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RESEARCH REPORT

ENVIRONMENT

Title: Water Consumption and Conservation Techniques Currently Available for Swine Production **– NPB #09-128**

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Production

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Executive Summary

Water conservation is important in any industry and swine production is no exception. Many water conservation technologies and practices are currently used in swine production, but not universally. The goal of this paper was to provide an in-depth review of water usage and conservation technology and practices currently employed by the swine industry, to investigate the conservation measure's effectiveness and cost efficiency, and to research water conservation technology and practices from other industries that may be applicable to the swine industry. This goal was accomplished via a thorough review of published literature, university extension and commodity group publications and fact sheets, and interviews with industry professionals and workers. A survey of swine producers representing 319 swine production facilities was conducted to collect water use and manure slurry production values as well as pig drinker types and facility washing and cooling practices. The collected data was organized by facility and water use technology and practice in order to analyze the effect of the various water management and conservation practices employed.

Swine production consists of two main phases: gestation/farrowing, and swine finishing. Some swine producers use an additional nursery phase between these two main phases but in terms of water use, gestation/farrowing and finishing are responsible for most of the water used in swine production. Swine finishing in the United States uses 62.2% of and estimated 41.3 billion gallons of water annually for all of swine production while gestation/farrowing and nurseries use the remaining 33.4% and 4.4% respectively. Through the literature review and producer survey it was found that animal drinking consumption was approximately 80% of total water usage. For these reasons, the most total reduction in water use can be realized through water conservation technologies and practices applied to finishing swine drinking systems.

Water is used for three main purposes in swine production: animal drinking, animal cooling, and facility/equipment washing. Water usage and conservation technologies and practices for each of these phases were investigated. Water cooling practices were reviewed and analyzed. It was found that if recommended cooling rates were used, cooling water usage could represent approximately 10% of total site water usage. However, in a survey of 144 Iowa swine producers, only 50% reported using water cooling systems. Swine facility and equipment washing water usage were obtained and analyzed primarily from the producer survey and found to account for 5-10% of total site water usage. There was some variability found in water used by different power washer performance ratings and facility presoak schemes. Use of an intermittent pre-wash facility soaking scheme versus a continuous soak was found to use about half the water without affecting total wash time. Water conservation technologies and practices from other industries such as washing and maintenance techniques as well as rain water capture were evaluated for applicability to swine production. In an analysis of rainwater capture for three areas of the United States it was found that monthly rainwater capture from the roof of a facility could account for 5-25% of monthly water requirements for that facility.

Technology and practices found to be the most effective were analyzed for cost efficiency. An analysis of leaking pig drinking water delivery systems showed how cost effective proper maintenance can be. If 25% of the drinkers in a 1000 head swine finishing facility leak at the rate of one drip per second,

43,800 gallons of water will be added to the manure storage. At a manure slurry handling cost of $0.012/gallon, that represents a cost of $526 to land apply the leaked water as manure slurry. A producer could spend approximately $26/leaking nipple to repair the leaks in this barn to equal the extra amount that would be spent on land applying that water as part of the manure slurry.

Collected data confirmed that pig drinker type and management significantly affected both water disappearance from drinkers and total facility water use. If it is assumed pigs in the same production phase consume similar amounts of water, the difference in water disappearance and total site water use between similar sites could be attributed to water wasted. Wasted water dilutes the nutrient density of the manure slurry and increases the amount of slurry to be handled, which increases operating costs. The literature review and producer survey revealed pig drinker selection and management could reduce water usage by up to 30%. Intense management of nipple drinker height and flow rate, cup drinkers, and wet/dry feeding systems was shown to reduce water wastage considerably. Using a manure slurry application rate of $0.012/gallon it was found that savings of approximately $2.00/pig space/year could be realized in reducing water usage by 25% while pig drinkers range in cost from less than $1 to $10/pig space to employ. Depending on the lifespan and amount of water saved by the drinker, it could be extremely cost efficient to use water conserving drinkers or management practices. Not only is water conservation in swine production environmentally responsible, it could result in sizable cost savings.

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Introduction

The swine production industry represents a sizable portion of the U.S. agriculture economy with over 18 billion in swine sales recorded in 2007 (NASS, 2101). Of the resources required to produce pork, locally available water is one of the most important, making water conservation an essential part of a sustainable swine industry. Besides being environmentally responsible, significant savings can be realized through water conservation and in reducing the amount of waste water handled as manure slurry.

The results that follow are an overview of water consumption, waste water production, and water conservation techniques and practices in the swine industry. The conservation techniques were evaluated for their effectiveness and cost efficiency. Additionally, the availability of water conservation techniques and practices in other industries has been investigated for applicability and effectiveness in the swine industry.

Methodology

This goal of this project was accomplished by obtaining information from multiple sources and applying robust cross examination and review to all information regarding water use and conservation in the swine industry as well as water conservation techniques found in other industries. An extensive review of the published literature was conducted. This included refereed, peer reviewed, and non peer reviewed literature from research institutions, industry professionals and periodicals, extension fact sheets from land grant universities, and commodity group information publications. Additionally, a survey of swine producers was conducted which in this report will be referred to as *the producer survey*. Water use and manure production data, swine facility washing and cooling practices, and general swine production information was obtained from multiple producers representing 319 swine production facilities. Also as part of the survey, swine industry workers and professionals were interviewed.

The results of the literature review and survey were reviewed for relevance and reliability. They were then sorted into sections on current water use and conservation in the swine industry and water conservation technology and practices from other industries applicable to the swine industry. Analysis was provided with emphasis on practices and technologies believed to have the most impact (or potential impact) on water conservation. A cost analysis of water conservation technologies and practices was conducted and discussed. Finally, conclusions were drawn based on all the information presented.

Current Water Use and Conservation Practices in the Swine Industry

Swine production can be divided into multiple phases, the two most distinct being gestation/farrowing and finishing. Depending on the operation, an additional nursery or grower phase may occur between farrowing and finishing. However, when analyzing water consumption, the bulk of water usage in swine production occurs during these two main phases. In 2007, the U.S. swine breeding herd consisted of 6.3 million pigs (gestating sows, farrowing sows, development guilts, and boars), while at any given point there were 4.8 and 47 million nursery and finish pigs respectively (NASS, 2010, NPB, 2009). Using estimates for water consumption of 6.0 gal/pig/day, 1.5 gal/pig/day, and 1.0 gal/pig/day for the gestation/farrowing, finishing, and nursery herds respectively, the estimated total U.S. swine production annual water consumption is shown in table 1.

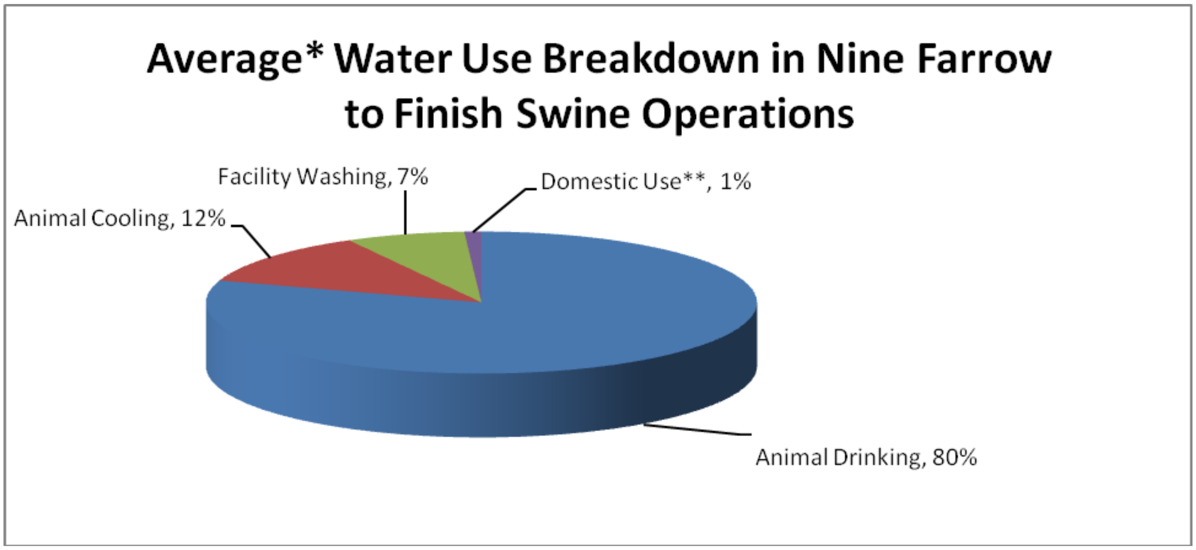
Table 1: Estimated water consumed by U.S. Gestation/Farrowing, Nursery, and Finishing Swine Production.

	U.S. total[1] (head)	Whole site water consumption[2] (gallons/pig/day)	Total annual water consumption (billion gallons)	Percentage of total water consumed by swine industry[3]
Breeding Herd	6,300,000	6.0	13.8	33.4%
Finishing Herd	47,000,000[4]	1.5	25.7	62.2%
Nursery Herd	4,800,000	1.0	1.8	4.40%
Total	40,200,000	7.5	41.3	100%

1. Taken from 2007 Agricultural Census (NASS, 2010) point in time total, rounded to nearest 100,000.
2. Rates estimated from literature review (Almond, 2002, Brumm, 2000, Froese, 2001) and the producer survey of water use at swine facilities. Farrowing values assumed to be gallons/sow/day.
3. Percentages calculated from rates given.
4. Total estimated by dividing finishing hogs marketed in 2007 (109,000,000, (NPB, 2009)) by 2.3 turns/year to find finishing pig spaces at a point in time.

Based on the estimates in table 1, water use for finishing swine is approximately twice that of gestation/farrowing. A study by Froese (2001) that monitored water usage at Canadian farrow to finish operations found swine finishing requires significantly more water than any other phase. That study reported swine finishing consumed 64%, gestation/farrowing consumed 25%, and nursery operations consumed the remaining 11% of total farm water use. This suggests water conservation technology and practices applied to swine finishing could be most effective at reducing total water use. Specific production practices in each phase may limit the water conservations technologies applicable to all phases, but the principles are the same; reducing water is environmentally responsible for sustainable agriculture, and it can save money in both securing water for swine production and manure slurry handling costs.

Water is used in every phase of pork production; here it was dividied into three basic uses: animal drinking, animal cooling, and facility/equipment washing. Figure 1 shows the distribution of water use in a survey of nine farrow to finish operations (Froese, 2001).



* Froese et al., 2001 reported 80% , 10-15%, 5-10%, and 1% for animal drinking, cooling, facility washing, and domestic use respectively. The values shown here are approximate averages of the reported ranges.

** Domestic use refers to human water usage (drinking, hand/boot washing, laundry, shower, etc.) and is related to office size/use of operation.

Figure 1: Average water use breakdown in nine farrow to finish swine operations (Small, 2001).

Animal Drinking

The results shown in figure 1 indicate most water consumed in pork production was used for animal drinking. This is confirmed in a report by Christianson (2002) that stated animal drinking water accounted for 72% of all water used on swine facilities. It was also evident in the producer survey conducted as part of this review. Whole site water consumption records were collected for 319 swine production sites from different production phases with different feed and drinker systems. Table 2 shows total swine production site water consumption reported in the survey compared to published values for swine drinking water consumption at different production phases with different drinker types.

The comparisons shown in table 2 support the assumption that the majority of water used in swine production was through pig drinking systems. While water conservation technology and practices could be applied to all water usage, the most water savings would be realized by reducing animal drinking water wastage.

Table 2: Whole swine site water usage from producer survey compared to published swine drinking water consumption at different production phases with different drinker types.

Production phase, feed and drinker type	Average whole site water usage (gal/pigspace/day) (standard deviation)	Animal drinking consumption reported in literature(gal/pigspace/day)[2]	Drinker water consumption as percentage of whole site water consumption
Finisher, dry feed/nipple	2.33 (0.32)[1]	1.87[3]	80%
Finisher, dry feed/cup	1.15 (0.17)[1]	1.00 (Brumm, 1999)	87%
Finisher, wet/dry	1.25 (0.33)[1]	1.19 (Brumm, 1999)	95%
Nursery, dry/nipple	1.34 (0.63)	0.93 (Magowen, 2007)	69%
Gestation (wet/dry trough)/ Farrowing (dry,nipple)	7.91 (2.15)	6.40 (Almond, 2002)[4]	81%
		Average	**80%**

1. Average of grow-finishers whole site water consumption with each particular drinker type, see Table 11.
2. Units changed from gal/pig/day to gal/pigspace/day to match the units reported in producer survey. It is also assumed pigspace is sow/guilt space in gestation/farrowing.
3. Average of water disappearance from nipple drinkers used by finishing pigs from Rantanen (1994), Brumm (1999), Christiansen (2003), Amornthewaphat (2000). See tables 4 and 5.
4. Average of reported water usage for wet/dry troughs in gestation and dry feed with nipples drinkers in farrowing.

Animal drinking accounts for the largest use of water in swine production. Pigs require water for tissue maintenance, regulation of body temperature and mineral homeostasis, excretion, growth, reproduction and lactation. The amount of water each pig drinks can vary greatly with temperature, humidity, airspeed, stocking density, flow rate, disease or stress level, and feed content (Stockill, 1991). Depending on the study, pig water intake was reported to vary from 2.1-3.5 lbs. water/lb. feed ingested (Almond, 2002). Based on these factors producers provide pigs with as much water as they want or need (ad libitum water). Modern pig watering systems were designed to provide ad libitum water; however, the amount of water spilled/wasted with each drinking system could vary substantially as a result of drinker design and management. It has been reported that water wasted (not actually consumed by the pig) from drinkers could be 25% of total water used and wastage has been estimated as high as 40% on some commercial farms (Li, 2005). These reports coupled with the fact that the majority of water used in swine production is for animal drinking means sizable water savings could be realized by addressing pig drinker water wastage. There are three main styles of pig drinking systems currently utilized in the swine industry with different benefits and management requirements: nipple drinkers, cup drinkers, and wet/dry feeder drinking systems.

Nipple Drinkers

Nipple drinkers are widely used in the swine industry. There are many styles and management practices; however, for this study a nipple drinker was any drinking device that allowed water not consumed by the pig during drinking to flow directly into manure storage (no bowl or tray to catch excess water, figure 2).

Figure 2: Solid mounted nipple drinker (The Pig Site, 2010). Note that water not consumed by pigs falls through the slatted floor into the manure slurry storage.

Nipple drinking systems are desirable because they provide a continuous supply of fresh water when a pig manipulates the mechanical nipple. However, because of this design, it is prone to water wastage. As the pig drinks, water can spill out of its mouth and run into manure storage. It is also prone to wastage because of pigs' tendency to manipulate the nipple knowingly to allow water to run over them or to unknowingly lean against the nipple allowing water to run into manure slurry storage. Also, as nipples age, they can begin to leak small amounts that dilute manure slurry and increase slurry handling costs. All these scenarios account for the water wastage associated with nipples.

Management techniques have been shown to decrease the wastage associated with nipple drinkers. Both nipple mounting height and flow rate have been shown to affect water wastage. Table 3 shows the results from a study by Li (2005), which reported the effect of nipple height and flow rate on water wastage by grower and finishing pigs.

Four different nipple drinker treatments were tested. Two water flow rates (0.132 and 0.264 gallons per minute) were tested as well has two mounting height management practices. The first practice was adjusting the nipple height every two weeks to be approximately two inches above the shoulder of the shortest pig in the pen. The second practice was leaving the nipple mounted at 13 inches high from the floor. As shown from the results in table 3, adjusting the nipple height and using the lower flow rate significantly reduced water wasted, especially in finishing pigs. Neither nipple height or flow rate affected average daily water or feed intake in either grower or finisher pigs, the difference was in water wasted (Li, 2005). In another test reported by Li (2005), adjusted nipples and unadjusted nipples with a step provided for smaller pigs to reach the drinker showed water wastage rates similar to cup style watering systems. While adjusting nipple heights may require more management than a producer is willing to perform, the results of this study showed that with height management and attention to flow rate, water wastage could be reduced to levels similar to cup drinking systems.

Table 3: Results of nipple height and flow rate on water wastage (abbreviated and converted to English units from Li, 2005).

	Nipple Drinker Treatment[1]			
	RL	RH	UL	UH
Growing Pigs				
Weight (lbs.)	49.6	54.2	53.6	49.2
Average Daily Feed Intake (lbs/day as fed)	2.62	2.84	2.87	2.78
Total water disappearance (gal/pig/day)	0.80	0.97	0.89	1.14
Pig water intake (gal/pig/day)	0.62	0.69	0.61	0.69
Water wasted (percent of total)	**22.2%**	**29.6%**	**30.8%**	**38.4%**
Finishing Pigs				
Weight (lbs.)	148	155	154	148
Average Daily Feed Intake (lbs/day as fed)	4.89	5.51	5.49	4.87
Total water disappearance (gal/pig/day)	1.27	1.45	1.77	2.03
Pig water intake (gal/pig/day)	1.07	1.13	1.11	1.18
Water wasted (percent of total)	**15.1%**	**20.3%**	**36.3%**	**41.8%**

1. No interactions (all variables P = 0.17 to 0.91) between nipple height and flow rate.
RL = Nipple mounted at recommended height (1.97 inches above the shoulder of the shortest pig in the pen, adjusted every two weeks) with lower flow rate (0.132 gal/min)
RH = Nipple mounted at recommended height and higher flow rate (0.264 gal/min)
UL= Unadjusted nipple mounted at 13 inches with lower flow rate for duration of test
UH = Unadjusted nipple with higher flow rate

Swinging nipple drinkers are hung from the ceiling and allowed to swing freely as opposed to the solid gate or wall mounted nipple drinkers. The advantage of swing nipple drinkers is the ease of height adjustment. As pigs grow, the height can be adjusted by shortening the hanging chain and taller pigs can swing the drinker up to their level. Swinging nipple drinkers may also reduce inadvertent water wastage because as a pig leans against the nipple, it will merely swing away as opposed to dispensing water like a solid mounted nipple. However, recreational water use (pigs dispensing water for cooling or out of boredom) may still occur with the swinging nipple system. Brumm (2000) showed that swinging nipple drinkers could reduce water usage by 11% versus solid mounted nipple drinkers.

There are other nipple style drinkers (no cup or tray to catch excess water) that have been reported to reduce water wastage. Some of these are the bite ball style drinkers and the Arato drinker. In a head to head, test the bite ball valve reduced overall water usage by 15% versus conventional nipple drinkers

(Rath, 2000). In a 52 week study, sows, nursery, and finishing pigs provided the Arato drinker used approximately 17%, 22%, and 8% less water respectively than pigs provided conventional nipple drinkers (Almond, 2002). These types of nipple drinkers require pigs to insert the drinker deeper into their mouth before water is dispensed. In doing so, less water is spilled from the sides of the pig's mouth. Additionally, because a pig has to insert it fully into its mouth, it could be assumed this style is less susceptive to inadvertent or recreational manipulation by pigs resulting in wasted water (Macleod, 2010).

Cup Drinkers

Cup type drinking systems come in many different shapes and styles. For the purpose of this review, they are considered any watering system (for the purpose of animal drinking only) that provides a cup or bowl for pigs to drink from and are filled by a pig actuated lever or nipple, or water level actuated float valve. Figure 3 shows a few popular cup drinker styles.

Deep cup drinker (The Pig Site, 2010)

Shallow cup drinker (Vittetoe, 2010)

Figure 3: Common cup drinkers found in swine production. Note that excess water not consumed by the pig is retained by the cup.

By design, cups decrease water wastage compared to nipple drinkers. All water released from the drinking lever/nipple falls into the cup for the pig to drink. This drinker type is less likely to be used recreationally or inadvertently by pigs because water only flows into the bowl whereas a nipple drinker may be manipulated to dispense water onto pig heads and bodies. The cup also catches water from the sides of a pig's mouth during drinking. While this certainly conserves water it may also put dirty (water containing saliva or feed) into the cup which could be a concern for producers even though studies have shown no change in pig performance because of drinker type, (Brumm, 2000).

Several studies are available that show the water conservation capable with cup drinking systems versus conventional nipple drinkers. Table 4 shows a summary of the results found in literature associated with cup style drinkers.

Cup style drinkers are attractive as a retrofit option for swine facilities currently equipped with nipple drinkers. The water supply line and sometimes even the mounting hardware can be reused when replacing a nipple drinker with a cup drinker.

Table 4: Summary of water savings possible with cup drinkers versus nipple drinkers.

Reference	Cup drinker consumption (gal/pig/day)	Nipple drinker consumption (gal/pig/day)	Percent reduction	Production phase
Magowen, 2007[1]	0.64	0.93	**31.2%**	nursery
Brumm, 1999[1]	1.00	1.33	**24.8%**	finisher
Energy, 2001	Not stated	Not stated	**20.0%**	finisher

1. Average of cup drinker arrangements versus average of nipple type drinkers, pig performance not negatively affected
2. Cup drinkers versus swinging nipple drinkers, pig performance not negatively affected

Wet/Dry Feeders

There is a wide variety of wet/dry feeders available for the swine industry. For this study, they are considered to be any feeding/drinking system that mixes the dry feed and water into the same bowl, tray, or trough. Figure 4 shows a few of the styles of wet/dry feeders used in swine production. Pig actuated lever or nipple valves may still be utilized but water is either dispensed directly into a trough or in the case of the nipple, any water not consumed by the drinking pig falls into the trough (figures 4b and 4c). In a shelf style wet/dry feeder, troughs will often have depressions in which the water collects while feed is dispensed on the raised part of the trough (figure 4a). The feed and water will still frequently mix.

4a: Shelf style wet/dry feeder commonly found in swine finishing facilities (Vaucluse, 2010)

4b: Wet/dry feeder sometimes found in swine farrowing stalls (Christiansen, 2009)

Figure 4: Common wet/dry feeding systems used in swine production.

Like cup drinkers, there are several studies available that show the water savings possible with wet/dry feeders. Table 5 summarizes these studies.

Table 5: Summary of water savings reported with wet/dry feeder systems.[1]

Reference	Wet/Dry feeder water consumption (gal/pig/day)	Nipple drinker water consumption (gal/pig/day)	Percent reduction	Production phase
Rantanen, 1994[2]	1.53	2.04	25.0%	finisher
Brumm, 1999	1.19	1.60	25.6%	finisher
Christiansen, 2002	1.42	1.58	10.1%	grower
Christiansen, 2002	1.62	2.46	34.1%	finisher
Amornthewaphat et al., 2000[3]	1.15	1.39	17.3%	finisher
Energy, 2001	Not stated	Not stated	30.0%	finisher

1. Values may have been converted to English units
2. Values averaged from summer and winter trials
3. Values averaged from two styles of dry feeder versus wet/dry feeder

As with the results of testing done on nipple and cup drinkers, pig performance was not negatively affected by drinker or feeder design.

Animal Cooling Requirements

Water is used to cool pigs in the gestation, farrowing, and finish phases of production. Water is dispensed onto the pigs via a drip, sprinkling, or misting. Water is also used in evaporative cooling pads that remain wet and remove heat from the fresh air being forced through the porous cooling pad as it enters a facility. In a drip or sprinkle cooling system, water is dispensed onto the animals, and as it evaporates, heat is removed from the animal. With misting or evaporative cooling pads, the air temperature is lowered allowing faster heat transfer from the animal to the surrounding air. All water cooling systems require air speed across the animal. Cooling water requirements vary greatly with outside temperature, facility type, and management.

Little literature is available on actual swine industry cooling water usage. However, cooling water recommendations have been made in publications like Midwest Plan Service - 34 Heating, Cooling and Tempering Air for Livestock Housing (MWPS, 1990). The Midwest Plan Service recommends 0.1 gal/pig/hour for sprinkle cooling systems and 0.5 to 1.0 gal/hour/sow for drip cooling systems. Evaporative cooling pads require approximately 0.6 gal/sow/hour (extrapolated from MWPS, 1990). All of the above mentioned cooling systems were recommended for use when outside temperatures exceed 85°F.

Based on the information available it was difficult to compare methods of water cooling for water consumption. Sprinkle cooling used less water than either drip systems or evaporative pads but is impractical for farrowing where piglets (that don't require cooling) occupy the same area as sows. For farrowing, drip cooing is practical as it only wets and cools the sow. Using the cooling rates recommended by the Midwest Plan Service and engineering weather data (Kjelgaard, 2001), table 6 provides estimated cooling water consumption values for different water cooling systems.

Table 6: Estimated water usage for different swine cooing systems in different geographic areas.

Cooling Type, Location	Recommended water use[1] (gal/pig/hr)	Number of hours[2] exceeding 85 F	Annual cooling water used[3] (gal/pig/year)	Average daily cooling water used[4] (gal/pig/day)	Percentage of total site water use[5]
Raleigh, NC					
Sprinker	0.1	334	33.4	0.09	6.1%
Drip	0.75	334	250.5	0.69	11.4%
Evaporative Pad	0.6	334	200.4	0.55	9.2%
Des Moines, IA					
Sprinker	0.1	278	27.8	0.08	5.1%
Drip	0.75	278	208.5	0.57	9.5%
Evaporative Pad	0.6	278	166.8	0.46	7.6%
Cedar City, UT					
Sprinker	0.1	344	34.4	0.09	6.3%
Drip	0.75	344	258	0.71	11.8%
Evaporative Pad	0.6	344	206.4	0.57	9.4%

1. Extrapolated from cooling recommendations from MWPS, 1991.
2. Yearly number of hours with temperatures exceeding 85 F (Kjeldaard, 2001).
3. Recommended water use multiplied by recommended use time.
4. Annual use average on per day basis.
5. Total site water usage obtained from the rates listed in table 1 and production phase most suited for each cooling type. Sprinklers for swine finishing (total site water use average equals 1.5 gal/pig/day) and drip and evaporative cooling for gestation/farrowing (total site average water use 6.0 gal/pig/day).

As seen in table 6, if recommended cooling rates are used cooling water consumption is only a small portion of total site water consumption.

In a survey of nine farrow to finish operations, Froese (2001) reported farrowing cooling water usage at 0.08 gal/sow/day, though cooling system type was not listed. This was reported to be approximately 12% of total site water consumption. However, this study also reported that water cooling was used all year to reinforce dunging habits. A survey of 144 Iowa finishing swine producers found that 50% used no water cooling system (Harmon, 1996) reinforcing the conclusion drawn from table 6 that water used to cool swine may be insignificant when compared to total industry water use.

Swine Facility and Equipment Washing Requirements

Water is used to wash swine facilities after each phase of production and before a new group of pigs is placed. Very little literature was available on water consumption used for swine facility and equipment washing. One study from Hurnik (2005) compared different methods of swine facility washing such as hot and cold water, soap usage, and presoaking the facility. This study reported that using hot water reduces washing time by an average of 22%, using a soap to wash reduced time an average of 8% and presoaking reduced washing time by half. No water consumption values or presoak times were reported.

The producer survey conducted for this report found common power washer specifications, swine facility wash times and water use. Tables 7 and 8 summarize the power washing data collected for finishing operations. Data was collected from four producers representing over 160 swine production sites as well as three custom power washing businesses. Producers were asked to report the rated pressure and flow rate of the power washers used and the time it took to wash swine facilities. The results showed the five distinct pressure/flow rate/time groups seen in table 7. These groups will be used for further analysis in tables 8-10.

Table 7: Power washing pressures, flow rates, time/pigspace washed and water consumption for swine finishing facilities. Data divided into five distinct groups taken from the producer survey.

Group	Power Washer Pressure (lbs./sq. inch)	Power Washer Flow Rate (gal/min)	Estimated Time (sec/pigspace)	Power Washing Water Use[1] (gal/pigspace/wash)
1	2500	4.0	47	3.12
2	3500	4.0	43	2.88
3	3500	5.0	32	2.70
4	2500	6.0	25	2.52
5	3500	8.5	23	3.32
Average	3100	5.50	34	2.91

1. Calculated by multiplying reported power washer flow rate by estimated washing time.

The results in table 7 were then extrapolated into daily and yearly totals for wean-finish and grow finish systems. Table 8 shows these daily and yearly values for power washing water use.

Table 8: Daily and annual power washing water use in wean-finish and grow-finish swine facilities.

Group	Wean-Finish Washing Water Use[1] (gal/pigspace/day)	Wean-Finish Annual Wash Water Use (gal/pigspace/year)	Grow-Finish Washing Water Use[2] (gal/pigspace/day)	Grow-Finish Annual Wash Water Use (gal/pigspace/year)
1	0.017	6.2	0.021	7.8
2	0.016	5.8	0.020	7.2
3	0.015	5.4	0.018	6.8
4	0.014	5.0	0.017	6.3
5	0.018	6.6	0.023	8.3
Average	0.016	5.8	0.020	7.3

1. Values taken from table 7, multiplied by 2 washes/year
2. Values taken from table 7, multiplied by 2.5 washes/year

The practice of presoaking a facility before washing was universal with all survey participants. The practice varied between continuous presoak for 12-18 hours and intermittent presoaking for 18-24 hours. The average reported water flow rate for presoaking was 10 gallons/minute and a common intermittent scheme reported included presoaking for five minutes out of every 30 minutes. There was no reported difference in washing time between facilities with continuous and intermittent presoak schemes. This is reasonable because the purpose of presoaking is to saturate the hard packed manure in swine pens. Presoaking at a rate higher than the absorbtion rate of the hard packed manure would result in water runoff into the manure storage pit. Using an intermittent presoak scheme does not appear to reduce the presoak affect because it takes time for water so soak into the hard packed organic materials (Zulovich, 2010). The only data to support this hypothesis acquired from the producer survey was the report of no change in washing time between facilities with continuous and intermittent presoak schemes. Table 9 shows the total water used (presoaking and power washing) for the five power washer groups. For the purpose of comparison, the continuous presoak scheme was defined as 12 hours at 10 gallons/minute. The intermittent scheme was defined as five minutes out of every 30 minutes for a total of 18 hours with the same flow rate of 10 gallons/minute when the presoak system was running.

Table 9: Total wash water used (presoak and power washing) estimated for swine finishing facilities at each of five distinct power washer pressure/flow rate/time group. Estimated from results of the producer survey.

Group, Presoak Scheme	Wean-Finish Wash Water Use (gal/pigspace/day)	Wean-Finish Annual Water Use (gal/pigspace/year)	Grow-Finish Wash Water Use (gal/pigspace/day)	Grow-Finish annual Wash Water Use (gal/pigspace/year)
1, continuous[1]	0.057	20.6	0.071	25.8
1, intermittent[2]	0.027	9.84	0.034	12.3
2, continuous	0.055	20.2	0.069	25.2
2, intermittent	0.026	9.36	0.032	11.7
3, continuous	0.054	19.8	0.068	24.8
3, intermittent	0.025	9.00	0.031	11.3
4, continuous	0.053	19.4	0.067	24.3
4, intermittent	0.024	8.64	0.030	10.8
5, continuous	0.058	21.0	0.072	26.3
5, intermittent	0.028	10.2	0.035	12.8

1. Based on results of producer survey. Assumed to be 12 hours presoak at 10 gallons/minute
2. Based on results of producer survey. Assumed to be 18 hours of presoak on a timer set run 5 minutes of every 30 minutes at 10 gallons/minute

The results in table 9 showed using an intermittent presoak scheme could reduce facility washing water consumption by approximately half. Another study from the Veterinary Infectious Diseases Organization (VIDO, 1998) conducted a survey of swine facility washing water use in western Canada swine facilities. The results of that survey are presented in table 10 as well as the summary of tables 7 through 9 that represent the results of the producer survey.

The VIDO study noted the wide range in reported wash water usage was due to differences in washing and specifically presoak practices. The producer survey showed a smaller value range. This could be attributed to the similarities in washing protocols of the large swine operations surveyed. While there were over 160 swine facilities surveyed, large portions of that group used similar washing protocol as they were managed by the same company. When comparing annualized daily averages of washing water use from the producer survey (0.04 – 0.26 gal/pigspace/day for finishing and gestation/farrowing respectively) to total site water consumption (0.5 – 10.5 gal/pigspace/day for finishing and gestation/farrowing respectively), it constituted 2.7 to 3.5% of water consumption. Like animal cooling, washing water usage was somewhat insignificant in terms of total site water consumption.

Table 10: Swine Facility washing water use (VIDO (1998) and producer survey).

Reference	Production phase	Average wash water use[1] (gal/pigspace/wash) (range)[2]	Average Wash Water Use[3,4,5] (gal/pigspace/day)	Average Annual Wash Water Use (gal/pigspace/year)	Percentage of total site water consumption[6]
VIDO, 1998	Farrowing*	40.1 (22.4 - 83.9)	0.264	96.4	4.4%
Producer survey	Farrowing*	31.6	0.208	75.9	3.5%
VIDO, 1998	Nursery	3.17 (1.58 - 6.86)	0.053	19.3	5.3%
VIDO, 1998	Finishing	21.1 (5.54 - 64.9)	0.174	63.5	11.6%
Producer survey	Wean-Finish, continuous soak	7.41 (4.32 - 10.5)	0.041	14.8	2.7%
Producer survey	Grow-Finish, continuous soak	7.41 (4.32 - 10.5)	0.051	18.5	3.4%

* In this table, for farrowing, pigspace is assumed to equal one farrowing crate

1. The average water use/wash for the producer surveys were calculated using the combined average of all power washer groups and presoak schemes shown in table 9
2. The ranges for the producer survey were calculated using the power washing group with the least waster used and intermittent presoak scheme and the power washer group with the most water used and the continuous presoak scheme (lowest total water used to highest).
3. VIDO, 1998 averages converted to English units
4. Average per wash times 2 washes per year for wean-finish
5. Average per wash times 2.5 washes per year for grow-finish
6. Percentage of total site water consumption calculated using average daily wash water use and average daily total site use from table 1: 6.0 gal/pigpsace/day for farrowing, 1.0 gal/pigspace/day for nursery, and 1.5 gal/pigspace/day for finishing.

Total Swine Facility Water Consumption

Total swine facility water usage values represented in table 1 showed rates for different production phases across the industry. The rates in table 1 were chosen from published literature and the producer survey. Both sources indicated wide water use ranges. Because animal drinking water consumption was the majority water sink, it is reasonable to assume the differences in total site water usage are due largely to differences in water wastage from various drinking devices. The producer survey provided total site water use values for 319 swine facilities to look specifically at differences in animal drinking systems and their affect on total site water use and manure volume. Table 11 shows type and number of sites surveyed as well as water consumption and manure slurry volumes. Of the 319 sites surveyed, 163 reported four year averages (2006 through 2009). The remainder of the sites reported for the calendar year 2009. Values are represented in gallons/pigspace/day. These values were obtained from yearly averages and each site's design capacity. For the gestation/farrowing sites, pigspace refers to sow capacity. Value ranges reported in the survey may be related to differences in management style, especially stocking density, and regional climate. Because of the distinct difference in water usage for sites in the dry, arid climate, they were separated as their own entity within table 11.

Table 11: Average total site water consumption and manure production by production phase and feed/water distribution type taken from producer survey (NR = not reported).

Production phase, feed/water type	Number of sites surveyed	Average total site water consumption (gal/pigspace/day)(range)	Average manure slurry volume (gal/pigspace/day)(range)
Wean-Finish, dry feed/nipple	4	**1.36** (1.10-1.53)	**0.96** (0.79-1.11)
Dry, Arid Climate grow-finish, dry feed/nipple	33	**2.46** (1.61-3.63)	NR
Grow-Finish, dry feed/ nipple	7	**2.33** (2.06-3.04)	**1.50** (0.82-2.13)
Wean-Finish, dry feed/cup	29	**1.48** (1.10-2.36)	**0.88** (0.64-1.07)
Grow-Finish, dry feed/cup	3	**1.15** (1.02-1.34)	**0.71** (0.66-0.74)
Wean-Finish wet/dry	116	**1.02** (0.76-1.92)	**0.65** (0.40-1.60)
Grow-Finish wet/dry	17	**1.25** (086-1.93)	**0.75** (0.47-1.03)
Wean-Finish wet/dry and cup	42	**1.37** (0.94-2.38)	NR
Grow Finish wet/dry and cup	4	**1.44** (1.31-1.61)	NR
Nursery, dry/nipple	6	**1.49** (0.73-2.39)	NR
Dry, arid climate Nursery dry/nipple	14	**1.18** (0.71-2.19)	NR
Gestation (wet/dry trough), Farrowing (dry feed/nipple)	21	**5.67** (3.20-8.19)	**5.39** (3.42-9.32)
Dry, arid climate Gestation (wet/dry trough), Farrowing (dry feed/nipple)	17	**10.16** (7.61-14.94)	NR
Gilt Development, wet/dry trough	6	**1.43** (0.63-2.84)	NR

Pigspace defined as site design capacity. For gestation/farrowing, pigspace refers to sows.
NR = Not reported

Figure 5 shows the water consumption values from table 11 in a bar graph with standard deviation bars and separated by production phase and animal feed and drinking system.

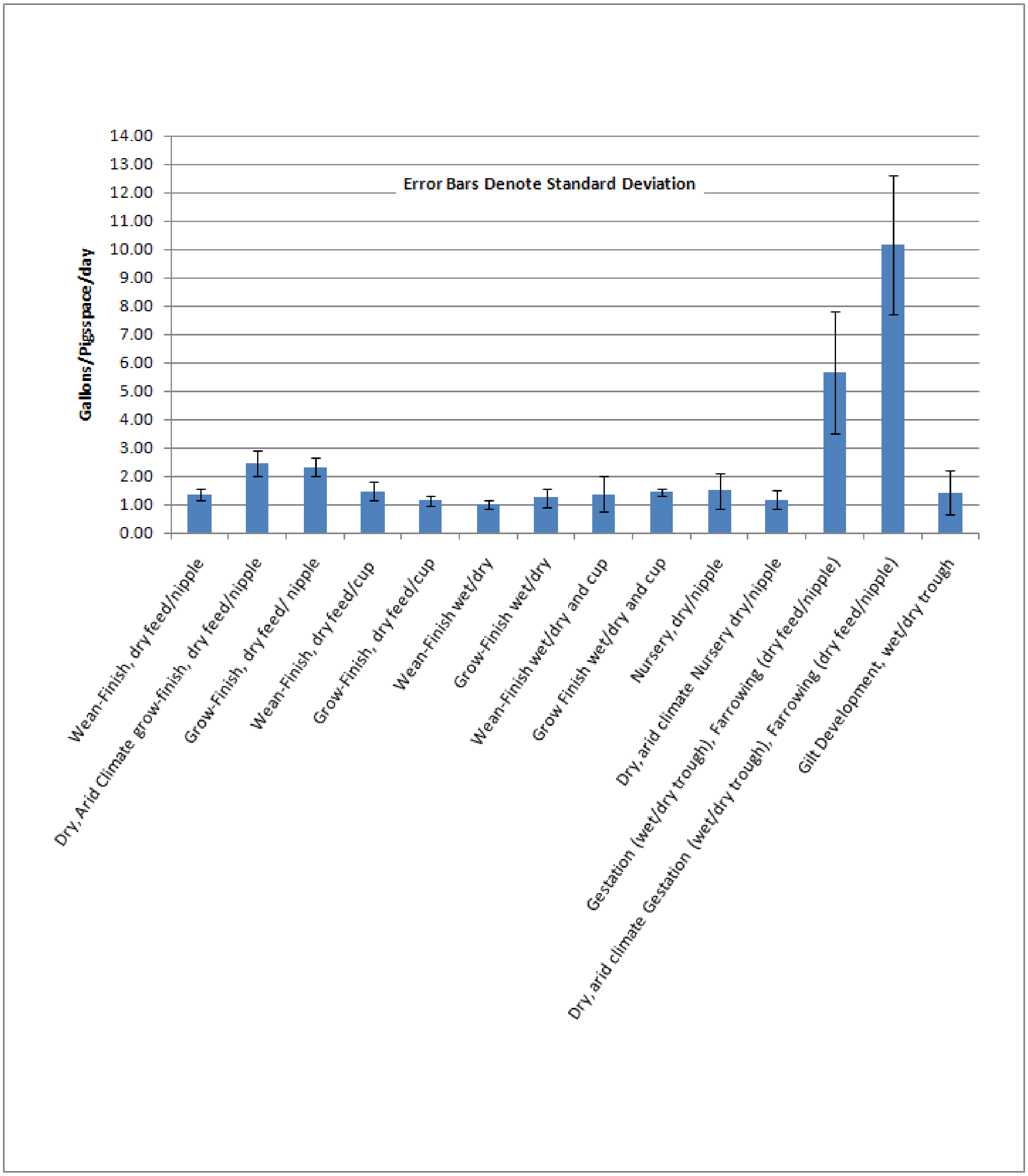


Figure 5: Average whole site water consumption for various swine production phases and feeder/water delivery systems taken from producer survey.

Figure 6 gives the site manure slurry volumes in a bar graph with error bars denoting standard deviation. Manure slurry values were not reported for all sites surveyed.

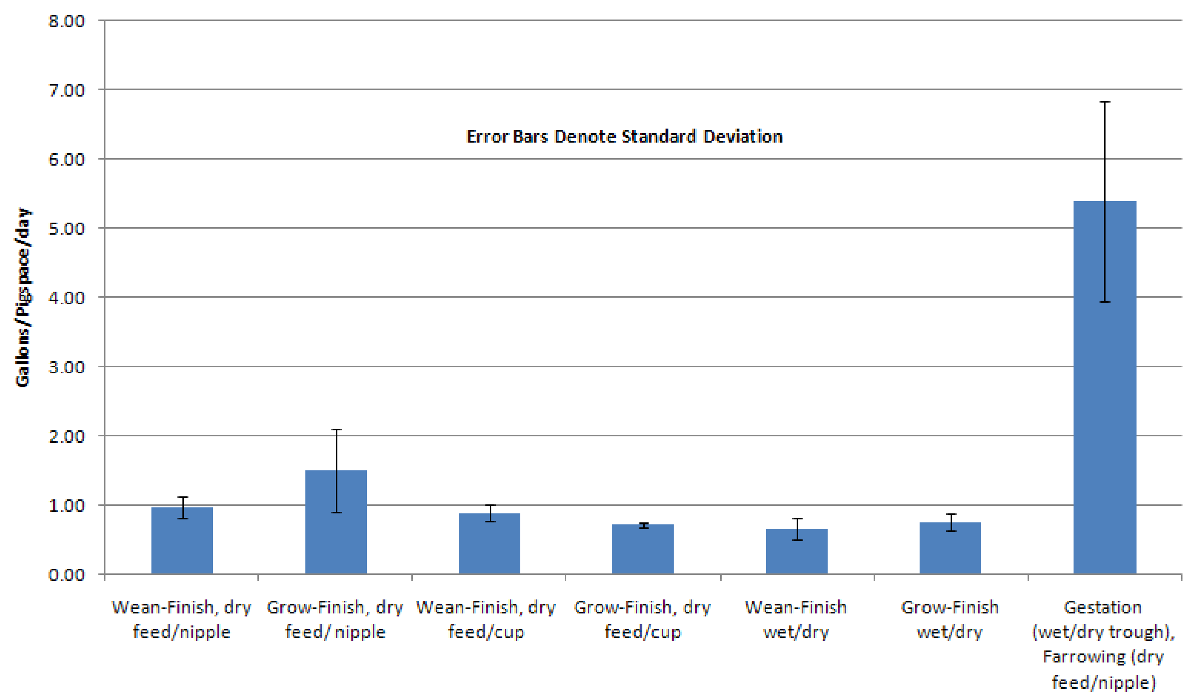


Figure 6: Average manure slurry production from various swine production phases and feeder/water delivery systems taken from producer survey.

The results of the producer survey reinforced previous conclusions from the studies on swine drinker water wastage summarized in tables 4 and 5. Drinker type significantly impacts total site water usage and manure slurry volume.

Water Conservation Technology and Practices in other Industry Applicable to Swine Production

Water conservation is important in any industry. An attempt was made to find water conservation technologies and practices used in other industries that may be applicable to swine production. The Environmental Protection Agency organized water conservation efforts into the two following categories (EPA, 2010):

1. Engineering practices: practices based on modifications in plumbing, fixtures, or water supply operating procedures
2. Behavioral practices: practices based on changing water use habits

In a report from the North Carolina Division of Pollution Prevention and Environmental Assistance (NCDENR, 2009) many general water conservation technologies and practices were outlined. Other water conservation technologies and practices for general and specific industries were found in reports from the Environmental Protection Agency, The Connecticut Department of Environmental Protection, The Ontario Ministry of Environment, and the Queensland Water Commission. The technologies and practices applicable to swine production are discussed below as well as some that may all ready be in use.

Water Audit and Facility Maintenance

A water audit is a necessary first step to a water conservation plan (CDEP, 2010). This could be as simple as taking time to note everywhere water is used in the operation and qualitatively describe the volume of water used for each process (i.e. pigs drink every day, the facility is only washed twice a year). A more effective audit would involve water metering and sub-metering. Metering total site water usage would allow the operator/producer to establish water use baselines. Once a baseline was known, any deviation from the baseline would be noticed and addressed. Sub-metering of individual processes would make it easier to notice deviations from the baseline as well as identify water use intensive operations within the total site water usage. It is important to monitor the performance of water delivery systems as they age and require maintenance. If system leakage occurred, monitoring the deviation from baseline would reveal the leak and expedite its resolution. The same would be true for water conservation technology or practices. Metering would allow the operator to monitor the effectiveness of recently installed or implemented water conservation technology or practices. Metering would also allow the operator to monitor water consumption when no pigs were in the facility to check for nonvisible leaks.

Simple checks, maintenance, and changes to operating practices could prevent leaks (Queensland, 2010). Water delivery system maintenance is necessary but much easier if a water audit is performed and water metering is implemented. A valve or fitting (like a nipple drinker) that leaked one drop per second would add approximately 6 gallons of water to the manure storage per day (Zulovich, 2010). That could add up to 2,190 gallons per year from one leaking nipple drinker.

While doing a water audit, a producer or operator should determine the price of the water being consumed (CDEP, 2010). Swine facilities with wells may receive all the necessary water fairly cheaply, but nearly all water that is pumped into a swine facility must be handled as part of the manure slurry. For this study, using cost avoidance logic in manure slurry handling and land application was an effective method to determine the cost of water and ultimately water conservation.

Dry Clean Up

By collecting or removing the majority of wastes and residue in dry form, large volumes of waste water could be eliminated (NCDENR, 2009). While the majority of swine are produced in facilities with liquid manure storage and handling systems that are cleaned with water, the practice of dry clean up still has value. While it may be impractical to remove manure solids from swine confinements with liquid manure storage and handling systems, the hard packed manure solids could be manually dislodged before the facility is washed. Manure solids can build up creating a "hard pack" in pen corners or non-slatted areas of facilities that use partially slatted floors. Using shovels or scrapers to dislodge this hard pack saves the water that would otherwise be needed to dislodge it. A second area where dry clean up tactics could be used is swine transport washing. Generally, swine transports are washed between every load. Manure solids and bedding can be removed with shovels or brooms prior to washing. This practice would reduce washing time and wash water usage.

Pressurized Wash Water, Wash Basins, and Automatic Shutoffs

Based on results from literature, the surveys from VIDO (1998), and the producer survey, swine production facilities are currently being washed with pressurized water as recommended by all the general water conservation reports reviewed for this project.

Wash basins could be utilized for domestic washing requirements in a swine facility. Instead of washing boots and hands with a hose, keep a basin full of disinfectant for washing boots with a brush. Only use a hose for the final rinse. When it is necessary to use hoses, ensure those hoses have spring loaded trigger shutoffs. This stops water flow between rinses or during wash item rearrangement. A food processor referred to in the Queensland Water Commission report found water savings of 35% by installing spring loaded shut-off valves on all hoses used for washing (Queensland, 2010).

Wash Water Recycle

Many commercial water recycle systems are available for fleet vehicle cleaning and have a proven track record (NCEDENR, 2009). For the same biosecurity reasons facilities are washed between grow outs, swine transports are washed and disinfected after swine transfer events. Besides swine transports, other swine production support vehicles (veterinary and maintenance service vehicles, slurry agitation and removal equipment) are often times washed between visits to swine facilities, especially when going to highly biosecure sites like guilt development and gestation/farrowing facilities. Large swine producers with multiple sites or swine production support service companies often use wash bays similar to commercial car washes to wash and disinfect transports, vehicles, and equipment. The producer survey concluded that wash bays consumed 750 gallons for standard (185-200 market pigs) swine transports. Water usage was less (30-50 gallons) per vehicle but similar for pieces of slurry agitation and removal equipment depending on size. Like manure slurry, the water consumed in these wash bays must be land applied. A wash bay water recycle system could substantially reduce the amount of water consumed for equipment washing. If biosecurity was a concern in wash water recycling, freshwater could be used for the final disinfectant wash.

Rainwater Harvest

Rainwater harvesting captures, diverts, and stores rainwater for later use (TAMU, 2010). Rainwater could be collected through the roof gutter system of swine facilities and then introduced into water supply stream. Tables 12-14 show the possible rainwater volume recoverable from finishing and gestation/farrowing facility roofs and the percentage of total site water consumption the rainwater would displace.

Table 12: Estimated rainwater recoverable from swine facility roof gutter systems in Raleigh, North Carolina.

Month	Rainfall[1] (inches)	Rain recovered from 2000 head finisher[2] (gallons)	Percentage of required usage[3]	Rain recovered from 1800 head gestation facility[4] (gallons)	Percentage of required usage[5]
January	4.02	47,610	38%	95,220	21%
February	3.47	41,096	37%	82,193	20%
March	4.03	47,729	38%	95,457	21%
April	2.8	33,161	28%	66,323	15%
May	3.79	44,886	36%	89,772	20%
June	3.42	40,504	34%	81,008	19%
July	4.29	50,808	41%	101,616	23%
August	3.78	44,768	36%	89,536	20%
September	4.26	50,453	42%	100,905	23%
October	3.18	37,662	30%	75,324	17%
November	2.97	35,175	29%	70,349	16%
December	3.04	36,004	29%	72,007	16%

1. 30 year average for Raleigh, NC, (NOAA, 2010).
2. Building dimensions assumed to be 190' x 100'. 100% rainwater capture assumed.
3. Rainwater volume as percentage of total required, required estimated from Table 1 as 2.0 gal/pigspace/day.
4. Building dimensions assumed to be 380' x 100'. 100% rainwater capture assumed.
5. Rainwater volume as percentage of total required. Gestation building assumed to be part of gestation/farrowing facility with required water used estimated from Table 1 as 8.0 gal/sow/day.

As seen in Tables 12-14, rainwater could displace approximately 5-20% of total site water consumption. At facilities that have to buy water from local municipalities this could be a viable option to lower operating costs, assuming the rainwater harvest equipment (storage, pumping, etc.) is cost effective. Whether or not rainfall harvesting conserves water depends on rainfall intensity. During a relatively intense rainstorm, it could be assumed some of the rain water falling on the swine facility roof would end up in surface water runoff and be transferred out of the area. A relatively gentle, steady rain fall could reasonably result in the water infiltrating the ground water supply and end up in the swine facility's water supply. The fate of rainfall of course depends on soil type and storm intensity which should be considered if a swine producer was contemplating a rainfall recovery system.

Table 13: Estimated rainwater recoverable from swine facility roof gutter systems in Des Moines, Iowa.

Month	Rainfall[1] (inches)	Rain recovered from 2000 head finisher[2] (gallons)	Percentage of required[3]	Rain recovered from 1800 head gestation facility[4] (gallons)	Percentage of required[5]
April	3.58	42,399	35%	84,798	20%
May	4.25	50,334	41%	100,668	23%
June	4.57	54,124	45%	108,248	25%
July	4.18	49,505	40%	99,010	22%
August	4.51	53,413	43%	106,827	24%
September	3.15	37,307	31%	74,613	17%
October	2.62	31,030	25%	62,059	14%

1. 30 year average for Des Moines, IA, (NOAA, 2010).
2. Building dimensions assumed to be 190’ x 100’. 100% rainwater capture assumed.
3. Rainwater volume as percentage of total required, required estimated from Table 1 as 2.0 gal/pigspace/day.
4. Building dimensions assumed to be 380’ x 100’. 100% rainwater capture assumed.
5. Rainwater volume as percentage of total required. Gestation building assumed to be part of gestation/farrowing facility with required water used estimated from Table 1 as 8.0 gal/sow/day.

Table 14: Estimated rainwater recoverable from swine facility roof gutter systems in Milford, Utah.

Month	Rainfall[1] (inches)	Rain recovered from 2000 head finisher[2] (gallons)	Percentage of required[3]	Rain recovered from 1800 head gestation facility[4] (gallons)	Percentage of required[5]
January	0.73	8,646	7%	17,291	4%
February	0.77	9,119	8%	18,239	5%
March	1.21	14,330	12%	28,661	6%
April	0.99	11,725	10%	23,450	5%
May	0.94	11,133	9%	22,265	5%
June	0.44	5,211	4%	10,422	2%
July	0.76	9,001	7%	18,002	4%
August	1.04	12,317	10%	24,634	6%
September	0.92	10,896	9%	21,792	5%
October	1.12	13,265	11%	26,529	6%
November	0.77	9,119	8%	18,239	4%
December	0.58	6,869	6%	13,738	3%

1. 30 year average for Milford, UT, (NOAA, 2010).
2. Building dimensions assumed to be 190’ x 100’. 100% rainwater capture assumed.
3. Rainwater volume as percentage of total required, required estimated from Table 1 as 2.0 gal/pigspace/day.
4. Building dimensions assumed to be 380’ x 100’. 100% rainwater capture assumed.
5. Rainwater volume as percentage of total required. Gestation building assumed to be part of gestation/farrowing facility with required water used estimated from Table 1 as 8.0 gal/sow/day.

Cost Efficiency of Water Conservation Technology and Practices

Not only is water conservation important for sustainable swine production, it could add up to sizable savings in water purchasing/pumping, water administered medication, and manure slurry handling costs. Because water purchasing/pumping cost can vary so greatly with region and facility, this cost analysis section will focus on medicated water savings and cost avoidance by reducing wasted water handled as manure slurry.

It can be assumed pigs are going to consume as much water as needed when given free access to water. The results of the producer survey showed significantly different water consumption values for pigs using different drinker systems (figure 5) within the same production phase. If it is assumed all pigs (within the same production phase) consumed similar amounts of water, and that animal drinking consumes 80% of whole site water use (table 2), it is reasonable to assume the differences in whole site water usage could be attributed to the amount of water wasted with each drinking system. The water wastage may be attributed to leaking systems or water drinker design. Wasted drinking water ends up in the manure slurry storage system, dilutes the nutrient density of the slurry and increases total manure application costs.

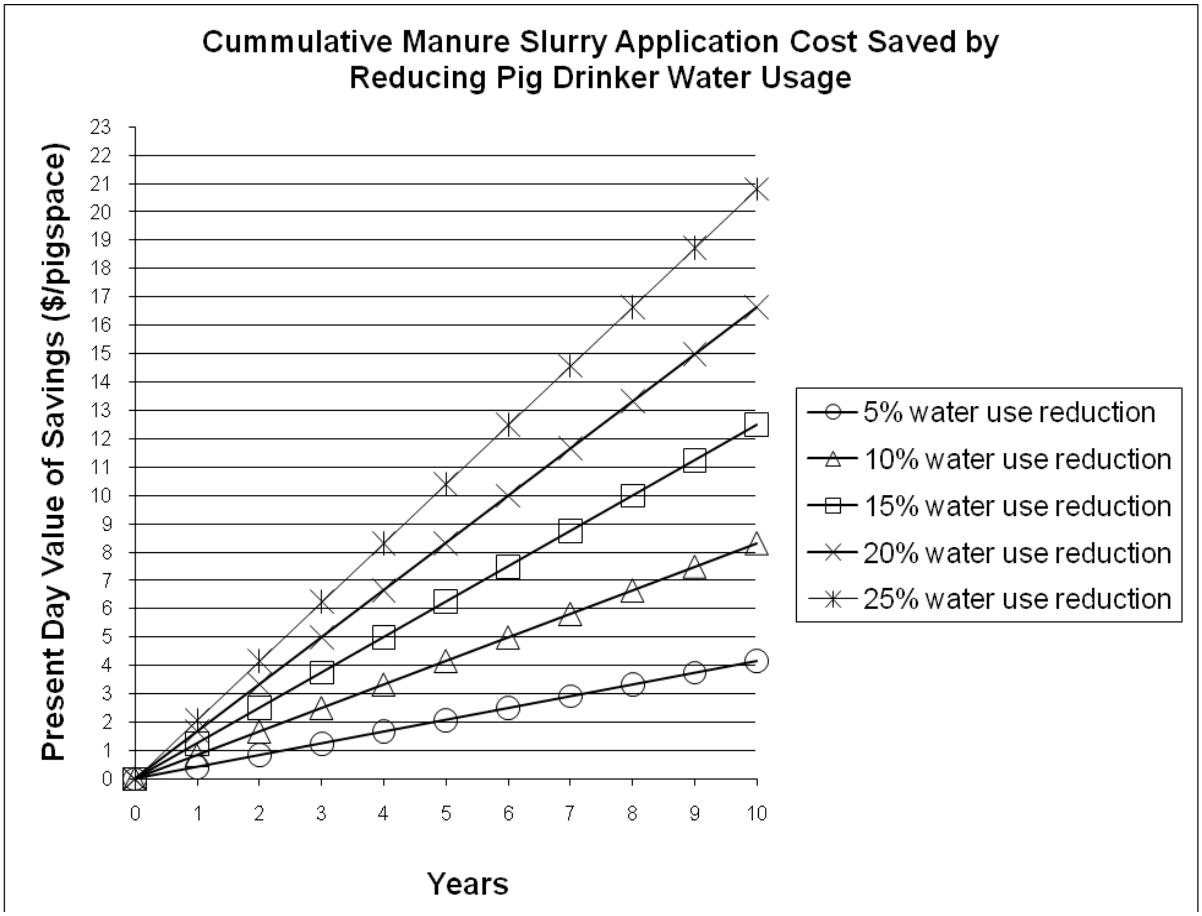
Leaking Water Delivery Systems

As previously mentioned, a leaking water delivery system could add a significant amount of liquid to the manure slurry storage. If that water is administering medication, the cost of the wasted medication can be added to the cost of land applying that water as manure slurry. Brumm (1999) reported the cost of medication supplied to pigs via drinking water increased proportionally with drinking water wasted.

A valve or fitting (such as a nipple drinker) leaking at a rate of one drop per second will add approximately six gallons of water to the manure slurry per day (Zulovich, 2010). A 1000 head finisher may have 80 nipple drinkers. If 25% of these nipples leak at the rate of one drip per second, 43,800 gallons of water will be added to the manure storage. At a manure slurry handling cost of $0.012/gallon, it represents a cost of $525.60 to land apply the leaked water as manure slurry. A producer could spend approximately $26/leaking nipple to repair the leaks in this barn to equal the extra amount that would be spent on land applying that water as part of the manure slurry.

Pig Drinker Systems

The style of pig drinker used can significantly affect drinking water disappearance as found in the literature review (Brumm, 1999, Li, 2005, Magowen, 2007) and whole site water usage as found in the producer survey (table 11). In the literature, the nipple drinker accounted for the most water used by animals drinking. In the producer survey, sites with nipple drinkers had higher whole site water usage than sites with other drinker types. This translates into higher manure slurry volumes as well, as seen in Brumm (1999) and the producer survey (table 11). Multiple studies have shown pig performance was not negatively affected by drinker type. Therefore it is assumed pigs that different drinking systems consume the same amount of water while the difference in total water disappearance is due to wastage associated with each drinker type. It can then be assumed all wasted water ends up being handled as manure slurry. Using this logic, reducing water wastage through drinker selection and management would reduce the total manure slurry volume. To perform cost analysis on the impact of reducing water usage, a grow-finish facility with dry feeders and nipple drinkers was used to represent baseline water use. A pig drinking water usage rate of 1.9 gallons/pigspace/day was assumed. This value was chosen based on rates reported in the producer survey for grow-finish facilities with dry feeders and nipple drinkers (table 11) and various studies (table 5) reporting water usage by pigs using nipple drinkers. An analysis was performed to find manure slurry application savings as the manure volume was reduced by reducing pig drinker water usage. Manure slurry application cost was assumed to be $0.012/gallon. The results of this analysis can be seen in figure 7.



Baseline (0% reduction) manure slurry production is assumed to be 1.9 gal/pigspace/day for a grow-finish facility with dry feeders and nipple drinkers

Figure 7: Cumulative manure slurry application savings as total manure slurry applied is reduced.

Figure 7 shows the savings possible by applying water conservation technology or practices to a swine finisher with nipple drinkers. The lines in figure 7 represent percentages of reduction in water use. Table 15 gives examples of technologies or practices that are proven to reduce water consumption in the swine industry and the percent reduction they can provide.

Table 15: Various technologies and practices that reduce water consumption in swine facilities.

Technology or Practice	Percent reduction in water consumption versus conventional nipple drinkers	Reference	Price[1]
Swinging nipple drinkers	11%	Brumm (2000)	< $1.00/pigspace[2]
Managing nipple height and flowrate	16-26%	Li (2005), table 3	Variable[3]
Bite style or Arato style nipple drinkers	8-22%	Rath (2000), Almond (2002)	$0.50-$0.60
Cup or bowl drinkers	9-31%	Magowen (2007), Brumm (1999), Energy (2001), producer survey	$2.50-$4.50/pigspace
Wet/dry feeders	10[4]-34%	Rantanen (1994), Brumm (1999), Christiansen (2002), Amornthewaphat (2003), producer survey	$8.00-$10.00/pigspace

1. Price estimated from results of producer survey, pigspace refers to finishing pigspace with 20-25 pigs per drinker
2. It is assumed solid mounted nipple drinkers can be converted to swinging nipple drinkers at a relatively low cost. Price will vary with procedure and materials used for conversion.
3. Variable depending on the amount of labor devoted to drinker management
4. Only Christiansen (2002) reported a reduction of 10% for grower pigs, the same study reported 34% reduction for finishing pigs, all other references reported reductions of 17-30%

Using table 15 and figure 7 it is possible to see the cost recovery time associated with various water conservation technologies and practices. The cost recovery time ranges from approximately one year for swinging nipple drinkers to approximately six to seven years for wet/dry feeders.

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