APPENDIX B.1a

July 2005
(Update of October 2004 Version)

Cost and Returns Analysis of Manure Management Systems Evaluated in 2004 under the North Carolina Attorney General Agreements with Smithfield Foods, Premium Standard Farms, and Front Line Farmers

Appendices A through I

Prepared as part of the Full Economic Assessment of Alternative Swine Waste Management Systems under the Agreements between the North Carolina Attorney General and Smithfield Foods, Premium Standard Farms, and Front Line Farmers

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APPENDIX A

Design Parameters and Assumptions

Assumptions and parameters common to all technologies are presented in this appendix. Assumptions and parameters that apply specifically to individual technologies are described in each technology section.

Table A.1 lists the steady state live weight (SSLW), design treatment volume, sludge treatment volume, and predicted manure, urine and excess water production for each type of swine operation. SSLW is an important design parameter for all farms and is the denominator for cost and returns reporting. Results are generally expressed per 1,000 lbs of SSLW. The incremental cost calculated here is reported in dollars per 1,000 lbs of SSLW. Design treatment volume and sludge treatment volume are used in calculations of lagoon volume. Manure, urine and excess water coefficients are used extensively throughout the analysis.

Pig inventory proportions by size and type of pig are listed in Table A.2. These data and assumptions are used to calculate aggregate parameters for each type of operation when only disaggregated data are available.

Table A.3 presents average and maximum manure volumes from four different literature sources. The average manure discharge used in our model is assumed equal to the average of all four sources. Maximum manure volume is assumed equal to average manure volume for farrow-wean, farrow-feeder and farrow-finish operations.[1] Maximum manure discharge on nursery farms and on finishing farms is assumed to occur when the animals approach their maximum weight before leaving the farm. A simple quadratic equation was developed to predict manure production by pigs at different weights. Predicted values from that quadratic regression of manure production on animal SSLW were used to calculate maximum discharge for nursery pigs and finishing hogs.[2]

Tables A.4-A.6 present average and maximum wastewater discharge estimates for flush and pit-recharge systems. The volume of wastewater generated at barns is an important design parameter for many technologies and therefore has a significant impact on technology costs. However, obtaining a representative value for barn discharges is difficult. Values found in literature vary widely and some do not distinguish between pit-recharge and flush systems. We requested wastewater discharge estimates from Smithfield Foods and Premium Standard Farms. They provided us with average and maximum discharge values for several types of operations. Representativeness of these estimates remains limited due to large farm to farm variation.

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[1] It is assumed that these operations maintain a constant inventory and live weight throughout the year.

[2] Three estimates of manure production by pigs of different sizes were available. According to our calculations in Table A.3, average production of manure and urine for a finishing hog at 135 lbs is 1.11 lbs/day and average production of manure and urine for a nursery pig at 30 lbs is 0.37 lbs/day. Another estimate was available from OkSU: a finishing hog at 212 lbs produces 1.71 lbs of manure and urine per day.

Average fresh water usage was based on Smithfield Foods fresh water usage targets. Since only a small portion of Smithfield Foods farms was able to meet the targets in 2002, the target water usage quantities were increased by 20% to be consistent with higher actual water usage. According to Smithfield Foods and Premium Standard Farms representatives, fresh water usage varies with temperature and production cycle. The increase in water usage due to warm temperature can reach as high as 1.24 times the average fresh water consumption. The cyclical component (defined as the effect of the size of growing pigs on the volume of manure produced) needs to be considered for wean-feeder and feeder-finish operations. Maximum fresh water usage is calculated here according to the following formula:

(1) Max Fresh Water Usage = 1.24*Average Fresh Water Usage +1.2*(Maximum Manure Volume – Average Manure Volume).

The addition of 20% of manure volume difference (1.2 *) in the equation is to account for spillage in proportion to the animals actual consumption and excretion of fresh water.

Estimates of recycled effluent for pit recharge systems were only provided for farrow-wean and feeder-finish operations by Premium Standard Farms. Farrow-feeder estimates are assumed to be identical to farrow-wean coefficients and wean-feeder numbers are assumed to be equal to feeder-finish estimates on a gallons per 1,000 lbs. SSLW basis. Flows for farrow-finish operations represent a weighted average of farrow-feeder and feeder-finish values. Average and maximum recycled effluent estimates for flush systems are presented for all five categories in Table A.4 and A.5.

In Table A.6 we present estimates of average and maximum wastewater discharge for all five farm type categories. These values were calculated using estimates in Tables A.4 and A.5 and represent the total wastewater leaving the barns.[3]

On some technology evaluation sites, the volume of recharge liquid (or number of flushes) was purposely decreased to reduce the required liquid handling capacity of the technology. While manure treatment technology providers may find reduced liquid volume beneficial, pig producers suggest the reduced flow may result in greater residue buildup on the pit/flush alley floors, perhaps leading to greater production costs.[4] Industry experts also suggested that while they can decrease somewhat the volume of recycled liquid for recharging and flushing, they may not be able to operate at the low levels of some technology evaluation sites. Table A.4-A.6 list our estimates of average and maximum discharge volume based on various data sources including on-farm measurements from Smithfield Foods and Premium Standard Farms. The result is a set

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[3] The estimate of wastewater leaving barns is equal to the sum of average or maximum fresh water usage and recycled effluent used for recharging pits or flushing.

[4] Greater production costs may be realized due to increased costs of removing the residue and a poorer environment for the hogs. Of course, cleaner flush water from the alternative technologies may offset this, and perhaps end up providing a cleaner environment, but that remains conjecture at this point.

of assumptions regarding wastewater discharge across different representative swine farm types and sizes.

Some technology components (e.g. digesters, reciprocating cells) are designed based on the *average* daily wastewater flow. Other components (e.g. equalization tanks) must be designed based on the *maximum* daily flow expected throughout the year. Wastewater flow depends on manure generated, fresh water usage, evaporation, and recycled liquid used for recharging pits and flushing. Sources of data and description of our calculations in Tables A.3-A.5 are described below each table.

Nitrogen, phosphorus and potassium (K) content in discharged barn effluent is shown in Tables A.6-A.11. These parameters are from various literature sources and calculated average values are shown in Table A.12. Average of grab samples on six farms evaluated under the Agreement are shown in Table A.13. Since there are no alternative swine manure management technologies being evaluated on farrow-feeder, farrow-finish or wean-feeder farms, the data are only for farrow-wean and feeder-finish operations. Feeder-finish estimates were used to calibrate the average literature values in Table A.12 to approximate the current situation on North Carolina farms (Table A.14).

Nitrogen, phosphorus and potassium concentrations in lagoon effluent are shown in Table A.15. The table represents the most commonly used sources found in literature and their averages. The data provided in Bicudo et al. (1999) were used to calculate N, P, and K content for farrow-feeder, farrow-finish, and feeder-finish types (Table A.16). Nutrient content of lagoon effluent measured at two finishing farms evaluated under the Agreement is shown in Table A.17. The average of lagoon nutrient concentrations on these two operations is used to calibrate representative concentration values in Table A.18.[5]

Table A.19 shows literature sources for nitrogen, phosphorus and potassium content in sludge. Some of these sources are rather dated and have limited use in our analysis. Rapid changes in industry organization, swine diets, feed efficiency, and nutrient excretion have occurred since 1988. Bicudo et al. (1999) studied sludge accumulation and sludge nutrient content in anaerobic lagoons. Based on their data, we have calculated sludge accumulation for various types of swine operations and sludge nutrient content (Table A.20). Since the values for farrow-wean and wean-feeder cannot be calculated based on the Bicudo et al. paper, the average of farrow-feeder, farrow-finish and feeder-finish was used as an approximation (Table A.21).

Commonly used values of chemical oxygen demand (COD) and their sources are shown in Table A.22. Average chemical oxygen demand for six experiments evaluated under the Agreement is shown in Table A.23. The feeder-finish estimate of COD was used to calibrate literature values from Table A.22 to calculate representative parameters listed in Table A.24.

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[5] Nutrient values were not found for farrow-wean and wean-feeder operations in Table A.16. The average of values for farrow-feeder, farrow-finish and feeder-finish was used to approximate missing values in calculations in Table A.18.

Total solids (TS) concentrations in raw manure were assembled from various sources and are listed in Table A.25 along with their average for different types of operations. Volatile solids (VS) concentrations are presented in Table A.26.

Price assumptions are listed in table A.27 for a wide variety of parameters that are necessary for economic modeling. Excavation prices ($ per cubic yard) range from $1.30 for large projects to $3.30 for small projects (Table A.28 and Figure 1). The excavation price includes charges for compaction of clay liners where appropriate. A real discount rate is used to discount future costs and returns to the current year. A real discount rate was selected since all prices in future periods are assumed equal to current prices. A nominal interest rate is used to calculate current annual amortization payments for assets that last more than one year to reflect nominal costs to farmers. The maximum economic life of all structures (earthen containments, steel tanks, substantial buildings, etc.) is assumed to be 10 years as specified in the Attorney General / Smithfield Foods agreement. In our model, motors, pumps and blowers are generally assumed to have a three year economic life. These values are the default parameters. The default values are replaced with actual life expectancy if it was provided by a reliable source and it did not exceed 10 years. (Note that this assumption presumes that the pig farm will remain in operation for 10 years in order to "pay off" the total costs of assets with a life of 10 years. Revenue from energy production is based on the electricity production at Barham Farm. Progress Energy provided us with their calculation that, had the generator not been used, the total energy bill for November, 2001 through October, 2002 would have been $59,456.51. From using the generator and producing 166,102 kWh of energy, his bill was reduced to $52,333.84 (not much energy was produced because the generator was down for about two months). This implies a net savings of $7,122.67, or **$0.0429** per kw for this period. Other parameters shown in this table were obtained from various literature sources and consultations with industry experts.

Overhead cost as a percentage of construction cost is shown in Table A.29. Categories of costs included in overhead cost are: engineering design services (11% of total capital costs), taxes and insurance (1.5% of total construction costs), and several contractor related charges (mobilization (3% of direct construction costs); bonds (3% of direct construction costs); contractor's profit and overhead (12.5% of total construction costs); contingencies (10% of total construction costs)). Together, these costs add 43.1% to the direct construction costs (sources for this information include Cavanaugh and Associates, Wells Brothers Construction and Means Estimating Handbook). The default assumption in the model is that the farm owner pays all of the overhead costs. A number of questions remain. In the past NRCS and other government agencies have provided some engineering design services without charge. In addition, some technology providers are proposing to charge fees and royalties for their services and it is possible that some of the overhead charges would be included in their fees. Finally, it is difficult to know when some of the overhead charges are built into the prices quoted by contractors for some construction jobs.

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(WB) Wells Brothers Construction. Personal communications. 2004.

Table A.1: Anaerobic Lagoon Volume Design Parameters in North Carolina: Treatment, Sludge Storage, and Manure, Urine and Excess Water Accumulation

Farm Type	Average Live Weight (lbs. SSLW per head capacity)	Design Treatment Volume (ft^3 / lb SSLW)	Sludge Storage Volume (ft^3 / lb SSLW)	Manure, Urine, and Excess Water (gallons / day)
Farrow-to-Wean	433 (lbs. per sow)	0.67	0.17	7.2 per sow
Farrow-to-Feeder	522 (lbs. per sow)	0.67	0.17	8.0 per sow
Farrow-to-Finish	1,417 (lbs. per sow)	1.00	0.25	23.0 per sow
Wean-to-Feeder	30 (lbs. per pig)	1.00	0.25	0.5 per head
Feeder-to-Finish	135 (lbs. per pig)	1.00	0.25	2.3 per head

Source: NC NRCS

Table A.2: Assumed Swine Inventory Proportions by Farm Type

Farm Type	Metric	Number of Lactating Sows	Number of Gestating Sows	Number of Replacement Gilts	Number of Nursery Pigs	Number of Finishing Pigs
Farrow-to-Wean	per 100 sows	14	76	10	0	0
Farrow-to-Feeder	per 100 sows	14	76	10	290	0
Farrow-to-Finish	per 100 sows	14	76	10	290	600
Wean-to-Feeder	per 100 head capacity	0	0	0	100	0
Feeder-to-Finish	per 100 head capacity	0	0	0	0	100

Sources: Adapted from NPPC; Cross, Campbell, and Stalder; PSF; and SF.

Table A.3: Average and Maximum Manure Discharge Volume

Farm Type	Production Unit	Manure Volume (MWPS)	Manure Volume (OSU)	Manure Volume (NRCS)	Manure Volume (ASAE)	Average	Maximum Manure Volume
	(PU)	Gallons / PU / Day					
Farrow-Wean	**sow**	**1.14**	**1.4**	**1.58**		1.37	1.37
Farrow-Feeder	**sow**	**2.01**	**2.1**	**2.68**		2.16	2.16
Farrow-Finish	**sow**	**9.21**	**7.1**	**8.68**		8.33	8.33
Wean-Feeder	**head**	**0.3**	**0.42**	**0.38**		0.37	0.51
Feeder-Finish	**head**	**1.2**	**0.9**	**1.00**	**1.35**	1.11	1.71

Note: Maximum manure volume for wean to feeder and feeder to finish are predicted using a simple quadratic equation of manure production as a function of live weight.

Table A.4: Average Expected Wastewater Discharge

Farm Type	**Average Fresh Water Usage (7 Day Week)**[a]	**Average Manure Volume (7 Day Week)**	**Recycled Effluent for Recharging Pits (5 Day Week)**[b]	**Recycled Liquid pumped to Flush Tanks (7 Day Week)**[c]
	gallons / 1,000 lbs. SSLW / day			
Farrow-to-Wean	19.56	3.16	55	72
Farrow-to-Feeder	20.16	4.14	55	100
Farrow-to-Finish	19.48	5.88	33	60
Wean-to-Feeder	25.20	12.33	20	242
Feeder-to-Finish	20.45	8.22	20	37

Sources: Adapted from NPPC; Cross, Campbell, and Stalder; PSF; and SF.

a) Assumes the same amount of fresh water is used all seven days of the week.

b) Pits are assumed to be only recharged on weekdays while employees are present so this number represents the typical amount used for recharging each weekday. The weekly total then equals this number multiplied by five. These data are based on pit volumes and recharging frequency from Premium Standard Farms operations (Norwood). Data were only available for farrow-wean and feeder-finish farms. The per 1,000 lb SSLW flows are assumed identical on wean-feeder as on feeder-finish, and numbers for farrow-feeder farms were assumed equal to farrow-wean farms. Flows for farrow-finish are a weighted average of farrow-wean and feeder-finish estimates. The recharge liquid volume in each pit was assumed equal to the total pit volume minus expected manure and excess water volume accumulating in the pit between flushings.

c) Flush systems flush the barns seven days a week, so this number represents the typical amount used for flushing all seven days. These numbers are from Smithfield Foods farms.

Table A.5: Maximum Expected Wastewater Discharge

Farm Type	Maximum Fresh Water Usage (7 Day Week)[a]	Maximum Manure Volume (7 Day Week)	Recycled Effluent for Recharging Pits (5 Day Week)[b]	Recycled Effluent for Flush Tanks (7 Day Week)[c]
	gallons / 1,000 lbs. SSLW / day			
Farrow-to-Wean	24.25	3.16	55	72
Farrow-to-Feeder	25.00	4.14	55	100
Farrow-to-Finish	24.16	5.88	33	60
Wean-to-Feeder	35.92	17.00	20	242
Feeder-to-Finish	30.70	12.67	20	37

Sources: NPPC; Cross, Campbell, and Stalder; PSF; and SF.

a) Assumes the same amount of fresh water is used all seven days of the week

Max Fresh Water Usage = 1.24*Average Fresh Water Usage +1.2*(Maximum Manure Volume -Average Manure Volume).

b) Pits are assumed to be only recharged on weekdays while employees are present so this number represents the typical amount used for recharging each weekday. The weekly total then equals this number multiplied by five. These data are based off of pit volumes and recharging frequency from Premium Standard Farms operations (Norwood). Data were only available for farrow-wean and feeder-finish farms. The per 1,000 lb SSLW flows are assumed identical on wean-feeder as on feeder-finish, and numbers for farrow-feeder farms were assumed equal to farrow-wean farms. Flows for farrow-finish are a weighted average of farrow-wean and feeder-finish estimates. The recharge liquid volume in each pit was assumed equal to the total pit volume minus expected manure and excess water volume accumulating in the pit between flushings.

c) Flush systems flush the barns seven days a week, so this number represents the typical amount used for flushing all seven days. These numbers are from Smithfield Foods farms.

Table A.6: Average and Maximum Wastewater Discharge

Farm Type	Average Daily Discharge For Pit-Recharge (5 Day Week)	Average Daily Discharge For Flush Systems (7 Day Week)	Maximum Daily Discharge For Pit-Recharge (5 Day Week)	Maximum Daily Discharge For Flush Systems (7 Day Week)
	gallons / 1,000 lbs. SSLW / day			
Farrow-to-Wean	82.38	91.56	88.95	96.25
Farrow-to-Feeder	83.24	120.16	90	125.00
Farrow-to-Finish	60.27	79.48	66.24	84.16
Wean-to-Feeder	55.28	267.20	70.28	277.92
Feeder-to-Finish	48.63	57.45	62.98	67.70

Note: Calculated using data in Tables A.3 and A.4.

Table A.6: Nutrients in Raw Swine Manure (ASAE)

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow			
Farrow-Feeder	sow			
Farrow-Finish	sow			
Wean-Feeder	head capacity			
Feeder-Finish	head capacity	25.64	8.87	14.30

Source: ASAE, 1993

Table A.7: Nutrients in Raw Swine Manure (NRCS)

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow	34.51	10.98	21.62
Farrow-Feeder	sow	53.58	18.92	32.74
Farrow-Finish	sow	177.83	66.26	97.83
Wean-Feeder	head capacity	6.58	2.74	3.84
Feeder-Finish	head capacity	20.71	7.89	10.85

Source: NRCS, 1999

Table A.8: Nutrients in Raw Swine Manure (MWPS)

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow	24.70	8.41	16.08
Farrow-Feeder	sow	45.88	13.07	24.87
Farrow-Finish	sow	221.20	61.28	97.63
Wean-Feeder	head capacity	7.31	1.61	3.03
Feeder-Finish	head capacity	29.22	8.04	12.13

Source: Midwest Plan Service (MWPS), 2003

Table A.9: Nutrients in Raw Swine Manure (Carter et al.)

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow	29.05	8.70	
Farrow-Feeder	sow	62.21	14.07	
Farrow-Finish	sow	252.12	46.45	
Wean-Feeder	head capacity	11.44	1.85	
Feeder-Finish	head capacity	31.65	5.40	

Source: Carter et al., 2003

Table A.10: Nutrients in Raw Swine Manure (OSU)

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow	29.00	10.12	
Farrow-Feeder	sow	43.00	15.84	
Farrow-Finish	sow	150.00	57.20	
Wean-Feeder	head capacity	7.70	3.21	
Feeder-Finish	head capacity	18.00	7.04	

Source: OSU

Table A.11: Nutrients in Raw Swine Manure (Chastain et al.)

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow	70.40	24.39	39.29
Farrow-Feeder	sow	90.72	31.43	50.63
Farrow-Finish	sow	295.79	102.50	165.11
Wean-Feeder	head capacity	6.81	2.36	3.80
Feeder-Finish	head capacity	30.65	9.77	15.74

Source: Chastain et al., 1999

Table A.12: Average of Nutrients in Raw Swine Manure Reported in Tables A6-A.11

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow	37.53	12.52	25.66
Farrow-Feeder	sow	59.08	18.67	36.08
Farrow-Finish	sow	219.38	66.73	165.11
Wean-Feeder	head capacity	7.97	2.35	3.56
Feeder-Finish	head capacity	25.97	7.84	13.26

Table A.13: Average of Nutrients in Raw Swine Manure Measured at Experimental Sites

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Number of Samples
		lbs / PU / year		
Farrow-Wean	sow	70.52	18.13	1
Farrow-Feeder	sow			
Farrow-Finish	sow			
Wean-Feeder	head capacity			
Feeder-Finish	head capacity	20.24	5.80	6

Source: AG/SF/PSF/Frontline Experiments

Table A.14: Average Nutrients in Raw Swine Manure Calibrated by Experimental Sites Averages for Feeder-Finish Operations

Farm Type	Production Unit (PU)	Nitrogen	Phosphorus	Potassium
		lbs / PU / year		
Farrow-Wean	sow	29.25	9.26	19.25
Farrow-Feeder	sow	46.04	13.81	27.06
Farrow-Finish	sow	170.98	49.37	123.83
Wean-Feeder	head capacity	6.21	1.74	2.67
Feeder-Finish	head capacity	20.24	5.80	9.95

Table A.15: Nutrients in Lagoon Effluent

Source	Nitrogen	Phosphorus	Potassium
	lbs / 1,000 gallons		
NRCS	2.91	0.63	3.16
MWPS	4.00	0.88	4.15
Chastain et al.	4.80	1.23	2.98
James Barker	5.00	0.86	4.06
Average	**4.18**	**0.90**	**3.59**

Table A.16: Nutrients in Lagoon Effluent (Bicudo et al.)

Farm Type	Nitrogen	Phosphorus	Potassium
	lbs / 1,000 gallons		
Farrow-Wean	-	-	-
Farrow-Feeder	3.32	0.60	2.48
Farrow-Finish	3.99	0.70	3.83
Wean-Feeder	-	-	-
Feeder-Finish	4.34	0.64	4.87
Average	**3.89**	**0.65**	**3.72**

Source: Bicudo et al., 1999

Table A.17: Nutrients in Lagoon Effluent (Experimental Sites)

Source	Nitrogen	Phosphorus	Potassium
	lbs / 1,000 gallons		
Stokes	3.76	0.48	8.57
Moore	5.17	0.60	7.46
Average	**4.47**	**0.54**	**8.02**

Note: Stokes–average of four surface grab samples taken on two different days
Moore– average of six surface grab samples taken on three different days

Table A.18: Nutrients in Lagoon Effluent (Bicudo et al.) Calibrated by Experimental Sites (Table A.17)

Farm Type	Nitrogen	Phosphorus	Potassium
	lbs / 1,000 gallons		
Farrow-Wean	4.00	0.55	6.13
Farrow-Feeder	3.42	0.51	4.08
Farrow-Finish	4.11	0.59	6.31
Wean-Feeder	4.00	0.55	6.13
Feeder-Finish	4.47	0.54	8.02

Source: Bicudo et al., 1999 , calibrated to average of Moore and Stokes farm data.

Table A.19: Nutrient Content of Sludge

Source	Nitrogen	Phosphorus	Potassium
	lbs / 1,000 gallons		
NRCS	25.00	22.50	6.31
James Barker	22.38	21.70	5.89
Chastain et al.	21.60	20.81	5.23
Average	**22.90**	**21.11**	**5.81**

Table A.20: Sludge Accumulation Rates and Nutrient Concentration of Sludge

Farm Type	Sludge Accumulation (gal / PU / year)	Nitrogen	Phosphorus	Potassium
		lbs / 1,000 gallons		
Farrow-Wean	156	-	-	-
Farrow-Feeder	188	27.80	27.45	3.94
Farrow-Finish	509	31.07	30.40	5.01
Wean-Feeder	11	-	-	-
Feeder-Finish	49	43.71	42.04	6.96
Average		**34.19**	**33.30**	**5.30**

Source: Bicudo et al., 1999

Table A.21 Sludge Accumulation Rates and Nutrient Content of Sludge

Farm Type	Sludge Accumulation (gal / PU / year)	Nitrogen	Phosphorus	Potassium
		lbs /1,000 gallons		
Farrow-Wean	156	34.19	33.30	5.30
Farrow-Feeder	188	27.80	27.45	3.94
Farrow-Finish	509	31.07	30.40	5.01
Wean-Feeder	11	34.19	33.30	5.30
Feeder-Finish	49	43.71	42.04	6.96

Note: Average nutrient values from Table A.20 used to approximate Farrow-Wean and Wean-Feeder sludge nutrient content

Table A.22: COD in Raw Swine Manure: Theoretical Values

Farm Type	Production Unit	COD (NRCS)	COD (ASAE)	COD (OSU)	Average Value
	(PU)	lbs / PU / year			
Farrow-Wean	**sow**	**429.23**	**-**	**356.192**	392.71
Farrow-Feeder	**sow**	**740.64**	**-**	**716.33**	728.49
Farrow-Finish	**sow**	**2,533.51**	**-**	**2,454.85**	2,494.18
Wean-Feeder	**head**	**107.38**	**-**	**124.19**	115.79
Feeder-Finish	**head**	**298.81**	**414.20**	**289.76**	334.26

Table A.23 COD: Average of Values Measured at Experimental Sites

Farm Type	Production Unit	COD
	(PU)	lbs / PU / year
Farrow-Wean	**sow**	**756.50**
Farrow-Feeder	**sow**	**-**
Farrow-Finish	**sow**	**-**
Wean-Feeder	**head**	**-**
Feeder-Finish*	**head**	**272.63**

*Average of six experiments

Table A.24: Average Literature Values Calibrated by Experimental Sites Averages for Feeder-Finish Operations

Farm Type	Production Unit	COD
	(PU)	lbs / PU / year
Farrow-Wean	**sow**	**320.30**
Farrow-Feeder	**sow**	**594.17**
Farrow-Finish	**sow**	**2,034.31**
Wean-Feeder	**head**	**94.44**
Feeder-Finish	**head**	**272.63**

Table A.25 Total Solids in Raw Swine Manure - Theoretical Values

Farm Type	Production Unit	Total Solids (NRCS)	Total Solids (MWPS)	Total Solids (ASAE)	Total Solids (Chastain et al.)	Total Solids (OSU)	Total Solids (Average)
	(PU)			lbs / PU / year			
Farrow-Wean	**sow**	**451.78**	**273.67**	**-**	**933.10**	**371.10**	507.41
Farrow-Feeder	**sow**	**788.61**	**511.04**	**-**	**1,277.43**	**763.01**	835.02
Farrow-Finish	**sow**	**2,664.32**	**2,329.99**	**-**	**4,813.30**	**2,669.61**	3,119.31
Wean-Feeder	**head**	**116.20**	**81.85**	**-**	**120.54**	**135.14**	113.43
Feeder-Finish	**head**	**312.62**	**303.16**	**542.40**	**542.40**	**317.77**	403.67

Table A.26: Volatile Solids in Raw Swine Manure- Theoretical Values

Farm Type	Production Unit	Volatile Solids (NRCS)	Volatile Solids (MWPS)	Volatile Solids (ASAE)	Volatile Solids (Chastain et al.)	Volatile Solids (OSU)	Volatile Solids (Average)
	(PU)			lbs / PU / year			
Farrow-Wean	**sow**	**391.96**	**239.24**	**-**	**711.69**	**324.70**	416.90
Farrow-Feeder	**sow**	**671.60**	**432.66**	**-**	**972.37**	**653.07**	682.43
Farrow-Finish	**sow**	**2,269.20**	**1,887.81**	**-**	**3,726.43**	**2,373.40**	2,564.21
Wean-Feeder	**head**	**96.43**	**66.70**	**-**	**93.14**	**113.23**	92.38
Feeder-Finish	**head**	**266.27**	**242.53**	**419.12**	**419.12**	**286.72**	326.75

Table A.27: Cost Assumptions

Input	Parameter Estimate	Unit
Excavation Cost	See Figure 1	
Interest and Discount Rates		
Interest rate (nominal)	8.00 %	%
Discount rate (real)	4.00 %	%
Planting cost of grass / acre	$226.00	$ / acre
Importing cost of clay	$5.00	$ / cubic yard
Sludge removal cost	$0.025	$ / gallon sludge buildup
Nitrogen price (synthetic)	$0.29	$ / lb
Phosphorus price (P, synthetic)	$0.57	$ / lb
Potassium price (K, synthetic)	$0.25	$ / lb
Life	10	years
Life of motors and blowers	3	years
Opportunity cost of land	$60.00	$ / acre
Price of energy	$0.08	$ / kWh
Revenues from energy production	$0.043	$ / kWh
Disc, seed, and mulching cost	$1,000.00	$ / acre
Geological investigation cost	$975.00	$ / acre
Property Taxes	0.71 %	%
Clay imported	50 %	%
% of earthen cell requiring excavation	70 %	%

Table A.28: Examples of Excavation Cost

Volume Excavated (Cubic Yards)	Excavation Cost ($)
1,000	**3.26**
10,000	**3.10**
20,000	**2.92**
30,000	**2.75**
40,000	**2.59**
50,000	**2.44**
60,000	**2.30**
70,000	**2.16**
80,000	**2.03**
90,000	**1.91**
100,000	**1.80**
150,000	**1.35**

Table A.29: Overhead Cost

Input	Point Estimate Price / Unit	Unit
Mobilization	3.00 %	% of direct construction costs
Bonds	3.00 %	% of direct construction costs
Mobilization and bonds costs	6.00 %	% of direct construction costs
Total capital costs = construction costs + mobilization costs + bonds costs		
Engineering design services	11.00 %	% of total capital costs
Construction services and startup	0.00 %	% of total capital costs
Contractor’s overhead and profit	12.50 %	% of total capital costs
Taxes and insurance	1.50 %	% of total capital costs
Contingencies	10.00 %	% of total capital costs
Total overhead	**35.00 %**	% of total capital costs
Mobilization, bonds, and total overhead cost	**43.10 %**	% of direct construction costs

Figure 1: Excavation Cost

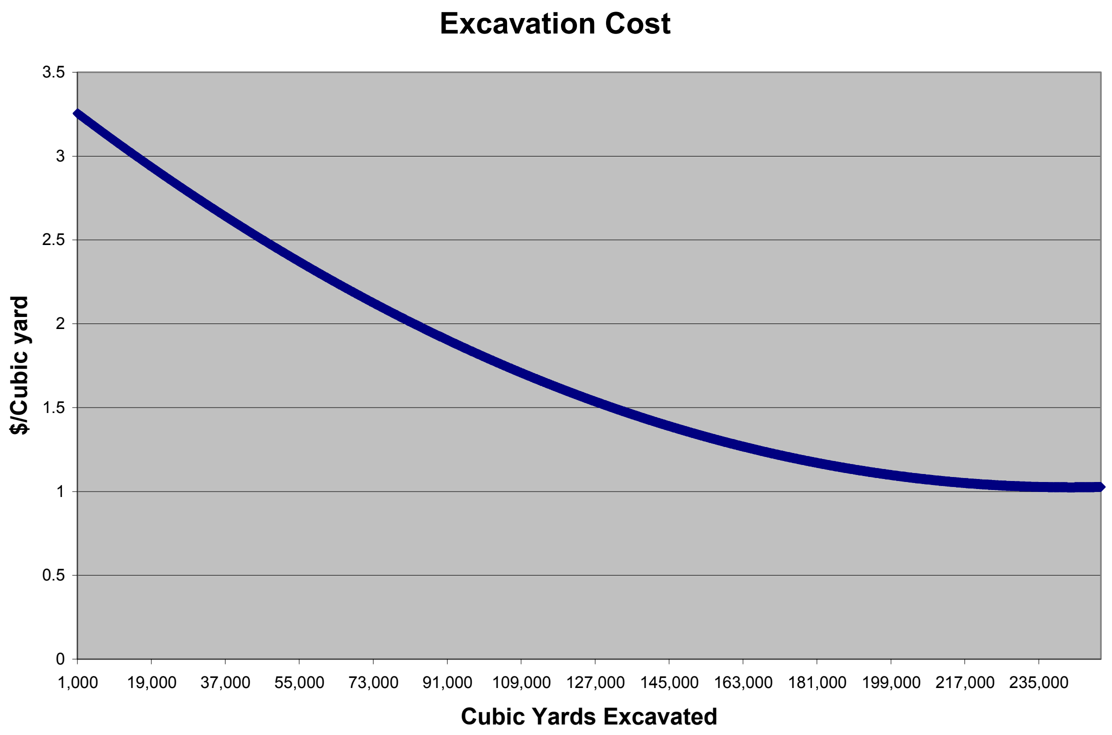


Figure 2: Sludge Accumulation (gallons / sow) based on SF Data (Farrow-Wean)

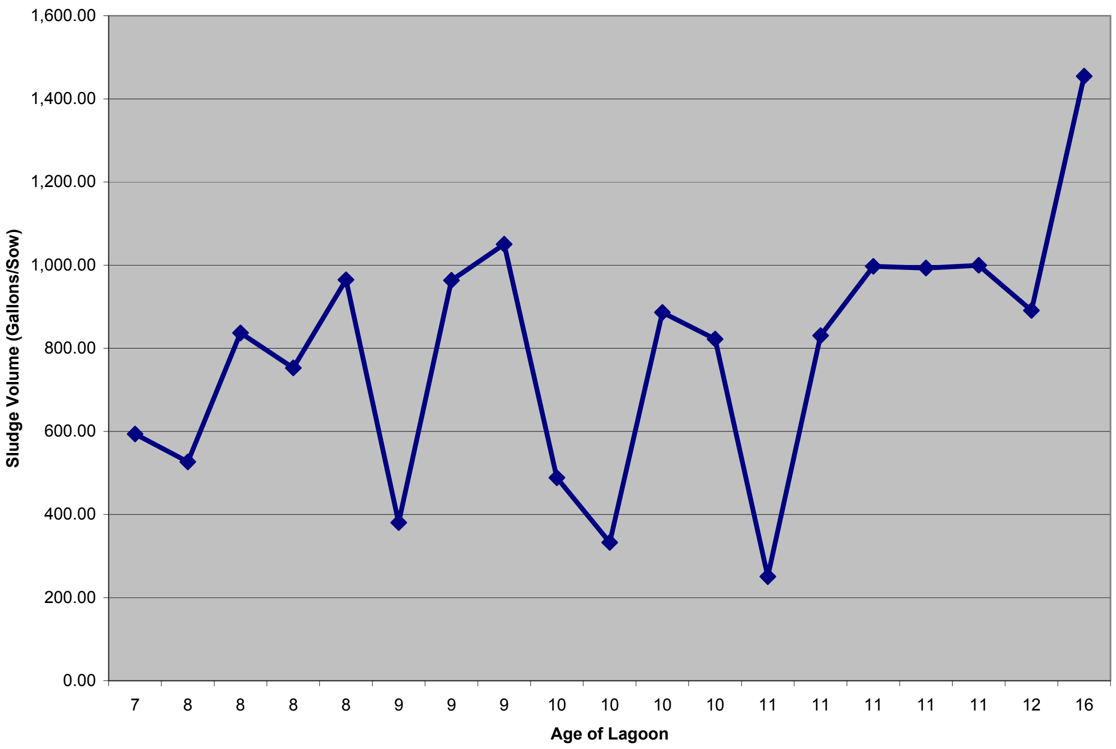


Figure 3: Sludge Accumulation (gallons / sow) based on SF Data (Feeder-Finish)

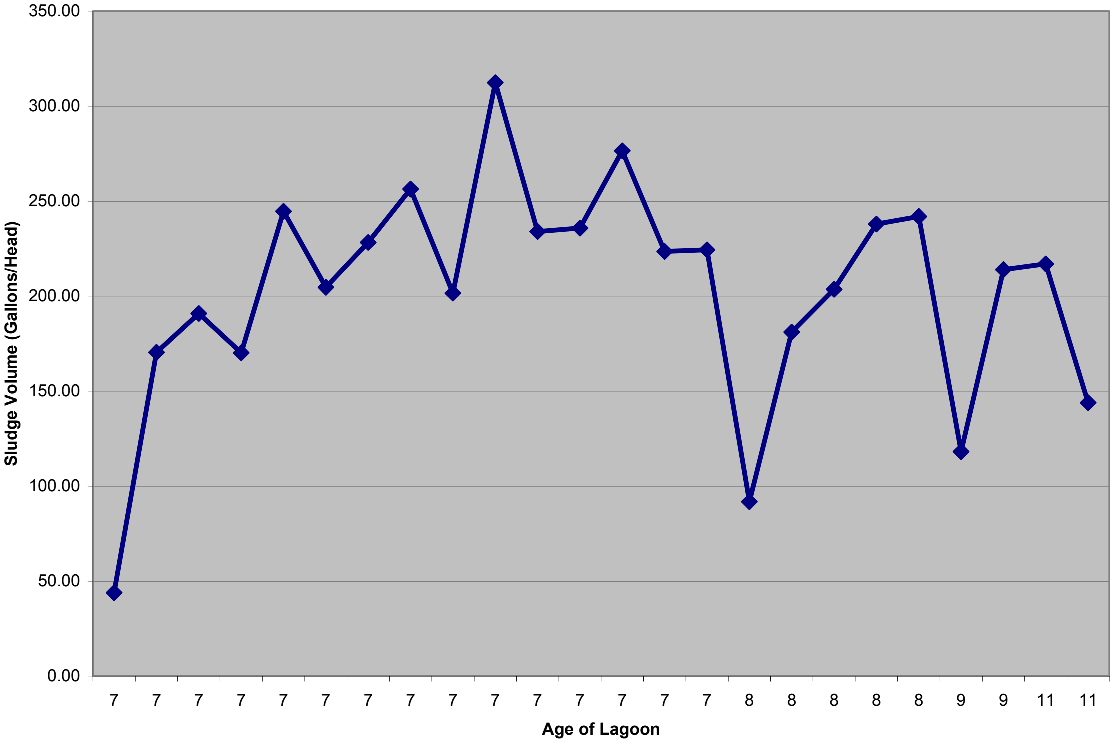
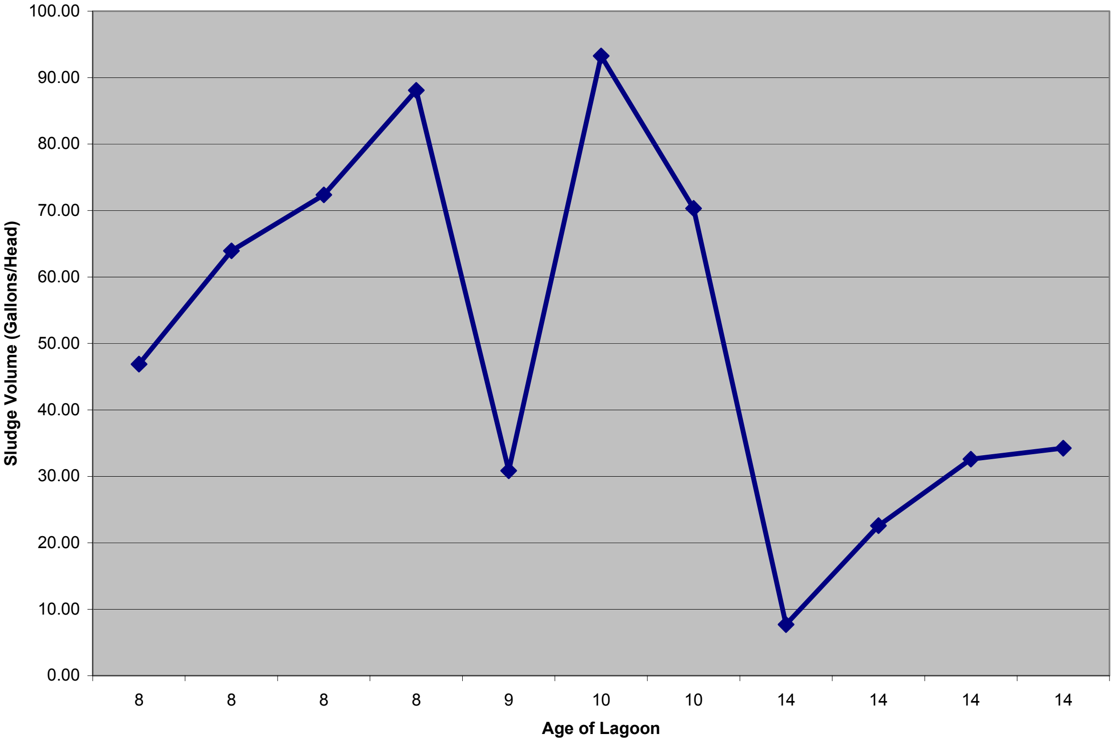


Figure 4: Sludge Accumulation (gallons / sow) based on SF Data (Feeder-Finish)



APPENDIX B
Predicted Cost of Irrigation of Liquid Effluent From Swine Manure Treatment Systems in North Carolina

This document details a cost model for irrigation of liquid effluent onto crop or forage land. The model and assumptions are designed to reflect pig production in North Carolina. The model portrays four combinations of limiting nutrient and crop type: nitrogen-based applications or phosphorus-based applications applied to row-crops or to forages (see Table B.1).

A. Liquid Effluent Characteristics and Acreage Requirements

The volume and nutrient content of liquid effluent for any farm type and size is estimated by the broader model for each alternative swine manure management technology and for the baseline.

The sprayfield acreage needed for each of the four combinations is calculated first. If the application is nitrogen-limited, total biologically active nitrogen generated in the liquid effluent stream each year is multiplied by the plant availability coefficient (e.g. 50%) for nitrogen, and divided by the annual per-acre plant available fertilizer recommendation (see Table B.2) for the crop. For phosphorus-limited irrigation, total phosphorus generated in the liquid effluent stream each year is multiplied by the plant availability coefficient (e.g. 70%) for phosphorus, and divided by the annual per-acre plant available phosphorus recommendation of the crop(s) (see Table B.2).

(1) Required Acres = Total Nutrient *Plant Availabilty Coefficient / Crop Fertilizer Recommendation.

where Total Nutrient represents the total quantity of nutrient (lbs/year) left in the effluent after treatment, Plant Availability Coefficient predicts the nutrient availability after land application and Crop Fertilizer Recommendation represents the amount of plant available nutrient required to produce a certain yield.

B. Annual Opportunity Cost of Sprayfield

It is assumed that row-crops are the most profitable use of land in sprayfields. No opportunity costs are assumed for irrigating liquid effluent onto row-crops. Forage crops are assumed to generate no net return to the land so an annual opportunity cost of $60 per acre is applied. The $60 per acre charge is assumed to approximate the average annual return or rental rate that would be received above all other costs if the land was producing row crops. Revenue from forage crops is assumed to exactly offset all of the costs of producing and harvesting the forage crops with the exception of fertilizer costs and with the exception of opportunity costs of the land.

C. Annual Gross Irrigation Costs

Irrigation costs depend on the volume of liquid effluent to be applied and the number of acres irrigated. Cox and Bosch, Zhu, and Kornegay provide a simple formula for estimating irrigation costs. Inputs to the formula are; A = sprayfield acreage, D = acre-inches applied per acre (depth of total effluent applied), H = hours to spray an acre-inch, and AI = acre-inches of lagoon effluent. The depth, D, can be calculated by dividing the total acre-inches of lagoon effluent by the number of acres (AI/A). The formula reports costs in 1992 dollars for traveling gun irrigation, which can be multiplied by 1.31 to convert to 2004 dollars (NASS).

(2) $\text{Irrigation Costs} = [7097.44 + 36.05(A) + 403.9(D) - 2546.16(H) + 281.44(H)^2][1.31]$

D. Annual Savings from Not Having To Buy Commercial Fertilizer

Plant available nutrients in the manure that would otherwise have to be purchased are subtracted from total costs. Table B.2 gives plant available nutrient requirements for each crop. The nutrient savings equal the minimum of the plant available nutrients applied per acre and nutrient recommendation divided by the plant availability coefficient. Prices are \$0.29 / lb N, \$0.57 / lb P, and \$0.25 / lb K (NCSUg).

E. Annual Additional Fertilizer Purchases

It is possible that application of treated effluent from some technologies and application types will cause soil to be nutrient deficient. For example, if land applications are phosphorus-limited the manure will be spread over more acres, causing the soil to remain nitrogen deficient for the crop and expected yield. Commercial nitrogen fertilizer must be added. The amount of nutrients to be purchased and applied equals:

(3) $\text{Nutrients Purchased} = \min(0,N_F-N_A)*(\text{Price / lb N}) + \min(0,P_F-P_A)*(\text{Price / lb P}) + \min(0,K-K)*(\text{Price / lb K}),$

If $F=(N_F, P_F, K_F)$ and $A=(N_A, P_A, K_A)$, vectors F and A represent the recommended nutrient application rate of plant available nutrients and A represent the actual nutrient application rate of plant available nutrients. The cost of additional fertilizer purchased is only added for forages. Since row crops represent the most profitable use of land in the area and the crop would be grown even without swine farms, fertilizer purchases are not considered to be additional costs.

F. Annual Net Cost of Irrigating Liquid Effluent

The annual net cost of irrigating liquid effluent onto *row crops* is the gross cost of irrigation (C) minus the savings from not having to buy commercial fertilizer (D). Neither returns to row-crops or commercial fertilizer purchase are included as they are included in the costs and returns to the crop in the absence of effluent irrigation. The annual net cost of the irrigating liquid effluent onto *forages* is the opportunity cost of land (B) plus the gross cost of irrigation (C) plus the cost of additional fertilizer purchased (E).

An example of an output from the liquid effluent irrigation model is provided in Table B.3.

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Table B.1: Four Combinations of Limiting Nutrient and Crop

	Crop	
Limiting Nutrient	Forages[a]	Row-Crops[b]
Nitrogen-Based Application	Combination 1	Combination 3
Phosphorus-Based Application	Combination 2	Combination 4

a) The forage crop sprayfield is assumed to produce hybrid Bermuda grass hay in the summer and overseeded ryegrass hay in the winter.

b) The row-crop sprayfield is assumed to be apportioned equally to the average mix of soybeans, wheat, and corn in Sampson County. This mix is 20% corn, 21% wheat, and 59% soybeans (NASSb).

Table B.2: Annual Nutrient Recommendation for Each Combination (lbs. nutrient / acre)

	Crop	
Limiting Nutrient	Forages[a]	Row-Crops[b]
Nitrogen-Based Application	290 lbs N	90 lbs N
Phosphorus-Based Application	35 lbs P	13 lbs P

Note: This is based on North Carolina crop conditions and crop mixes found in Sampson County, North Carolina (NASSb).

a) Assumes 5.5 tons / acre Bermuda grass yield and ryegrass yields are 2.5 tons / acre (NCSUe; Schwabe 2001; NCSUf). If applied according to agronomic rates, bermuda grass can take up 37.6 lbs N / ton, 3.82 lbs P / ton, and 28 lbs K / ton; ryegrass can take up 33.4 lbs N / ton, 5.44 lbs P / ton, and 28.40 lbs K / ton

b) Row-crops consist of 20% corn, 21% wheat, and 59% soybeans. Each crop's nutrient requirement is (1) corn; 0.9 lbs N / bu, 0.1548 lbs P / bu, and 0.22 lbs K / bu (2) wheat; 1.25 lbs N / bu, 0.3655 lbs P / bu, and 0.3154 lbs K / bu; and (3) soybeans; 3.75 lbs N / bu, 0.3784 lbs P / bu, and 1.13 lbs K / bu. Average yields in Sampson County are; corn 78 bu / acre, wheat 46 bu / acre, and soybeans 25 bu / acre (Shaffer). These yields are increased by 10% due to irrigation from the lagoon effluent.

Table B.3: Cost of Liquid Effluent Irrigation onto Sprayfields (Sample Report)

A. Acres Required	**Forages**	**Row Crops**
If nitrogen-based application (acres)	35	113
If phosphorus-based application (acres)	52	141
B. Annual Opportunity Cost of Land ($60 Per acre)	**Forages**	**Row Crops**
If nitrogen-based application	$2,090	-
If phosphorus-based application	$3,102	-
C. Annual Gross Irrigation Costs	**Forages**	**Row Crops**
If nitrogen-based application	$10,409	$10,872
If phosphorus-based application	$9,685	$11,925
D. Annual Savings From Not Having To Buy Commercial Fertilizer	**Forages**	**Row Crops**
If nitrogen-based application	-	$(2,382)
If phosphorus-based application	-	$(3,086)
E. Annual Additional Fertilizer Purchases	**Forages**	**Row Crops**
If nitrogen-based application	-	-
If phosphorus-based application	$1,419	-
F. Annual Net Cost of Irrigating Liquid Effluent	**Forages (= B + C + E)**	**Row Crops (= C + D)**
If nitrogen-based application	$12,499	$8,490
If phosphorus-based application	$14,206	$8,839

APPENDIX C
Cost of Land Application of Swine Manure Solids and Slurries

This document details a cost model for land application of swine manure solids and slurries. Solids are defined here as material which cannot be handled as a liquid or semi-solid liquid (solids may have less than 85% moisture). Slurries are defined here as materials that include greater than 1% solids but less than 12% solids. Slurries may have too high a solids content to be pumped through irrigation systems but are sufficiently liquid that they can be pumped and handled as liquids. The model and assumptions are designed to reflect pig production in North Carolina. The model calculates results for each of four combinations for solids application and for slurry application; nitrogen-limited or phosphorus-limited applications to row crops or to forages. (See Table C.1).

A. Characteristics of Solids and Slurries and Acreage Requirements

The volume and nutrient content of solids and slurries produced by any farm type and size is calculated by the broader model for each alternative swine manure management technology and for the baseline system. These parameters are passed to the land application model which calculates land application cost.

The acreage needed for each of four combinations is calculated by the land application model. The inputs to the model are the quantity of solids or slurry produced in pounds or gallons and its nutrient content. The model requires plant availability coefficients for each nutrient, which refers to the portion of the total nutrients that are plant available upon land application. The assumed plant availability coefficients are 70% for N, 80% for P, and 80% for K for soil incorporated slurries and 60% for N, 80% for P, and 80% for K for soil incorporated applications of separated solids.

B. Annual Opportunity Cost of Land

It is assumed that row-crops are the most profitable use of land in the area. No opportunity costs are assumed for applications of solids or slurries onto row-crops. Forage crops are assumed to generate no net return to the land so an annual opportunity cost of $60 per acre is applied. The $60 per acre charge is assumed to approximate the average annual return or rental rate that would be received above all other costs if the land was producing row crops. Revenue from forage crops is assumed to exactly offset all of the costs of producing and harvesting the forage crops with the exception of fertilizer costs and with the exception of opportunity costs of the land.

C. Annual Gross Application Cost

Unless there is continuous land application, farms have to store solids and slurries between applications. Where year-round land application is feasible and permitted, farms may use one or two spreaders to collect haul, and spread separated solids. Where less frequent land application is feasible, a storage facility is required. We assume a storage building is built with a capacity to hold one-quarter of the yearly solids production. The cost of building such a facility is about $2.10 / ft^3 of storage space (Soil and Water Conservation Commission). If X ft^3 of manure is produced each year, the storage building cost is (X/4)($2.10). This cost is annualized over 10 years. Land application costs depend on the number of acres the manure is spread over and the distance one must travel to the field. In the case of slurries, a steel tank is assumed installed to hold one quarter of yearly slurry production. Once the predicted volume of slurry that accumulates during the three month period is known, the least expensive tank offered by Engineered Storage Products Company that holds this volume is selected by the model.

To calculate the acres needed for nitrogen-based applications, the total nitrogen in the manure is multiplied by the nitrogen plant availability coefficient (e.g. 60 or 70%), and divided by the nitrogen fertilizer recommendation per acre given in Table C.2. To calculate acres under phosphorus-based applications, total phosphorus in manure is multiplied by the phosphorus plant availability coefficient (80%), and divided by the phosphorus fertilizer recommendation per acre.

Costs are calculated following a model (MDAC) developed by the University of Missouri-Columbia. Table C.3 describes the manure-spreading equipment used in these cost calculations. See Table C.4 for a summary of inputs and cost assumptions. This model assumes a six-ton spreader or 6,000 gallon slurry applicator with a swath of 12 feet that is being pulled by a 130 PTO horsepower tractor. The tractor is assumed to be used 200 hours / per year for other activities unrelated to manure applications.

Road travel time entails costs. The time spent traveling to a field equals the number of miles to the field, times two (must go back and forth), times the number of trips (total tons of manure divided by six tons per load), divided by ten (assuming the road tractor speed is ten miles / hour) (MDAC).

EQ(1) ROAD TRAVEL TIME IN HOURS = [(tons manure)(6 ton spreader)$^{-1}$](miles to field)(2)(10 miles / hour)$^{-1}$

where: [(tons manure)(6 ton spreader)$^{-1}$] = number of trips

The field travel time equals 0. 80 hours for every ten acres, and the field application time is 2.75 hours for every ten acres (MDAC). The loading time is assumed 20 minutes per trip. There is also a per-acre plowing cost (including tractor) to incorporate solids or slurries into soil of $5.97 (BUDSYS).

Total tractor cost is a function of annual hourly use of the tractor. As seen in Table C.3, it is assumed for this model that the tractor will be used for 200 hours that are unrelated to land application of solids/slurries. Total annual tractor use, therefore, is equal to:

EQ(2) TOTAL ANNUAL TRACTOR USE IN HOURS = 200 + road travel time + field travel time + field application time

Total annual tractor hours can then be used to calculate the salvage value of the tractor. Wherever hours is seen in the following equations, it is referring to the value calculated using EQ(2). Assuming an initial tractor price of \$63,000 (MDAC), the tractor's salvage value will equal:

EQ(3) SALVAGE VALUE OF TRACTOR = $63{,}000 * [0.8445 - (0.0012 * (\text{hours})^{0.6})]^{3.85}$

As annual tractor hours increase, salvage value of the tractor will decrease. Using the salvage value, ownership costs of the tractor can next be calculated. Ownership costs include depreciation, interest, and insurance. This model assumes a 10 year tractor life, an 8% annual interest rate, and a 1% annual insurance rate (MDAC).

EQ(4) PER HOUR DEPRECIATION COST OF TRACTOR = (63,000 – salvage value) / (tractor life * hours)

EQ(5) PER HOUR INTERST COST OF TRACTOR = [((63,000 + salvage value) / 2) * 0.08] / hours

EQ(6) PER HOUR INSURANCE COST OF TRACTOR = [((63,000 + salvage value) / 2) * 0.01] / hours

Summing EQ(4), EQ(5), and EQ(6) provides a total per hour tractor ownership cost. To find the annual tractor ownership cost associated with land application, this sum (ownership cost / hour) is multiplied by the total tractor hours used for land application (field travel time + road travel time + field application time).

There are also operating costs associated with using a tractor for land application of solids/slurries. In this model, labor, fuel, and repair are included as tractor operating costs. Labor cost is assumed to be \$13.40 / hour in this model (MDAC). The model assumes the cost of fuel to be \$1.50 / gallon, and the resulting hourly cost of fuel is equal to \$10.26 (assuming a 130 PTO horsepower tractor). Repair cost of the tractor is a function of annual hours, as determined in equation (2). Life of the tractor is again assumed to be 10 years (MDAC).

EQ(7) HOURLY REPAIR COST OF TRACTOR = $[441 * (((\text{tractor life} * \text{hours}) / 1000)^2)] / (\text{tractor life} * \text{hours})$

Hourly operating costs of using the tractor are equal to repair cost (as calculated in EQ(7)) + labor cost (\$13.40) + fuel cost (\$10.26). To find annual land application operating costs of the tractor, this sum is multiplied by the sum of road travel hours, field travel hours, and field application hours.

To summarize, total ownership costs of the tractor are equal to:

EQ(8) TRACTOR OWNERSHIP COSTS = [EQ(4) + EQ(5) + EQ(6)] * (road travel time + field travel time + field application time)

Total operating costs of the tractor are equal to:

EQ(9) TRACTOR OPERATING COSTS = [EQ(7) + \$13.40 + \$10.26] * (road travel time + field travel time + field application time)

There are also costs associated with using the spreader. It is assumed that the initial cost of the spreader is \$25,000 and that the spreader will need replaced after 10 years (MDAC). Unlike with the tractor, the spreader's salvage value is only a function of its initial price and life expectancy—not of its hourly use. Thus, the spreader will have a fixed salvage value and subsequently a fixed ownership cost component. Total annual ownership cost of the spreader is this model will equal \$3,333.45 (or a per-acre cost of \$3,333.45 / acres spread).

The spreader will also have a variable operating cost (for repairs) that is a function of acres. The operating cost of the spreader is defined as:

EQ(10) SPREADER OPERATING COST = [((((10 * acres) / 5818)$^{1.6}$) * 4000) / (10 * acres)] * acres

.The total annual cost of using the spreader is equal to \$3,333.45 + EQ(10).

The loading time is assumed 20 minutes per trip and is multiplied by the \$13.40 / hour labor rate (MDAC). The annual gross cost of applying solids/slurries to land is equal to tractor costs (variable ownership and operating costs) plus spreader costs (fixed ownership cost and variable operating cost) plus plowing costs (\$5.97 / acre) plus loading costs. Using the above equations, the annual gross land application cost of solids/slurries is equal to:

EQ(11) ANNUAL GROSS APPLICATION COST = EQ(8) + EQ(9) + \$3,333.45 + EQ(10) + (\$5.97 * acres) + ((number of trips * (20/60)) * \$13.40)

D. Annual Savings From Not Having To Buy Commercial Fertilizer

Plant available nutrients in the manure that would otherwise have to be purchased are subtracted from total costs. Table B.2 gives plant available nutrient requirements for each crop. The nutrient savings equal the minimum of the plant available nutrients applied per acre and nutrient recommendation. Prices are \$0.29 / lb N, \$0.57 / lb P, and \$0.25/ lb K (NCSUg).

E. Annual Additional Fertilizer Purchases

It is possible that application of solids or slurries from some technologies and application types will cause soil to be nutrient deficient. For example, if land applications are phosphorus-based the manure will be spread over more acres, causing the soil to remain nitrogen deficient for the crop and expected yield. Commercial nitrogen fertilizer must be added. The amount of nutrients to be purchased and applied equals:

$$(3) \qquad \text{Nutrients Purchased} = \min(0,N_F-N_A)*(\text{Price / lb N}) + \min(0,P_F-P_A)*(\text{Price / lb P}) + \min(0,K_F-K_A)*(\text{Price / lb K}),$$

where $F=(N_F, P_F, K_F)$ and $A=(N_A, P_A, K_A)$, vector F represents the recommended nutrient application rate of plant available nutrients and A represents the actual nutrient application rate of plant available nutrients. The cost of additional fertilizer purchased is only added for forages. Since row crops represent the most profitable use of land in the area and the crop would be grown even without swine farms, fertilizer purchases are not considered to be additional costs.

F. Annual Net Cost of Application of Solids and Slurries

The annual net cost of applications of solids or slurries onto *row crops* is the gross cost of irrigation (C) minus the savings from not having to buy commercial fertilizer (D). Neither returns to row-crops or commercial fertilizer purchase are included as they are included in the costs and returns to the crop in the absence of solids or slurry application. The annual net cost of the land application of solids or slurries onto *forages* is the opportunity cost of land (B) plus the gross cost of application (C) plus the cost of additional fertilizer purchased (E).

An example of an output from the application of solids model is provided in Table C.6.

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Table C.1: Four Combinations of Limiting Nutrient and Crop

Limiting Nutrient	*Crop* Forages[a]	Row-Crops[b]
Nitrogen-Based Application	Combination 1	Combination 3
Phosphorus-Based Application	Combination 2	Combination 4

a) The forage crop sprayfield is assumed to produce hybrid Bermuda grass hay in the summer and overseeded ryegrass hay in the winter.

b) The row-crop sprayfield is assumed to be apportioned equally to the average mix of soybeans, wheat, and corn in Sampson County. This mix is 20% corn, 21% wheat, and 59% soybeans (NASSb).

Table C.2: Annual Nutrient Recommendation for Each Combination (lbs. nutrient / acre)

Limiting Nutrient	*Crop* Forages[a]	Row-Crops[b]
Nitrogen-Based Application	290 lbs N	90 lbs N
Phosphorus-Based Application	35 lbs P	13 lbs P

Note: This is based on North Carolina crop conditions and crop mixes found in Sampson County, North Carolina (NASSb).

a) Assumes 5.5 tons / acre Bermuda grass yield and ryegrass yields are 2.5 tons / acre (NCSUe; Schwabe 2001; NCSUf). If applied according to agronomic rates, bermuda grass can take up 37.6 lbs N / ton, 3.82 lbs P / ton, and 28 lbs K / ton; ryegrass can take up 33.4 lbs N / ton, 5.44 lbs P / ton, and 28.40 lbs K / ton

b) Row-crops consist of 20% corn, 21% wheat, and 59% soybeans. Each crop's nutrient requirement is (1) corn; 0.9 lbs N / bu, 0.1548 lbs P / bu, and 0.22 lbs K / bu (2) wheat; 1.25 lbs N / bu, 0.3655 lbs P / bu, and 0.3154 lbs K / bu; and (3) soybeans; 3.75 lbs N / bu, 0.3784 lbs P / bu, and 1.13 lbs K / bu. Average yields in Sampson County are; corn 78 bu / acre, wheat 46 bu / acre, and soybeans 25 bu / acre (Shaffer).

Table C.3: Description of Equipment

	Tractor	Spreader
List price	$63,000	$25,000
Years to replace	10	10
Annual spreader use (acres)	-	Varies with field size
Annual tractor use other than manure application (hours)	200	-
Tractor PTO HP	130	-
Spreader capacity	-	Solids spreader: 6 tons Slurry spreader: 6000 gallons

Source: MDCA

Table C.4: Costs and Inputs

Fuel ($ / gallon)	$1.50
Labor ($ / hour)	$13.40
Interest (% / year)	8.00 %
Insurance (% / year)	1.00 %
Distance to field (miles)	4
Road speed (miles / hour)	10
Field speed (miles / hour)	5
Spreader capacity (tons for solids, 1,000 gallons for slurries)	6*
Swath width (feet)	12
Minimum Manure application rate (tons / acre for solids, 1,000 gallons / acre for slurries)	0.413**
Loading time per load (minutes / load)	20

* In tons for solids application and in 1,000 gallons for slurry application.

** In tons / acre for solids application and in 1,000 gallons / acre for slurry application.

Source: MDCA for data or Assumed for other parameters.

Table C.5: Cost of Application of Solids/Slurries (Sample Report)

A. Acres Required	Forages	Row Crops
If nitrogen-based application (acres)	11	35
If phosphorus-based application (acres)	30	80
B. Annual Opportunity Cost of Land ($60 Per acre)	**Forages**	**Row Crops**
If nitrogen-based application	$653	-
If phosphorus-based application	$1,797	-
C. Annual Gross Application Costs	**Forages**	**Row Crops**
If nitrogen-based application	$7,140	$7,524
If phosphorus-based application	$7,441	$8,218
D. Annual Savings From Not Having To Buy Commercial Fertilizer	**Forages**	**Row Crops**
If nitrogen-based application	-	$ (775)
If phosphorus-based application	-	$ (1,724)
E. Annual Additional Fertilizer Purchases	**Forages**	**Row Crops**
If nitrogen-based application	$65	-
If phosphorus-based application	$2,961	-
F. Annual Net Cost of Application of Solids	**Forages (= B + C + E)**	**Row Crops (= C + D)**
If nitrogen-based application	$7,858	$6,749
If phosphorus-based application	$12,199	$6,494

APPENDIX D
Sludge Removal Costs

Sludge is generally defined as a mixture of solid waste material and water resulting from the concentration of contaminants in water and wastewater treatment processes (Environmental Engineering Glossary). A wastewater treatment textbook refers to sludge as as liquid or semi-solid liquid that contains between 0.25% and 12% solids by weight (Metcalf and Eddy). In the manure management context, sludge is the term generally applied to the higher-solids material that collects in the bottom of anaerobic treatment lagoons. Characteristics of sludge in anaerobic lagoons on pig farms in North Carolina are described in Bicudo et al. (1999). Anaerobic lagoons built in accordance with NRCS specifications provide an allowance for sludge accumulation in the lagoon (sludge storage volume). NRCS conservation practice standard for waste treatment lagoons suggests that this sludge be removed every five years (NRCSb). Sludge is produced each year and its nutrient content can be estimated using the information in Table D.1.

Sludge is handled differently than lagoon effluent due to its higher concentration of solids. It should be noted that sludge removal is not a common practice in North Carolina, so the data on which to base volume and cost estimates are quite limited. Many of the cases of sludge removal involve the closure of lagoons that pre-date 1992 construction standards and recent feeding practices. The applicability of data from those cases to current lagoons is debatable. Although several methods of removal are used, the most common is to agitate the sludge so that it mixes with lagoon liquid and then to pump the sludge/water mixture out of the lagoon. Sludge typically cannot be applied to the farmer's sprayfield, as its nutrient content is higher than lagoon effluent and the sprayfield may not have been designed to accommodate additional nutrients. Sludge may be pumped or hauled to crops in fields other than the designated sprayfield. In older lagoons with deep, highly-concentrated sludge, agitation and pumping may not work, so more expensive removal methods are required.

Sludge removal is often contracted out and paid for on a per gallon of sludge/water mixture removed basis. Sources stated that for every gallon of accumulated sludge, two gallons of sludge/water mixture require removal (Edwards, Triple S Farms). Our discussions with industry experts indicate that the cost of sludge removal starts at $0.0075, is typically $0.015, and can be as high as $0.07 and that typical hauling distance is less than 10 miles (Elkin, Guthrie). Prices increase with increased travel distance between field and land application site and with more expensive removal methods. A charge of $0.0125 per gallon of sludge/water removed is assumed here. Multiplying the gallons of sludge by two and then by the per gallon charge yields the effective sludge removal price of $0.025 per gallon of sludge. At this time, no data were available to suggest how price per gallon removed might vary across farm sizes or types.

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Table D.1: Accumulation Rates and Nutrient Content of Sludge in Anaerobic Lagoons on Swine Farms in North Carolina

Farm Type	Sludge Accumulation	Nitrogen	Phosphorus	Potassium	COD	Solids Content
	gal / PU / year	lbs. /1,000 gallons				%
Farrow-Wean	156	34.19	33.30	5.30	0.53	10
Farrow-Feeder	188	27.80	27.45	3.94	0.39	10
Farrow-Finish	509	31.07	30.40	5.01	0.61	10
Wean-Feeder	11	34.19	33.30	5.30	0.53	10
Feeder-Finish	49	43.71	42.04	6.96	0.58	10

Note: Adapted from Bicudo et al. For more detail, see Tables 20-22 in Appendix A. Nutrient content of sludge for farrow-wean and wean-feeder operations is not available from Bicudo et al. The average of farrow-feeder, farrow-finish and feeder-finish operations was used to approximate values for farrow-wean and wean-feeder values

APPENDIX E
Steel Tank Sizing and Cost

Several technologies under evaluation use steel tanks for various treatment procedures (e.g., mixing, storing, nitrification, denitrification). There are seven tanks located on the Super Soil Systems site; five tanks located on the EKOKAN site; two located on the BEST sites; one located on the Constructed Wetlands site; and two on the AgriClean site. Approximately one-third of technologies under evaluation use steel tanks for treatment of swine waste. This document is intended to describe steel tanks available and outline issues associated with their sizing, pricing, and construction that we encountered in our modeling to extrapolate to typical North Carolina representative farm types and sizes (matrix of 21 sizes and types).

The tanks are manufactured by Engineered Storage Products Company based in DeKalb, IL and distributed locally by Brock Equipment Company based in Bailey, NC. Volume of tanks can range from approximately 4,000 gallons to well over a million gallons. Table E.1 shows sizes commonly installed by Brock Equipment Company in North Carolina. The tank typically consists of a concrete base and several rings mounted together. Each ring is assembled from several sheets depending on the diameter of the structure. A pricing schedule was provided to us by Engineered Storage Products Company and Brock Equipment Company. They provided us with a retail price structure as shown in table E.2.[6] The pricing table does not include state tax or any labor and/or materials for piping/plumbing work. Additional charges are assessed per tank penetration needed for pipes and equipment installation.

In our model, the volume of tank needed for the treatment process is calculated first and then matched to the least expensive tank size available above the required volume.[7] The technology providers were asked about scaling of equipment installed in tanks. If the equipment is scalable we calculate per gallon of tank charges based on tanks installed on experimental sites and multiply selected tank sizes by these per gallon charges to obtain approximate equipment cost. If the equipment does not need to be scaled, a standardized fixed charge per tank is used.

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[6] There are other variables that effect final price of a tank not captured in this scheme. Table E.2 represents charges that would likely occur on a typical North Carolina farm. Individual tank prices may vary due to variation in freight charges from DeKalb, Illinois, local labor rates, distance traveled FOB, site conditions, time of year, and costs for concrete, rebar, stone. Any and all work would be subject to standard terms and conditions of sale.

[7] Treatment volume is the total tank volume minus freeboard volume.

Table E.1: Volume of Engineered Storage Products Company Tanks

Number of sheets/ring	Diameter (ft.)	2 Rings	3 Rings	4 Rings	5 Rings	6 Rings
3	8	3,900	5,800			
4	11		10,400			
5	14		16,300	21,600	26,800	32,100
6	17		23,500	31,100	38,700	46,200
7	20	21,700	32,000	42,300	52,600	63,000
8	22		41,800	55,300	68,800	82,300
9	25		52,900	70,000	87,000	104,100
10	28		65,300	86,400	107,500	128,500
11	31		79,100	104,600	130,100	155,500
12	34		94,100	124,500	154,800	185,100
13	36		110,500	146,100	181,700	217,300
14	39		128,100	169,400	210,700	252,000
15	42		147,100	194,500	241,900	289,300
16	45		167,400	221,300		
17	48		188,900	249,800		
18	50	143,600	211,800	280,100		
19	53		236,000	312,100		
20	56		261,500	345,800		
21	59	195,400	288,300	381,200		
22	62		316,400	418,400	520,400	622,300
23	64		345,900	457,300		
24	67		376,600	498,000		
25	70	277,000	408,600	540,300		
26	73		442,000	584,400		
27	76		476,700	630,200		
28	78	347,400	512,600	677,800		
29	81		549,900	727,100	904,200	1,081,400

Table E.2: Cost of Engineered Storage Products Company Tanks

Number of sheets/ring	Diameter (ft.)	2 Rings	3 Rings	4 Rings	5 Rings	6 Rings
3	8	$6,563	$6,875			
4	11		$10,234			
5	14		$9,500	$12,585	$14,333	$17,895
6	17		$11,965	$15,203	$20,413	$24,078
7	20	$13,119	$16,406	$20,125	$25,440	$30,700
8	22		$19,255	$23,361	$29,014	$34,585
9	25		$22,183	$26,603	$32,141	$37,984
10	28		$25,179	$29,849	$35,268	$33,236
11	31		$28,236	$33,100	$38,395	$29,082
12	34		$31,187	$36,438	$41,522	$68,175
13	36		$34,045	$39,854	$44,649	$77,369
14	39		$36,822	$43,337	$47,776	$78,567
15	42		$39,198	$46,014	$54,031	$61,780
16	45		$42,677	$49,294		
17	48		$46,155	$52,574		
18	50	$42,683	$49,633	$55,854		
19	53		$51,842	$59,808		
20	56		$54,051	$63,763		
21	59	$46,308	$56,260	$67,718		
22	62		$64,433	$75,053	$88,342	$103,399
23	64		$67,119	$79,137		
24	67		$69,804	$83,221		
25	70	$58,382	$72,489	$87,305		
26	73		$75,807	$91,394		
27	76		$79,125	$95,482		
28	78	$67,377	$82,443	$99,571		
29	81		$91,408	$110,250	$135,506	$162,297

Figure E.1: Engineered Storage Products Company Tanks Installed on EKOKAN Site

Figure E.2: Engineered Storage Products Company Tanks Installed on Super Soil Systems Site

APPENDIX F
Earthen Containment Design and Costs

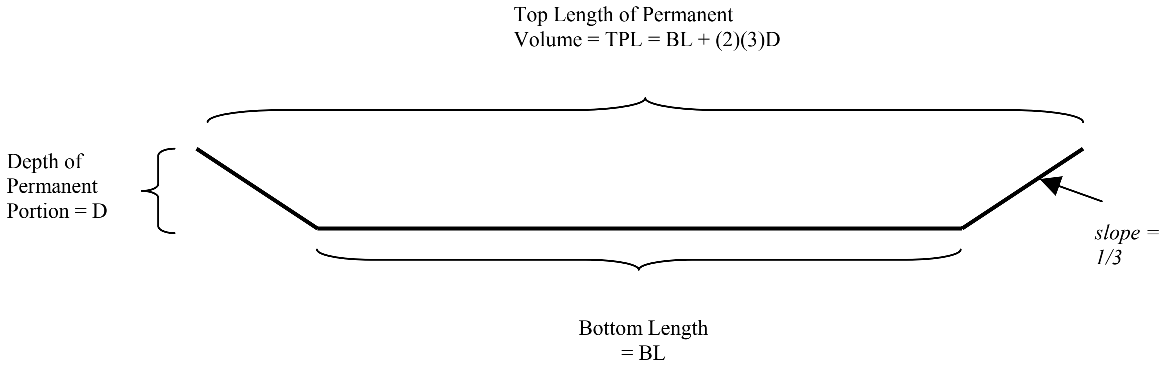
Earthen structures are widely used throughout the Agreement experiments. In most cases, they serve as storage ponds or treatment cells. The shape can vary from cube to pyramid to trapezoidal hexahedron with square or rectangular base to other less regular shapes. The minimum or maximum structure depth may be given by regulations governing its use or various treatment requirements. Design and cost of a few of the most common containments are described here as they are applied in the analyses. Considerable detail is provided in deriving the calculations used to find the dimensions of the structures. Professor F. Bailey Norwood, now of Oklahoma State University, derived these equations while he was working on this analysis. Towards the end of each section of this appendix, the cost calculations are provided.

Basins with Clay or Plastic Liner

If the sides of the structure are slanted, the side slope is often 1:3 (for every foot of depth, the top length increases by 3 feet on each side)[8] in eastern North Carolina soils. Two- and three-dimensional views of a trapezoidal basin with a square bottom that could serve as an anaerobic lagoon or anaerobic digester are depicted in Figure F.1.

Figure F.1: Illustration: Cross Section of a Trapezoidal Basin with Squared Bottom

Two-Dimensional View



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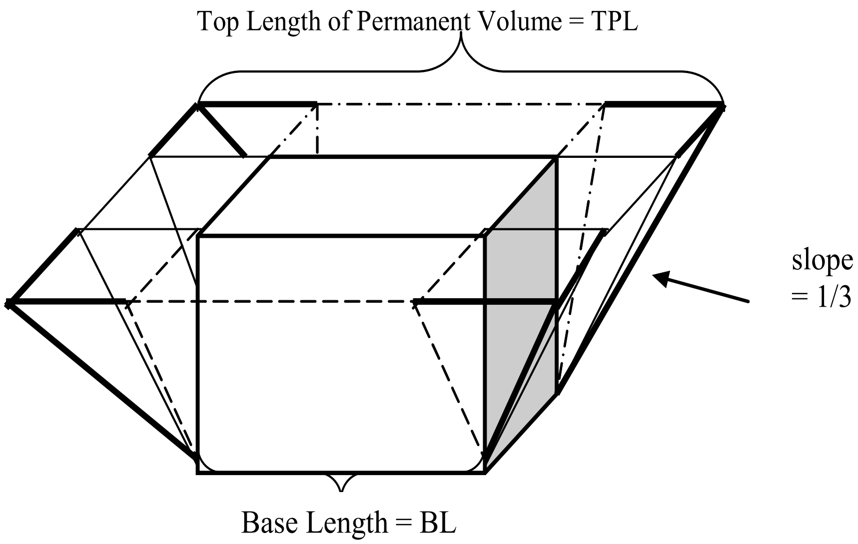
[8] NRCS specifications require this slope to be less than 1 (NRCSa).

Three-Dimensional View

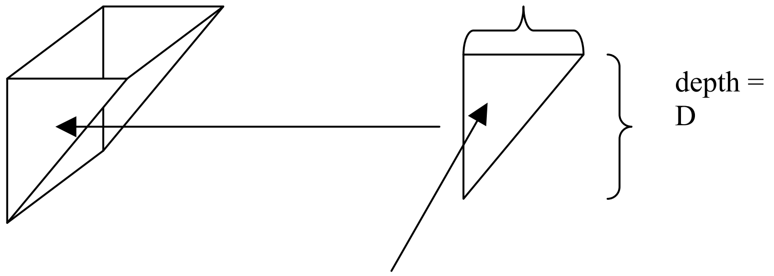


The design volume is determined by inflow into the structure and desired retention time. If we denote the permanent volume of a trapezoidal basin as PV, assume certain depth (D), and particular ratio of base length (BL) to base width (BW) of γ (γ = base length/base width), we can solve for the basin's dimensions. The volume of the three-dimensional rectangle shown above is simply the length*width*depth. Let the depth be denoted "D". The volume of the cube in the three-dimensional view in Figure F.1 is then $\{BL\}\{BW\}D = \gamma\{BW\}^2D$. Due to the fixed (1:3) side-slope, TPL always equals BL + (2)(3)(D).

Four triangular solid shapes (prisms) represent the sides and ends of the basin as depicted below:

Ends: base = ½*(TPL - BL) = 1/2 (BL + 2*3*D - BL) = 3D

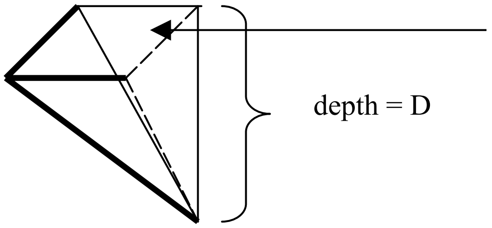
Sides: base = ½*(TPW - BW) = 1/2 (BW + 2*3*D - BW) = 3D



area = ½(base*depth) = ½{3D}{D} = $(3/2)D^2$

The volume of these triangular solids is then $½\{3D\}\{D\}\{BL\} = (3/2)\{D^2\}\{BL\} = (3/2)\{D^2\}\{\gamma BW\}$ for the length sides and $(3/2)\{D^2\}\{BW\}$ for the width sides (ends), making the total volume of all four three-dimensional triangles $(2)(3/2)\{D^2\}\{\gamma BW\}+(2)(3/2)\{D^2\}\{BW\} = (1+\gamma)(3)(D^2)(BW)$.

Then, there is a quarter pyramid in each corner. The volume of any pyramid is the depth of the pyramid times the area of the base of the pyramid divided by three.



Each side of the base has a length of ½(TPL - BL) = 3D.

Area of base is then $9D^2$.

The volume of each quarter pyramid is then $3D^3$ making the volume of all corners $12D^3$.

Combining the cube, four triangular solids, and four quarter pyramids yields equation (F.1) where total permanent volume (PV) is equal to:

$$\text{(F.1)} \quad PV = \gamma\{BW\}^2(D) + (1+\gamma)(3)\{D^2\}\{BW\} + (12)(D^3).$$

Solving for the positive quadratic roots of equation (F.1) in terms of base width (BW) yields equation (F.2):

$$\text{(F.2)} \quad BW = \frac{-(1+\gamma)(3)D^2 + \sqrt{(1+\gamma)^2(9)D^4 - (4)\gamma D\left[(12)D^3 - PV\right]}}{(2)\gamma D}$$

The top width equals TW = BW + (2)(3)(D) and the top length equals TL = BL + (2)(3)D = γ(BW) + (2)(3)D.

Example F.1 below shows the calculation for a 4,000 head capacity feeder-to-finish farm equipped with an anaerobic lagoon in a square shape with a 1:3 side slope.

Example F.1: Lagoon Dimensions before Including Precipitation Volume

Design volume of the lagoon calculated according to NRCS specifications is equal to 971,390 ft^3.

Assume depth of lagoon not including precipitation volume = 10 feet = D. Assume $\gamma = 1$ (square).

$$\text{Base Length (BL)} = \frac{-6(10)^2 + \sqrt{(36)(10)^4 - (4)10\left[(12)(10)^3 - 971{,}390\right]}}{(2)(10)} = 281\,\text{feet}$$

Top length of permanent portion = TPL = 281 + (2)(3)(10) = 341 feet.

If the basin is not covered, emergency storage volume is added to the top of the basin. Average annual rainfall minus average annual evaporation for NC is about 10 inches (Schwabe 2001), but specific data for each county is available. NRCS standards state an additional depth must be added to anaerobic lagoons in North Carolina to hold two 24-hour, 25-year rainfalls. One 24-hour, 25-year rainfall in eastern North Carolina is about 7 inches (Schwabe 2001). Standards also specify an additional depth (referred to as the freeboard) is needed for further insurance against spills. For open structures, a 1-foot freeboard is typically prescribed. Let the additional depth be denoted A. The new total volume of the basin (V) including additional volume is equal to:

(F.3) $V = \gamma\{BW\}^2(D+A) + (1+\gamma)(3)\{[D+A]^2\}\{BW\} + (12)([D+A]^3)$,

where the base width is solved for previously and the new top widths and lengths are:

(F.4) $TW = BW + (2)(3)(D+A)$ and $TL = \gamma\{BW\} + (2)(3)(D+A)$.

It is assumed that the structure has a perimeter around its edges that is planted in grass. For example, Roka assumes land within 20 feet of a lagoon is planted in grass and acts as a barrier between the lagoon and farm activities. This model assumes a barrier extending P feet from each side of the basin. The total area taken up by the basin (including the basin and grass perimeter) is (TL +2*P)(TW+2*P) and the area planted in grass is (TL +2*P)(TW+2*P) - (TL)(TW). Example F.2 shows calculations of additional volume and grass perimeter for the lagoon used in Example F.1.

Example F.2: Lagoon Dimensions after Including Precipitation Volume

Volume given in Example F.1is 971,390 ft^3
Assumed depth of permanent volume = D = 10 feet and $\gamma = 1$. A = 3 feet.
Grassed perimeter = P = 20 feet.

$$\text{Base Length (BL)} = \frac{-6(10)^2 + \sqrt{(36)(10)^4 - (4)10\left[(12)(10)^3 - 971{,}390\right]}}{(2)(10)} = 281\,\text{feet}$$

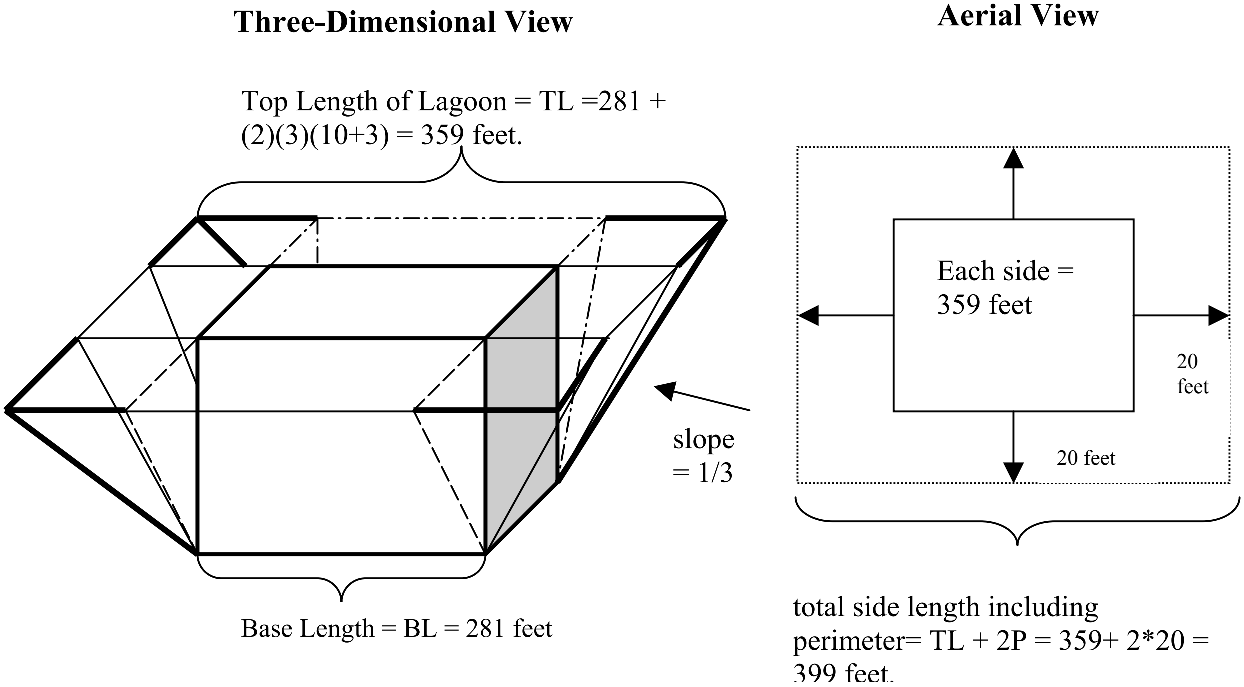
Top length of permanent portion = TPL = 281 + (2)(3)(10) = 341 feet

Lagoon Volume = $V = \gamma\{BW\}^2(D+A) + (1+\gamma)(3)\{[D+A]^2\}\{BW\} + (12)([D+A]^3) =$ 1,339,370 ft^3.

Top Length of Lagoon = TL = 281 + (2)(3)(10+3) = 359 feet.
Area used by lagoon = $(359 + 2*20)^2$ / (43,560 ft^2 /acre) = 3.66 acres.

Three-dimensional and aerial views of the lagoon calculated in Example 2 are shown in Figure F.2.

Figure F.2: Anaerobic Lagoon Dimensions Calculated in Example 2 (Three-Dimensional and Aeriel View)



Once the dimensions are calculated, construction cost requires only a few key cost assumptions. Excavation cost is usually specified in dollars per cubic yard. Our model uses equations described in Appendix A to calculate the excavation cost. It is typically in the $1.50-2.80 range depending on the size of the project. In Example F.2, the total lagoon volume is (1,339,370 ft^3 * (1/27) yd^3/ft^3) = 49,606 yd^3. When the earthen structures are built, it is unlikely that the total volume is excavated. Making use of existing land features and using excavated soil to create a berm reduces the total volume requiring excavation. Previous studies assumed 75% (Schwabe, Roka) or 80% (ED) required excavation. Others cite 70% as an upper bound (Simmons). In the case of box or cubed structures, it is assumed that 100% of volume is excavated. Multiplying basin volume by percent requiring excavation times the excavation cost per cubic yard yields the total excavation costs, as seen in Example F.3.

Example F.3: Excavation Cost Calculation

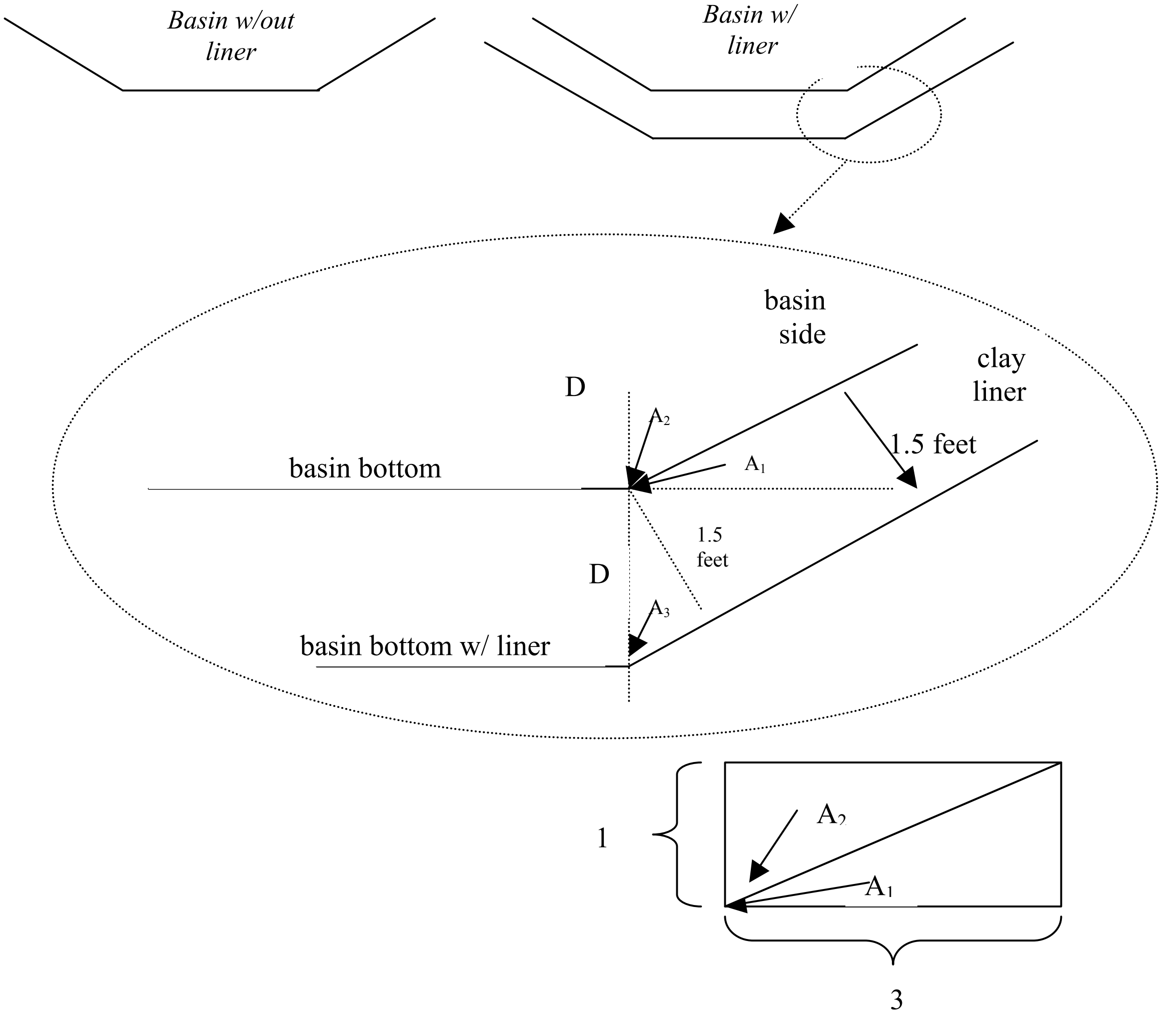
Example of Excavation Cost Calculation for a 4,000 Head Feeder-to-Finish Farm:
Assume 70% requires excavating at $2.45 per cubic yard

Excavation Costs = $(49{,}606\ yd^3)*(0.70)*(\$2.45/yd^3)$ = ***$85,074.29***

Clay Liner Costs

Anaerobic lagoons in eastern North Carolina generally must have a liner constructed. Typically, this liner is either compacted clay or plastic. Box or cube structures (such as lift stations, some solids settling basins, or smaller volume treatment cells) typically have concrete walls. Clay liners are constructed by surrounding the basin with a 1.5-foot thick compacted clay wall, where the 1.5 foot measurement is made perpendicular to the structure wall's slope. Because the measurement is perpendicular to the slope, the liner extends greater than 1.5 feet from the basin edge at the ground level. Clay liner costs are computed by calculating the volume of clay needed and multiplying it by a per-cubic-yard charge. Clay volume is estimated by first calculating the depth and top length of the earthen structure including the liner. Due to the angle in which the liner is measured, the basin depth increases more than 1.5 feet. The depth of the basin plus its liner can be seen using Figure F.3. Three angles, A_1, A_2, and A_3 are shown, where angles A_2 and A_3 are equal.

Figure F.3: Illustration: Basin with Clay Liner



Using the fact that the structure slope is 1/3, angle A_1 must equal $\sin^{-1}\left\{1/\sqrt{3^2+1^2}\right\} =$ 18.43 degrees, implying angle A_2 must equal 90 - 18.43 = 71.57 degrees. Finally, since sin(71.57) = 0.9487 must equal 1.5 feet/D_{LINER}, the maximum depth of the basin under the sides and ends including the clay liner equals the depth without the liner (denoted previously as D + A) plus D_{LINER} = 1.5/0.9487 = 1.58. If the total depth including the liner is D + A + 1.58, the length of each basin side at the surface including the clay liner is BL + (2)(3)(D + A + 1.58). We assume the base width, including the liner, remains the same. Thus, the total volume of the earthen structure, including the clay liner, is:

(F.5) $V_{w/liner} = \gamma\{BW\}^2(D+A+1.50) + (1+\gamma)(3)\{[D+A+1.58]^2\}\{BW\} + (12)([D+A+1.58]^3)$.

Finally, the volume of clay needed is the volume with liner minus volume without liner plus 15 % to account for compacting of clay (Elkin).

(F.6) $V_{liner} = (V_{w/liner} - V)(1.15)$

Multiplying this volume by the percentage of clay requiring importing and the per-cubic-yard charge yields the clay liner costs. A cited cost is \$4.40 / yd^3 (ED) but has recently trended toward the \$5.00-\$5.50 / yd^3 range (Elkin). Higher estimates are \$6.00 / yd^3 (NRCSb). Prices of liner material vary with local supply and demand conditions and the distance that the material must be transported. Since clay liner costs are almost as large as excavation costs, earthen structure construction costs will vary significantly across farms that do and do not require liner material to be imported. Where clay liner material becomes too expensive, a plastic liner may become the least cost alternative. See Example F.4 for a sample calculation of clay liner costs.

Example F.4: Clay Liner Cost Calculation

Assume a 4,000 Head Feeder-to-Finish Farm, $\gamma = 1$, 100 % of clay must be imported, @ \$5.50 per yd^3 charge.

Clay Liner Volume = $V_{w/liner} - V = \{[10 + 3 + 1.50]\{281\}^2 + [(6)(10 + 3 + 1.58)^2]\{281\} + (12)(10 + 3 + 1.58)^3 - \{[10 + 3]\{281\}^2 + [(6)(10 + 3)^2]\{281\} + (12)(10 + 3)^3\}/(27ft^3/yd^3) = 7{,}509\ yd^3$

Plastic Liner Costs

Plastic liner costs are specified on a per-square-foot basis, where the square feet refer to the basin's total ground area including base and sides. An extra 8 % should be included for anchoring (Elkin). All things considered, the total surface-ground area to be covered with a plastic liner is:

(F.7) Plastic Liner Area in square feet =

$$[\gamma(BW)^2 + (2+2\gamma)(BW)(10^{1/2})(D+A) + 12(10^{1/2})(D+A)^2](1.08)$$

The installation of the liner incurs several fees (Elkin). First is the fixed initialization fee that is approximated at $4,000 per farm. If more than one structure is being lined on the same farm, this cost can be divided evenly among both structures. This cost will also decrease if multiple farms in the same general location are being lined. Then, there is a $0.32 per square foot charge that can be multiplied by the plastic liner area. If pipes must penetrate the liner, there is a charge of $300 per penetration. In the case of an open structure, installation of a non-slip surface is also needed so that if someone falls into the structure they can climb out. The cost of installation of the non-slip surface is approximated at $1,380 per basin.

Example F.5 shows a plastic liner cost calculation using the same feeder-finish farm as in the previous examples. There are six barns on the farm.

Example F.5: Plastic Liner Cost Calculation

Assume a 4,000 Head Feeder-to-Finish Farm, and $\gamma = 1$. Six barns are predicted.

Initialization Fee = ***$4,000***
*Liner Fee = Lagoon Surface Area in ft^2*1.08*$0.32/$ft^2$ = (142,257) ($0.32) =* ***$45,522***
Penetration Fee = $300(number of barns=6 + 1) =* ***$2,100***
Non-slide surface = ***$1,380***

Total Cost = $4,000 + $45,522 + $2,100 + $1,380 = ***$53,002***

As Examples F.4 and F.5 illustrate, plastic liners are typically more expensive than clay liners. In some cases, however, the plastic liner may be preferred. The total cost of a lined earthen basin is calculated by summing all unit costs described above including one of the liners.

Basin with Concrete Walls

If the sides of the structure are not slanted, calculations of the structure's base width (BW) and length (BL) when a treatment depth (D), permanent volume (PV) and base width to base length ratio (γ) is known are relatively simple.

$$BL = \sqrt{\frac{PV}{\gamma D}}, \quad \text{(F.8)}$$

$$BW = \gamma BL. \quad \text{(F.9)}$$

If a freeboard of A feet is needed, equation (F.8) can be rewritten as:

(F.10) $BL = \sqrt{\dfrac{PV}{\gamma(D+A)}}$

The box or cube structures typically have concrete walls. If the thickness of the wall (TW) is known and the base width and length are calculated as in equation (F.8), (F.9), and (F.10), the total excavation volume is calculated as follows:

(F.11) Volume = (BW+2TW)(BL+2TW)(D+A),

and concrete volume needed is equal to

(F.12) Concrete Volume = Volume – BW(BL)(D+A).

Cost of Basin with Concrete Walls

Now that the volume of concrete can be derived, the cost of the concrete basin can be calculated. Using equations (F.8)-(F.17) and the unit costs found in Table F.1, a cost can be computed for constructing a basin with concrete walls.

Table F.1: Unit Prices for Concrete Basins

Unit	Price
Gravel fill (6")	\$9.56 / cubic yd.
Sand fill (4")	\$48.55 / cubic yd.
Wall form work	\$4.90 / square ft.
Wall reinforcement bars	\$0.45 / ft.
Ready mix concrete	\$63.70 / cubic yd.
Finishing slab (concrete)	\$0.33 / square ft.

In addition to the cost of the concrete, there are costs associated with the gravel and sand needed to build the basin. The total volume of necessary gravel and sand equals the volume underneath the settling basin (including the walls) and assumes a depth for the layers of gravel and sand. The layer of gravel is assumed to be six inches deep, while the layer of sand is assumed to be four inches deep. The volume of gravel needed, in cubic yards, is equal to:

(F.13) Volume of Gravel = $\{(BW + 2TW)(BL + 2TW)(0.5)\}*(1/27)yd^3$

The volume of sand needed, in cubic yards, is equal to:

(F.14) Volume of Sand = $\{(BW + 2TW)(BL + 2TW)(0.33)\}*(1/27)yd^3$

Additional costs of the concrete basin include wall form costs, wall reinforcement costs, and finishing slab costs. Wall form costs apply to the entire surface area of the basin's four walls. The total area for which wall form costs can be applied is:

(F.15) Area of wall forms (surface area of 4 walls) = 4 walls * (BW)(D+A)

Reinforcement bars are assumed to be spaced every 12 inches along the entire length and width of the basin. This includes the four walls and the floor of the basin. Thus, to calculate the total length of reinforcement bars, the following equation is used:

(F.16) Total length of reinforcement bars = 2 bars/ft. * {(BW+2TW)(BL+2TW) + (4)(BW)(D+A)}

Finally, the basin's concrete floor must be finished. The addition of this finishing slab is only applicable to the floor of the concrete basin—not the walls. Total area needing finished is:

(F.17) Area to be finished (surface area of the floor) = (BW+2TW)(BL+2TW)

In summation, the total cost of a basin with concrete walls is found by totaling the costs of the six inputs described above (concrete, gravel, sand, wall form work, reinforcement bars, and finishing slab). Example F.6 shows the total cost of constructing a 15,000 cubic foot basin with a depth of 6 feet and a 1-foot freeboard. Walls are 6 inches thick in this example and γ is equal to 1.

Example F.6: Basin with Concrete Walls Cost Calculation

Assume a permanent volume (PV) of 15,000 cubic feet and a treatment depth (D) of 6 feet. Also assume a freeboard (A) of 1 foot, a wall thickness (TW) of 0.5 feet, and that $\gamma = 1$.

$BW = \{(15{,}000)/(6^*\gamma)\}^{0.5} = 46.29$ ft.
$BL = \gamma\,(46.29) = 46.29$ ft.
Volume of basin = (46.29 + 2(0.5))(46.29 + 2(0.5))(6+1) = 15,654.41 ft.^{3}
Volume of concrete = 15,654.41 – (46.29)(46.29)(6+1) = 655.06 ft.^{3} = 24.26 yd.^{3}
*Cost of concrete = 24.26 * $63.70 = **$1,545.46***
Volume of gravel = {(46.29 + 1)(46.29 + 1)(0.5)}(1/27) = 41.41 yd.^{3}*
Volume of sand = {(46.29 + 1)(46.29 + 1)(0.33)}(1/27) = 27.61 yd.^{3}*
*Cost of gravel = 41.41 * $9.56 = **$395.88***
*Cost of sand = 27.61 * $48.55 = **$1,340.47***
*Cost of wall form work = (4)(46.29)(7) * $4.90 = **$6,350.99***
Cost of reinforcement bars = [(2){(46.29+1)(46.29+1) + (4)(46.29)(7)}] * $0.45 = **$3,179.22***
*Cost of finishing slab = (46.29+1)(46.29+1) * $0.33 = **$737.99***

*Total cost of basin with concrete walls = $1,545.46 + $395.88 + $1,340.47 + $6,350.99 + $3,179.22 + $737.99= **$13,550.01***

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Appendix G
Excess Water Management

The default assumption in the model is that the only cost associated with excess liquid management for the representative farms is the cost of pumping the additional precipitation out of the lagoon and onto the sprayfields. This cost is captured by the average cost of irrigation which includes the average precipitation accumulation over wet years and dry years. Some farms have experienced much higher costs of managing excess liquid accumulation as described below. These additional costs contribute to the range of possible costs for the representative farms. The avoidance of these costs can be included in the range of possible benefits that might accrue to each alternative manure management system.

Adverse weather poses challenges for operators of lagoon-sprayfield systems because excess precipitation causes lagoon levels to increase and recent regulations prohibit irrigation of swine manure effluent onto sprayfields that may have saturated soil. If wet conditions last for extended periods of time, lagoon levels may reach emergency (storm) storage and structural freeboard levels which typically require an emergency action. In some cases, farmers expend substantial resources for emergency effluent disposal to avoid stiff penalties levied by the Division of Water Quality (DWQ). The compliance with regulations can be difficult due to uncertainty about future weather conditions.[9] For instance, spring 2003 was one of the wettest springs since the National Weather Service started recording data over 100 years ago. It followed one of the driest recorded springs and summers in 2002, making it difficult to predict in the beginning of 2003 that land application of effluent would be challenging. This appendix describes the modeled impact of alternative swine manure management technologies on swine liquid effluent disposal. The discussion focuses on reduction of daily liquid accumulation rates (e.g. by application of effluent to an indoor environment (greenhouse)) and on increased temporary storage capacity that might be created by alternative technology installations (e.g. the addition of a separate anaerobic digester that releases previous lagoon treatment capacity to become additional temporary storage).

NRCS Guidance on Design and Operation of Anaerobic Lagoons and Sprayfields

The North Carolina Natural Resources Conservation Service (NRCS) and the NC Division of Water Quality (DWQ) set and regulate the state's standards for design and operation of manure treatment lagoons. The lagoon must meet a minimum depth requirement and is otherwise sized by the number and type of pigs that it will serve. Six components typically comprise the volume of a lagoon and, listed from bottom to top of the structure, they are:

1) Sludge storage volume
2) Minimum treatment volume
3) Temporary liquid storage volume
4) Emergency storage for chronic rainfall
5) Emergency precipitation storage for a 25-year, 24-hour storm event

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[9] For an example of precipitation recorded at a weather station in Duplin County, see Figure G.1

6) Structural freeboard (1-foot minimum)

The lagoon cannot be pumped below its design treatment volume, as this is the minimum depth necessary for anaerobic treatment to occur. NRCS recommends that the temporary storage volume be sufficient to handle 180 days of expected liquid accumulation. North Carolina's average annual rainfall less its average annual evaporation is about 10 inches. Moreover, eastern North Carolina's 25-year, 24-hour storm precipitation level is seven inches (Chvosta, et. al). In general, it is recommended that a lagoon have up to 36 inches of additional depth—24 inches of emergency storage plus 12 inches of structural freeboard (Schwabe).

Irrigation is also regulated, and spraying on saturated (or nearly saturated) fields is forbidden. Saturation level is determined by the soil type and its ability to drain water after rainfall or spraying. Typically, farmers irrigate when the plant available water (PAW) is depleted by 50 percent. Farmers are allowed to apply effluent when the PAW drops below a threshold that is suitable for irrigation, there is a crop growing that allows irrigation, and the lagoon level exceeds the minimum treatment volume (NCCES). If these three conditions are not simultaneously met on a given day, the farmer must wait before applying lagoon effluent to the crops (Chvosta, et. al).

When the lagoon liquid level rises into the emergency storage portion of the structure, lagoon operators are required to inform DWQ of the elevated level. No immediate action is necessary, however, as the owner of the lagoon is given 30 days to lower the level below the emergency storage threshold. Immediate action must be taken when the lagoon liquid level reaches the structural freeboard. The liquid level must be lowered under the freeboard portion of the lagoon within three days of the event to avoid DWQ's stiff penalties. In such emergency situations, the liquid level can be lowered by hauling lagoon liquid to other fields that are not saturated. In extreme conditions, the farm can be depopulated in order to stop the daily accumulation of manure and spilled water in the lagoon. These forms of emergency excess water management are generally very costly. Farmers will minimize costs of manure management subject to a set of constraints (including many of those listed above). The total annual costs of manure management are computed by summing three components of manure management—1.) annualized lagoon cost, 2.) irrigation cost, and 3.) cost of removing excess lagoon liquid (Chvosta, et. al).

Alternative Technologies' Potential to Reduce Excess Liquid Management Costs

Some of the technologies evaluated under the Agreement show potential to lower the cost associated with emergency liquid management. For example, greenhouses can provide an outlet for manure effluent when land application would not be allowed (such as when fields are saturated). This outlet for effluent is valued as the avoided costs of emergency liquid removal when lagoons' emergency storage capacity is filled, effluent cannot be land applied, and liquid continues to accumulate. Variables entering the calculation of this value include the expected number of days per year that the emergency conditions above exist, the volume of liquid accumulating in the lagoon each day, and the marginal price per gallon of removing this volume of liquid. Note that the marginal price per gallon of emergency liquid removal is the actual price reduced by the cost of irrigation (already listed elsewhere in the model as a cost saving).

The addition of a greenhouse to an existing farm affects the first two variables listed above. First, if the original temporary and emergency storage capacity, spray field area, and irrigation capacity are maintained, then the additional removal of 1,700 gallons per day would reduce the expected number of days per year that emergency liquid removal would be required. In effect, the additional removal of 1,700 gallons per day would have the same effect as increasing 180 day temporary storage capacity by (180 x 1,700) 306,000 gallons or about 15 days of effluent accumulation on the Barham farm. In the case of the Barham farm, it is unlikely that storage capacity would ever be filled since the addition of the covered in-ground digester added 6.5 million gallons of storage capacity.

The second variable affected by the addition of a greenhouse is the volume of liquid accumulating in the lagoon each day when the lagoon is already filled to capacity. On the Barham farm, if lagoons ever were filled to capacity, there would be 1,700 gallons per day less to be removed by emergency means. The additional liquid removal capacity of the greenhouse is relatively small. For example, assume that a storm brought 5 inches of rain. According to NRCS design specifications, a 13-foot deep anaerobic lagoon for a 4,000 sow farrow-wean operation would have a surface area of 269,550 square feet. In a five-inch storm, this area would collect approximately 840,097 gallons of rain water which would take about 494 days to dispose in Mr. Barham's current greenhouses.

It is possible that excess precipitation could be dealt with in other ways that are less costly and more effective. As described previously, installing the in-ground digester may have significantly reduced emergency liquid removal requirements by increasing the former lagoon storage volume. NRCS standards require farmers to maintain a minimum depth for anaerobic treatment in the lagoon year round. This requirement prevents farmers from pumping lagoons below the treatment volume when the weather is favorable. When the in-ground digester is added to an existing farm, the original required treatment volume is converted to temporary storage volume because the storage pond no longer operates as an anaerobic lagoon. This conversion may provide several feet of additional storage capacity so the risk of costly emergency liquid removal is significantly reduced. No net rainfall accumulation occurs in the in-ground digester since rainfall accumulation is pumped off of the impermeable cover using a small pump. In the simulation presented in Figure G.2, treatment volume that is no longer needed because the earthen cell does not serve as an anaerobic lagoon was converted into additional storage. The storage volume was effectively increased by 8,680,000 gallons because the farmer does not have to maintain the treatment volume at the lagoon to maintain anaerobic activity.[10] This scenario is presented by the black line (Lagoon Accumulation with Digester) in Figure G.2. If the greenhouse was added to this scenario (Lagoon Accumulation with Digester and Greenhouse), its benefit would only be marginal. The original setting on Barham Farm is represented by the line labeled Lagoon Accumulation without Digester. It is noticeable that under our "without digester" scenario, the lagoon

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[3] We assume that the farmer can pump the effluent down to the sludge volume using the lagoon treatment volume as an additional storage. This is effectively increasing his storage by almost nine million gallons.

level would regularly have risen into the storm volume and in some years nearly have risen into the structural freeboard volume. This problem was completely eliminated by the digester installation and the release of an additional nine million gallons of storage. The lagoon level does not even exceed the minimum pumping volume for the original lagoon (Figure G.2). Note that the irrigation management simulated here is that the entire sprayfield area receives the maximum allowable application each time the conditions are met for permitted irrigation. It is also notable that the model used for this simulation may not accurately reflect sprayfield moisture conditions experienced by eastern North Carolina farmers (Chvosta, et al.). These limitations do not detract from the overall finding that additional storage released by alternative treatment systems can greatly reduce the risk of excess liquid management costs.

References

Chvosta, Jan, Kelly Zering, and Bailey Norwood. "Blame It On the Weather: Cost and Design of Manure Management Under Extreme Weather Conditions on North Carolina Swine Farms." selected paper abstract, Journal of Agricultural and Applied Economics, 36(2):524. August, 2004. Presented at the SAEA Meetings. Tulsa. February, 2004.

(NCCES) North Carolina Cooperative Extension Service. "Certification Training for Operators of Animal Waste Management Systems." 2003.

(NRCSa) National Resource Conservation Service. Natural Resource Conservation Service Practice Standard. Waste Utilization (Acre) Code 633. Made available by North Carolina National Resource Conservation Engineer Henry Gibson.

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Figure G.1: Duplin County Monitoring Station Monthly Precipitation 1993 - 2003

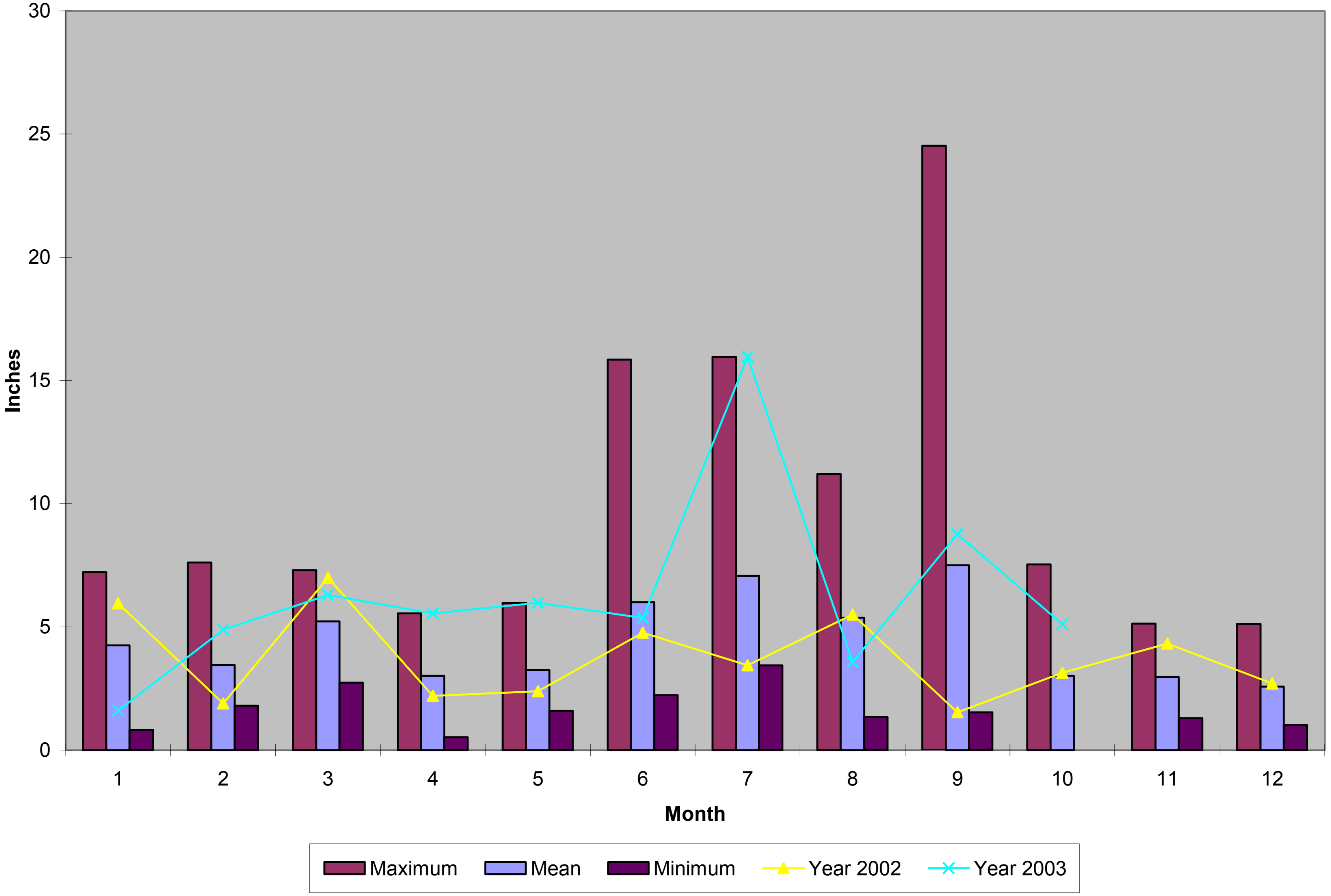
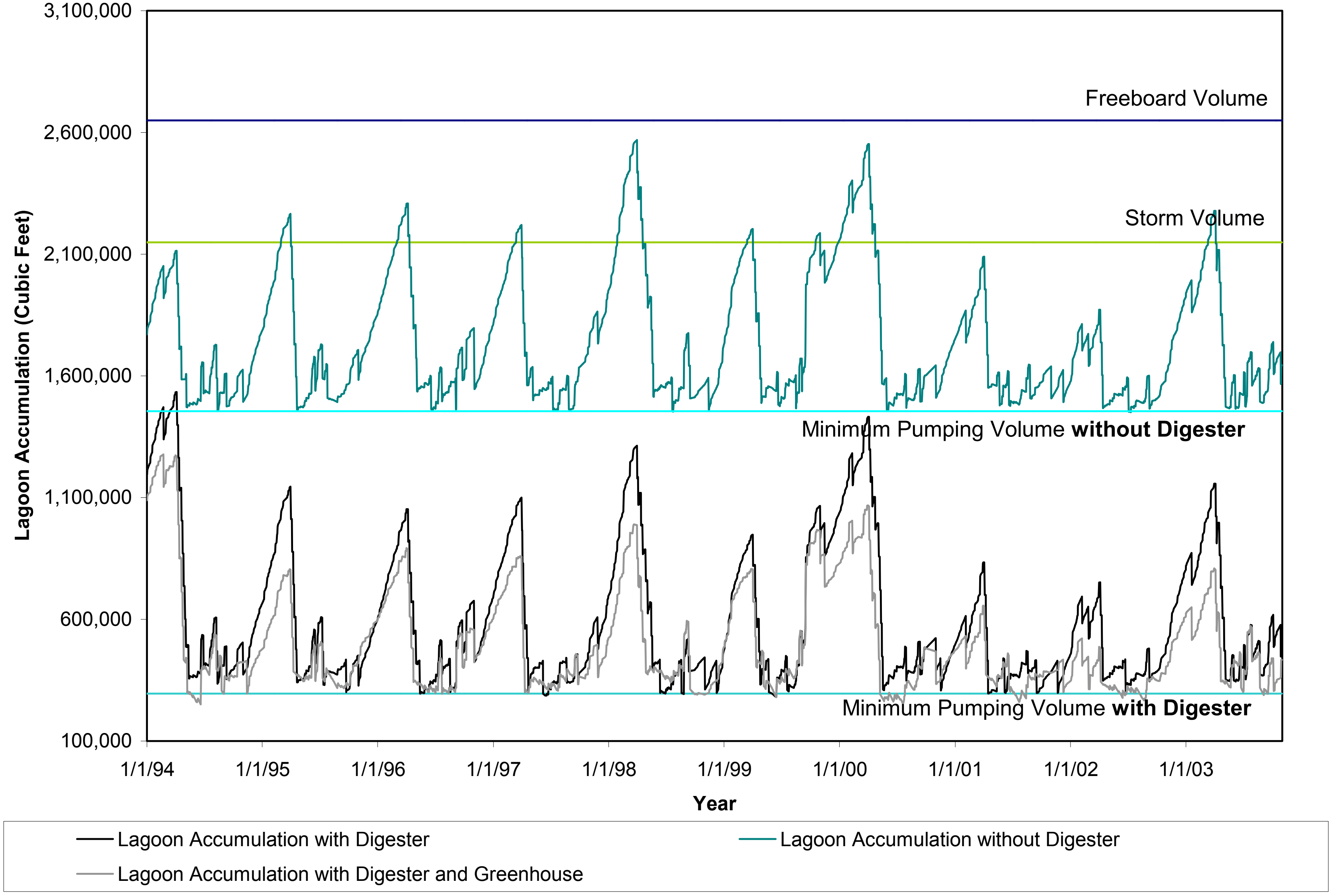


Figure G.2: Simulated Lagoon Liquid Volume with and without Digester and Greenhouse



APPENDIX H
Property Taxes

Each of North Carolina's 100 counties applies a different tax to property. As defined by North Carolina's property tax system, property can consist of real property, personal property, or motor vehicles. Real property includes land and buildings, while personal property includes all property that is tangible and not permanently affixed to real property. Property taxes rates are the same county-wide for the three types of property.

The tax table that lists the property tax rates for each county is entitled "Property Tax Rates and Latest Year of Revaluation for North Carolina Counties and Municipalities" and is available at:

http://www.dor.state.nc.us/publications/propertyrates.html.

The assumed property tax rate in our model is the average of property tax rates for Duplin and Sampson Counties—North Carolina's top hog-producing areas. It is assumed that farms are in rural regions of these counties and not within city or town limits. As such, the county-wide property tax rates can be applied with no additional taxes for cities or towns. For Duplin County, the county-wide property tax rate is 0.745%. For Sampson County, the county-wide property tax rate is 0.675%. The number used in the model (averaging the two counties) will be 0.71 %. See Tables H.1 and H.2 for a detailed summary of property tax rates in these two counties. The tax rate is applied to one half of total construction costs to assess annual taxes owed.

Table H.1: Duplin County* Property Tax Schedule

Municipality	County-wide tax	City or town tax	Other taxes**	Total
Beulaville	0.745	0.490	0.000	1.235
Calypso	0.745	0.470	0.000	1.215
Faison	0.745	0.530	0.000	1.275
Greenevers	0.745	0.250	0.000	0.995
Harrells	0.745	0.130	0.060	0.935
Kenansville	0.745	0.470	0.000	1.215
Magnolia	0.745	0.600	0.000	1.345
Mount Olive	0.745	0.590	0.000	1.335
Rose Hill	0.745	0.665	0.000	1.410
Teachey	0.745	0.450	0.000	1.195
Wallace	0.745	0.660	0.000	1.405
Warsaw	0.745	0.565	0.000	1.310

* Duplin County was last revaluated in 2001.

** Other taxes include property taxes from other districts and special school districts.

Table H.2: Sampson County* Property Tax Schedule

Municipality	County-wide tax	City or town tax	Other taxes**	Total
Autryville	0.675	0.450	0.000	1.125
Clinton	0.675	0.410	0.130	1.215
Faison	0.675	0.530	0.000	1.205
Garland	0.675	0.600	0.000	1.275
Harrells	0.675	0.130	0.060	0.865
Newton Grove	0.675	0.360	0.000	1.035
Roseboro	0.675	0.650	0.000	1.325
Salemburg	0.675	0.320	0.000	0.995
Turkey	0.675	0.250	0.040	0.965

* Sampson County was last revaluated in 2003.

** Other taxes include property taxes from other districts and special school districts.

APPENDIX I
Annualized Construction Cost

Construction costs refer here to infrequent costs; costs that pay for services that last more than one year. They include "direct" construction costs (materials and services at the site) and indirect construction costs (mobilization, overhead, contractor and engineering fees, etc.). Indirect costs are listed in Table I.1. Costs for services that last less than a year are termed operating costs and are not the subject of this section. The method for calculating construction costs in annual terms is discussed here. **All costs and returns are expressed in current (2004) dollars and amortized over their expected economic life (subject to the terms of the agreement) to obtain an annualized value in current dollars**.

Costs (investments) of goods and services that last more than one year are expressed on an annual basis to allow calculation of the annualized total cost estimate required by the agreement.. The most common method of annualizing such costs is to assume the farmer "pays off" (amortizes) the cost in equal yearly payments for the input's service life (much as a homeowner would "pay off" a mortgage for the entire purchase cost of their home). If "A" is the annual payment, the interest rate is r, the initial cost of the input is "C", and the life of the input is T, then the annual payment is calculated as:

(1) $A = [r/\{1-(1+r)^{-T}\}]C.$

The term "$[r/\{1-(1+r)^{-T}\}]$" is referred to as the capital recovery factor (CRF) and since it is a function of the service life and interest rate only, is denoted CRF(r,T). The annualized cost of any input can be calculated by multiplying it by the capital recovery factor.

Under the terms of the Agreements, technologies are to be modeled with a **10-year maximum economic life expectancy**. As such, all cost models here assume a maximum technology life of 10 years unless specified otherwise.

The **salvage value** minus the **closure and removal costs** is assumed to be zero for all inputs unless otherwise stated. The portion of the initial cost of an input to be amortized can be reduced by salvage value and increased by removal or closure costs. For example, suppose an easily portable device such as a diesel engine might still have value (above relocation costs) at the end of a 10 year period. The net salvage value expected to be received 10 years in the future would be discounted to a present value. The present value of the expected net salvage value of the engine could be deducted from the initial cost of the engine to arrive at an amount to be amortized over 10 years. Similarly, suppose a permanent structure must be closed and removed at the end of its useful life. The net cost of closure and removal 10 years in the future could be discounted to a present value. The present value of the expected closure and removal cost would be added to the initial cost to arrive at the amount to be amortized over the 10 year period. We acquired very little or no data about expected salvage value or closure and removal costs for most inputs in the analyses. In some cases, closure and removal costs are highly contingent on state regulations that may not exist currently for many of the inputs being considered. Therefore our default assumption is that salvage value minus closure and removal costs equals zero.

Some **costs occur periodically** within the 10 year period. For instance, it may be necessary to replace a pump every three years. The cost of the pump is amortized over its 3 year life and the resulting annualized cost is reported. The cost of a replacement pump after three years is assumed to be equal to the original pump price and is assumed to be identically amortized so that the annualized cost remains constant over the 10 year life of the project.

Indirect costs such as mobilization and bonds are accounted for as a fixed percentage (6%) of direct construction costs (CA, WB). Total capital costs can then be calculated by summing direct construction costs, mobilization costs, and bonds costs. Based on these total capital costs, one can calculate overhead construction costs. As seen in Table I.1, engineering design services, construction services and startup, contractor's overhead and profit, taxes and insurance, and contingencies are all fixed percentages of total capital costs. When aggregated, these items comprise the total overhead construction cost (35% of total capital costs). A question remains regarding to whom these indirect costs accrue. **Our default assumption is that the farm owner incurs the indirect costs unless otherwise stated**. In the past, NRCS has provided some engineering design services through government funded programs. Furthermore, some technology providers propose charging royalties and fees and may absorb some direct and indirect costs as part of the service they provide for those fees.

References

(CA) Cavanaugh and Associates. Personal communication with and/or data submitted by Gus Simmons or Jason Wilson. 2002-2003.

(WB) Wells Brothers Construction. Personal Communications. 2004.

Table I.1: Indirect Construction Costs

Input	Point Estimate Price / Unit	Unit
Mobilization	3.00 %	% of direct construction costs
Bonds	3.00 %	% of direct construction costs
Mobilization and bonds costs	6.00 %	% of direct construction costs
Total capital costs = construction costs + mobilization costs + bonds costs		
Engineering design services	11.00 %	% of total capital costs
Construction services and startup	0.00 %	% of total capital costs
Contractor’s overhead and profit	12.50 %	% of total capital costs
Taxes and insurance	1.50 %	% of total capital cost
Contingencies	10.00 %	% of total capital costs
Total overhead	**35.00 %**	% of total capital costs
Mobilization, bonds, and total overhead cost	**43.10 %**	% of direct construction cost

Source: CA