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A Cradle to Farm Gate Life Cycle Analysis of Water Use in U.S. Pork Production

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by

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ABSTRACT

The intent of this study was to analyze water use across a range of regions, scales and practices of the U.S. pork industry. A Life Cycle Assessment of water use within the pork supply chain was performed. Cumulative water use was the environmental impact category used in the LCA to evaluate the impacts of pork production processes throughout the pork supply chain. The functional unit for the analysis was the volume of water required to produce one kilogram of swine (live weight) at the farm gate.

A comprehensive literature review was used to design and propagate algorithms for the National Pork Board Pig Production Environmental Footprint Calculator (version 2.0). The outputs from the calculator were used to generate lifecycle inventory inputs for unit processes in SimaPro (Pre' Consultants, The Netherlands), an LCA modeling program. The LCA method was then used to assess the water footprint for swine production from cradle to farm gate production scenarios. There were 240 different scenarios analyzed that were a combination of ten regions, three production strategies and three scales.

The grow/finish barn phase of the on farm water footprint requires approximately five times as much water as the sow and nursery barns irrespective of the barn infrastructure. Water used to irrigate swine feed crops contributed 89% of the total cradle to farm gate footprint. Since all 240 scenarios were analyzed with the same ration inputs, the final footprints did not vary drastically between scenarios. There were small deviations such as tunnel ventilated production systems consistently required more water than hoop barns due to cooling systems in warmer regions. Smaller scale operations consistently had higher water footprints due to economy of scale, although the footprint differences between scales were

marginal. Regarding the water use that occurred on the swine farm, drinking water was by far the most significant contributor to the footprint (81%). Production strategies, production scale and region of production were all statistically significant ($p < 0.0001$) and affected the blue water footprint. This may seem self-evident, but these processes have not been quantified at this scale prior to this analysis.

ACKNOWLEDGEMENTS

I would first and foremost like to thank my family, especially my mother Lowell Collins and father Daryl Boles for their guidance, inspiration, and mentoring throughout my life. I am the person they shaped me to be. Immense gratitude is due to Drs. Marty Matlock and Greg Thoma for their guidance throughout this project. This project would not have been possible without their support. I would like to acknowledge the generous support of the National Pork Board, whose generous support made this work possible.

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Introduction

In recent history, the meat production sector of the agricultural market has been under increasing scrutiny from a portion of the public due to the perceived impacts of production practices on our natural resources. As a result, producers of agricultural products including pork producers and the general public have both become aware of the importance of understanding the sustainability of the products they produce and purchase. Water footprint is defined as the total volume of freshwater that is used to produce the goods and services consumed by the process being analyzed. With water resources declining in many regions of the U.S. and around the globe, production costs will likely increase in many regions. The embodied water in pork products (water footprint) may become an argument against pork consumption in some regions. Continued profitability of the swine production sector depends upon producers having an understanding of how water scarcity will impact their production decisions. Consequently, the water footprint determination for animal products has become an important area of research in water resource management.

Life Cycle Assessment (LCA) is a tool that can be used to account for the combined effects in an agricultural production supply chain. LCAs provide quantitative, confirmable, and manageable models to evaluate production processes, analyze opportunities for innovation, and enhance awareness of the complexity in systems. LCAs have been used as a tool to identify "hot spots" in the supply chain that may introduce opportunities for simultaneously lowering environmental impacts and improving efficiency and profitability. Water footprint analysis is an important aspect of a comprehensive LCA.

Using a systematic LCA approach, this study has expanded the knowledge-base of water usage within the US pork industry by analyzing the entire scope of the US pork production process in a more expansive way than any single previous study. Existing studies, whether national or international, relating to pork or another agricultural industry, were insufficient for development of the Live Swine Production Water Footprint Calculator. For example, a recent LCA (Stone et al. 2012) evaluated the life cycle impacts of feed for grow-finish swine operations in the Northern Great Plains region but did not include irrigated water as an input for corn or soybean production in that region. However, our study found that irrigated water used for feed accounted for as much as 85% of the entire water footprint for pork production in the same region. A literature review by Muhlbauer et al. (2010) consolidated available water conservation techniques for the swine industry and even made valuable recommendations as to how pork producers could reduce their on-farm water usage but did not provide a view of the pre nor post swine farm environmental impacts.

1. DEFINING THE PROBLEM

Sustainability

Water

On our planet, water is abundant and is renewable through the hydrologic cycles. However, 83% of our water is salt water, 14% is chemically bond, 2% is ice and only 0.5% is available as freshwater. Of that 0.5% freshwater that is available to use, 98% is in underground aquifers (Patience, 2012). Not all aquifers are considered sustainable since recharge rates are known to be measured in geologic time and most often slower than the rate of depletion. Although it freshwater sometimes feels plentiful in the Western world, water that can efficiently be converted into potable water is not readily available everywhere throughout the world. Water is a resource that is gaining respect as our economy continues to become more globalized and as our local reserves become depleted.

Animal Production

In animal production, water is required in larger quantities than any other nutrient. Water scarcity will likely limit swine production in some areas of the US, and will certainly impact the availability and cost of feeds. The meat production sector of the agricultural community has been under increasing scrutiny and criticism from the consuming public due to perceived impacts of production scales on environmental conditions. Water resources have been declining in many regions of the US and around the globe. The embodied water in agricultural products (water footprint) may become a valid concern for consumers in some regions. In addition, water scarcity will likely increase costs of production in many regions. Continued profitability of the swine production sector depends upon producers having an understanding of how water scarcity will impact their production decisions.

Life Cycle Analysis

Introduction

There is increasing interest among consumers, food manufacturers, retailers and other food system stakeholders in quantification of product sustainability. As the food industry improves metrics and measurements of environmental impacts it has become clear that a life cycle perspective is necessary to summarize the many variables and impacts associated with the complex set of processes associated with agricultural production, processing, distribution and consumption. Life Cycle Assessment (LCA) is an effective tool for achieving the goals of this project.

Life Cycle Analysis as a Tool

Life Cycle Assessment is a technique to assess the environmental aspects and potential impacts associated with a product or process by: compiling an inventory of relevant energy and material inputs and environmental emissions, evaluating the possible environmental impacts associated with identified inputs and releases, and interpreting the results to assist in making more informed decisions. Broadly, an LCA consists of four stages:

- Define the goal and scope – including appropriate metrics (e.g. greenhouse gas emissions, water consumption)

- Conduct life cycle inventories (collection of data that identifies the system inputs and outputs and discharges to the environment)
- Perform impact assessment
- Analyze and interpret the results

The goal and scope definition phase is a planning process, which includes delineating and describing the product, process or activity; establishing the aims and context in which the LCA is to be performed; and identifying the life cycle stages and environmental impact categories to be reviewed for the assessment. The depth and breadth of LCA can differ considerably depending on the goal of the LCA.

The Life Cycle Inventory (LCI) phase takes stock of an inventory of all the input/output material and energy flows with regard to the system being studied. During this phase, all water, energy, materials and environmental releases (e.g.: air emissions, solid wastes, wastewater discharge) are identified and quantified for each stage of the life cycle.

The life cycle impact assessment phase (LCIA) is the third phase of the LCA. This step calculates human and ecological effects of material consumption and environmental releases identified during the inventory analysis. For this study, Water Use was analyzed and reported. Life cycle interpretation is the final phase of the LCA procedure, in which the results are summarized and reviewed. Its goal is to recognize the most significant environmental impacts and the associated life cycle stage, and emphasize opportunities for potential change or innovation.

Objectives of this Project

The primary goal of this project was to perform a detailed Life Cycle Assessment of water use in the U.S. pork supply chain. This LCA is a cradle to farm gate detailed water footprint analysis of three production strategies at three scales across 10 regions.

Effect on the US Pork Industry

The U.S. pork industry is potentially vulnerable to risks associated with water shortages in areas of intense production. This analysis will provide swine producers with information and tools to anticipate and manage for changing water resource conditions. These impacts vary by location, production strategy, life-phase and operation scale. The pork industry will use the results to identify opportunities to reduce water use, consumption of other natural resources and the support of other internal decisions for increasing the efficiency, profitability, safety and security of the U.S. pork supply chain.

Hypothesis Statements

H(0)1: All swine production strategies have approximately the same water footprint.

H(A)1: Some swine production strategies have a larger footprint than others.

H(0)2: All swine production facility scales have approximately the same water footprint.

H(A)2: Large scale swine production facilities often have a smaller water footprint than small scale facilities.

H(0)3: All regions of swine production have approximately the same water footprint.

H(A)3: Water footprints vary with the region of production.

2. LITERATURE REVIEW

Overview of Water Use in Swine Production

This review includes water usage information for feed and swine production as shown in Figure 2.1. Each arrow in the diagram represents a range of water usage to or from each unit process. The following documents the water usage reported for each phase of the pork life cycle, with additional detail placed on the processes from the field to the farm gate (Figure 2.2).

Blue vs. Green Water Definition

In water accounting, water can be classified as either blue or green water. Green water is the precipitation that remains in or on top of the soil and vegetation, and does not run off the land or recharge the groundwater. Blue water is the available surface or groundwater that can be distributed to and competed for by multiple end users. Only blue water quantity was considered in this literature review. In addition, the quality of the blue water was beyond the scope of this study.

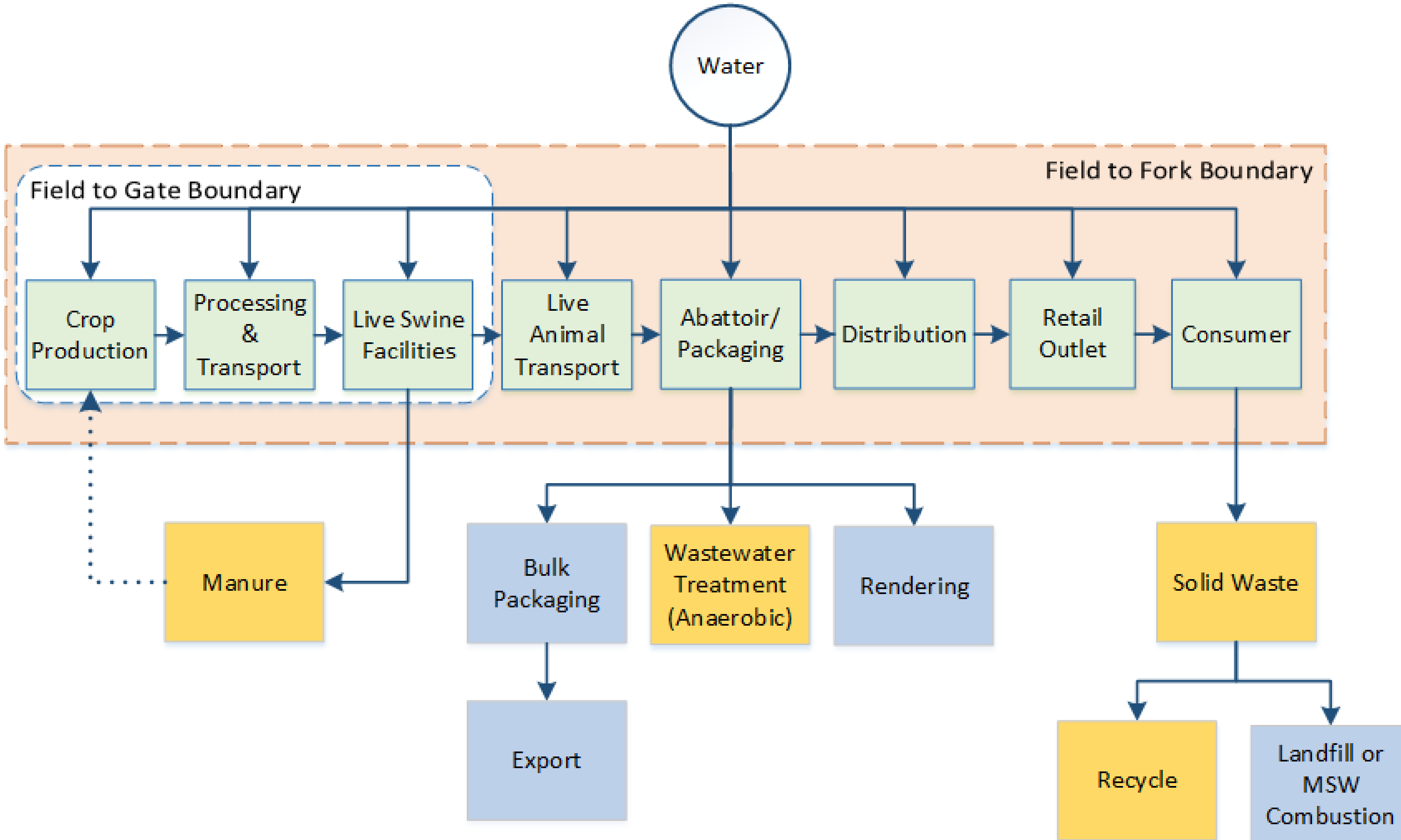

Figure 2.1. Process flow diagram of the entire pork supply chain with water inputs in pork production unit processes.

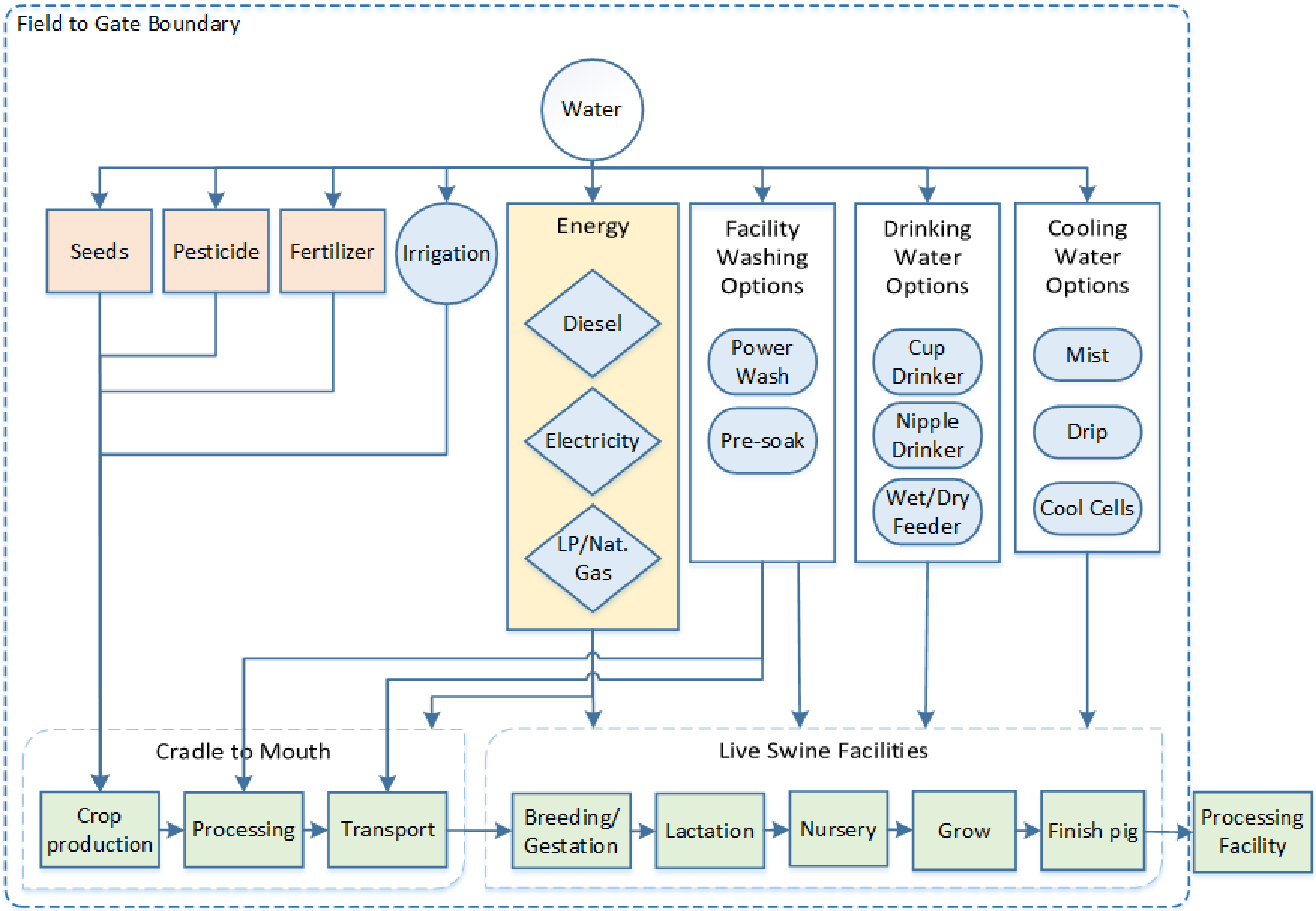

Figure 2.2. Process flow diagram of the field to gate boundary for water utilization.

Water Use from Field to Farm Gate

All of the water consumption that occurs from crop production, through the live swine facility, and to a market ready pig was considered to be the "field-to-gate" water footprint. The boundary of water utilization in pork production processes from field to gate is shown in Figure 2.2. The largest components of the pork production process included within the system boundaries are crop production for feeds and the live swine production facilities.

Water Use in Crop Production

Of the water used in the production of meat products, the majority has been shown to come from water usage in the cultivation of feed crops (Figure 2.3). Of the water used directly in the live swine production facilities, the majority is used in the consumption of drinking water by the animals (57%) and in the use of service water (41.5%) (Figure 2.3). Service water is defined as the amount of water used in facility cleaning, animal cooling, etc.

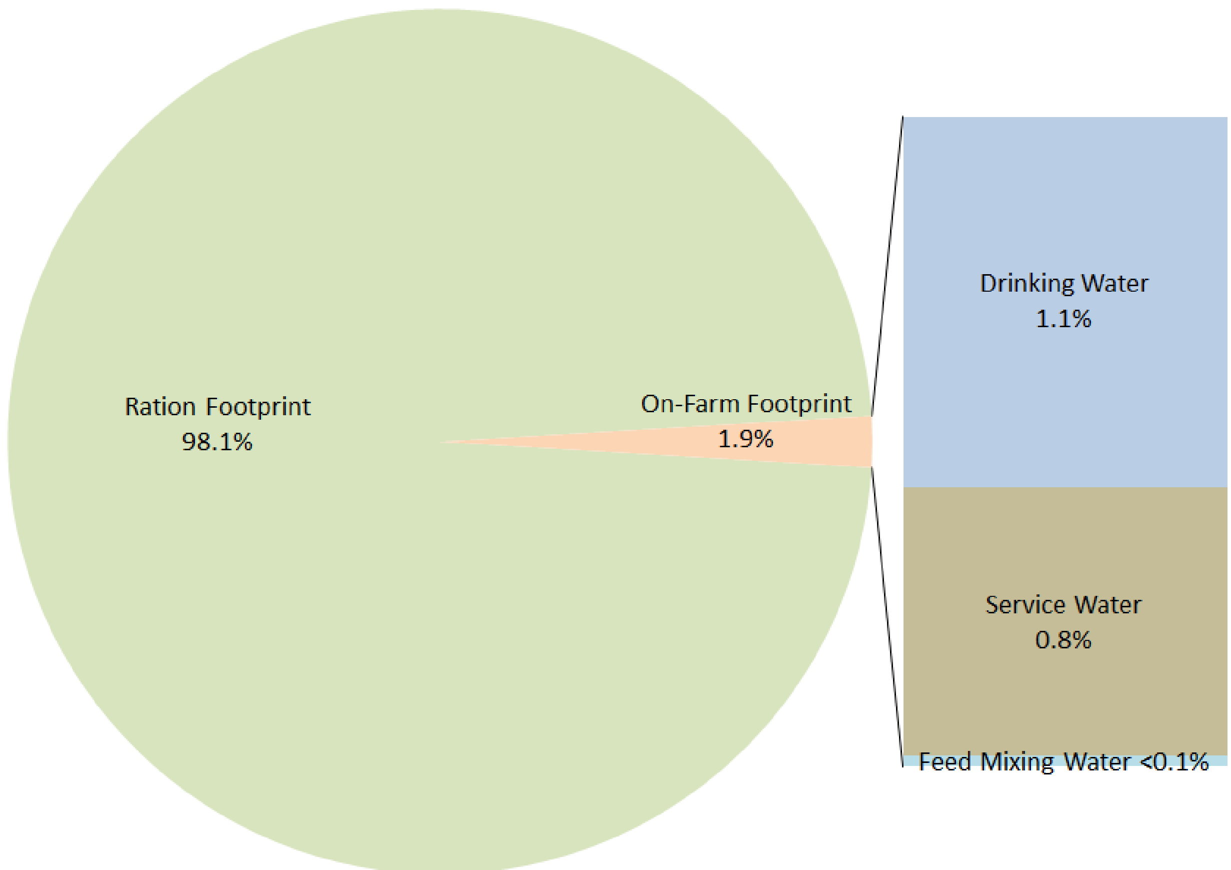

Figure 2.3. Distribution of water use in global meat production (excluding processing). Service water refers to cleaning water, washing water, and other services necessary to maintain environment (Mekonnen & Hoekstra, 2012).

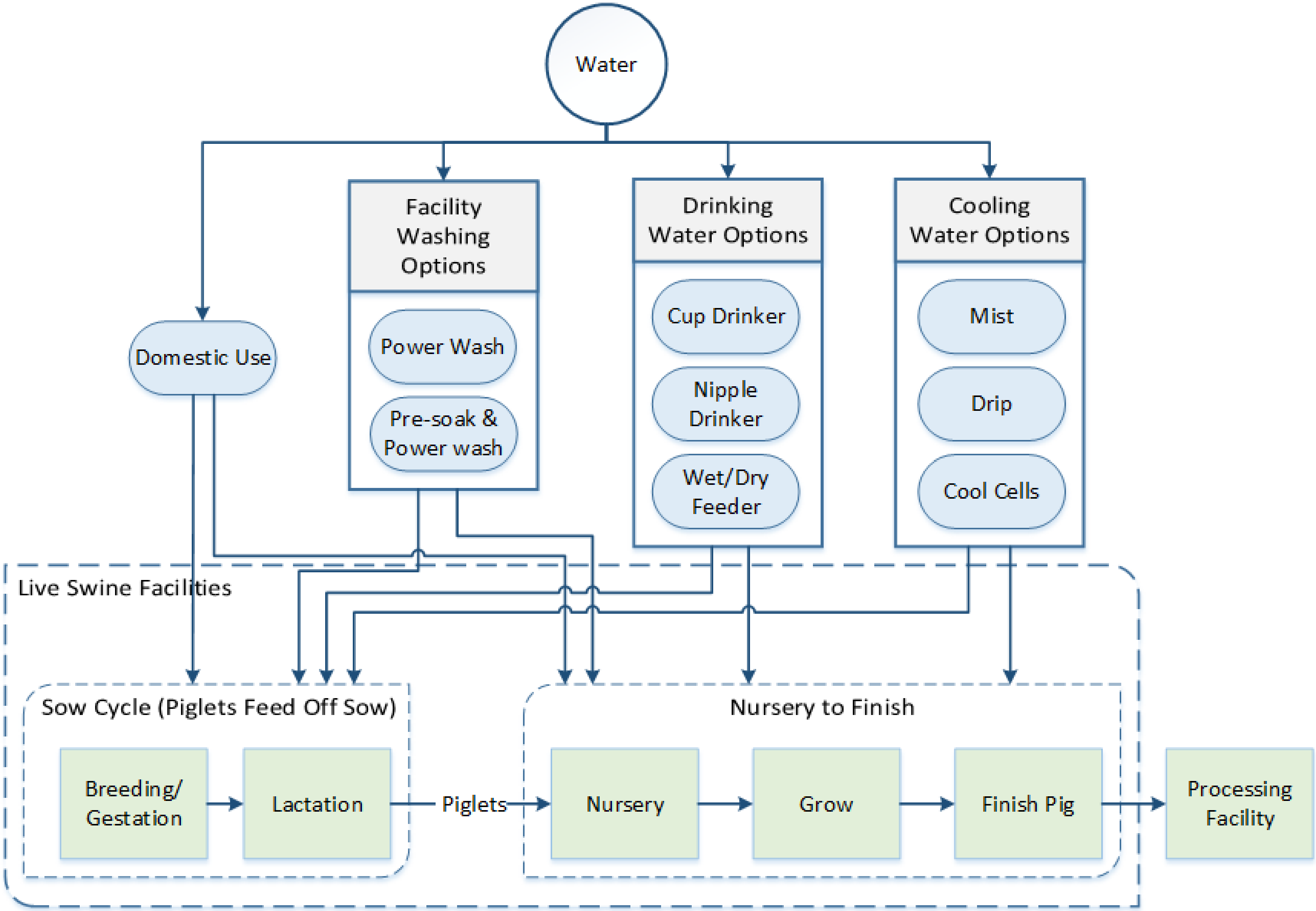

Figure 2.4. Live swine facility water use diagram

Water Use at the Swine Production Facility

Pork production at a live swine facility is the next step in the supply chain. We defined the system boundaries for a typical production facility as shown in Figure 2.4. Within the production facility, the system was broken down further into different stages including gestation, farrowing, nursery, and finishing. Muhlbauer et al. (2010) reported the percentage of the total facility water usage consumed in each production stage. The largest amount of water was used in the finishing barn (64%) followed by gestation (16%), nursery (11%), and farrowing (9%) (Muhlbauer et al., 2010).

Water inputs and their associated technologies were considered for each life phase of pork production. For example, drinking water is consumed in each phase, and drinking water consumption varies depending on which of the water delivery technologies were modeled. The same was true for facility washing water and cooling water. It was important to determine the appropriate volume of water for the given life phase, region and scale, in addition to the most common dispensing methods for a particular production strategy. The use of drinking water, cooling water, and cleaning water for manure management and transport are discussed in more detail in the following sections.

As shown in Figure 2.3, the vast majority of water use in pork production is related to the swine ration. The on farm water footprint consists of drinking water, washing water, cooling water and other water sinks. Figure 2.3 from Mekonnen & Hoekstra (2012) disagrees with Figure 2.5 from Muhlbauer et al. (2010) with respect to animal drinking water. The survey data collected by Muhlbauer et al. shows the pig drinking water comprises 80% of the on farm water footprint which is 23% more than Mekonnen & Hoekstra estimated. However, both sources agree that pig drinking water makes up the largest percentage of the on farm blue water footprint.

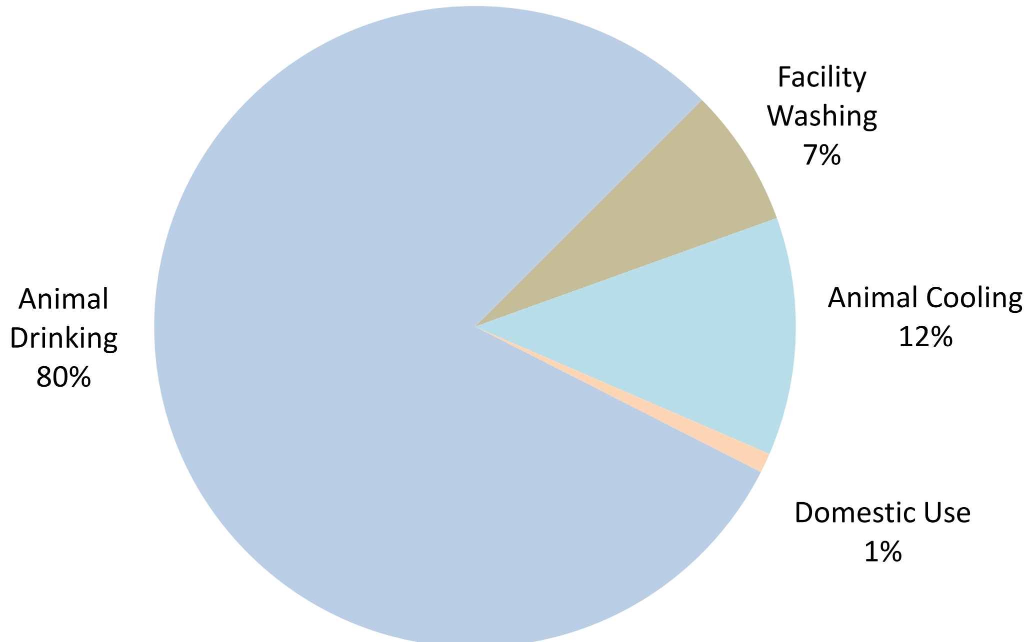

Figure 2.5. The average water usage breakdown from nine farrow to finish swine operations (excluding feed footprint) from survey data. Adapted from Muhlbauer et al. (2010).

Drinking Water Consumption in Swine Production Facilities

Pig Drinker Systems

Drinking water has been predicted to make up the largest amount of the live swine facility water footprint (Muhlbauer et al., 2010). For this reason, it was important to fully understand drinking water consumption at each life stage. The drinking systems considered here are the most commonly used technologies in the U.S. pork production industry: nipple drinker systems, cup drinking systems, and wet/dry feeders. Nipple drinkers are emphasized in this report as they are the most commonly used system in North American swine production (Patience, 2012).

Nipple Drinker System

In general, nipple drinkers are water dispensers that do not capture excess water that is spilled while the animal is drinking. These drinkers provide an outflow of water when pigs place their mouths against a small exposed outlet (Figure 2.6). Instead of being directed to a collection apparatus, the excess flow is routed into manure storage, and is lost from the system (Muhlbauer et al., 2010). As a result of the absence of a water collection vessel in nipple drinker systems, and the tendency of swine to move against the nipples when they are not being used for drinking, nipple drinker systems are associated with the highest wastage rate (Muhlbauer et al., 2010).

However, there are management techniques that are currently in use that can decrease the amount of water lost from nipple systems. By altering the mounted height of the nipple, and the system flow rate, producers have been able to improve the water usage efficiency of nipple drinkers. In their comparison of nipple drinker efficiency studies, Muhlbauer et al. (2010) reported that by periodically adjusting the nipple height to the

Figure 2.6. Nipple drinking system (Mountainharvestorganic.com, 2011)

shoulder level of the swine, and by reducing water flow rates, water wastage can be decreased by 15% (Li & Chénard, 2005). The alterations in the drinker systems did not result in changes in the daily water intake by the pigs. Commonly used swing nipple-type drinker systems are mounted on the ceiling and are allowed to move freely within the production area. The height of these systems can be easily adjusted to improve water usage efficiency. In addition, the swinging nipple systems allow them to be displaced when the swine move against them, resulting in an 11% decrease in water wastage from conventional nipple drinkers (Brumm, 2000).

Other systems use a variation of the nipple drinker known as bite ball style drinkers, which require that the outlet be inserted further in the pig's mouth before water is dispensed, reducing wasted water (Muhlbauer et al., 2010). Li and Chénard (2005) showed that unadjusted height nipple drinkers with 1000mL/min peak flow rates had the largest wastage (41.8%) compared to recommended height with 500mL/min flow rates (15.1%). Studies of bite ball style drinkers showed reductions in overall water usage of 8-22% compared to traditional nipple drinker systems over different growth stages (Muhlbauer et al., 2010). By altering the mounted height of the nipple, and the system flow rate, producers have been able to approach but not reach the efficiency of other drinker systems. To the extent that pig watering is a water use of concern, these technologies could be employed to reduce water use.

Cup Drinking System

Cup drinkers use a collection basin to provide drinking water. A lever, when moved by a pig, releases water into a basin or bowl that the pig can then drink from. Alternatively, the basin could have a liquid-level float switch to control water delivery.

In general, cup style drinkers have higher water use efficiencies than nipple drinkers. The collection of excess water in a basin minimizes wastage, as all of the water pumped into the system can be used by the pigs, though water is still wasted in small volumes due to evaporation and splashing by the pigs in drinking or play. Muhlbauer et al. (2010) cited studies comparing water usage in cup and nipple drinker systems, and the reduction in usage from the cup drinkers ranged from 20-31.2% in the nursery and finisher phases. A potential problem associated with cup drinkers is the retention of potentially contaminated water in the drinking water basins; however, studies have not identified any impacts on pig performance resulting from changes in drinker type (Muhlbauer et al., 2010).

Figure 2.7. Cup drinking system (Gillisag.com, 2010)

Wet/Dry Feeder

A wet/dry trough mixes feed and water in the same container. These troughs allow for a reduction in water consumption per day, with the savings occurring mostly in the growing and finishing stages. Shelf style feeders separate the water and feed within the container using depressions to collect only the drinking water (Muhlbauer et al., 2010).

As with the cup drinkers, the capture of water in the feed basin increases water usage efficiency compared to nipple style drinkers. The concerns with wet/dry troughs mirror those of cup drinkers, most notably the retention of contaminated water in the reservoir. Some producers say that pigs find the food less appetizing after it is saturated, causing them to eat less food; however, no changes in gains have been documented between the different drinker types (Muhlbauer et al., 2010).

Figure 2.8. Wet/dry feeder trough (Christianson et al., 2009).

Effects of Temperature on Drinking Water Consumption

The temperature and relative humidity of a pig’s surroundings is known to affect the pig’s desire to consume food and water (NRC, 2012). Climate can also have non-physiological effects on pigs that impact water consumption. According to Patience (2012), it is common for bored or heat stressed pigs to waste more water while playing with drinkers. As a result, higher ambient temperatures result in an increase in water usage.

The overall relationship between swine drinking water use and temperature is not straightforward. Since pigs do not sweat, they rely on evaporative heat transfer from respiration as a cooling mechanism. From a behavioral perspective, it becomes unclear which external factors most affect drinking water demand. Ingram & Stephens (1979) evaluated the relative importance of thermal conditions on pig drinking water and concluded that there was insufficient evidence to predict drinking water by manipulating the pigs’ thermo-receptors.

In contrast to water consumption, food consumption shows a strong decreasing trend as temperature increases, with a corresponding increase in respiration rates (Renaudeau, 2010). This decline in daily feed consumption is most likely the result of a physiological mechanism that is triggered to reduce the metabolic heat produced by the pig. Increasing respiration is a pig's main physiological pathway to accelerate heat exchange. These phenomena are accounted for by the daily water requirement averages shown in Table 2.1.

Table 2.1. Average daily water intake of pigs in each life stage used to create and parameterize algorithms within the PPEFC.

Pig Life Stage	**Drinking System**	**Average Daily Water Intake (l/pigspace/day)**	***Standard Deviation***	***Min***	***Max***
Gestation[1,2,5,7]	nipple	18	4.7	13	24
Lactation[1,2,5,7]	nipple	26	8.3	18	37
Nursery[1,7,9]	nipple	3	0.5	3	4
Grower[1,5,6,7,8]	nipple	6	3.2	5	8
Finisher[1,3,4,6,8,10]	nipple	8	3.6	5	15

[1]*Almond, 1995*
[2]*Almond, 2002*
[3]*Amornthewaphat et al., 2000*
[4]*Brumm, 1999*
[5]*Brumm, 2006*
[6]*Christiansen, 2002*
[7]*Froese & Small, 2001*
[8]*Li, 2005*
[9]*Margowen, 2007*
[10]*Rantanen, 1994*

The volume of water each pig consumes will fluctuate (not always predictably) with environmental conditions such as age, temperature, humidity, airspeed, stocking density, drinker flow rate, disease or stress level, and feed composition (Stockill, 1991, Nyachoti, 2001). As a result, most drinking systems have been designed to provide pigs with as much water as they will drink. A downside of this approach is high wastage rates related to water delivery systems, flow rates, barn temperature and pig behavior. Phillips et al. (1989) reported that drinking systems could result in wastage rates of up to 80% in commercial sow barn operations. Li (2005) recorded water waste to be as high as 42% with high flow unadjusted nipple drinkers in finishing operations.

Sow Drinking Water for Gestation and Lactation

The sow stage is more water intensive per head than the subsequent production stages, as shown in Table 2.1. The higher consumption rates require maximum nipple flow rates of 1000mL/min for gestating sows and 1500mL/min for lactating sows. The high nipple flow rates likely account for the reported water wastage rates of 23-80% (Patience, 2012).

During the farrowing and lactation phase it has been shown that, within a reasonable range, water consumption of the sow does not affect the gain of piglets (Almond, 2002). The lactating sows' daily water intake is the highest of all growth phases and ranged from 18-37 l/day (Almond, 1995, Froese & Small 2001). The higher water intake in the lactation phase can be partially attributed to the piglets' nutritional reliance upon the sow. Lactation and gestation have the greatest standard deviation of reported drinking water values (Table 1.1).

Nursery Drinking Water Consumption

Water-to-feed ratios are reported by Patience (2012) for all life cycles other than the nursery phase. Nursery barns do not have consistent correlations between the quantity of water and the quantity of feed consumed. The nursery stage is known to have the lowest drinking water requirements per pig of all the growth stages (2.1). Lower peak flow rates 500 mL/min than other growth stages are recommended for nursery pigs (Patience, 2012).

Grow-Finish Water Consumption

As finishing pigs near market weight, water weight declines to about 50% of their total body mass (Patience, 2012). Water usage for growing/finishing pigs mostly occurs immediately before or after feeding with approximately 85% of daily water consumption occurring at that time (Patience, 2012). Pigs will employ extra effort in order to obtain water from lower flow (100 ml/min) drinkers, suggesting that lower flow rates will not significantly affect pig performance (Brumm, 2008). Patience (2012) recommends nipple flow rates 750mL/min for growing and finishing pigs.

Cooling Water Consumption in Swine Production Facilities

After drinking water systems, cooling systems are the second largest consumer of water in the live swine production facility (Figure 2.5). The influence of cooling technologies, climate, barn type and stocking density on cooling water consumption are discussed in the following sections.

Cooling Technologies

In warmer climates, depending on the type of barns employed, water may be needed to cool pigs in the gestation, farrowing, and finish production phases. It should be noted that nursery barns do not often require cooling since nursery pigs easily tolerate temperatures as high as 90°F. Water is usually dispensed onto the pigs using a drip or sprinkling/misting system. Water is also used in evaporative cooling pads (cool cells) that remain wet and remove heat from the fresh air being forced through the porous cooling pad with electric fans as it enters a barn. In a drip or sprinkler cooling system, water is dispersed onto the pigs, and as it evaporates, heat is removed from the animal. With evaporative cooling pads, the air temperature is lowered allowing better heat transfer from the pig to the passing air. All water cooling systems require air flow across the animal. As shown in *Table 2.2*, cooling water requirements vary with cooling technology and regional temperature (Muhlbauer et al., 2010).

Table 2.2. Estimated water use for different swine cooling systems used to create algorithms within the PPEFC (Midwest Plan Service, 1991).

Cooling Technology	**Recommended water flow rate when above 85°F (l/pig/hr)**
Sprinkler	0.4
Drip	2.8
Evaporative Pad	2.3

Effects of Regional Climate on Cooling Requirements

Cooling requirements for swine facilities are affected by the local climate. Where water is used for cooling animals, the quantity required is affected by regional climate and cooling technology, and can vary from 100 l/pig/year to 1000 l/pig/year. In *Table 2.2*, the Midwest Plan Service (1991) has recommended water flow rates for each of the three most common cooling technologies. Humidity also affects cooling requirements but its effects are not well quantified in swine literature.

Effects of Barn Infrastructure on Cooling Requirements

The three barn infrastructure types reviewed in this study were drop curtain, tunnel ventilated and hoop barns. Drop curtain barns are often used in warmer climates since they can be naturally ventilated without additional energy input. When supplemental cooling is required, sprinkler/misting systems are generally used in drop curtain barns. Tunnel ventilated barns, on the other hand, are well suited for the use of evaporative pad cooling, with fans at each end of the barn forcing air across the production area. In warmer climates, some tunnel ventilated barns also have sprinkler systems installed.

The cooling requirements for hoop barns are very similar to drop curtain barns since they also utilize natural ventilation. Some hoop barns may also have sprinkler/misting systems in warm climates, but it is not desirable to wet the natural bedding (corn stalks, straw, wood shavings, etc.). Hoop barns may require less water, electricity and/or natural gas for climate control, but in harsh climates, pig health and growth could suffer.

Effects of Stocking Density on Water Consumption

Pigs add significant heat to their environment when closely confined. Stocking density, which is defined as the number of animals per given floor space based on animal size and stage of growth, can thus have a significant effect on the amount of cooling necessary to keep the pigs healthy.

Research trials have consistently shown that reducing the amount of space per pig leads to a reduction in feed consumption from nursery to finish (Kornegay and Notter, 1984; Brumm, 2006). Average daily gain decreases as daily feed intake decreases. Some researchers have tried to overcome this problem by increasing the nutrient density of the food, but daily gain was still depressed in crowded facilities (Brumm, 2006). Since there are significant water requirements associated with feed production, a reduction in daily feed reduces daily water consumed, but that effect is countered by the reduction in daily gain. Since it is not extensively studied, stocking density is not a reliable predictor of carcass characteristics (Brumm, 2006).

Turner et al. (1999) documented that pigs will use more water when they are in larger groups than smaller groups, even when the pig per drinker ratio was maintained.

Cooling Requirements by Life Phase

Sow Cooling

Piglets in the farrowing barn with sows have a much higher preferred temperature range than sows (Table 2.3). In fact, piglets are often supplied with heating pads or lamps to provide supplemental warmth. In *Table 2.2* above, sprinkler cooling uses less water than other technologies, but it is not optimal for a sow barn during farrowing since the piglets would also receive cooling (MWPS, 1991). When the sow is in a farrowing room, drip cooling can effectively cool only the sow. If supplemental cooling is employed at sow barns it is typically evaporative pads (cool cells).

Table 2.3. Recommended thermal conditions for swine used to parameterize cooling system activation within the PPEFC (FASS, 2010; Thompson, 1996).

Life stage	Body weight (kg)	Preferred range (°F)	Lower intervention[1] (°F)	Upper intervention[2] (°F)
Sow	>100	60 - 75	5	90
Lactating sow	>100	60 – 80	60	90
Piglets	< 5	>90	80	100
Pre-nursery	5 - 15	80 – 90	60	95
Nursery	15 - 35	65 – 80	40	95
Growing	35 - 70	60 – 75	25	90
Finishing	70 - 100	50 – 75	50	90

[1] *Supplemental heating in some form needs to be considered when temperatures at the pig near the lower intervention temperature.*

[2] *Supplemental cooling in some form needs to be considered when temperatures at the pig near the upper intervention temperature.*

[1,2] *Without intervention, pig health and growth may be compromised.*

Nursery Cooling

Nursery pigs do not require as much cooling water as older pigs because they prefer warmer temperatures (Table 2.3). Water-based cooling systems are not usually used for pre-nursery or nursery pigs. In nursery barns, warming is often of greater concern than cooling, depending on the climate.

Grow-Finish Cooling

Grow-finish barns may use sprinkler/mister cooling, evaporative pad cooling (cool cells) or a combination of the two technologies. The body heat from grow pigs can significantly increase the barn temperature. Larger pigs need more cooling to stay healthy.

Manure Management Systems and Washing Water

Facility washing, which is the third largest area of water consumption in a live swine production facility, accounts for 7% of the water used (Figure 2.5). In order to maintain a sanitary environment for the pigs, the manure must be removed or flushed from production areas, and the stalls must be cleaned and sanitized. The following sections discuss the types of manure management and cleaning systems currently used in swine production facilities.

Types of Manure Management Systems

Manure management varies from operation to operation. In most swine operations, a slatted floor with sub pits collect pig excrement and wasted food and water. In a typical application, the water required to flush and maintain a manure management system is recycled from a previous application or is drawn directly from a storage lagoon. The only additional water consumed in manure management is associated with the cleaning and sanitization of pig space. Hoop barns make use of dry collection methods and use no additional washing water. The two most common types of sub pits include subfloor to lagoon or formed (above or in-ground) storage structures and deep pits.

Subfloor to Lagoon System

This manure management technique involves the periodic flushing or scraping of subfloor pits into lagoons or formed (above or in-ground) storage structures. Pig manure is excreted in a highly liquid form, and the additional urine and drinking water wastage keep subfloor pits in a liquid state. The flushing of a subfloor pit is often initiated by the removal of a sub pit plug and followed by cycling recycled lagoon water through the pit. There are also systems that use shallow below building pits and mechanical scrapers rather than flushing manure with recycled water to the lagoon or storage system. Using data for manure management systems from the EPA (2011) and farm demographics from NASS Census (2007) data, we were able to estimate that anaerobic lagoons are the second most common manure management system and are used in the production of approximately 35% of the pigs produced in the U.S.

Deep Pit

This method of manure management utilizes deep subfloor pits to collect and store manure until removal for land application and does not require additional water. The manure can be removed by physical methods and is often land applied. Deep pits are estimated to be the most common method and account for over 40% of manure management systems (NASS Census, 2007, EPA, 2011).

Dry Cleanup Techniques

This technology is best for removing solid manure that has collected on bedding or shelter flooring. The manure and bedding is usually removed by a skid loader, tractor bucket and is most often land applied. Generally dry cleanup techniques will be used to remove the bulk of bedding and manure and then a presoak (to soften dried manure) followed by power washing can be used to remove the remainder of residues. The initial dry bedding/manure removal can significantly reduce the quantity of water needed to power wash a barn or transport vehicle.

Factors Affecting Washing Water Use Requirements

It is commonly known that water temperature, presoaking, cleaning agents, water pressure and flow rate all affect washing time and water consumption. A study by Hurnik (2005) compared different washing techniques and concluded that hot water reduced washing times by an average of 22%, presoaking reduced washing time by an average of 50%, and cleaning agents (soap) reduced washing time by an average of 8%. The study did not report actual water consumption values. Variation between washing techniques is common, but for this study we adopted an industry average as shown in Table 2.4.

All-in, all-out facilities, where pigs enter a barn and are sent to market as a cohort at the same time, are increasingly common in the pork industry. Facility washing is much more efficient when the entire facility can be washed between cycles of pigs rather than washing each pig space individually as in a continuous flow barn.

A Veterinary Infectious Diseases Organization (VIDO, 1998) survey of western Canadian swine barns reported a wide range of wash water usage due to differences in washing and presoaking practices. Iowa State University conducted a survey (Muhlbauer et al., 2010) of 160 large swine operations that showed a smaller range of values than the VIDO study that had more variance in washing practices. Averages of the values from both surveys are shown in Table 2.4.

Table 2.4. Average wash water usage by pork production phase used to parameterize the PPEFC.

Production phase	Average wash water usage[1] (l/pigspace/wash)	Range (l/pigspace/wash)
Gestation/farrowing	136	85 - 318
Nursery	12	6 - 26
Grow-Finish	28	16 - 38
Finishing	80	21 - 242

[1]The water usage per wash was calculated using averages from VIDO (1998) and Mulhbauer et al. (2010).

Wash Water Requirements by Life Phase

Sow Barn Washing

Breeding/gestation barns and farrowing barns are less likely to be all-in all-out facilities and therefore require each stall to be cleaned individually when the sow transitions between the gestation barn and farrowing barn. Both gestation barns and farrowing barns are washed about 2.5 times per year if each stall is washed between each sow.

Nursery Barn Washing

Nursery barns have a much higher turnover than sow and finishing barns; therefore, the nursery barns get washed about 6 times per year-with each new cycle of nursery pigs. The wash water per pig space is less than grow and sow barns, but the ratio of floor space to wash water is consistent.

Water Used to Wash Pig Transportation Vehicles

Another consideration for water usage lies with cleaning the vehicles used to transport live animals. Live swine transportation vehicles are washed after every load of pigs. The transportation wash station can be physically located either on or off the swine farm.

Pig transportation systems require proper cleaning agents and techniques to minimize the spread of disease. Generally, swine transport trucks are washed after every load. The current biosecurity practice requires cleaning of all swine related vehicles (including veterinary and maintenance vehicles). Each of these vehicles must be cleaned and care taken to ensure the biosecurity of each facility, including gilt development sites, and gestation/farrowing sites.

In an Iowa State University survey, Muhlbauer et al. (2010) concluded that to clean the average 185-200 pig capacity transport vehicle requires approximately 15 l/pig/transport. A system that relied partially on scraping and shoveling in addition to recycling other waste water would reduce water use. However, in order to maintain biosecurity it is important to continue using fresh water for final disinfection.

For consistency between scenarios, the live swine transport water use has not been assigned to the swine farm operation.

Wasted Water

There are many techniques which could be used to reduce water usage (Froese, 2001) but some of them fall beyond the scope of this report since the stated goal was to find the most common water consumption practices and associated values for each scenario. Beyond the typical amounts of water use and waste, improper installation and poor design can lead to large yearly wastage of water. Some of this can be managed by simple, routine maintenance.

Current Gaps in Knowledge

Since crop production is expected to make up a large percentage of the water footprint, there is a critical need for comprehensive LCAs to be established on all feed inputs. The advent of least cost formulation of swine feed has created constantly changing feed compositions that make it challenging to quantify feed impacts beyond common feed configurations. The challenge is the lack of a uniform and consistent feed formulation reporting system across the pork industry. As more feed production LCAs are completed, the ability to more accurately estimate water footprints of animal products will be greatly increased.

3. METHODS OF PORK WATER LCA

Goal

The primary goal was to perform a detailed assessment of water use in the pork supply chain in the U.S., from cradle to farm gate. The primary audience of this LCA is the pork producers who may use the results to identify opportunities to reduce water use, and in the support of other internal decisions for increasing the efficiency, profitability and security of the U.S. pork supply chain. This LCA is a field-to-gate detailed water footprint analysis of three production strategies at three scales across 10 regions.

Functional Unit

The functional unit for the LCA was defined as the volume of water embodied in a kilogram of swine (live weight) at the farm gate.

System Boundaries and Scope

This life cycle assessment was a field (crop production for feed) to gate (live swine ready for transport to processing) analysis of the water footprint of U.S. pork production. The system boundaries began with feed production, and ended with swine at the farm gate ready for transport. Three swine production categories were included in this analysis:

1. Sow (Breeding/Gestation/Lactation)
2. Nursery
3. Growing/Finishing

Production practices included bedded hoop, total confinement/tunnel ventilated, and total confinement/drop curtains. Production categories and practices were analyzed for three production scales (100, 1200, and 2500 head barn capacity) across ten production regions (Figure 3.1, Table 3.1). It was assumed that all barns from a single scenario were located at a single facility and that there was an insignificant water footprint associated with the movement of pigs between barns. Effects embodied in infrastructure (e.g., water emissions associated with manufacture of new equipment necessary for farm equipment, which would be amortized over the expected life of the equipment) were not included in the analysis. Boar water footprints were not considered since boar-to-sow ratios are nearly 1:50 and each sow produces nearly 25 piglets per year, which would make for an annual boar to market hog ratio of 1:1250, and would fall below the 1% contribution threshold. Where data were incomplete, surrogate unit operations were identified from the EcoInvent database.

Scenario Development

The literature review and discussion with industry representatives including NPB representatives helped refine the selected matrix of scenarios to be analyzed. The Pig Production Environmental Footprint Calculator (PPEFC) Version 2.0 was used to establish the on-farm feed usage and water usage which were used as life cycle inventory for the SimaPro LCA barn unit processes. Separate models were created for the sow, nursery and grow-finish barns. The combined analyses of production strategies, production scales, production life stages, and production regions yielded a total of 240 scenarios that were developed and analyzed; not all strategies applied to all scales or life stages (Table 3.2).

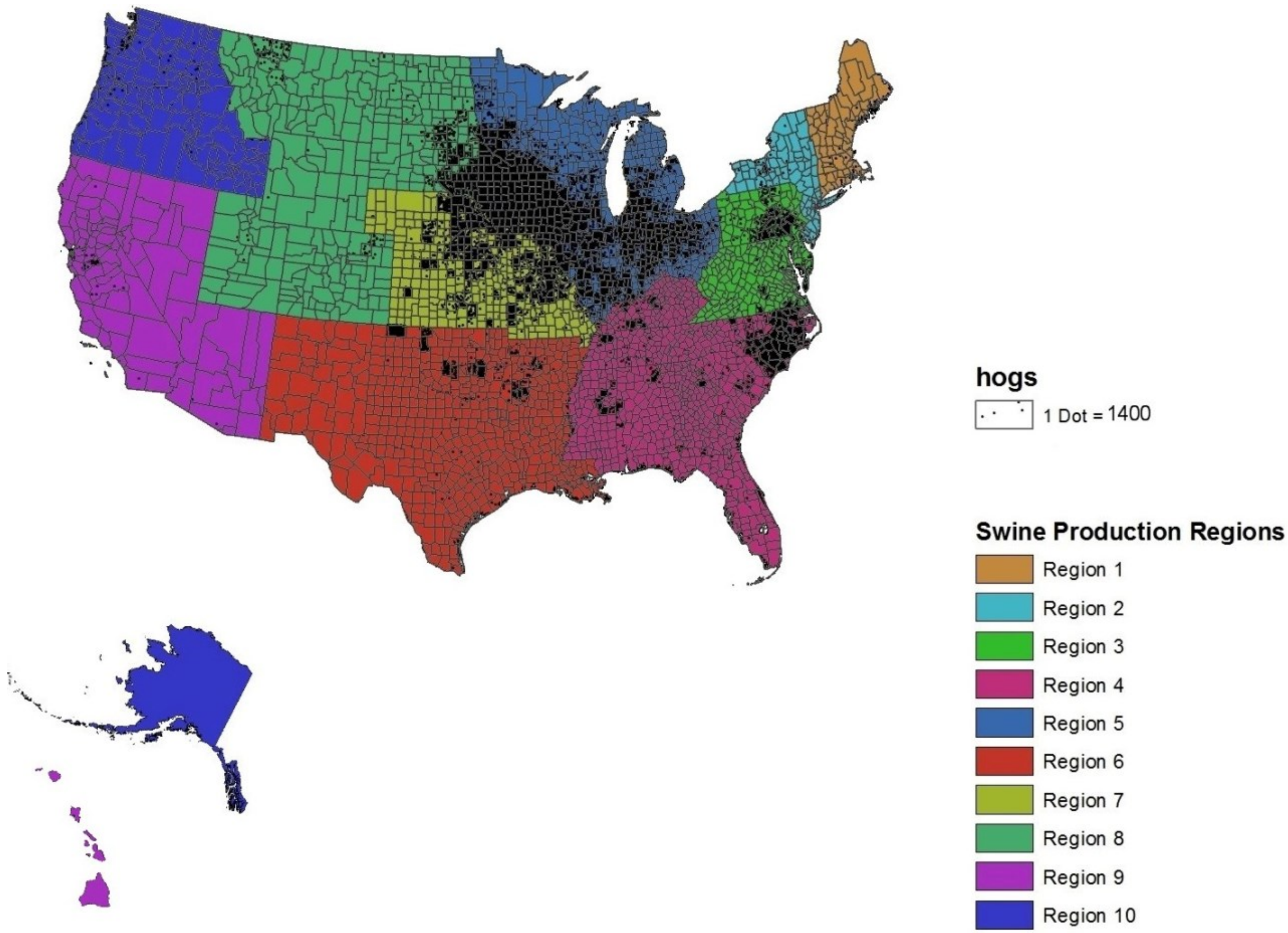

Figure 3.1. Swine Production Regions used in this analysis. The Distribution of hogs is from the 2007 NASS Census.

Table 3.1. Scenario matrix of Live Swine Production Detailed LCA of Water Use. The sow life stage includes breeding, gestation and lactation.

Production Strategy	Production Scale	Life Stage	Production Region
Drop Curtain	100	Sow	R1 (CT ME NH VT MA RI)
Tunnel Ventilated	1200	Nursery	R2 (NY NJ)
Hoop Barn	2500	Growing/Finishing	R3 (DE MD PA WV VA)
			R4 (AL FL GA KY MS NC SC TN)
			R5 (IL IN MI MN OH WI)
			R6 (AR LA NM OK TX)
			R7 (IA KS MO NE)
			R8 (CO MT ND SD UT WY)
			R9 (AZ CA HI NV)
			R10 (AK ID OR WA)

Table 3.2. Scenario matrix of the production strategies that were analyzed for each scale. An "x" indicates that the combination was analyzed.

Scale	Production Strategies		
	Drop Curtain	Tunnel Ventilated	Hoop Barn
100	-	-	x
1200	x	x	x
2500	x	x	-

Production Strategies

There are distinct production methods within the swine industry. These facilities range from low cost hoop barns to more costly confinement operations. The key differentiating factor between production methods is the structure of the swine housing. Each of the methods studied provide moderate to substantial protection from the elements, but must be well suited for the geographic location of the operation. An important consideration in the structure would be cooling capacity; due mainly to pig's inadequate ability to dissipate their heat. With this in mind, many production strategies may include extra measure to cool pigs (e.g. drip cooling systems or cooling pads). There are many combinations and possibilities for pig production in the US. For this research, the most common production structures were selected to be tunnel ventilated, drop curtain ventilated, and hoop barn.

Tunnel Ventilated

Tunnel ventilated operations are the most common production structures and typically coincide with confinement swine production. In this method the close proximity of each pig requires an intricate flooring system. This flooring system typically consists of concrete with openings or slates allowing pig waste to fall through to a swine lagoon. Using slated flooring allows pig waste to be managed without extra labor or removal of pigs. The main structure consists of a tunnel open on both ends. These openings often have fans that can be adjusted to regulate temperature and fresh air required to keep pigs healthy. Another feature is solid side walls which are often insulated to help maintain a livable climate with less energy input.

Drop Curtain

Drop curtain operations are another strategy often related to confinement swine production. This structure also works to increase the number of pigs per area and utilizes the same flooring system as tunnel ventilated (i.e. slated concrete). This also allows for pig waste removal with minimal labor inputs. The main difference between drop curtain structures and tunnel ventilated structure would be the side wall setup. Each side has an adjustable insulated curtain surrounding the building, this allows for climate management through altering the curtain coverage. In addition, to adjustable curtains drop structures also use fans to help facilitate fresh air to the pigs. Drop curtain structures are well suited to environments that require maximum ventilation to aid in heat dispersal from the pigs.

Hoop Barn (open front)

Hoop barns are often the simplest structures, tented barns placed on even ground. These structures are low cost but do not deliver the same level of efficiency per land area as the previous strategies. The flooring method used in hoop barns is deep bedding which collects waste while also helping increase the thermal efficiency of this structure. Since the bedding must be changed, the pigs must be moved and the waste bedding must be relocated and managed. This structure is often less expensive to set-up and with proper management strategies can be an efficient swine production strategy.

Regional Analysis

Water scarcity varies greatly with location throughout the United States. The two overarching factors that affect water scarcity are supply and demand of water. Scenarios were generated for 10 swine production regions in the U.S. (Figure 3.1). Baseline scenarios for the sow, nursery and grow barns for each were region were primarily derived from a prior project Pork Management LCA (Thoma et al., 2013). Ten archetypal counties were selected to represent the regions. The selected counties were obtained by geospatially overlaying the 2007 USDA NASS hog and pig inventory map onto the production region boundaries and choosing counties that would represent the average swine production within the region (*Table 3.3*; Figure 3.1).

Table 3.3. Archetypal swine production regions. NASS 2007 Survey data was used to calculate “Total Head”.

		Archetypical Climate Region	
Region	**Total Head (1000)**	**State**	**County**
1	24	M	Hampshire
2	194	NY	Cayuga
3	2,335	PA	Perry
4	14,912	NC	Wake
5	32,800	IN	Jasper
6	5,621	OK	Texas
7	44,277	IA	Hardin
8	4,349	SD	Edmunds
9	238	CA	Stanislaus
10	94	OR	Clackamas

Production Scales

Production scale was defined as the approximate number of head in a single barn (sow, nursery or grow) at any given moment. The most common barn size has been established to be 1200 head in a single barn. To provide better resolution three barn sizes where selected; 100 head, 1200 head and 2500 head. Barn sizes as large as 2500 head do exist but are uncommon.

Pig Production Environmental Footprint Calculator (PPEFC)

The Pig Production Environmental Footprint Calculator (PPEFC) was used to develop the scenarios which served as the life cycle inventory data for the analysis. The PPEFC uses mathematical relationships to simulate growth, feed intake and water consumption, electricity and natural gas use, manure handling, and greenhouse gas emissions during each production cycle of pig. Separate model were created for the sow, nursery and grow-finish barns. Depending on model input parameters, the grow barn model can simulate nursery, feeder-to-finish, or wean-to-finish barns.

The on farm water calculations within the PPEFC were accomplished by integrating the literature review of swine production water use into the PPEFC. This included equations for drinking water, cooling water and wash water use:

Wash water per pig per yr = f(number of cycles per yr, barn infrastructure)

Drinking water = f(pig weight)

Cooling water = f(climate, barn thermodynamic properties, evaporative pad, sprinkler or drip)

The PPEFC is now able to calculate the volume of water consumed by the pigs per year, the water consumed in cooling cells, the water required for barn washing and the volume of water required for evaporative pad, drip or sprinkler systems in the barn infrastructure. The drinking water model used during this study did not link drinking water to feed intake. Future iterations of the PPEFC will include algorithms that connect drinking water to feed intake and will be responsive to environmental conditions.

As with all models, the PPEFC is a useful tool but has limitations. With further iterations of the model, the complex relationships between pigs and their environment will become more integrated. For example, the Version 2.0 PPEFC model has assumed linear relationships for scaling and pig crowding. The simplification of the complex processes within the live swine facility is intrinsic to modeling and produces outputs that should be viewed with these shortcomings in mind. Metabolic and thermodynamic algorithms have been included in the Barn Model to account for the additional cooling needed to compensate for large pig quantities. Since hoop barns provide pigs 50% more space per pig than confinement pigs (Purdue Handbook, 2008), less cooling water is likely to be needed.

SimaPro LCA Model

The SimaPro software platform was used for calculating the final water footprint for each of the 240 analysis scenarios. Data obtained from the literature review was used to create all of the input files and water algorithms for the PPEFC. Next, aspects of the PPEFC output were used in a life cycle inventory for the life cycle analysis model developed in SimaPro V7.3 (Pre' Consultants, The Netherlands). The two models were used to produce cradle-to-grave water footprints for all 240 scenarios (Figure 3.2)

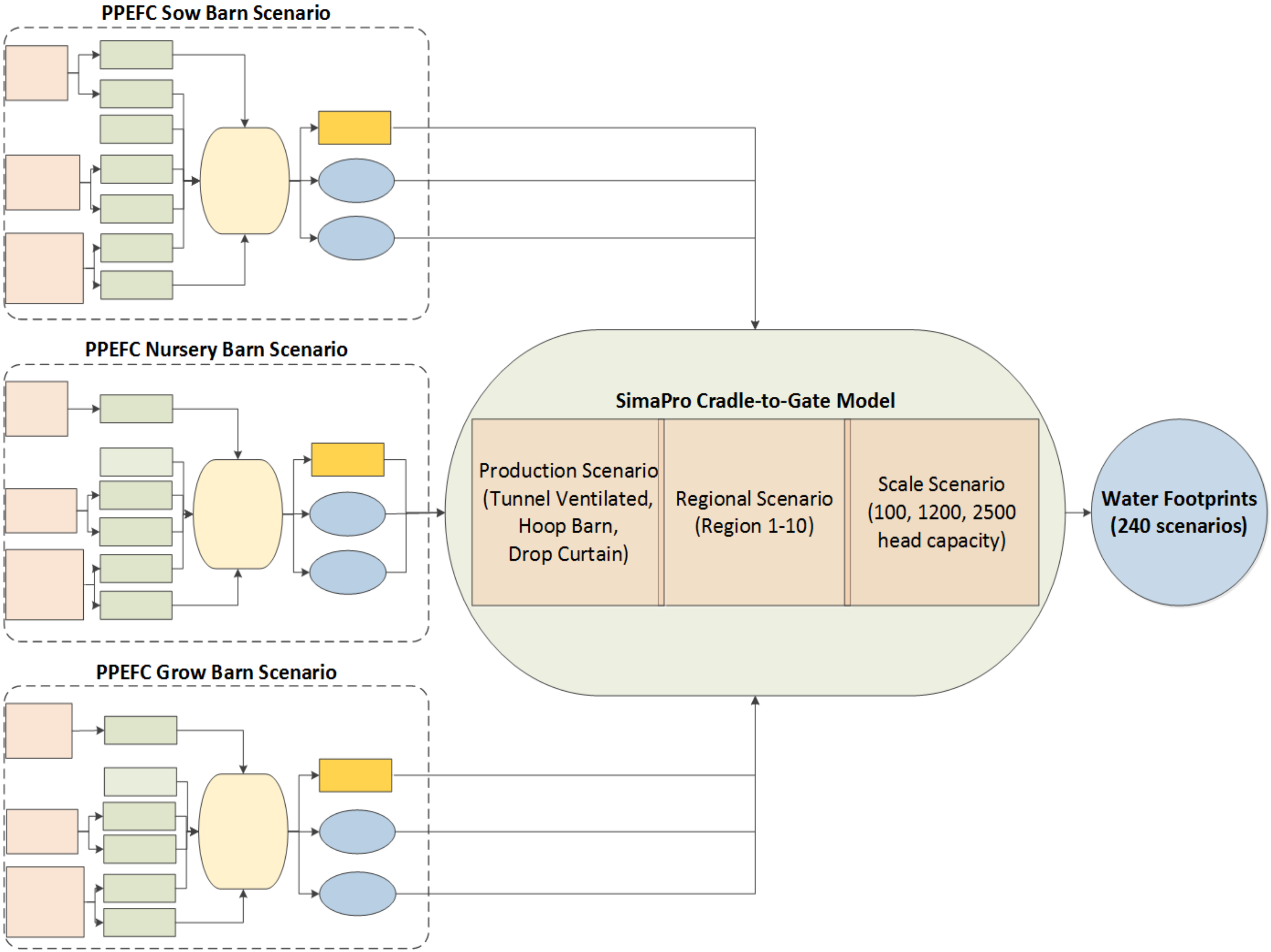

Figure 3.2. Network diagram showing the links between the Pig Production Footprint Model and the SimaPro model.

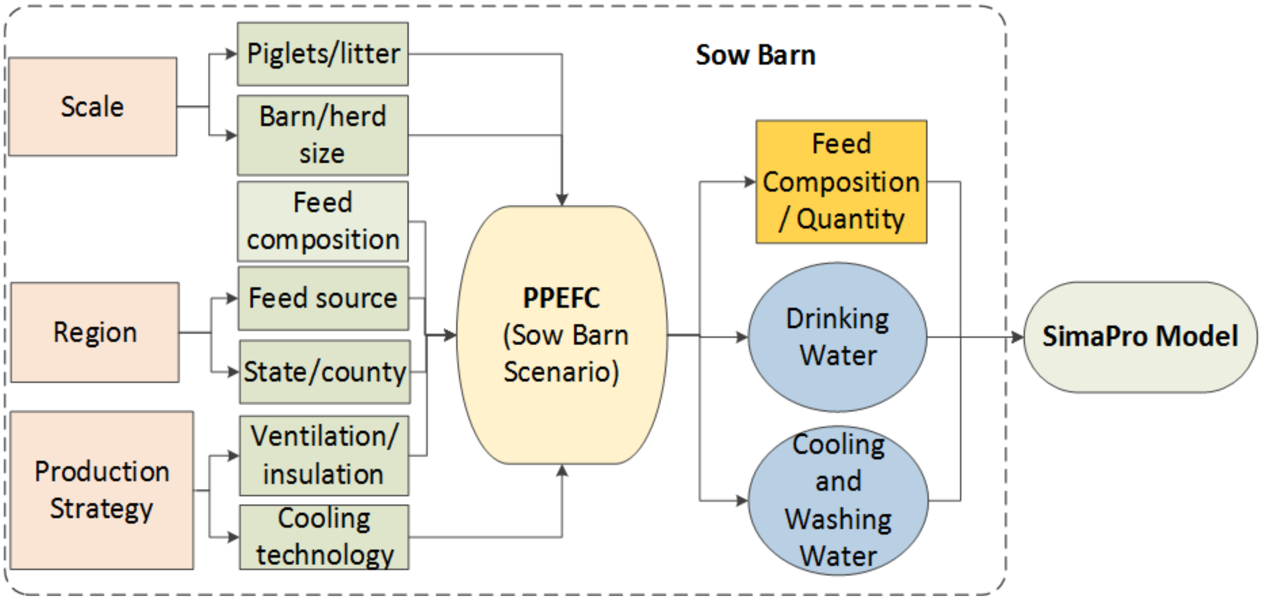

Figure 3.3. Sow barn Pig Production Environmental Footprint Calculator scenario in detail.

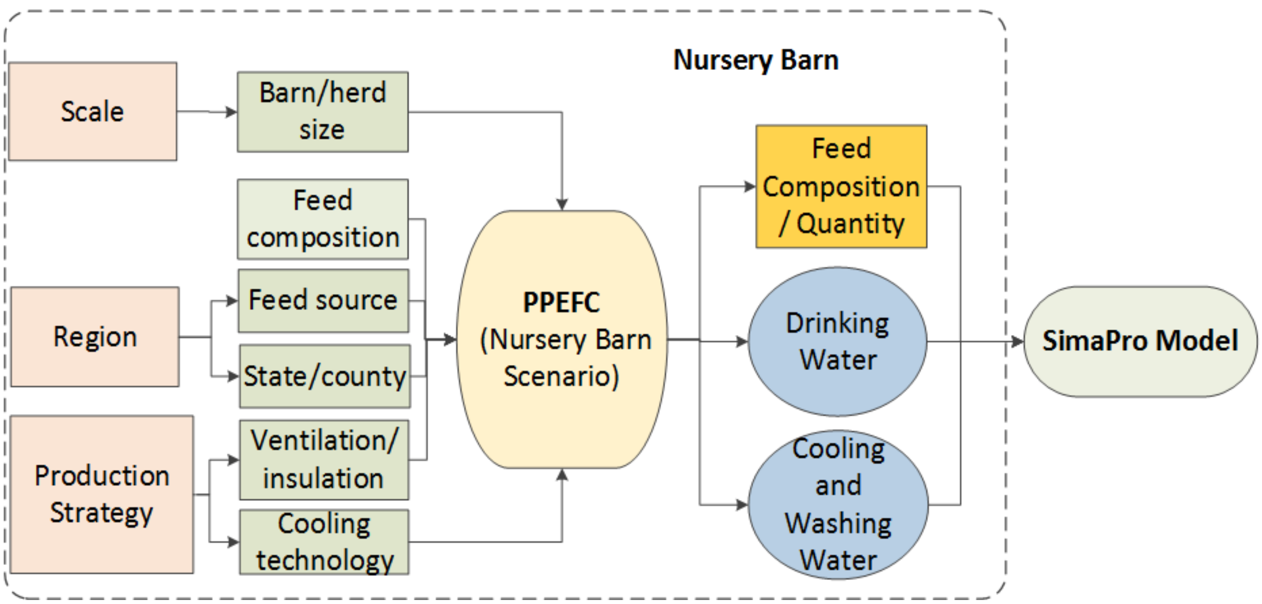

Figure 3.4. Nursery barn Pig Production Environmental Footprint Calculator scenario in detail.

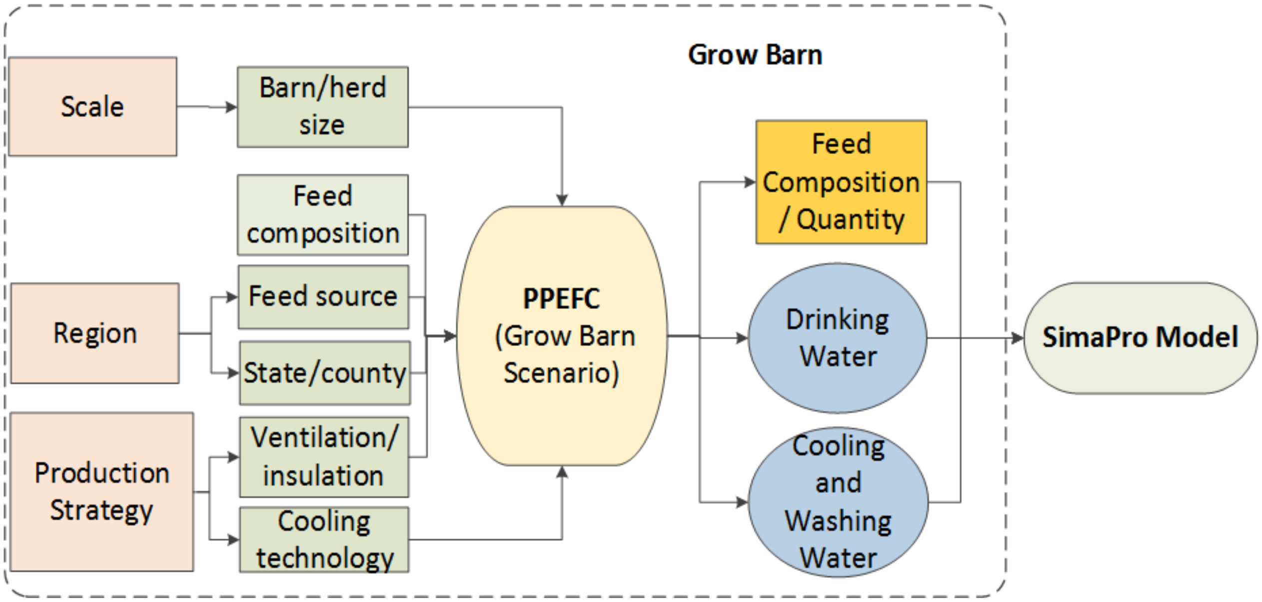

Figure 3.4. Grow barn Pig Production Environmental Footprint Calculator scenario in detail.

Life Cycle Inventory

The literature review, Ecoinvent unit processes and the previously conducted Pork Carbon Footprint LCA (Thoma et al., 2011) served as the basis for much of the life cycle inventory data which was generated through the PPEFC. Also, additional discussions with industry representatives and other experts helped fill in the data gaps. The production system encompassed activities performed in support of pork production up to the farm gate. The PPEFC was run for three separate barns: the nursery and grow barns (Table 3.4) and the sow barn (Table 3.5).

Table 3.4. Nursery and grow barn PPEFC parameter examples for assessing the tunnel ventilated, 1200 head scale water footprint of U.S. pork production.

Parameter	Nursery	Grow/Finish	Units
Barn infrastructure	Tunnel Ventilated	Tunnel Ventilated	NA
Pigs in per cycle	1200	1200	pig/cycle
Age entering	19	54	days
Weight entering	11	50.1	lbs
Weight leaving	50	275	lbs
Pig death per cycle	35	47	pig/cycle
Mortality	2.9	3.9	%
Mortality disposal method	Composting	Composting	NA
Time to clean between cycles	5	5	days
Barn area	3600	11375	ft2
Heat source	Natural Gas	Natural Gas	NA
Outside temp to activate cooling cells	85	80	F
Outside temp to activate sprinkler	no sprinkler	85	F
Sprinkler cooling water	no sprinkler	0.1	gal/pigspace/hr
Manure system	Deep Pit	Deep Pit	NA
Drinking water	0.93	1.87	gal/pig/day
Washing water	3.17	7.41	gal/pigspace/wash

Table 3.5. Sow barn PPEFC parameter examples for assessing the tunnel ventilated, 1200 head scale water footprint of U.S. pork production.

Parameter	Sow Barn	Units
Barn infrastructure	Tunnel Ventilated	NA
Adult sows	1200	pigs
Gilts	660	gilts/year
Avg. age gilt	180	days
Culled sows	600	sows/year
Sow deaths	60	pigs/year
Mortality	3.9	%
Disposal method	Composting	NA
Piglets per liter after weaning	9.3	piglets/liter
Death per liter before weaning	2	piglets/liter
Age piglets removed	21	days
Piglet cycle	16	days
Barn area	26500	ft2
Heat source	Natural Gas	NA
Heating pads run for	5	days
Outside temp to activate cooling cells	85	F
Outside temp to activate drip cooling	80	F
Drip cooling water	0.77	gal/pigspace/hr
Manure system	Deep Pit	NA
Drinking water	6.4	gal/pig/day
Washing water	31.6	gal/pigspace/wash

Allocation of Co-Products

In LCAs involving systems with multiple products or co-products of economic value, it is necessary to allocate a fraction of the environmental burden of production to each co-product. However, in practice, it can be difficult to determine the most appropriate scheme for allocating environmental impacts. ISO standards recommend system separation as the highest allocation priority. When joint production of products cannot be independently varied, system expansion takes priority. In system expansion, a "credit" is applied to the system for the production of each co-product that is equivalent to other products on the market. The credit is based on the amount of environmental burden associated with the equivalent products. Other approaches include mass and economic allocation. Mass-based allocation involves applying the weight ratios associated with co-products to their impacts, while economic allocation is based on the relative revenue of each of the co-products (Thoma et al., 2011).

Water Use for Crop Production

Water usage for crop production was estimated for each of the ten regions (regional footprints) and for the entire U.S. (commodity footprint). It was assumed that the feed crops were produced in the continental United States and standard U.S. agricultural practices were used in their production. Two main sources of agricultural data were used to estimate regional blue water usage in the production of corn grain, soybeans, and wheat in 2007: crop production data from the 2007 Census of Agriculture on a state-by-state basis from the USDA National Agricultural Statistics Service (NASS), and the 2008 USDA NASS Farm and Ranch Irrigation Survey (FRIS). State-level data for acres harvested and average yield for irrigated and non-irrigated acres were obtained from the USDA NASS 2007 Census of Agriculture. The average irrigation amount applied (acre-feet) for irrigated production for each state was obtained from the USDA NASS 2008 Farm and Ranch Irrigation Survey (FRIS). Total irrigation water usage and total harvest mass was calculated from these values. Total irrigation water usage was divided by total harvest mass to obtain a volume of water usage per mass of harvest. These values were aggregated for each region. Missing yield data from the 2007 Census was supplemented using yield data from the 2008 FRIS. Missing irrigation data for states in the 2008 FRIS were supplemented using regional averages. Using the same data, a single commodity feed footprint that could be applied the entire U.S. was compiled using weighted averages. All ten regions were modeled with both their respective regional feed footprint and the U.S. commodity feed footprint. It must be noted that in the regional footprints we assumed that pigs in a region were fed feed from crops that were grown in that particular region.

Feed crop life cycle inventories directly correlated with the Pork Management LCA (Thoma et al., 2012), with the same feed compositions for each growth phase but focused on water usage in crop production. Those feed compositions were applied uniformly across all production strategies, regions and scales. The feed compositions are not assumed to be correct for all scenarios, but clearly documented differences between regional feed compositions are not available. Thus, use of region-specific rations would introduce additional uncertainty that would not facilitate well informed decision making. The relationship between pig water consumption and environmental conditions and housing is not well established in the literature. In this LCA, growth curves and water requirement algorithms were assumed to be consistent between production facilities. The values for the national average water footprint for corn and soybean meal were approximately 50 l/kg and 60 l/kg, respectively. These commodity water footprints were used for all scenarios throughout the LCA. This approach does not account for variation by region in animal rations. The information about this variation is very limited and often anecdotal.

4. RESULTS AND DISCUSSION

The pork water footprint varied with infrastructure type and region. Total water use was greatest in the tunnel ventilated barn (0.153±0.002 m^3 of water per kilogram live weight at farm gate; Figure 4.1). However, there was very little difference between the total water use of tunnel ventilated barns compared to the hoop barns (0.151±0.000 m^3/kg live weight) and drop curtain barns (0.152±0.001 m^3/kg live weight). Hoop barns did not have a standard deviation because the hoop barn footprint does not vary by region alone (Figure 4.2). Version 2.0 of the PPEFC did not have comprehensive enough algorithms to model complex climatic effects on pig performance or water consumption. As a result, barns with water based cooling systems (drop curtain and tunnel ventilated) use more water in warmer climates. The hoop barn uses less water for cooling systems, but the climate inside the barn may adversely affect pig performance. The variation from the region is due to heating and cooling within the barns, but hoop barns were modeled with no heating or cooling systems that require additional resources.

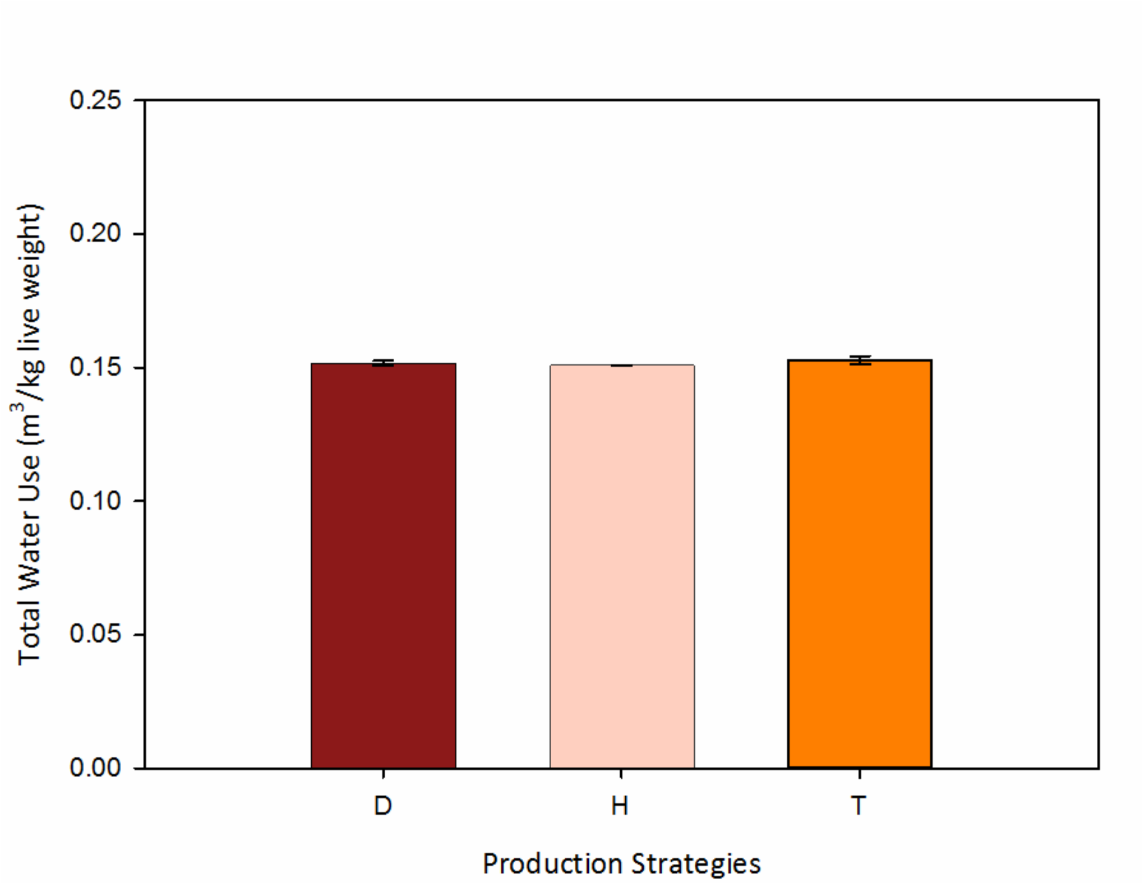

Figure 4.1. Total water use by barn type: drop curtain ventilated (D), hoop barn (H), and tunnel ventilated (T). The three totals are 1200 head scenarios averaged over all 10 regions.

Regionally, total water use per pound of live weight showed consistent trends (Figure 4.2). The tunnel ventilated barn water footprint was consistently higher, followed by the drop curtain and then the hoop barn in each of the regions. In region one, all three of the footprints were nearly the same since the colder climate does not have as many high temperature days, so cooling water is not necessary. The driving differences between regional footprints were climate, since all regions were using commodity sourced feed in this analysis. Variation in production strategies between regions was not accounted for other than in the heating and cooling technologies required to compensate for outside temperatures and relative humidity. Since the hoop barn doesn't use cooling systems, the water footprint remained steady from region to region. Tunnel ventilated barns had the most climate control, and as a result, the greatest reaction to climate fluctuations.

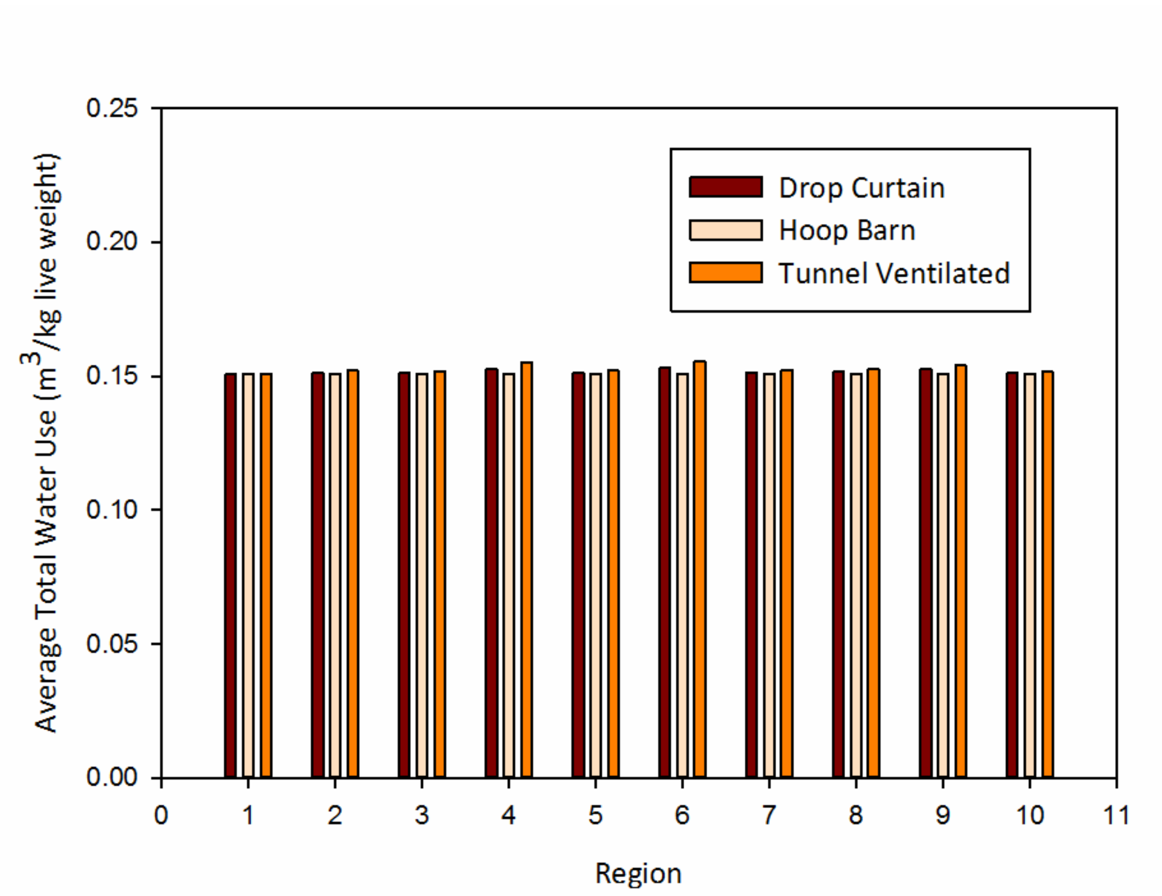

Figure 4.2. Total water use across for each barn type in each region. These totals have been averaged from the 1200 head scenarios.

Over the swine production life stages, the greatest water use comes from the grow barn, while the sow and nursery barn had much smaller water footprints in all three barn infrastructures (Figure 4.3). The higher grow barn footprint can be attributed to the longer period of time and larger increase in pig weight in the grow barn than the nursery barn. Sows consume three to four times as much water per pig space than a grow/finish pig, but that footprint gets distributed over all of the piglets (8 – 10 piglets/litter) they produce.

The box whisker plots in Figure 4.3 have boxes representing the 25th and 75th percentiles and dots at the 5th and 95th percentile points. Some of the model outputs (hoop barn) have so little variation in the data that the 25th to 75th percentile boxes look more like lines.

In this analysis, drinking water and food consumption algorithms were assumed to remained constant between all scenarios, because data were not available to support precise variances. Since the ration (75%) and drinking water (21%) footprints makeup 96% of the field-to-gate footprint, those assumptions do not allow for much variation in the model outputs (Figure 4.). Cooling water and washing water contribute about 10% of the facility footprint with the remainder from drinking water. It is clear that drinking water consumption and delivery play a relevant role in the water use efficiency of swine production.   Resources put into higher efficiency drinking systems would be much more valuable in terms of water reduction than cooling and washing systems. The “other” water in the pie chart below represents everything from water embodied in infrastructure to water used in the energy production. This category of water consumption is made up of many small fractions of water throughout the supply chain. The “other” category is not an easy target for water reductions.

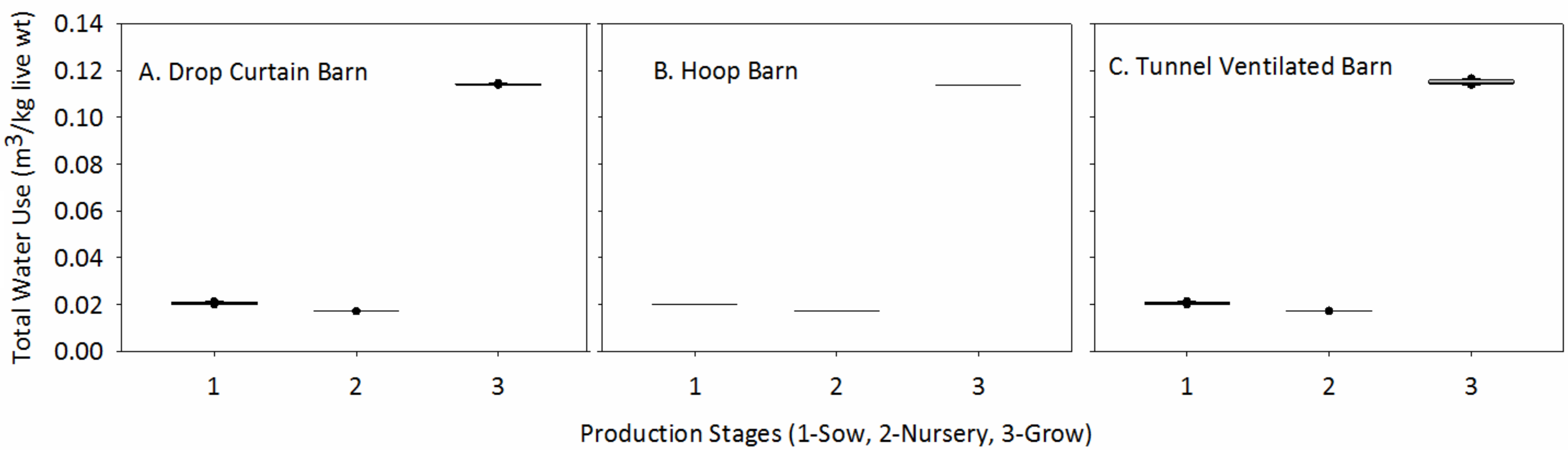

Figure 4.3. Total water use across swine production stages for each barn infrastructure type.

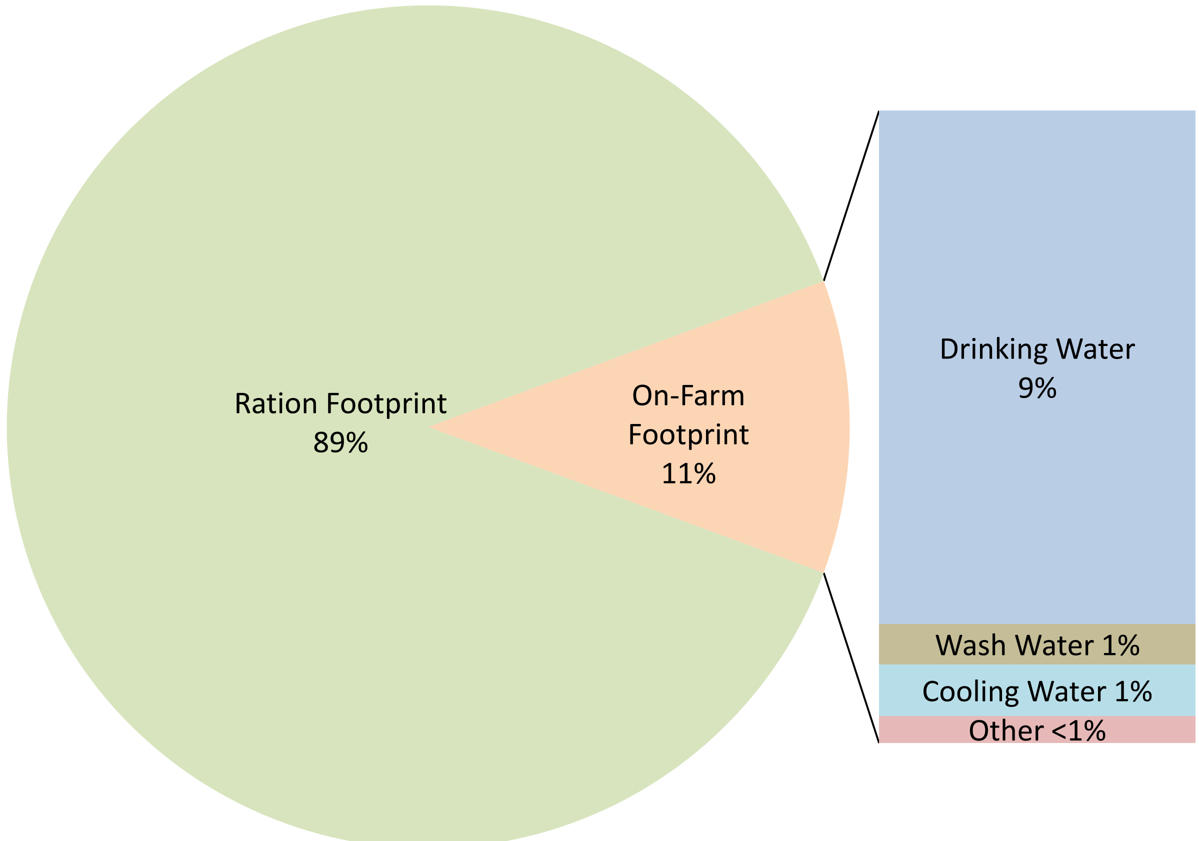

Figure 4.4. Field-to-gate water footprint contribution to U.S. pork production, averaged from all 240 field-to-gate scenarios.

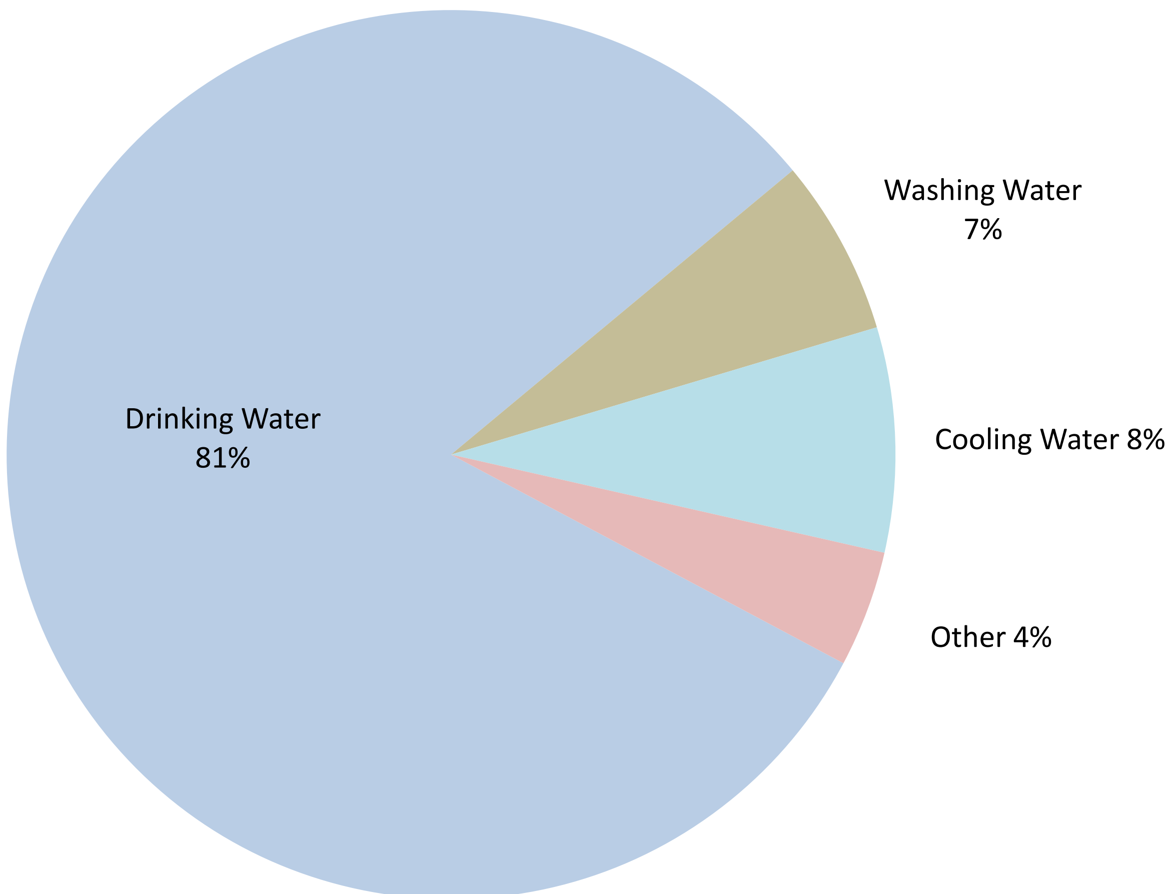

Figure 4.5. Breakdown of contributions to the on-farm water footprint in U.S. pork production, averaged from all 240 field-to-gate scenarios."Other" is mostly made up of water embodied in barn intrastructure and energy.

Sensitivity and Uncertainty Analysis

Sensitivity Analysis

A sensitivity test of the model inputs was conducted to evaluate the robustness of the study's conclusions. *Table 4.1* lists the model input parameters which were individually analyzed to gauge the sensitivity of the model output (water footprint). Each of the parameters was varied, ceteris paribus, by an increase and decrease of 10% to quantify the effect on the field-to-gate water footprint. The first iteration of the sensitivity analysis was an upper-level analysis that showed swine rations to have the most significant effect on the model output. We followed this with individual sensitivity analysis on all of the significant ration components to determine which ones had the greatest effect on the model output.

Table 4.1. Pig Production input parameters tested for sensitivity.

Upper Level Parameters		Ration Parameters	
Piglet heaters	Drinking water	Limestone	Ronozyme
Fans	Ration	Monocalcium Phosphate	Tallow
Lights	Washing water	Sodium Chloride	Plasma
Barn infrastructure	Transportation	Soybean Meal	L-Lysine HCL
Heaters	Nitrous Oxide	Trace Mineral Mix	DDGs
Gilt production	Methane produced	Vitamin Premix	Corn Grain
Manure spreading	Cooling Water	Dry Whey	

Sensitivity Analysis Results

Sensitivity analysis is a useful approach to help answer the question: “What information is most critical to collect to ensure high quality?” In the following charts, it is important to keep this question in mind and not to conclude that changing an operating characteristic of the facility to match the change in the parameter will result in an equivalent increase or reduction of the water footprint, but an indication of the level of accuracy required for that input into the LCA model to reduce the error in the model output. The swine production inputs were evaluated to determine the degree of influence that a 10% change in the parameter value would have on the final results. We used a threshold value of 0.5% or more change in impact to identify sensitive parameters. Parameters which were not reported were not identified as sensitive since a 10% change in that input resulted in less than 0.5% change in water footprint. Not surprisingly, the feed ration and their associated production processes (corn grain, soybean mean, and dry whey) had the greatest impacts (Figure 4.6), which is similar to findings reported in the literature review.

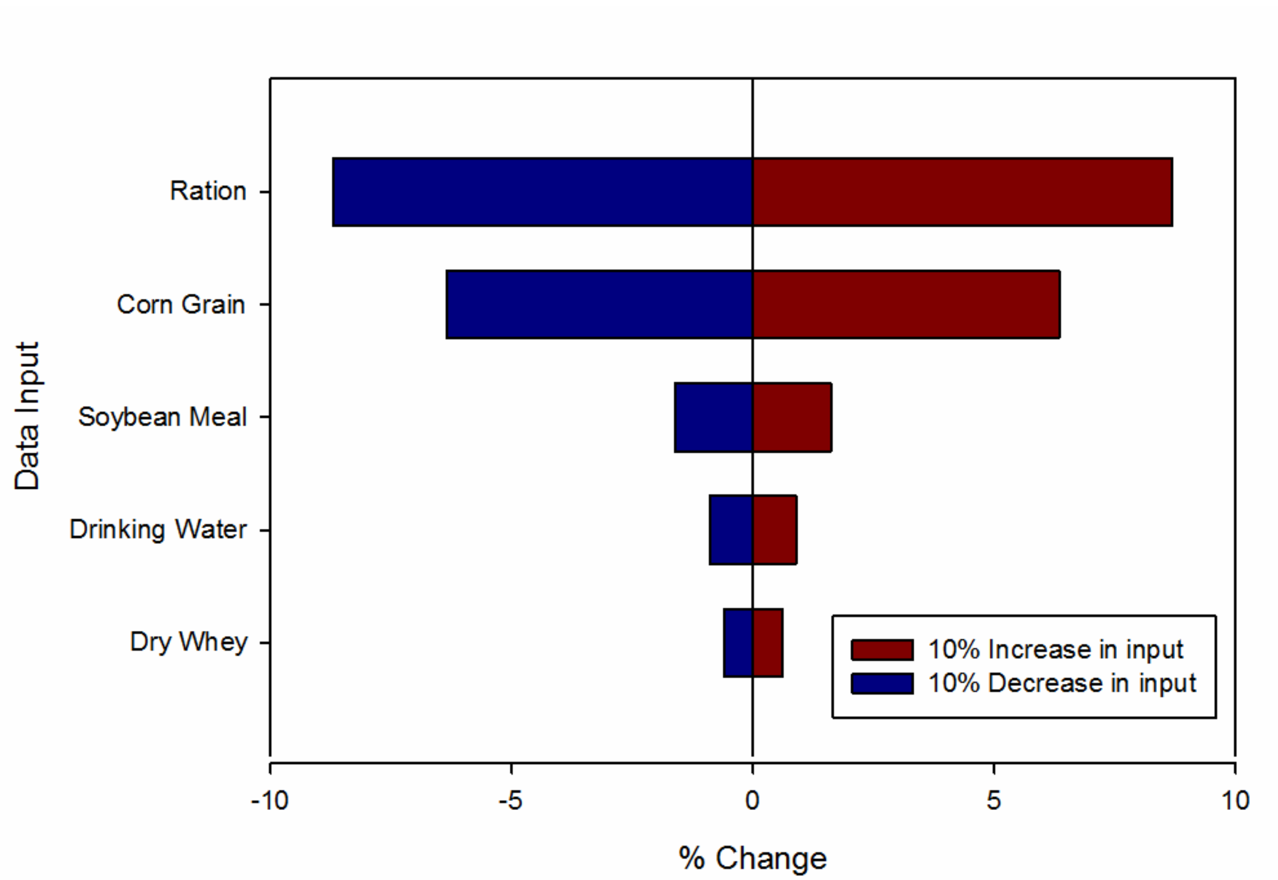

Figure 4.6. Tornado diagram showing the sensitivity of parameters to uncertainty in the water footprint for a 10% increase and decrease in parameter value. The "% Change" refers to the variation in the field-to-gate water footprint due to the parameter variation.

Uncertainty Analysis

We used stochastic methods to quantify and characterize uncertainty in the LCA results. It is important to understand that all of the water footprints calculated in this study were based on estimated values that have an associated range of uncertainty. Any conclusions from the results must therefore be made in the context of the uncertainties in the underlying data. This analysis is crucial for establishing defensible metrics for evaluating the progress toward a more sustainable supply chain.

Uncertainty is classified in two major types: knowledge-based uncertainty and process variability. Knowledge-based uncertainty reflects limits of what is known about a given parameter, while process uncertainty reflects the inherent variability within a process or parameter. Knowledge uncertainty can be reduced by collecting more data to decrease the possible range of the parameter estimate. Process uncertainty is the unexplained random variability which is a property of the system.

Each output of the PPEFC was represented as either a lognormal or triangular distribution (Table 4.2) to serve as an input to the SimaPro model. A 1000 run Monte-Carlo simulation was performed to characterize the probability distribution for the water footprint. Any foreground processes without an already established uncertainty distribution were assigned an inherent uncertainty of ±20% when used in the Monte-Carlo simulations. The result was a distribution for the water footprint rather than an average value. These distributions quantify the associated uncertainty in the results about the mean value. Uncertainty analysis was performed across regions, scales and production strategies. The combination of models used in this LCA is more useful for identifying differences between regions, production strategies, life phases and scales than it was for producing absolute footprints.

Table 4.2. Select parameter assignments for uncertainty analysis.

Type	*Units*	*Distribution*	*Average*	*SD*^{2}	*Min*	*Max*
Gestating Sow Drinking	l /pig/day	Lognormal	18[1, 2, 4, 7]	1.27	13	24
Lactating Sow Drinking	l /pig/day	Lognormal	26[1, 2, 4, 7]	1.32	18	37
Nursery Drinking	l /pig/day	Lognormal	3[1, 7, 9]	1.15	3	4
Grow Drinking	l /pig/day	Lognormal	6[1, 5, 6, 7, 8]	1.56	5	8
Finisher Drinking	l /pig/day	Lognormal	8[1, 3, 4, 6, 8, 12]	1.42	5	15
Sow Washing	l /pigspace/wash	Triangle	135[10, 13]		85	318
Nursery Washing	l /pigspace/wash	Triangle	12[10, 13]		6	26
Grow Washing	l /pigspace/wash	Triangle	28[10, 13]		16	40
Live Transport Washing	l /pig/wash	Triangle	15[10]		14	15
Sprinkler Cooling	l /pig/hr	Lognormal	0.5[11]	1.51		
Drip System Cooling	l /pig/hr	Lognormal	3[11]	1.51		
All Rations		Lognormal		1.2		

[1]*Almond, 1995*
[2]*Almond, 2002*
[3]*Amornthewaphat et al., 2000*
[4]*Brumm, 1999*
[5]*Brumm, 2006*
[6]*Christiansen, 2002*
[7]*Froese, 2001*
[8]*Li, 2005*
[9]*Margowen, 2007*
[10]*Muhlbauer, 2010*
[11]*MWPS, 1991*
[12]*Rantanen, 1994*

Uncertainty Analysis Results

Figure 4.7, Figure 4.8, and Figure 4.9 summarize the results of the 1000 Monte Carlo runs for the uncertainty analysis as box and whisker plots. The boxes define the 25th and 75th percentiles, the line within the box represents the median, and the blue dash line represents the mean of the 1000 Monte Carlo runs. The lower and upper error bars (whiskers) define the 10th and 90th percentiles respectively. Dots below and above the error bars represent the outlying points.

As an example, in Region 7 (Figure 4.7), the 25th percentile was approximately equal to 0.169 m^3/kg live weight 75th percentile was approximately equal to 0.142 m^3/kg live weight. The interpretation of this result is that we can state with 75% confidence that swine produced in region 4 will have a water footprint between 0.169 m^3/kg live weight and 0.142 m^3/kg live weight.

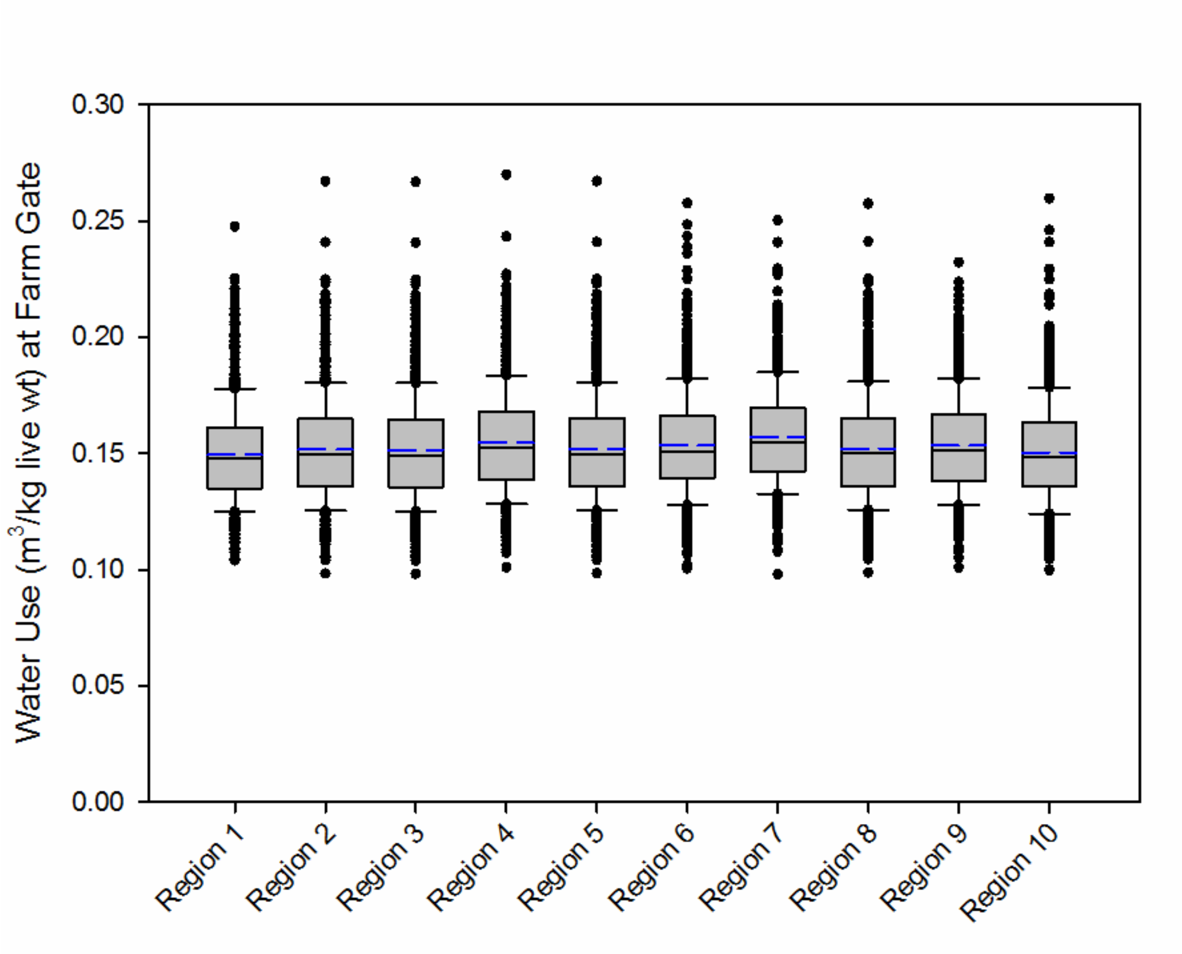

Figure 4.7. Estimated potential change in water footprint for U.S. Swine production across 10 regions.

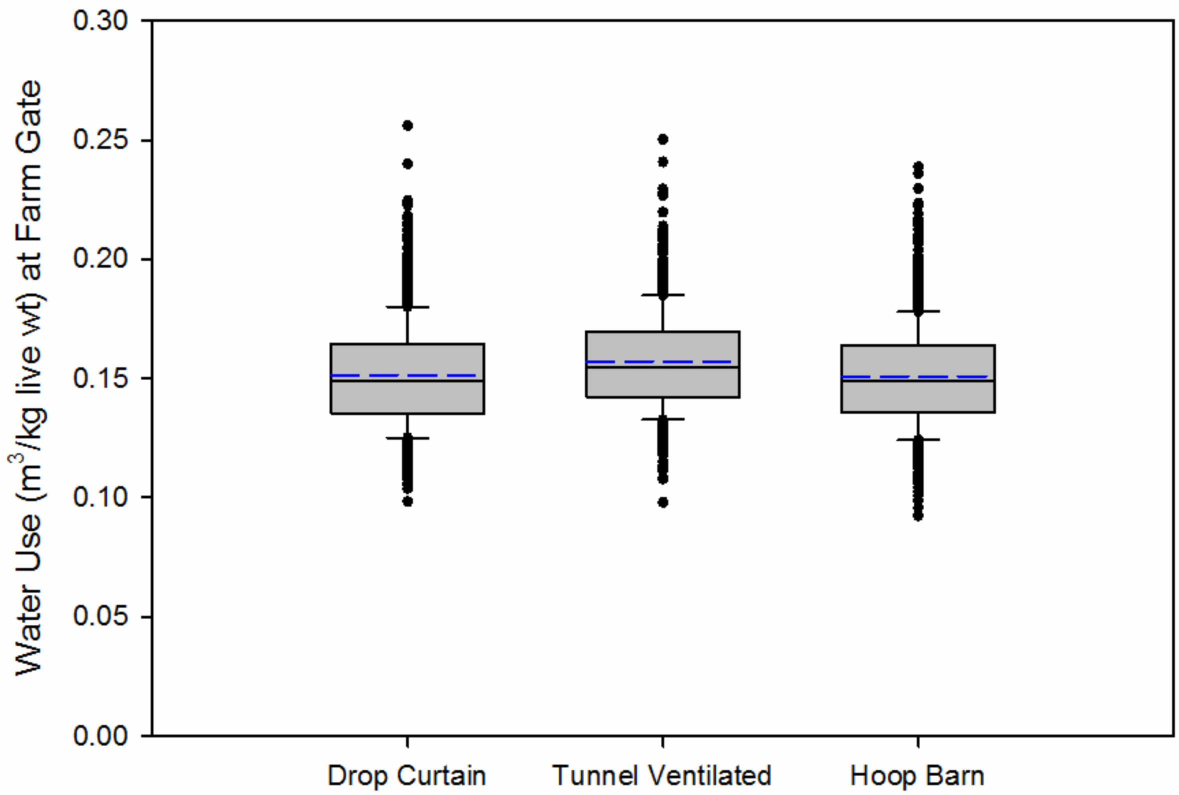

Figure 4.8. Estimated potential change in water footprint for three U.S. swine production strategies.

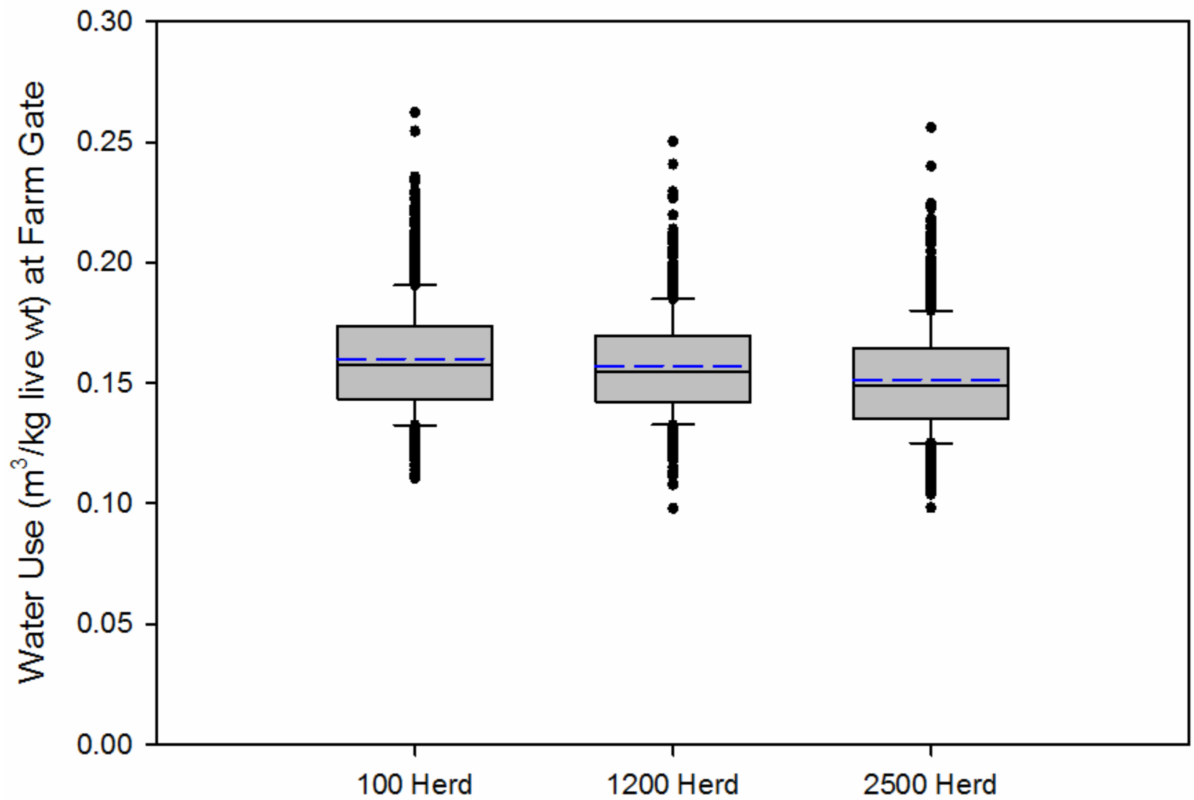

Figure 4.9. Estimated potential change in water footprint for three U.S. swine production scales.

A similar conclusion can be drawn from the swine production strategy scenarios (Figure 4.8). The swine produced using a tunnel ventilated infrastructure were estimated to have a slightly higher water footprint than the drop curtain and the hoop barn. When considering the scale of production, the 1200 and 100 head facilities had higher water footprints than the 2500 head production scale (Figure 4.9). One prevalent factor causing the 2500 head scale to have a lower water footprint per mass of pig is the higher ratio of piglets per litter in larger operations (NASS, 2013). Due to economy of scale, it is intuitive that larger farms would be more efficient, but this model could not account for most of those effects.

Statistical Analysis of Hypothesis Statements

Multiple statistical tests including an analysis of variance and least squares means T-tests were conducted for all data with the assistance of JMP Pro 11.0 (SAS Institute, 2013) statistical software. The analysis of variance was used to test differences of means as well as statistical significance in water footprints due to main effects and/or interaction effects (Appendix A). The least squares means tests were used to identify mean comparison effects of the different levels for each variable (Appendix B, C and D).

In Chapter 1, three hypothesis statements were established:

H(0)1: All swine production strategies have approximately the same water footprint.

H(A)1: Some swine production strategies have a larger footprint than others.

H(0)2: All swine production facility scales have approximately the same water footprint.

H(A)2: Larger scale swine production facilities often have a smaller water footprint than small scale facilities.

H(0)3: All regions of swine production have approximately the same water footprint.

H(A)3: Water footprints vary with the region of production.

The results of the assessment of the three hypotheses showed that production strategies, production scale and region of production affected water use. This may seem self-evident, but these processes have not been quantified at this scale prior to this analysis.

Analysis of variance of the water footprint across production strategies provided evidence to reject the Null Hypothesis and conclude that some swine production strategies require more water than others (Appendix A). The effect of the production strategy on the water footprint was statistically significant ($p < 0.0001$). The production practice that required the most water (M = 154 l/kg) was tunnel ventilated facilities while hoop barn facilities have the smallest footprint (M = 152 l/kg) (Appendix B). The larger footprint in tunnel ventilated and drop curtain facilities is a consequence of their climate control systems. The greater climate control likely increases pig growth and reduces health issues, but the model algorithms could not account for those interactions.

Analysis of variance of the water footprint across production scales provided evidence to reject the Null Hypothesis and conclude that some swine production scales require more water than others (Appendix A). The effect of the production scale on the water footprint was statistically significant ($p < 0.0001$). The production scale water footprint was the largest (M = 155 l/kg) in the 100 head scale and the smallest (M = 151 l/kg) in the 2500 head scale (Appendix C). The water footprint variance is due to economies of scale and reduced piglet mortality as operations increase in scale.

Analysis of variance of the water footprint across production regions provided evidence to reject the Null Hypothesis and conclude that some swine production regions require more water per head than others (Appendix A). The effect of the region of production on the water footprint was statistically significant ($p < 0.0001$). However, paired t-tests ($\alpha=0.05$) calculated between regions confirm that not all regions are statistically different from one another (Appendix D). Regions 4, 6 and 9 (the southern U.S.) are significantly different and have a larger footprint than the other seven regions. There are not significant differences within the two groups of regions. In other words, there is not a statistically significant difference between Regions 4, 6 and 9, but there is a statistically significant difference between Region 4 and the other seven regions or Region 6 and the other seven regions.

The production region that required the most water was Region 6 (M = 154 l/kg) (Appendix D). Region 6 contains Texas and its surrounding states which are all very hot climates in comparison to the rest of the states. Since the model activated cooling systems based on outside temperature, regions with the most days above the threshold cooling system activation temperatures will have the most cooling water. That attribute was what caused Region 6 to have the largest blue water footprint.

5. CONCLUSIONS AND RECOMMENDATIONS

The intent of this study was to analyze water use across a range of regions, scales and practices of the U.S. pork industry. A Life Cycle Analysis of the water footprint of U.S. pork production was conducted from cradle to farm gate. A comprehensive literature review was used to design and propagate algorithms for the National Pork Board Pig Production Environmental Footprint Calculator (version 2.0). The outputs from the calculator were used to generate lifecycle inventory inputs for unit processes in SimaPro (Pre' Consultants, The Netherlands), an LCA modeling program. There were 240 different scenarios analyzed that were a combination of ten regions, three production strategies and three scales. Integrating a mixture of modeling and life cycle assessment proved to be a powerful method for simulating pork production scenarios.

The results of these analyses showed water use ranged 150-155 l/kg live weight for each production strategy across the regions. Overall the results show that feed rations account for approximately 89% of the cradle-to-gate water footprint. On-farm activities are the second largest contributors to the water foot print with drinking water contributing 9% of the total cradle-to-gate water footprint and 81% of the water use at the farm. Barn washing and cooling water contribute about 3% of the total water footprint. The grow/finish barn phase of the on farm water footprint requires approximately five times as much water as the sow and nursery barns irrespective of the barn infrastructure.

Although the hoop barn has been shown to use less water in hot regions, it is misleading because pig health and performance would likely decline during periods of extremely hot weather without dedicated cooling systems. Extension of the model to account for these complex *in vivo* tradeoffs is important to fully understand the impacts and tradeoffs associated with using hoop barns as opposed to other housing systems.

The analysis of variance concluded that production strategies, production scale and region of production were all significant ($p < 0.0001$) and affected the blue water footprint. This may seem self-evident, but these processes have not been quantified at this scale prior to this analysis. The production practice that required the most water (154 l/kg) was tunnel ventilated facilities while hoop barn facilities have the smallest footprint (152 l/kg). The larger footprint in tunnel ventilated and drop curtain facilities is a consequence of their climate control systems. The production scale water footprint was the largest (155 l/kg) in the 100 head scale and the smallest (151 l/kg) in the 2500 head scale. The water footprint variance is due to reduced piglet mortality as operations increase in scale. Regions 4, 6 and 9 (the southern U.S.) are significantly different and have a larger footprint than the other seven regions due to their warmer climates and subsequent cooling requirements.

This analysis showed the power and limitations of model-linked LCA in addressing sustainability metrics for animal agriculture. The most critical challenge continues to be data availability. The type of data that could most improve this assessment would be more accurate water footprints for swine feed (particularly corn and soybeans) with a greater geographic resolution. Other types of data that could improve the algorithms of the model would include the ration's effect on pig growth, drinking water's effect on pig growth, climatic effects on pig growth and other unforeseen relationships between the applied treatments and the resulting effect on pork yield. In addition to higher quality data, a more clearly documented production life cycle would help the model pull from the correct data sources for the correct scenarios and subsequently increase the accuracy of this model. The model has been designed to accommodate new data as is becomes available in an effort to increase resolution and accuracy in future iterations.

Finally, this project not only met our goal of analyzing water use throughout the U.S. pork industry but more importantly created a benchmark and resource that the pork industry can utilize to make informed decisions regarding water use. The U.S. pork industry's forward thinking life cycle assessments will lead to reductions in their impacts while setting a precedent for the rest of the agricultural community. Removing all environmental impacts from the agricultural sector is not a realistic goal, but significant reductions in environmental impacts can be both attainable and profitable.

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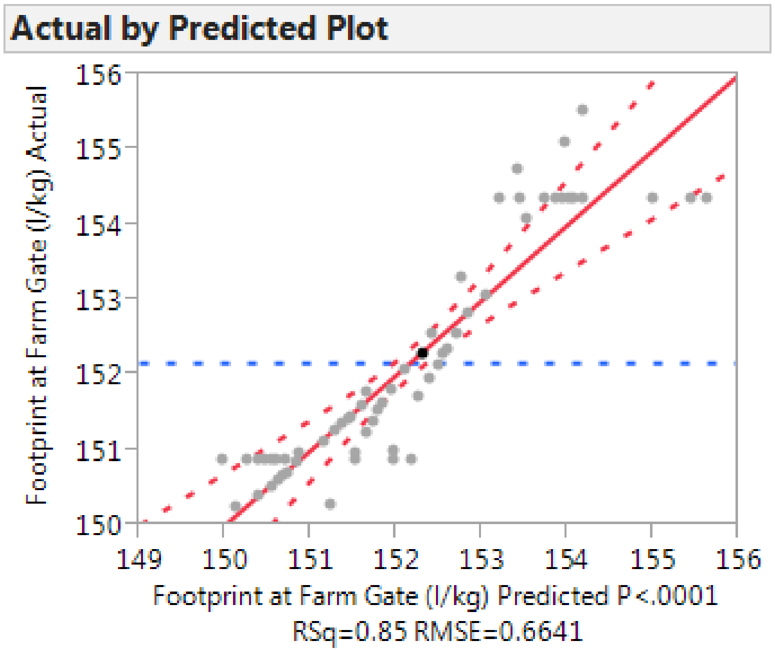
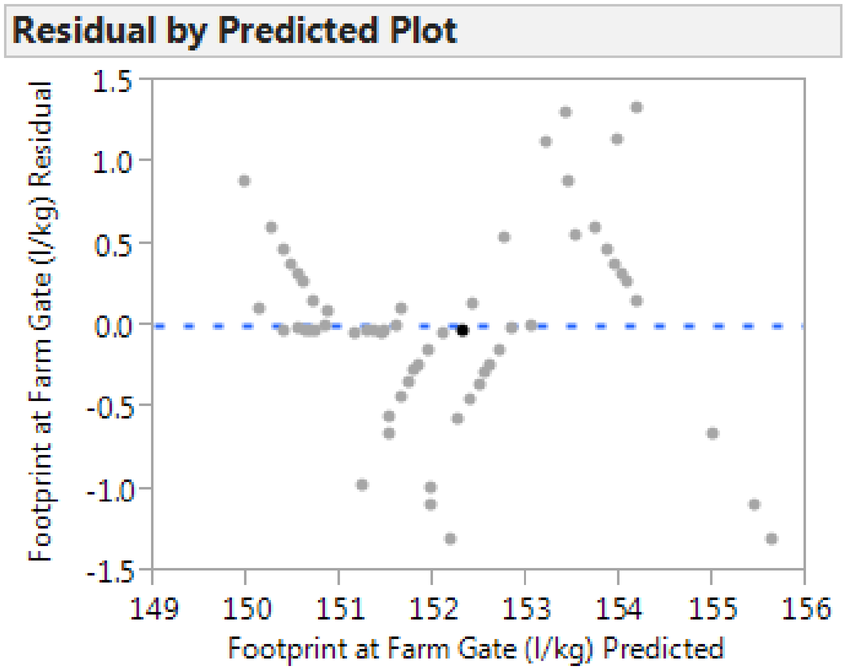
Appendix A: ANOVA Test for All Treatments



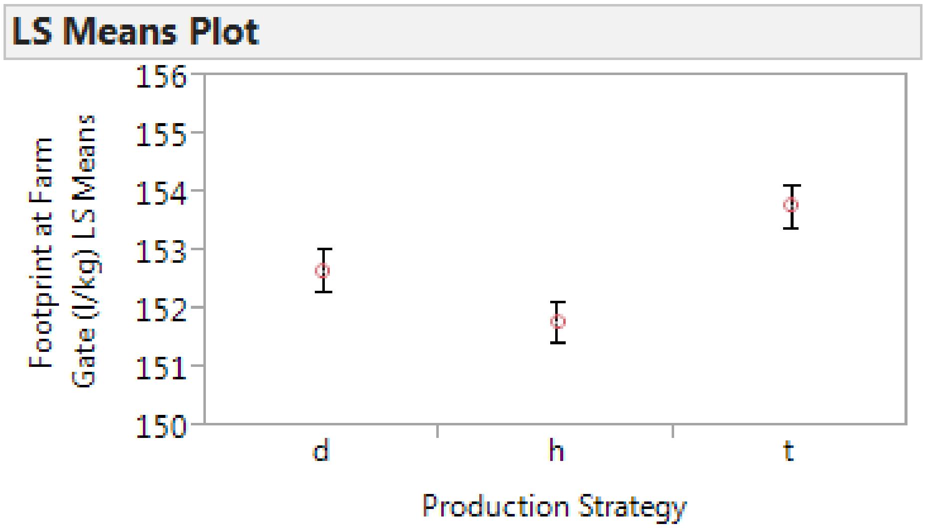
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Region of Production	9	9	30.280510	7.6291	<.0001*
Production Strategy	2	2	26.317866	29.8381	<.0001*
Production Scale (head)	2	2	65.970305	74.7943	<.0001*



Residual by Predicted Plot
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Footprint at Farm Gate (l/kg) Residual
149
150
151
152
153
154
155
156
Footprint at Farm Gate (l/kg) Predicted

Appendix B: Least Square Means Plot and T-tests Between Production Strategies



LSMeans Differences Student's t

α= 0.050 t= 2.0129

LSMean[j]

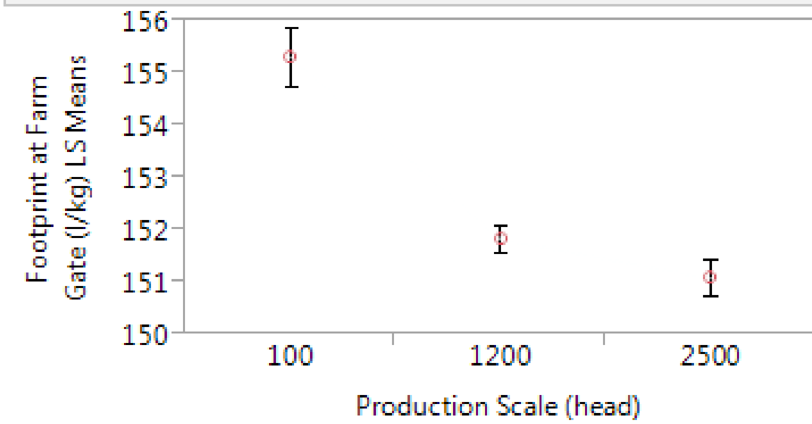
LSMean[i]	Mean[i]-Mean[j] / Std Err Dif / Lower CL Dif / Upper CL Dif	d	h	t
d	Mean[i]-Mean[j]	0	0.89164	-1.1114
	Std Err Dif	0	0.27781	0.21
	Lower CL Dif	0	0.33244	-1.5341
	Upper CL Dif	0	1.45084	-0.6887
h	Mean[i]-Mean[j]	-0.8916	0	-2.0031
	Std Err Dif	0.27781	0	0.27781
	Lower CL Dif	-1.4508	0	-2.5623
	Upper CL Dif	-0.3324	0	-1.4439
t	Mean[i]-Mean[j]	1.11141	2.00306	0
	Std Err Dif	0.21	0.27781	0
	Lower CL Dif	0.6887	1.44386	0
	Upper CL Dif	1.53413	2.56225	0

Level				**Least Sq Mean**
t	A			153.77446
d		B		152.66305
h			C	151.77141

Levels not connected by same letter are significantly different.

Appendix C: Least Square Means Plot and T-tests Between Production Scales

LS Means Plot



LSMeans Differences Student's t

α= 0.050 t= 2.0129

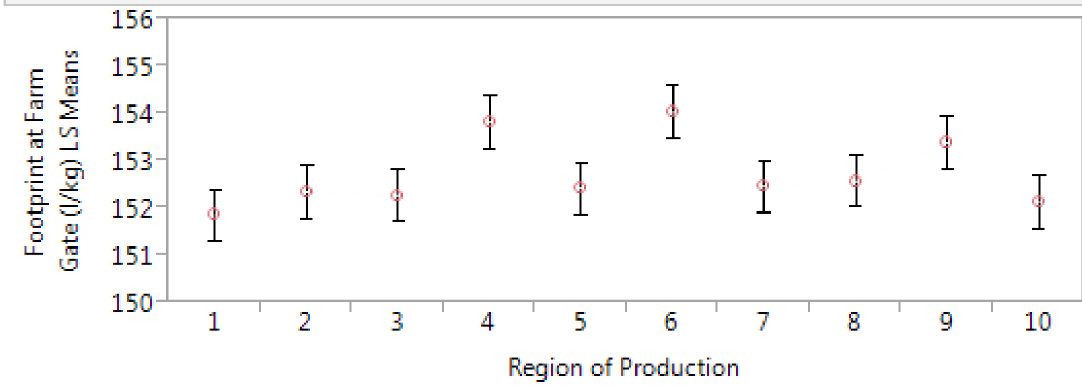
LSMean[i]	Mean[i]-Mean[j] / Std Err Dif / Lower CL Dif / Upper CL Dif	LSMean[j] 100	1200	2500
100	Mean[i]-Mean[j]	0	3.4731	4.22531
	Std Err Dif	0	0.29699	0.36374
	Lower CL Dif	0	2.87529	3.49315
	Upper CL Dif	0	4.07091	4.95747
1200	Mean[i]-Mean[j]	-3.4731	0	0.7522
	Std Err Dif	0.29699	0	0.21
	Lower CL Dif	-4.0709	0	0.32949
	Upper CL Dif	-2.8753	0	1.17492
2500	Mean[i]-Mean[j]	-4.2253	-0.7522	0
	Std Err Dif	0.36374	0.21	0
	Lower CL Dif	-4.9575	-1.1749	0
	Upper CL Dif	-3.4931	-0.3295	0

Level				Least Sq Mean
100	A			155.30244
1200		B		151.82934
2500			C	151.07713

Levels not connected by same letter are significantly different.

Appendix D: Least Square Means Plot and T-tests Between Regions of Production

LS Means Plot



Level			Least Sq Mean
6	A		154.04319
4	A		153.83530
9	A		153.39716
8		B	152.57987
7		B	152.46486
5		B	152.42220
2		B	152.35621
3		B	152.27293
10		B	152.13916
1		B	151.85216

Levels not connected by same letter are significantly different.

LSMeans Differences Student's t

α= 0.050 t= 2.0129

LSMean[i]	Mean[i]-Mean[j] / Std Err Dif / Lower CL Dif / Upper CL Dif	1	2	3	4	5	6	7	8	9	10
1	Mean[i]-Mean[j]	0	-0.504	-0.4208	-1.9831	-0.57	-2.191	-0.6127	-0.7277	-1.545	-0.287
	Std Err Dif	0	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341
	Lower CL Dif	0	-1.2758	-1.1925	-2.7549	-1.3418	-2.9628	-1.3845	-1.4995	-2.3168	-1.0588
	Upper CL Dif	0	0.26772	0.351	-1.2114	0.20173	-1.4193	0.15907	0.04406	-0.7732	0.48477
2	Mean[i]-Mean[j]	0.50404	0	0.08328	-1.4791	-0.066	-1.687	-0.1087	-0.2237	-1.041	0.21704
	Std Err Dif	0.38341	0	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341
	Lower CL Dif	-0.2677	0	-0.6885	-2.2509	-0.8378	-2.4588	-0.8804	-0.9954	-1.8127	-0.5547
	Upper CL Dif	1.27581	0	0.85504	-0.7073	0.70577	-0.9152	0.66311	0.5481	-0.2692	0.98881
3	Mean[i]-Mean[j]	0.42076	-0.0833	0	-1.5624	-0.1493	-1.7703	-0.1919	-0.3069	-1.1242	0.13376
	Std Err Dif	0.38341	0.38341	0	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341
	Lower CL Dif	-0.351	-0.855	0	-2.3341	-0.921	-2.542	-0.9637	-1.0787	-1.896	-0.638
	Upper CL Dif	1.19253	0.68849	0	-0.7906	0.62249	-0.9985	0.57983	0.46482	-0.3525	0.90553
4	Mean[i]-Mean[j]	1.98313	1.47909	1.56237	0	1.41309	-0.2079	1.37044	1.25542	0.43813	1.69613
	Std Err Dif	0.38341	0.38341	0.38341	0	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341
	Lower CL Dif	1.21137	0.70732	0.7906	0	0.64133	-0.9797	0.59867	0.48366	-0.3336	0.92437
	Upper CL Dif	2.7549	2.25086	2.33413	0	2.18486	0.56387	2.1422	2.02719	1.2099	2.4679
5	Mean[i]-Mean[j]	0.57004	0.066	0.14927	-1.4131	0	-1.621	-0.0427	-0.1577	-0.975	0.28304
	Std Err Dif	0.38341	0.38341	0.38341	0.38341	0	0.38341	0.38341	0.38341	0.38341	0.38341
	Lower CL Dif	-0.2017	-0.7058	-0.6225	-2.1849	0	-2.3928	-0.8144	-0.9294	-1.7467	-0.4887
	Upper CL Dif	1.3418	0.83776	0.92104	-0.6413	0	-0.8492	0.72911	0.6141	-0.2032	1.0548
6	Mean[i]-Mean[j]	2.19103	1.68698	1.77026	0.20789	1.62099	0	1.57833	1.46332	0.64603	1.90403
	Std Err Dif	0.38341	0.38341	0.38341	0.38341	0.38341	0	0.38341	0.38341	0.38341	0.38341
	Lower CL Dif	1.41926	0.91522	0.9985	-0.5639	0.84922	0	0.80657	0.69155	-0.1257	1.13226
	Upper CL Dif	2.96279	2.45875	2.54203	0.97966	2.39275	0	2.3501	2.23508	1.4178	2.67579
7	Mean[i]-Mean[j]	0.6127	0.10865	0.19193	-1.3704	0.04266	-1.5783	0	-0.115	-0.9323	0.3257
	Std Err Dif	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0	0.38341	0.38341	0.38341
	Lower CL Dif	-0.1591	-0.6631	-0.5798	-2.1422	-0.7291	-2.3501	0	-0.8868	-1.7041	-0.4461
	Upper CL Dif	1.38446	0.88042	0.9637	-0.5987	0.81442	-0.8066	0	0.65675	-0.1605	1.09746
8	Mean[i]-Mean[j]	0.72771	0.22367	0.30694	-1.2554	0.15767	-1.4633	0.11501	0	-0.8173	0.44071
	Std Err Dif	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0	0.38341	0.38341
	Lower CL Dif	-0.0441	-0.5481	-0.4648	-2.0272	-0.6141	-2.2351	-0.6568	0	-1.5891	-0.3311
	Upper CL Dif	1.49947	0.99543	1.07871	-0.4837	0.92944	-0.6916	0.88678	0	-0.0455	1.21247
9	Mean[i]-Mean[j]	1.545	1.04095	1.12423	-0.4381	0.97496	-0.646	0.9323	0.81729	0	1.258
	Std Err Dif	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0	0.38341
	Lower CL Dif	0.77323	0.26919	0.35247	-1.2099	0.20319	-1.4178	0.16054	0.04552	0	0.48623
	Upper CL Dif	2.31676	1.81272	1.896	0.33363	1.74672	0.12574	1.70407	1.58906	0	2.02976
10	Mean[i]-Mean[j]	0.287	-0.217	-0.1338	-1.6961	-0.283	-1.904	-0.3257	-0.4407	-1.258	0
	Std Err Dif	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0.38341	0
	Lower CL Dif	-0.4848	-0.9888	-0.9055	-2.4679	-1.0548	-2.6758	-1.0975	-1.2125	-2.0298	0
	Upper CL Dif	1.05877	0.55472	0.638	-0.9244	0.48873	-1.1323	0.44607	0.33106	-0.4862	0