 percent, respectively, to ISW, given the energy for refrigeration necessary at both these stages. The other large contributor to ISW generation was the processing plant, which resulted from this stage's high utility usages in milk processing. Strategies to off-set energy consumption from large MSW generators (i.e. coal plants) would reduce this impact. These could be achieved by supplementing power with renewable energy options, such as solar-thermal to reduce the load required for water heating, and power generation through photovoltaics or wind turbines.

Given the additional assessments of MSW generation at each stage individually through the EPIs, recommendations on where to target improvement strategies within stages were possible. These recommendations point to the udder wipes at the farm stage, leaky gabletops at the milk processing stage, and again, reiterating low recycling rates for gabletops at the Consumer/End-of-Life stage.

A previous study by the authors of this study was conducted to analyze the effect of switching from disposable udder wipes to washable reusable udder wipes (See Appendix XX). Findings indicated the reusable wipes were preferable with regard to energy consumption, GHG emissions, water use and waste generation. These findings encouraged AOD to start a pilot program is currently underway at the Coldwater farm facility, with a full switch anticipated if the test proves to be successful. This will have a large impact with regard to reducing Farm Operations DMSW.

As was mentioned the processing plant waste stream is dominated by the disposal of leaky, defective gabletop cartons, which comprise 65% of the processing plant's DMSW. Efforts to reduce the number of defective cartons would, therefore, lower amounts of DMSW generated by the plant.

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Appendices

Appendix A. Life Cycle Assessment of Disposable and Reusable Udder Wipes

Project Purpose

The focus of our study is on the milking parlors of AOD's Platteville, Colorado operation. Currently, workers in the parlors use disposable paper towels to wipe the udders of the cows before milking, and they are then disposed of in landfills after one use. Our study compares the economic and environmental (energy and greenhouse gas) impacts of the disposable paper towels with two alternative systems: reusable cotton towels and reusable synthetic microfiber towels. After describing and evaluating the impacts of the life cycle of each towel type—including raw material extraction, manufacturing, transportation, use and end-of-life—this paper makes recommendations about which system is optimal for AOD's milking parlors, discusses performance and policy issues, and summarizes conclusions.

Methods

To compare the three udder wipe types—paper, cotton, and microfiber—we selected a functional unit (FU) of 1000 cow washings. A "washing" is the process of cleaning the cow udder with the wipe before connecting the cow to the milking apparatus. Each wipe, no matter which type, is assumed to be 9.5" x 10" and to have the same liquid absorbency capacity.

AOD supplied the information that each udder washing requires on average 1.2 towels. This number was multiplied by the number of cow washings in our functional unit to determine how many towels would be used per 1000 cow washings (1000 x 1.2 = 1200 wipes per FU).

To account for the reuse factor of the cotton and microfiber wipes, the number of towels per functional unit had to be corrected. The number of towels per FU was divided by factors of reuse:

Paper: 1200 wipes / 1 use = 1200 wipes per FU
Microfiber: 1200 wipes / 500 uses = 2.4 wipes per FU
Cotton: 1200 wipes / 50 uses = 24 wipes per FU

The number of wipes per functional unit was used to calculate the weights of corresponding wipe material per functional unit. This was done by dividing the number of wipes per FU by the weight of the wipe. All final numbers were converted to kilograms per functional unit.
The paper wipes consist of 60 percent virgin paper and 40 percent recycled paper, and the weight per FU was allocated accordingly.

Calculations of raw material inputs, manufacturing inputs, the use phase, and transportation were performed in SimaPro. The manufacturing energies of paper and cotton in the SimaPro database were used. Additional factors for the manufacturing energy of polyester and polyamide (for the microfiber material) were calculated using data found in a woman's blouse LCA.[1]

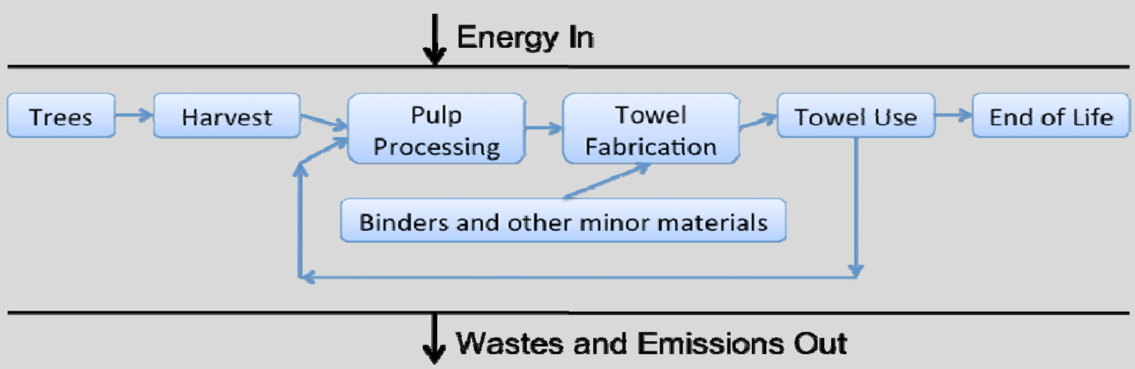
The manufacturing energies of the washing machine and dryer were calculated using the EIOLCA database. Assuming a 30% profit margin, we entered a value corresponding to 70% of the retail price to calculate washer and dryer impacts.

No use phase inputs were calculated for the paper wipes since no there is no energy associated with their one-time use. The use phase of the cotton and microfiber wipes was calculated using the energy corresponding to a 60-pound capacity industrial washer and dryer. Due to the lighter weight of the microfiber, more wipes could be washed in fewer cycles, resulting in less overall energy use than the cotton wipes.

The transportation energy was calculated by converting kg/FU to ton-mi/FU using the distances traveled by each type of wipe. Transportation energies for transport from wipe manufacturer to supplier, and transport from supplier to AOD, were included. The transportation of the washer and dryer from manufacturer to distributor to AOD were also included in the microfiber and cotton scenarios. Because we did not believe they would be significant, we did not include the transportation of towels to landfill. End-of-life scenarios were calculated using SimaPro databases.

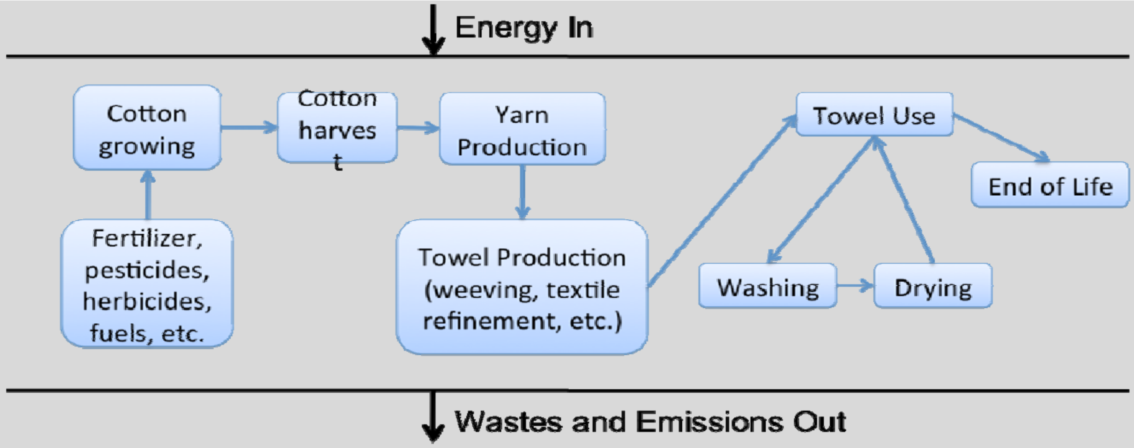
<u>Process Flow Diagrams</u>

Figure 1. Paper towels



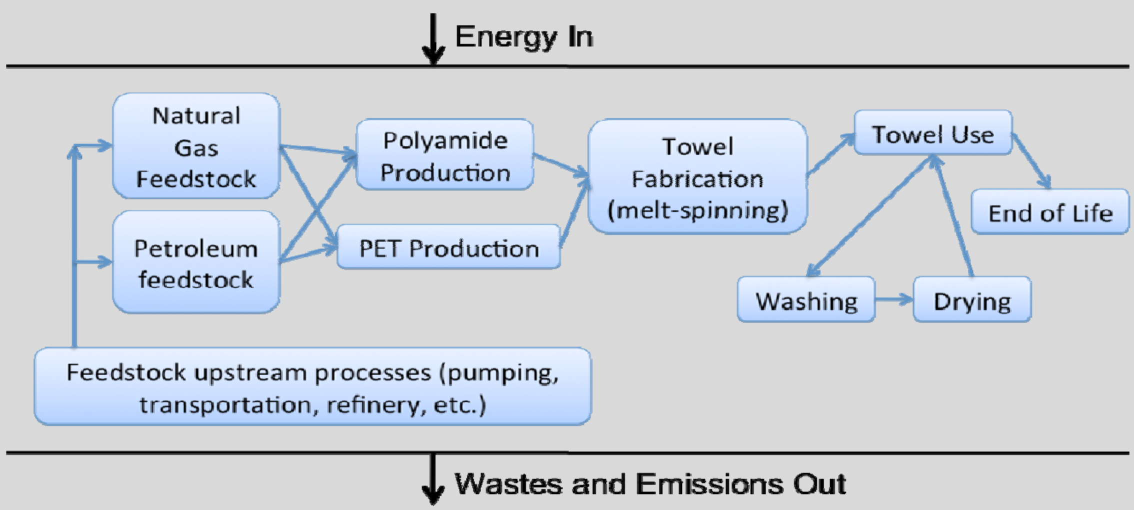
Paper towel production begins with a tree that has been harvested and processed into a pulp for paper towel manufacture. These upstream stages require energy in the form of various fuels for processing, tree felling, and other processes. The towel fabrication stage adds other minor materials like binders to the paper towel and the use phase involves udder washing for our analysis. The end-of-life phase for AOD towels is a landfill. The above diagram shows a generic recycling loop since the towels are 40% post-consumer content, but in practice, the towels used at AOD are not recycled back into the production chain. Energy is added and wastes and emissions are generated at each stage, including transportation.

Figure 2. Cotton towels



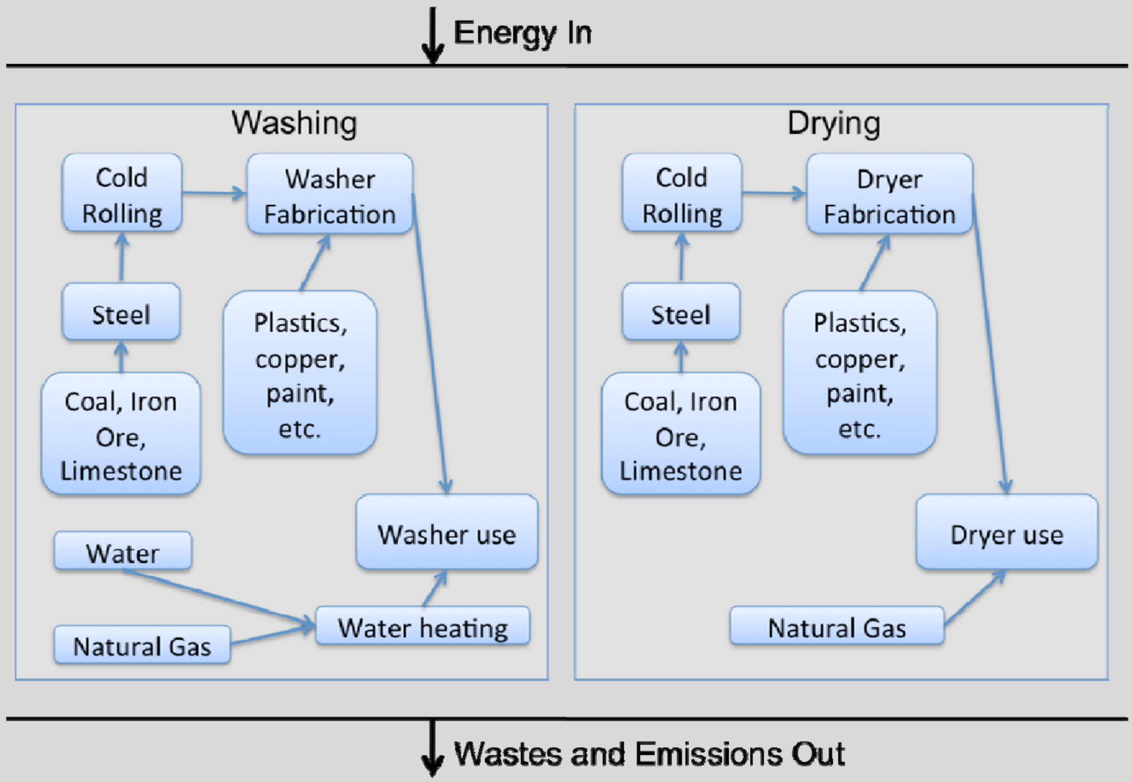
The cotton towel life cycle begins with cotton production (they are 100% cotton), which uses a variety of fuels and inputs such as fertilizers, and harvesting, which consumes fuel. Yarn production, weaving and towel production are energy-intensive processes that ultimately produce the finished towel. At AOD, the use phase lasts for 50 washing cycles. The end-of-life for cotton towels is a landfill. Energy is added and wastes and emissions are generated at each stage, including transportation.

Figure 3. Microfiber towels



Since microfiber towels require petroleum and natural gas as feedstocks, the life cycle starts with the extraction, refinery and delivery of fuels of both petroleum and natural gas for use as feedstock and processing energy. Both polyamide and PET (polyester) can be made from either feedstock; the towels are 30% polyamide and 70% polyester. Towel fabrication involves an energy intensive melt-spinning process that turns plastic material pellets into fabric. At AOD, the use phase corresponds to 500 washing cycles. The end-of-life for microfiber towels is a landfill. Energy is added and wastes and emissions are generated at each stage, including transportation.

Figure 4. Expanded use phases for the cotton and microfiber towels



The use phase at AOD involves energy and burdens from the production of the washer and dryer, from water pumping and heating, and from dryer heating. The functional unit corresponds to only a very small portion of the upstream impacts because burdens from machine production are spread out over the machine lifetime of three years, which includes multiple washing drying cycles per day. Energy is added and wastes and emissions are generated at each stage, including transportation.

Environmental Impacts

Impact Categories

Primary energy use and greenhouse gas (GHG) emissions were chosen as the impact categories in our analysis for three reasons:

1. These two categories tend to be the best studied environmental impacts, and so have the best chances of being accurate, compared with other categories like water use.
2. The results of this analysis may be used by the client, so the choice was made to focus exclusively on two categories to increase overall confidence and decrease uncertainty in our results. Processes were carefully evaluated and cross-checked against a variety of databases, and results that seemed unreasonable (such as the impacts of commercial laundering through EIOLCA) were left out of the analysis.
3. These are the impact categories evaluated for the whole company by the recent SNRE Master's project team. Thus, the magnitude of impacts from towel use can be compared to the impacts of other parts of the operation.

Results

Our analysis shows that the microfiber towel alternative is clearly the best option in both economic and environmental terms, when considering the total product life cycle. Because microfiber is much lighter and lasts longer, it performs better than cotton, which in turn performs better than the paper towels (except on a cost basis).

We originally believed the analysis would be highly sensitive to the assumption that the microfiber towels last about ten times longer than the cotton towels, because the fabrication of synthetic fabrics like microfiber can be twice as energy-intensive as the fabrication of cotton, and release ten times as many GHG emissions per unit mass, according to the SimaPro library IDEMAT database. Thus, at low reuse factors cotton is preferable. However, our sensitivity analysis showed that microfiber has lower primary energy use per FU than cotton after only nine washing cycles, and lower GHG emissions after only 47 washing cycles. Thus, if the actual reuse factors are even close to those we assumed in our calculations (50 cycles for cotton and 500 for microfiber), microfiber is the clear winner.

Transportation, packaging, and disposal phases were found to have very little impact compared to the use and upstream stages for all towel systems.

Environmental impacts from the paper towel product system

Most of the environmental burdens of the paper towel result from the towel fabrication stage, of which virgin wood pulp is the largest piece. Natural gas and electricity use in these stages are the processes that contribute the most to both categories.

Environmental impacts from the cotton towel product system

Environmental burdens from the cotton towel system come mostly from the use phase, where natural gas use by the dryer is the largest contributor. There is a correlation between energy use and GHG emissions, but there is also a disparity between the two impacts due to the difference in emission factors between natural gas burned on-site and electricity delivered through the grid. Natural gas is mostly used for dryer heat and water heating, while washer use is responsible for the most electricity use, as seen in the figures below.

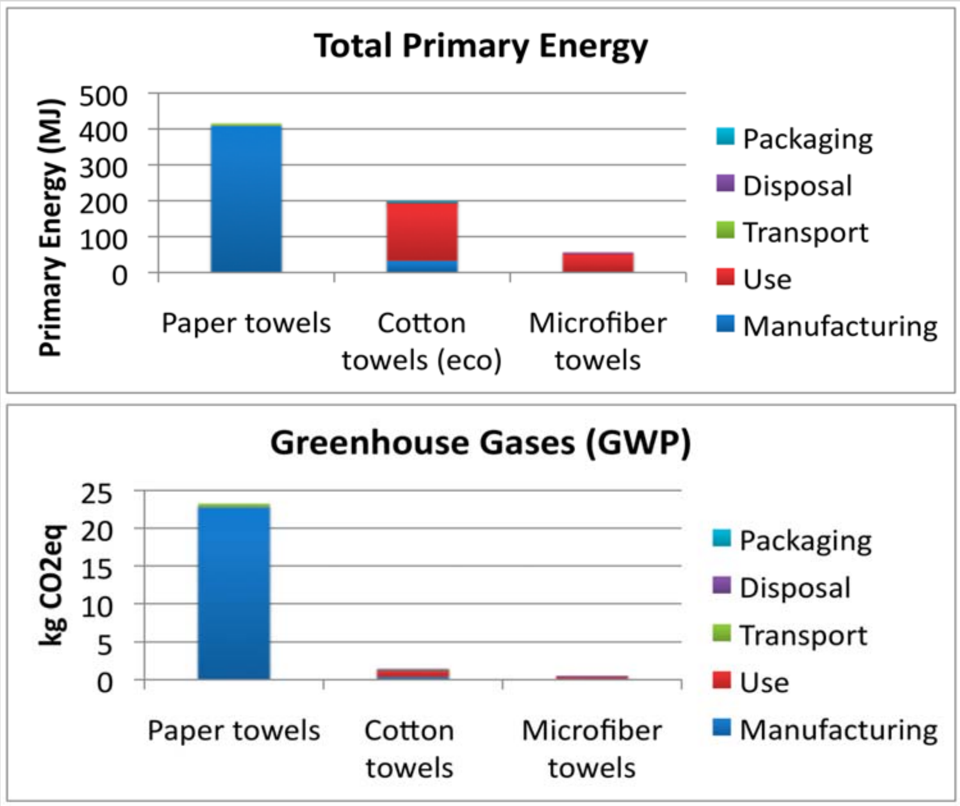


Figure 8. Comparison of total primary energy use and greenhouse gas emissions of the three towel systems across all life cycle stages.

Environmental impacts from the microfiber towel product system

Like the cotton towel system, the use phase is responsible for most of the environmental burdens of the microfiber towels. The fabrication energy and GHG emissions are responsible for a much smaller proportion of the total burdens than in the cotton system because of a higher reuse factor, due to a longer product lifetime. There is a noticeable disparity between primary energy and GHG emissions in the use phase, as with the cotton system.

<u>Life Cycle Cost Analysis</u>

Towel fabrication and upstream cost calculations were made by multiplying the cost per towel by the number of towels per functional unit (FU) for each type, which varied for each type depending on reuse factor. Washer and dryer purchase prices were added together, then divided by the number of days in the lifetime of the machine (3 years), then multiplied by the fraction of a day our FU corresponded to for both towels, to yield cost per FU. Also, AOD informed us that we should not include any additional labor costs for the reusable towels. Colorado municipal water prices were multiplied by the quantity of water draw per FU and water heating natural gas costs were calculated for this same quantity of water per FU using a heating efficiency of 90%, and the 2008 average natural gas rate from the EIA. Electricity draw from the washing machine per FU was found and multiplied by a $0.10 per kWh estimate. Dryer use costs were found using natural gas prices and energy draw product specifications. Transportation costs per FU were calculated using distances from product distributors to AOD, shipping costs per FU from towel manufacturers, AOD shipment data, and tons of each towel per FU. The per-pound landfill disposal rate ($0.02/lbs.) was estimated from NRE 557 lecture material, converted to kilograms, and multiplied by the weight of towel disposal for each towel system per FU to find disposal costs.

As with energy use and GHG emissions, microfiber towels have the lowest economic cost. They have a total life cycle cost of $7.89 per functional while unit, while cotton and paper towels have a total cost of $25.48 and $19.89, respectively. Paper towels have the highest manufacturing cost per functional unit because they are simply thrown out and not reused. There are no use phase costs associated with them, while the use phase makes up the highest proportion of the costs for cotton and microfiber towels. Cotton towels are more expensive to produce than microfiber towels, largely because microfiber is synthetic, and cotton is more expensive to clean and has a shorter lifetime. Since the cotton is heavier, and the load capacities for the washer and dryer are based on weight, cotton towels involve more loads per functional unit, which increases their cost as well. In purely economic terms, then, microfiber is the clear winner. However, there are other considerations and factors which could alter AOD's decision about which towels to use.

Comparison of Environmental Impacts and Costs for All Towel Systems

Figure 9. Comparison of impacts and costs of towel product systems

Towel Type	GHG Emissions (kg CO2eq/FU)	Primary Energy (MJ/FU)	Cost ($/FU)
Paper	23.2	415	19.89
Cotton	1.41	198	25.48
Microfiber	0.512	55.2	7.89

Performance Considerations

It should be noted that when making the decision to switch from one type of wipe to another, issues beyond the scope of this analysis should be considered. For example, this study was conducted for an operation which prides itself on its sustainable practices. The use of a cotton wipe made from a renewable resource, as opposed to a microfiber wipe made from nonrenewable petroleum feestocks, may be important. The farming operation relies on composting as a means of waste management, and therefore factors such as biodegradability, eco-toxicity, and other impact categories are very important to take into account.

The impacts from the use phase of these systems could also be mitigated by the use of the most efficient washers and dryers available. However, in operations like dairy facilities the benefits of energy savings need to be weighed against the additional costs. After discussions with laundry equipment sales personnel, it was determined that the lifespan of washers and dryers is reduced when they are located in a dairy, thus making the extra costs of more efficient machines more difficult to recoup with energy savings.

Policy Issues

There are several regulatory drivers which could alter our life cycle energy and cost results in the future. Regulations which relate to use phase energy will have a significant impact since most of the energy requirements for both cotton and microfiber come from this phase. Therefore, more stringent efficiency standards for industrial washers and dryers could substantially reduce the energy required for the washing and drying of towels. The washer and dryer recommended by Unimac for the purposes of our study were not the most energy-efficient options available. Energy Star appliances incorporate advanced technologies and are typically 10-50% less energy- and water-intensive than standard models.[2] Therefore, if AOD chooses to use an Energy Star model, there will be much lower energy requirements associated with the use phase of cotton and microfiber towels, making them appear even more attractive from a sustainability perspective. From a cost perspective, more advanced models typically have a higher purchase price but result in economic savings on energy costs in the long-run. In addition, as Energy Star standards become more stringent in the future, there will be even greater energy and cost savings for washing and drying because of decreased need for electricity, water, and decreased production of wastewater.

Use phase GHG emissions would be reduced through the implementation of Colorado's Renewable Portfolio Standard. In 2007, the Colorado Public Utilities Commission mandated that 20% of retail electricity sales come from renewable energy by 2020.[3] Eligible renewable-energy resources include solar-electric energy, wind energy, geothermal-electric energy, biomass landfill gas, animal waste, hydropower, recycled energy, etc. Therefore, the environmental impacts of washing and drying cotton and microfiber towels could be greatly reduced if a larger fraction of Colorado's electricity comes from renewable sources. In addition, AOD has begun to consider installing on-site wind turbines or solar panels to power various processes at their facilities. This power could be used to generate energy for the washing and drying of the reusable towels. Colorado's Small Wind Incentive Program and Solar Rebate

Program, which provide rebates to private firms for the installation of wind turbines and solar panels, could encourage them to undertake such projects.

Aside from regulations that impact life cycle energy use, emissions and cost, AOD's decision of which towel to use in their milking parlors could be heavily influenced by changing USDA organic standards. Maintenance of animal health is the foremost consideration in organic standards, as well one of AOD's top priorities. Udder health is very important for the health of cows and the quality of milk produced. In addition, organic standards state that "Antibiotics, hormones, and most synthetic therapies are not allowed in animals whose products will be certified organic."[4] Since the microfiber towels contain synthetic materials, organic standards may prohibit their contact with dairy cows in the future.

Conclusions

Our results suggest that AOD should switch from disposable paper towels to reusable towels, and that microfiber offers the greatest reduction in greenhouse gas and energy impacts, as well as the lowest cost.

Drying is the most energy- and GHG-intensive part of the reusable towel use phase. Thus, eliminating the drying stage would help reduce these impacts. It should be noted, however, that the use of a dry towel is better for the cow's health and important for the organic standards necessary at AOD, and also that drying towels without a dryer may be impractical given the sheer volume of towel use. The second most intensive use phase factor was the heating of water for the washer. This impact could be reduced by incorporating the use of solar hot water heating technology.

In addition, AOD should consider high-efficiency washing and drying machines, and composting of towel waste to reduce environmental impacts. Lastly, as mentioned above, AOD could install wind turbines or solar panels at its facilities in order to produce renewable electricity and thus reduce its fossil energy consumption and GHG emissions.

Figure 10. Life Cycle Results for One Year, by Towel Type

Category	Paper	Cotton	Microfiber
Energy (GJ)	5,600	2,900	1,000
GHG Emissions (kg CO_2 eq)	314,000	19,000	7,000
Solid Waste (lbs.)	4,240	530	18
Water Use (m^3)	34,440	93,300	2,000

Figure 11. Savings Over One Year by Switching from Paper to Microfiber Towels

Category	Savings (equivalent to…)
Energy	764 barrels of oil
GHG Emissions	59 passengers off the road
Solid Waste	9,288 lbs.
Water Use	13 Olympic-size swimming pools

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Appendix B. Crop and bedding nutrient and moisture contents used for all AOD usage

AOD record crop	CNT Crop used	N percent of dry matter	P percent of dry matter	Moisture percentage
Alfalfa, Dry	Alfalfa, for hay	2.79	0.26	9.65
Corn (from premix and cracked corn)	Corn-Field, for grain (shelled, yellow dent, grade #1)	1.64	0.31	13.52
Barley (from premix)	Barley-2 row, for grain	2.32	0.35	13.30
Bermuda	Bermudagrass, for green chop	1.3746	.19	9.05
Prairie Grass hay	Grass, for hay	1.52	0.22	10.6
Sorghum silage	Sorghum, for silage	1.01	0.21	71.6
Soymeal (from premix)	Soybean, for grain	6.57	0.67	10.12
Soy Hulls (from premix)	Soybean, for hay	2.57	0.24	10.66
Corn silage	Corn-Field, for silage (mature)	1.3	0.38	70.08
Wheat (for premix)	Wheat-durum, for grain	2.43	0.42	11.83
Wheat silage	Wheat, for green chop	2.336	0.31	73.55
Cottonburrs (for bedding)	Cotton, for seed with lint or seed cotton	3.296	0.41	7.8
Straw (for bedding)	Barley-2 row, for straw	0.688	0.08	9.2
Oat straw (for bedding)	Oat, straw (not including Pacific coast)	0.7062	0.0851	9.68
Triticale seed (for pasture forage)	Wheat-durum, for grain	2.43	0.42	11.83
Ryegrass seed (for pasture crop)	Rye, for grain	2.14	0.38	11.88
Wheat seed (for pasture forage)	Wheat-durum, for grain	2.43	0.42	11.83
Clover seed (for pasture forage)	Clover-Red, for seed	5.89	0.61	12.23
Perennial grass mix seed (for pasture forage)	Bromegrass, for seed	1.55	n/a	55.8
Millet (for pasture forage)	Millet-Pearl, for grain	2.22	0.38	10.10

Appendix C. Nitrogen farm gate balance

INPUTS (kg N)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Herd N	5,263	0	8,182	18,799	1,047	14,492	18,799	33,290
Non-pasture feed N	187,915	434,052	745,664	851,824	143,806	1,077,385	1,285,875	2,363,261
Bedding N	3,087	4,179	4,768	3,129	3,983	11,837	7,308	19,145
N contained in pasture seed	348	1,981	1,793	2,288	112	2,252	4,269	6,522
Atmospheric	1,284	4,966	1,917	3,545	363	3,563	8,512	12,074

N deposition								
N fixation from pasture crops	0	17,240	0	0	0	0	17,240	17,240
OUTPUTS (kg N)								
Herd N	12,352	22,660	42,147	53,937	12,172	66,670	76,597	143,267
Milk N	39,252	64,373	166,236	188,869	25,720	231,208	253,242	484,450
Total N emissions from N2	5,808	75,685	35,124	107,707	13,227	54,158	183,392	237,551
Total N emissions from N2O	12,123	9,967	35,536	9,220	1,167	48,826	19,187	68,014
Total N emissions from NH3	25,909	80,830	91,214	222,710	34,912	152,034	303,539	455,574
Total N emissions from NO3	2,163	3,456	6,442	8,133	1,255	9,860	11,590	21,449
Exported manure N, by difference (kg N)	100,289	205,447	385,624	289,008	60,859	546,772	494,455	1,041,228

Appendix D. Nitrogen herd mass balance

INPUTS (kg N)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Herd N	5,263	0	8,182	18,799	1,047	14,492	18,799	33,290
Non-pasture feed N	187,915	434,052	745,664	851,824	143,806	1,077,385	1,285,875	2,363,261
Pasture forage N	57,927	-27,325	150,039	264,066	14,535	222,502	236,741	459,243
OUTPUTS (kg N)								
Herd N	12,352	22,660	42,147	53,937	12,172	66,670	76,597	143,267
Milk N	39,252	64,373	166,236	188,869	25,720	231,208	253,242	484,450
Manure N	199,500	319,694	695,503	891,882	121,498	1,016,501	1,211,576	2,228,077

Appendix E. Nitrogen soil surface (pasture) balance

INPUTS (kg N)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Manure and urine N from grazing animals	19,231	30,729	57,272	72,314	11,160	87,663	103,043	190,706
Lagoon water N	4,403	3,657	6,991	3,040	991	12,385	6,697	19,083

Spread manure N	8,867	30,507	0	0	0	8,867	30,507	39,374
N fixation from pasture crops	0	17,240	0	0	0	0	17,240	17,240
Atmospheric N deposition	1,284	4,966	1,917	3,545	363	3,563	8,512	12,074
N content of pasture seed	348	1,981	1,793	2,288	112	2,252	4,269	6,522
Unaccounted for N inputs to pasture forage	32,053	-101,081	104,640	211,077	6,003	142,696	109,997	252,693
OUTPUTS (kg N)								
Gaseous N2 from soil denitrification	2,769	5,619	4,981	5,701	938	8,688	11,320	20,008
Gaseous N2O from soil denitrification	680	1,006	3,139	4,151	381	4,201	5,157	9,358
Gaseous NH3 from manure and urine	4,751	7,592	14,150	17,866	2,757	21,658	25,458	47,116
Pasture forage N uptake	57,927	-27,325	150,039	264,066	14,535	222,502	236,741	459,243
Aqueous NO3- losses	57	1,109	305	479	17	378	1,589	1,967

Appendix F. Phosphorus farm gate balance

INPUTS (kg P)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Herd P	1,517	0	2,358	5,418	302	4,176	5,418	9,594
Non-pasture feed P	27,355	62,851	110,351	141,326	21,374	159,081	204,177	363,258
Bedding P	359	520	554	364	463	1,377	884	2,261
P contained in pasture seed	60	339	284	370	17	361	709	1,070
OUTPUTS (kg P)								
Herd P	3,543	6,488	12,083	15,450	3,497	19,123	21,938	41,061
Milk P	7,210	11,824	30,533	34,690	4,724	42,467	46,514	88,981
P losses	818	2,213	713	243	140	1,670	2,456	4,127
Exported P	10,279	23,042	63,731	89,979	12,522	86,532	113,021	199,553
STOCKS (kg P)								
Soil pool P, AOD pastures and exports	7,442	20,143	6,488	7,115	1,273	15,203	27,258	42,461

Appendix G. Herd phosphorus mass balance

INPUTS (kg P)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Herd P	1,517	0	2,358	5,418	302	4,176	5,418	9,594
Non-pasture feed P	27,355	62,851	110,351	141,326	21,374	159,081	204,177	363,258
Pasture forage P, by difference	2,230	2,708	10,106	9,529	554	12,890	12,237	25,127
OUTPUTS (kg P)								
Herd P	3,543	6,488	12,083	15,450	3,497	19,123	21,938	41,061
Milk P	7,210	11,824	30,533	34,690	4,724	42,467	46,514	88,981
Manure P	20,349	47,247	80,200	106,133	14,009	114,558	153,380	267,938

Appendix H. Field (pasture) phosphorus balance

INPUTS (kg P)

	Platteville	Dipple	High Plains	Coldwater	Ray-Glo	Colorado	Texas	All Annual
Manure and urine P from grazing animals	1,778	3,403	5,166	6,473	1,125	8,069	9,877	17,946
Lagoon water P	1,282	1,065	2,035	885	288	3,605	1,949	5,555
Spread manure P	5,199	17,888	0	0	0	5,199	17,888	23,087
P content of pasture seed	60	339	284	370	17	361	709	1,070
OUTPUTS (kg P)								
P losses	818	2,213	713	243	140	1,670	2,456	4,127
Pasture forage P uptake	2,230	2,708	10,106	9,529	554	12,890	12,237	25,127
STOCKS (kg P)								
Soil pool P, AOD pastures only	5,272	17,774	-3,334	-2,044	737	2,674	15,730	18,404

Appendix I. Bull calves and culled cows energy-based allocation

Allocation between milk and meat production on dairy farms is a difficult challenge and one that can have a strong effect on reported results. In this study, the allocation of impacts between milk and meat was made on an energy basis at the farm level. The energy for producing bull calves, which are sold shortly after birth on AOD farms, was estimated using the net energy requirement for pregnancy according to equation 2-19 from National Research Council's Nutrient Requirements of Dairy Cattle 2001, based on an average calf birth weight of 45 kilograms (see Appendix C: Net Energy Requirement for Pregnancy Equation [National Research Council, 2001] for equation).

The embodied energy in the empty body mass of culled cows is used to allocate this co-product. Assuming a 635 kg cow with a body condition score of 3, Table 2-4 from National Research Council's Nutrient Requirements of Dairy Cattle (2001) estimates the cow's empty body mass to be 18.8% fat and 16.8% protein, with the remaining percentages composed of ash and water. Fat and protein are assumed to be the primary energy embodiment of the cull cow; using energy densities obtained from National Research Council's Nutrient Requirements of Dairy Cattle 2001 (9.4 Mcal/kg for fat and 5.6 Mcal/kg for protein) an embodied energy for the cull cow is estimated.

The above energy estimates are then multiplied by the respective numbers of animals (bull calves and culled cows) sold on each farm and added together to give the energy of animal (meat) co-product.

$E_{\text{meat, farm } i} = E_{\text{pregnancy}} \cdot (\text{\# bull calves})_{\text{farm } i} + E_{\text{embodied, culled cow}} \cdot (\text{\# culled cows})_{\text{farm } i}$

The energy in the milk co-product is estimated by first correcting for fat and protein content according to Bernard (1997), and then multiplying by a standard energy content of 3.14 MJ/kg of milk:

$E_{\text{milk, farm } i} = 3.14 \cdot [0.3246 + 12.86 \cdot (\text{fat fraction})_{\text{farm } i} + 7.04 \cdot (\text{protein fraction})_{\text{farm } i}] \cdot (\text{kg milk produced})_{\text{farm } i}$

The fraction of the farm burdens allocated to the meat co-product is then:

$\text{Allocation fraction}_{\text{meat, farm } i} = E_{\text{meat, farm } i} / (E_{\text{meat, farm } i} + E_{\text{milk, farm } i})$

This allocation fraction is applied to Feed and Bedding Production stage and Transport stages, enteric fermentation, manure management, managed soils and pasture operations. It is *not* applied to farm utilities, purchased supplies, farm building embodied energy, and farm employee transport, which are allocated wholly to the fluid milk co-product because it is felt that these operational burdens exist largely for the milk production system.

Appendix J. Process waste methodology

Individual Product Methods:

Udder Wipes:

Phase I data on towel purchases was combined with data regarding the number of milking cows at corresponding farms. The number of cows in milk and udder wipe use from individual farms was summed. Next the total udder wipes used per month was divided by the total number of cows milked 3 times per day, times the number of days in each corresponding month. All months were averaged to obtain a usage rate, total number of towels per milking.

The kilograms of udder wipe use per month was multiplied by the percent of total milking cows at each farm to obtain the kilograms of udder wipes used at each farm by month.

This resulted in the number 2.22 towels used per milking.

The 2.22 towels used per milking were multiplied by the total milkings per month to obtain the total towel use for corresponding months. These numbers were multiplied by the 0.0045 kg/towel (taken from PI) to obtain the kilograms of udder wipes used.

Next the kilograms of udder wipes used for each month was multiplied by the percentage of total cows in milk at each farm to determine kg of use for each farm on a monthly basis.

Nitrile Gloves:

Invoices from a sampling of 4 months were used. All glove purchases were recorded. The number of gloves per box was multiplied by the number of boxes purchased. This was multiplied by an estimate of 0.005kg per glove.

Glove purchases recorded in PI purchase files were also compared with the results of the 4 month sampling and found to be comparable.

The number of gloves purchased at each farm for the four months (April, July, October, and January) were divided by the corresponding farms' milkings per the given month(milked three times multiplied by days in given month). An average of all of these numbers was obtained to determine the average number of gloves used per milking (0.078). This number was used to determine the total amount of gloves thrown away during the study.

The total number of gloves was calculated by multiplying the number of milkings per month by the 0.078 gloves per milking. This was then multiplied by 0.005kg per nitrile glove to determine the total kg used per month. Next the total kg nitrile was multiplied by the percentages of cows in milk at each farm to obtain the kg nitrile that corresponded with each farm.

Twine:

The waste associated with the hay and straw consists of the plastic twine which serves to hold bales of hay and straw together during transport. Hay and straw usage was obtained from the AOD feed usage files. These files indicate amounts of feed fed by weight. Two sizes of bales exist at AOD, 4 x 4 x 8, and 3 x 3 x 8. Total feed per month (in pounds) was divided by the average pounds corresponding to a given bale of a specified feed type to obtain number of bales. This was then multiplied by the number of feet of twine used in the given bale type (119.8 ft/ (4 x 4 x 8)) and (124 ft./ (3 x 3 x 8)). The total amount of twine per farm over the period of study was totaled and then divided by 0.0104 oz. per foot of twine to obtain the weight of twine disposed of during the course of the study. This was converted into pounds.

Filter Socks:

All milk is fed through filters before entering storage tanks where it awaits transportation to the processing facility. These filters are changed after each pen is milked. Thus, usage rates were calculated based on the number of pens at each farm facility, multiplied by the number of times each pen was milked per day by the number of days in each month for the period of study. The total number of filter socks was then multiplied by 0.5 kg to obtain overall weight of associated waste.

Silage Plastic

High Plains and Coldwater both have on site silage piles. These piles are covered with a plastic. As silage is used the plastic covering is peeled off and discarded. The total weight of the covers were obtained from the contractors and added to these farms' (High Plains and

Coldwater) total direct solid waste amounts.

Appendix K. ISW generated per MJ of energy production by fuel type

	kg/MJ
Coal	3.27E-03
Hydro	0
Oil	9.48E-05
Uranium	8.29E-05
Natural Gas	0

Appendix L. Comparison of three container systems

Percent Differences for the PLA Milk Container System Versus the Remaining Milk Container Systems

	Gable Top Carton System	Glass Bottle System	HDPE Bottle System
Total Energy	44%	71%	51%
Postconsumer Solid Waste	54%	63%	33%
Total Greenhouse Gases	30%	10%	57%

Source: Franklin Associates, a Division of ERG

Appendix M. Recycling ratio EPIs for various life cycle stages

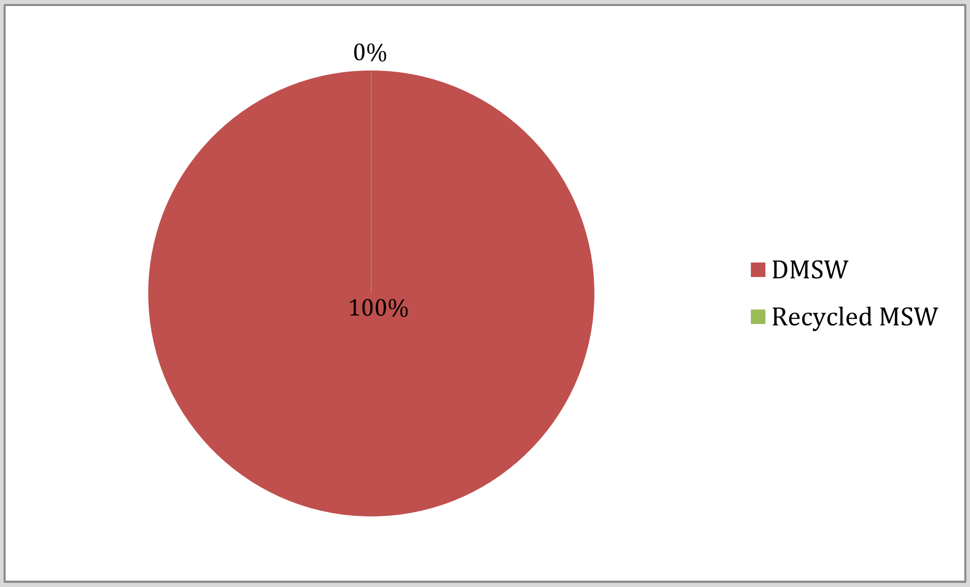

Figure 1. Farm Operations stage DMSW and recycling

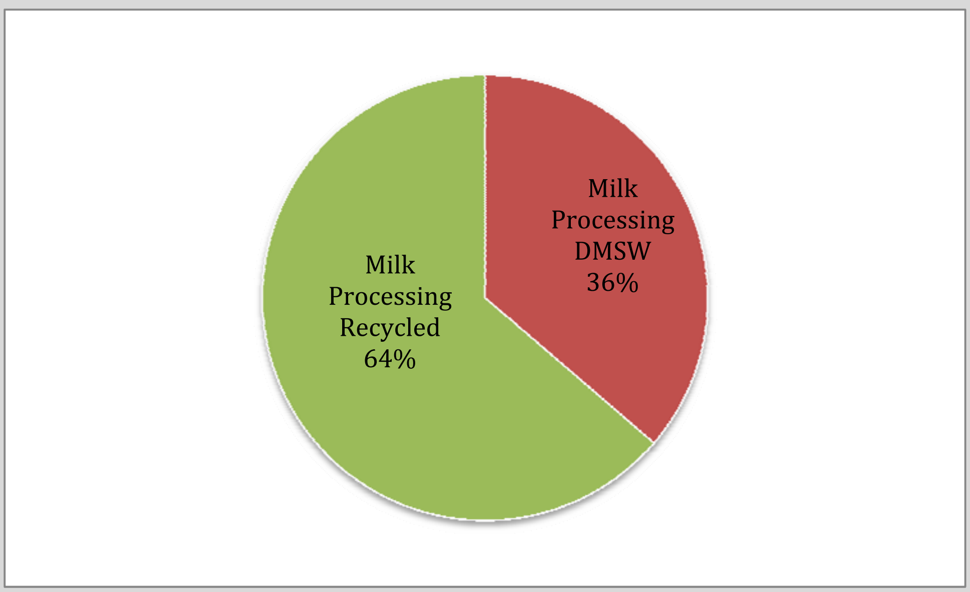

Figure 2. Milk Processing and Management DMSW and recycling

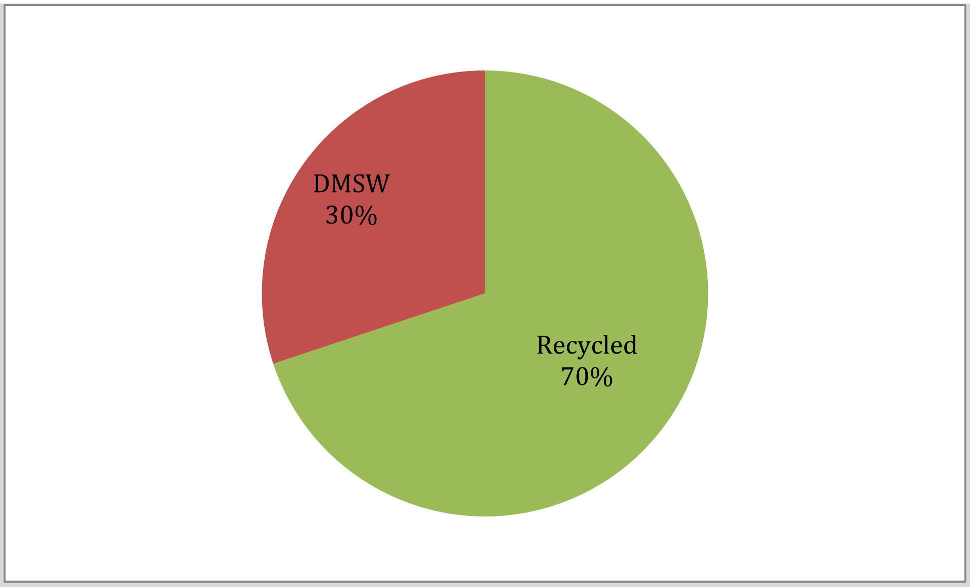

Figure 3. Retail DMSW and recycling

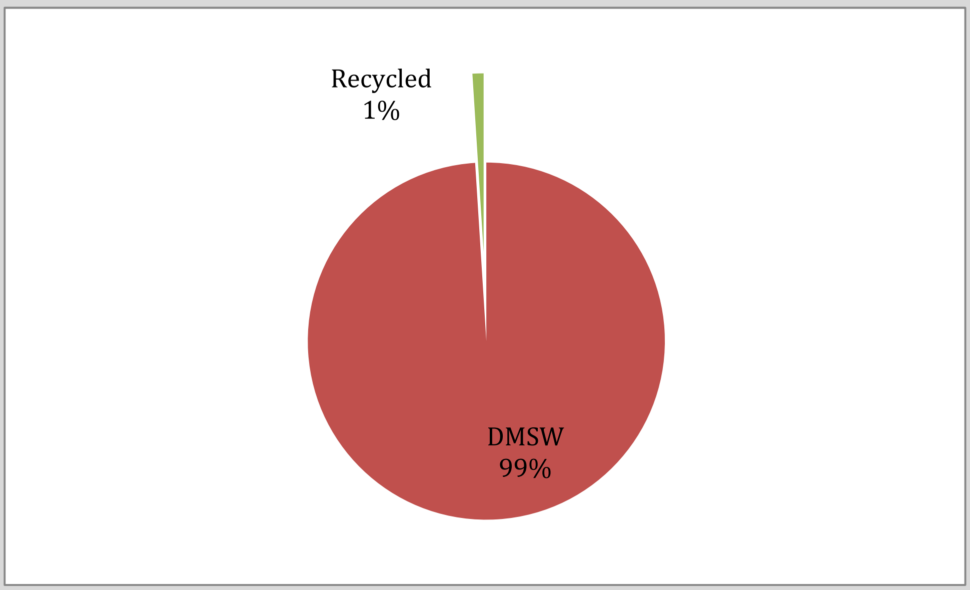

Figure 4. Consumer/End-of-Life DMSW and recycling