CBP/TRS-330-21

Estimates of Nutrient Loads from Animal Mortalities and Reductions Associated with Mortality Disposal Methods and Best Management Practices (BMPs) in the Chesapeake Bay Watershed

DRAFT for partnership feedback: July 27, 2021

Chesapeake Bay Program
Science. Restoration. Partnership.

Prepared for

Chesapeake Bay Program
1750 Forest Drive
Annapolis, MD 21403

Prepared by

Animal Mortality Management BMP Expert Panel:

Douglas W. Hamilton, PhD., P.E., Oklahoma State University (Panel Chair)
Thomas M. Bass, Montana State University
Amanda Gumbert, PhD., University of Kentucky
Ernest Hovingh, PhD., Pennsylvania State University
Mark Hutchinson, University of Maine
Teng Teeh Lim, PhD, P.E., University of Missouri
Sandra Means, P.E., USDA NRCS, East National Technology Support Center (Retired June 2021)
George “Bud” Malone, Malone Poultry Consulting; University of Delaware (retired)

With:
Jeremy Hanson, Virginia Tech and the Chesapeake Bay Program Office (Panel Coordinator)
Brian Benham, PhD, Virginia Tech
Loretta Collins, University of Maryland
Mark Dubin, University of Maryland
Jeff Sweeney, EPA Chesapeake Bay Program
Mark Zolandz, EPA Region 3

Support Provided by

VirginiaTech
Invent the Future

EPA Grant No. CB96326201

Acknowledgements
The panel acknowledges, with thanks, the contributions of those who provided input or assistance to the panelists or support personnel. This includes but is not limited to: the generous farmers who welcomed the panelists for tours in June 2019, who are not named here to respect their privacy; Gary Felton (UMD); Robb Meinen (PSU); Chris Brosch and Clint Gill (DE Dept. of Ag); Victor Clark (Farm Freezers & Greener Solutions).

Suggested Citation: Hamilton, D., Bass, T.M., Gumbert, A., Hovingh, E., Hutchinson, M., Lim, T.-T., Means, S., and G. Malone. (2021). Estimates of nutrient loads from animal mortalities and reductions associated with mortality disposal methods and Best Management Practices (BMPs) in the Chesapeake Bay Watershed. Edited by J. Hanson, A. Gumbert & D. Hamilton. Approved by the CBP WQGIT on MONTH DD, YYYY. Available at <insert URL>

Cover Image: Amanda Gumbert

Executive Summary

This Expert Panel (panel) was charged with defining and configuring the Animal Mortality Management Best Management Practice (BMP) for use in the Phase 6.0 Chesapeake Bay Watershed Model (model). Specifically, the panel was charged with defining the load reduction efficiencies for Nitrogen (N) and Phosphorus (P) for selected mortality management methods and determining how the practice can be represented in the model.

The panel chose to approach this charge by breaking the problem into two parts:

I. Determine the mass of mortalities, N, and P per Animal Unit (AU, 1 AU = 1,000 pounds liveweight) per year produced by the most important animal agricultural practices in the Chesapeake Bay Watershed.

II. Determine the N and P reduction efficiencies of selected mortality disposal methods, and categorize the fractional masses of carcass nutrients removed from agricultural systems, recycled by producers in a Nutrient Management Plan (NMP), volatilized to the atmosphere, and leaving the practice by all other pathways (leaching, overland flow, etc.).

This division of investigation is reflected in the two parts of the Expert Panel Report: Part I: Routine Mortality Production, and Part II: Disposal Methods.

In addition to the charge given by the Ag Working Group, the panel also investigated ancillary benefits of mortality disposal methods, specifically biosecurity and reduction of nuisance conditions.

Part I: Routine Mortality Production

The panel focused on the routine day-to-day losses encountered in agricultural systems. It did not focus on mass mortalities due to natural disasters, Foreign Animal Disease (FAD), or other catastrophic events. Agricultural systems considered were poultry (broilers, layers, turkeys), cattle (dairy, beef cow-calf, cattle on feed), swine (hogs and pigs for breeding, hogs for slaughter), and Equidae (horses, donkeys, mules). Annual mass of N and P contained in mortalities estimated by the panel for all animal groups are given in Table ES.1.

Procedures Used to Estimate Annual Mass of Nutrients Produced

In a departure from previous methods of determining mortality losses, which have focused on average death loss times average animal size to determine mass of mortalities produced, the panel examined the production and housing systems used in the watershed in depth in order to estimate the mass of mortalities produced per AU in the production unit.

In the case of broilers, the panel estimated the mass of N and P contained in mortalities during the grow-out of 1,000 birds by combining the effect of several non-linear phenomena: the death loss pattern through the length of broiler grow-out, the liveweight of birds at each in the point growth pattern of broilers, and the nutrient concentration of carcasses throughout the bird's life. The mass of nutrients contained in carcasses was then normalized by dividing by live mass of birds at the end of the grow-out period.

Table ES.1. Estimated weight of mortality nutrients produced by farms on a per AU (1,000 pounds liveweight) basis.

Type of Farm	Characteristic Animal(s)	Weight of Mortality Nutrients Produced per Farm (Lbs. AU^{-1} $year^{-1}$)	
		TN	TP
Poultry			
Broiler	6 lb. Market Birds	1.8	0.25
Layer	Laying Hens	2.2	0.40
Tom Turkey	48 lb. Market Toms	2.5	0.33
Hen Turkey	25 lb. Market Hens	2.5	0.32
Swine	270 lb. Market Hog	1.5	0.34
Cattle			
Cow-Calf Herd	Mother Cow	0.65	0.19
Cattle Feedlot	Heifer and Steer Capacity	0.47	0.14
Dairy	Mature Cows (Milking and Dry)	1.9	0.57
Equidae	1,150 lb. Horse	0.34	0.12

Mortality of some animal groups, such as horses, is less predictable on a per-farm basis. Horse owners are more likely to experience the unexpected loss of a single animal than a predictable percentage of animals in a herd. In these cases, the panel considered a large population of animals housed on more than one farm and potentially more than one state. Mortality losses for a 1,000 head herd were then calculated using published data of animal populations, body weights, and average death rates within age groups of various breeds of horses, donkeys, and mules. Mortality nutrient masses within a jurisdiction can be estimated by multiplying the estimated mortality production per AU by Equine AUs housed in the jurisdiction.

Comparison of the Panel's Results to Previous Attempts to Estimate Mortality Masses

Table ES.2 compares the per AU values determined by this panel to those estimated in the Simpson Weammert Report (Felton et al., 2009). In the case of broilers, the approach taken by the panel determined a lower production of mortality nutrients than the estimates of Felton et al. (2009) which used an average death rate times average body mass approach. The method used by this panel estimated a much lower mass of mortalities produced per five-pound market weight broiler than Felton et al. (2009); however, the nutrient composition used in both estimations was very similar. Results for other types of poultry were similar to Felton et al. (2009).

Importance of Mortality Nutrients to the Model

Another finding of the panel is the nutrients contained in mortalities produced on a farm are somewhat insignificant when compared to the manure nutrients produced on the same farm (Table ES.3). This conclusion should be considered when determining how routine mortalities are incorporated in future phases of the model.

Table ES.2. Comparison of estimated production of mortalities and the nutrients contained in mortalities for different types of poultry operations based on the method of this report and the methods used in the Simpson Weammert Report (Felton et al., 2009).

	The Method of This Report			The Method of Felton et al. (2009)		
	Mortalities (lbs.)	Total N (lbs.)	Total P (lbs.)	Mortalities (lbs.)	Total N (lbs.)	Total P (lbs)
Broilers 5 lb. market weight, 1,000 bird grow-out	51	1.3	0.2	175	5.1	0.8
Tom Turkeys 48 lb. market weight, 1,000 bird grow-out	1,700	50	6.5	1,500	n.d.[1]	n.d. [1]
Layers 1,000 birds, annual mass produced	210	8.3	1.5	250	6.9	1.2

[1]Felton et al. (2009) did not estimate the nutrient composition of turkeys.

Table ES.3. Percentage of manure and mortality nitrogen and phosphorus contributed by mortalities for typical animal operations in the Chesapeake Bay Watershed.

Type of Farm	Percentage of Farm Nutrients (Manure and Mortalities) Originating with Mortalities	
	TN	TP
Poultry		
Broiler	1.3 - 2.4	0.65 – 1.2
Layer	0.70	0.40
Turkey	4.0	2.0
Swine	3.2	3.8
Cattle		
Cow-Calf Herd	0.45	0.58
Cattle Feedlot	0.26 – 0.32	0.45 – 0.75
Dairy	0.55 – 0.65	0.93 – 1.2
Equidae	0.30 - 0.52	0.51 – 1.5

Part II: Disposal Methods

The panel looked in depth at five mortality disposal methods: burial, composting, incineration, landfilling, and rendering. The panel conducted an extensive literature review of the environmental impact of each method. Although the literature of nutrient movement during disposal of animal mortalities is limited, the panel was able to estimate the fraction of nutrients leaving each method along the pathways shown in Figure ES.1. The estimated mass of nutrients leaving by each pathway are given in Table ES.3.

The panel did not attempt to judge the benefits of one disposal method over another. Furthermore, reduction in nutrient load may not be the best criteria by which to judge the benefits of a disposal method. Biosecurity considerations, reduction in nuisance conditions, ease of operation, and implementation cost may be the greatest factors determining the choice of a method to an individual producer.

As shown in Table ES.3, composting and incineration showed the greatest potential to recycle nutrients within a farm nutrient management plan; however, these methods also had the greatest potential of those studied to release nitrogen into the atmosphere. When implemented properly, incineration showed the greatest potential to remove pathogens from mortalities. Burial is also a good method to reduce nuisance conditions and slow the movement of disease vectors off farm, but the greatest setback to a producer using burial as a disposal method is loss of productive land tied up in the practice. Burial also had the greatest potential to leach nutrients into the surrounding soil.

Movement of nutrients to the on-farm environment using landfilling and rendering is essentially zero in terms of the model. This is due to the fact that these methods result in carcasses being removed from the agricultural system. Although not specifically studied by the panel, use of refrigerated storage units are an essential component for the success of multiple-farm landfilling and rendering systems – particularly for small animals such as poultry and swine piglets.

Future Research Needs

The panel universally found a deficit of whole carcass nutrient content data. Although the panel is confident in the data produced for this report, some values were produced through limited published data on mortalities, unpublished industry estimations of death losses, information provided by breeders, and/or personal communication with top researchers in the field. Research should be undertaken to determine the actual mass of mortalities produced on farms under the cultural practices used in the watershed.

Reference

Felton, G., Timmons, J., & Ogejo, J.A. (2009). Mortality composting, definition and nutrient and sediment reduction effectiveness estimates, pp 393-412, In Simpson, T. and J. Weammert. *Final Report, Developing Best Management Practices and Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay Watershed*. College Park, MD: Univ. of MD Mid Atlantic Water Program.

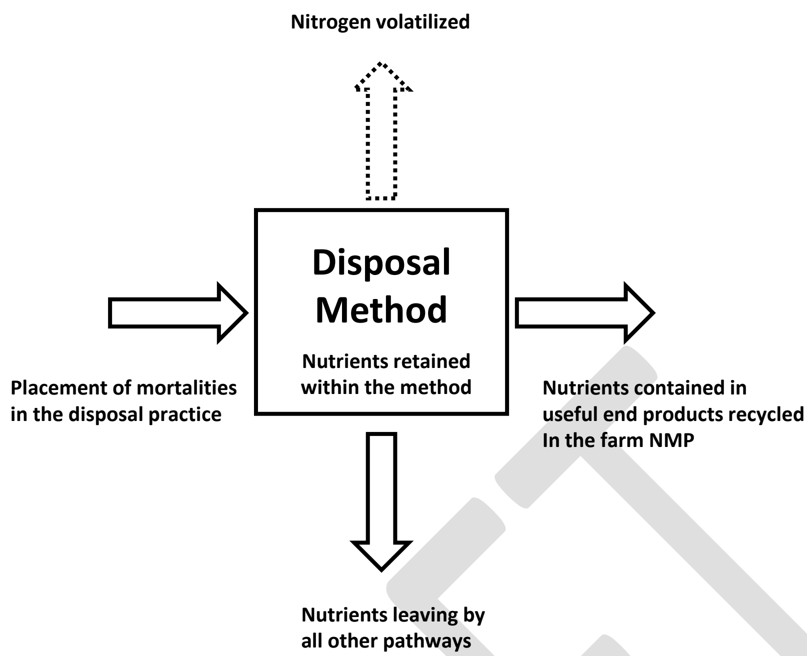

Figure ES.1. Potential movement of nutrients during the implementation of a disposal method.

Table ES.3. Potential movement of nutrients during implementation of a disposal method, fallback values.

	Mass Percentage of Carcass Nutrients Exiting the Method (%)				
	Nutrients recycled with end products in the farm nutrient management plan		Nutrients emitted to the atmosphere	Nutrients leaving the method by all other pathways	
	TN	TP	TN	TN	TP
Burial	0	0	0	15	5
Composting	80	100	10	10	0
Incineration	25	100	75	0	0
Landfilling	0	0	0	0	0
Rendering	0	0	0	0	0

Table of Contents

Appendices

[Editor's note: Appendices are kept as separate documents for the review and feedback process and may not be available until later in the process, such as Appendices E & F.]

Background

1. **Expert panel process**

Expert panels formed to evaluate nonpoint best management practices (BMPs) by the Chesapeake Bay Program's Water Quality Goal Implementation Team (WQGIT) or its workgroups follow the expectations and process laid out in the *Protocol for the Development, Review, and Approval of Loading and Effectiveness estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed*, aka the "BMP Protocol."

1.1 Panel history and panel membership

In 2017 the Chesapeake Bay Program's Agriculture Workgroup (AgWG) formed an expert panel establishment group (EPEG) to:

- Determine the necessity for a Phase 6.0 Animal Mortality Management Expert Panel (EP).
- Identify priority tasks for the Phase 6.0 Animal Mortality Management EP,
- Recommend areas of expertise that should be included on the Animal Mortality Management EP, and
- Draft the Animal Mortality Management EP's charge for the review process.

The EPEG met from November 2017 through January 2018, and recommended that the AgWG form an expert panel that would be coordinated through Virginia Tech's cooperative agreement with the EPA-CBPO. The EPEG's memo, which was approved by the AgWG in March 2018, is provided as Appendix A of this report.

Virginia Tech issued a request for proposals and selected the proposal submitted by Doug Hamilton from Oklahoma State University. As per the WQGIT BMP Review Protocol, partnership feedback was solicited on the draft scope of work and proposed panel membership. Following partnership feedback, the panel membership was amended to include an additional regional expert (Bud Malone). The AgWG subsequently approved the panel membership (Table 1) on August 16, 2018.

The panel convened for its first call in November 2018 and held its required public stakeholder session on November 25, 2018 near Baltimore, MD. The panel met face-to-face twice, in November 2018 and June 2019, plus another 14 times by conference call through its duration. Summaries of the meetings and discussions are included as Appendix D to this report. The panel was convened to deliver its recommendations as laid out in the WQGIT's BMP Review Protocol, with their specific charge summarized in the next section.

Table B.1.1 – Expert Panel membership and support

Name	Role	Affiliation
Douglas W. Hamilton, PhD, P.E.	Panel Chair	Oklahoma State University
Thomas M. Bass	Member	Montana State University
Amanda Gumbert, PhD	Member	University of Kentucky
Ernest Hovingh, PhD	Member	Pennsylvania State University
Mark Hutchinson	Member	University of Maine
Teng Teeh Lim, PhD, P.E.	Member	University of Missouri
Sandra Means, P.E.	Member	USDA NRCS, East National Technology Support Center
George "Bud" Malone	Member	Malone Poultry Consulting; University of Delaware (retired)
Panel support		
Jeremy Hanson	Panel Coordinator	Virginia Tech, CBPO
Brian Benham, PhD	VT Project Lead	Virginia Tech
Jeff Sweeney	WTWG & CBPO Modeling Team rep	EPA, CBPO
Mark Zolandz	Regulatory contact	EPA Region III
Loretta Collins	AgWG Coordinator	University of Maryland, CBPO
Mark Dubin	Senior Ag Advisor	University of Maryland, CBPO

1.2 Panel charge

The general scope of work for the Animal Mortality Management Expert Panel (EP) will be to define and configure the Animal Mortality Management BMPs in the Phase 6 model. Specifically, the Animal Mortality Management EPEG recommends the following charge with associated tasks for the Phase 6.0 Livestock and Poultry Mortality Management EP, supplemented by Figure B.1.1 and Table B.1.2 below:

1. Determine scope of the EP based on available data and impact on water quality
    - Animal groups and/or group components to be addressed
        - Definitions available on CBP's Chesapeake Assessment Scenario Tool (CAST)
    - Mortality management practices to be addressed (Table B.1.2)
2. Define load reduction efficiencies for N and P of selected practices for agricultural feeding space areas.
    - Consider fate of N and P across selected practices
        - Decomposition and mineralization
        - Leachate
        - Volatilization
        - Field application
        - Removal from agricultural system

Potential Credit Mechanisms:

Option 1: If an EP finds a water quality benefit, that benefit could be added as a % reduction to feed space loads in a future milestone period.

Option 2: Ag Workgroup could request a change to the manure calculations from the Water Quality GIT and Modeling Workgroup in a future milestone period if an EP defines:

- % mortality
- nutrients available in carcasses
- water quality benefit

Figure B.1.1. Potential mechanisms to simulate estimated contribution of mortality management

Table B.1.2. Initial framework suggested by EPEG for articulating mortality contributions and possible load source for BMP application

General Animal Group (defined by EPEG)	BMP Animal Groups	% N per Carcass	% P per Carcass	Mortality %	Avg. Dead weight?	Mortality Management Baseline (1984)	Mortality Management Today**	
Primary Animal Group	Poultry	?	?	?	?	Burial	Burial	Yes
							Freezer	Yes
							Compost	Yes
							Incineration	Yes
	Swine	?	?	?	?	Burial	Burial	Yes
							Freezer	Yes#
							Compost	Yes
							Incineration	Yes
Secondary Animal Group	Cattle	?	?	?	?	Burial	Burial	Yes
							Freezer	No
							Compost	Yes
							Incineration	No
	Equine*	?	?	?	?	Burial	Burial	Yes
							Freezer	No
							Compost	Yes
							Incineration	No
	Other? (e.g. Sheep, Goats)	?	?	?	?	Burial	Burial	Yes
							Freezer	No
							Compost	Yes
							Incineration	No

*Direct-to-rendering also practiced
** Current mortality management in the Bay watershed, as understood by EPEG members
#Piglets (nursery) only

3. Determine how the selected mortality management practices can be represented in the model.
    - Consider the information necessary to address Options 1 and 2 (Figure B.1.1)
        - Option 1: applicable to 2020-2021 milestone planning
        - Option 2: applicable to post-Phase 6.0 Watershed Model

The charge from the EPEG also outlined the elements of an EP report as stipulated in the BMP Review Protocol. Those report elements are not re-stated here, but are listed in the appendices of this report. The sections of this report are structured to convey the necessary information requested in the panel charge. As the panel deliberated their work, they agreed that the logical organizing theme for this report would follow from Table B.1.2 above, specifically (a) the animal type(s), their mortality rate estimates and carcass nutrient content, and; (b) disposal methods for the mortalities, and the effect of those methods on the nutrients from animal mortalities.

2. Overview of the Phase 6 Watershed Model animal input and waste simulation processes

The Chesapeake Bay Program has a suite of models that work together to estimate changes to tidal water quality in the Chesapeake Bay. Best management practices are simulated as part of the Watershed Model, which estimates the amount of nitrogen, phosphorus and sediment that reaches the Chesapeake Bay from its tributaries and watershed. The Watershed Model is currently in its "Phase 6" version, which is updated every two years according to rules established by the Chesapeake Bay Program partnership through collaboration of the WQGIT, Modeling Workgroup, Bay Program modelers and other partners.

The Watershed Model combines a wide range of inputs, including the outputs from the CBP's Airshed Model and Land Use Change Model. Animal mortality management occurs in the agricultural sector and its role in the Watershed Model relates most closely to the Model's existing livestock and poultry inputs. As previously noted, the current Watershed Model does not include explicit estimates of nutrients contributed by dead animal carcasses. Nutrient inputs in the modeling tools from livestock and poultry are represented by animal manure. This section includes a brief summary of how manure nutrients are simulated within the model, especially since routine animal mortalities and animal manure are sometimes managed concurrently as part of an operation's waste. There are differences between manure management and mortality management, and this report attempts to parse the issues to the best of panel's ability. However, since the panel's recommendations are expected to contribute to the Watershed Model's overall process and assumptions for the management of animal waste nutrients on agricultural operations, it is best to understand and to frame the estimates of mortality nutrients in relation to manure nutrients, at least until a future version of the Model can build on this panel's work and include an individual load source for mortalities, if desired.

The overall processes for manure generation, dispersal and subsequent loss or application are illustrated in Figure B.2.1 below. First, the amount of manure is estimated at a county level based on the livestock and poultry populations within that county. The manure generated per animal is based on either as-excreted values from the American Society of Agricultural and Biosystems Engineers (ASABE), or other national or regional datasets, as documented in Chapter 3 of the Model Documentation.

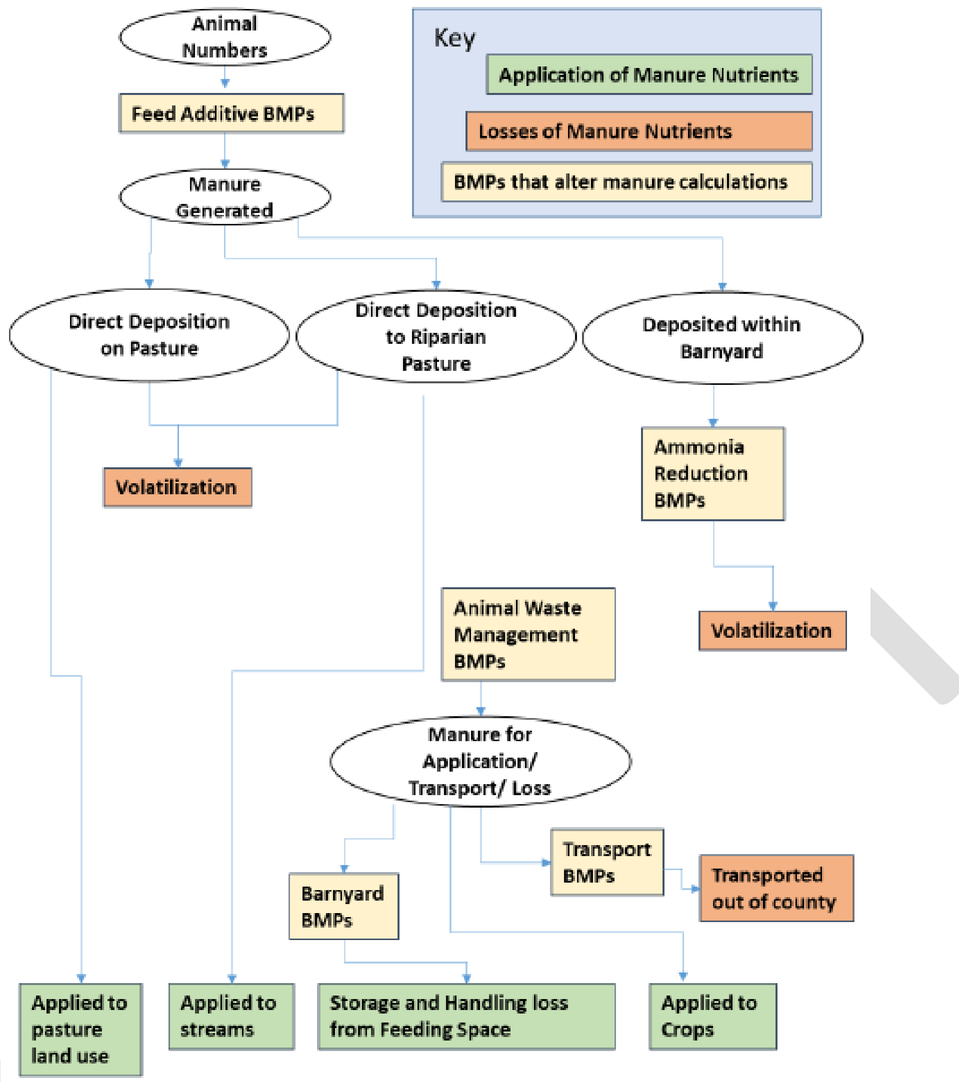

Figure B.2.1. Manure application processes in the Watershed Model (Source: copied from Figure 3-6 in Watershed Model Documentation)

Note: All documentation for the Watershed Model is available on CAST at https://cast.chesapeakebay.net/Documentation/ModelDocumentation

Note: Detailed manure source data, including manure nutrients per animal, is available at https://cast.chesapeakebay.net/Home/SourceData

Once there is a county level estimate of total manure nutrients, from there the manure is placed in three conceptual areas that determine the subsequent fate and transport of the manure. For the purposes of the mortality management EP, the focus is on the "barnyard deposition," which in turn defines the amount of manure nutrients available for land application or transport.

Figure B.2.1 reiterates the point made by the EPEG that the Watershed Model does not explicitly represent the amount of nutrients from animal mortalities within the agriculture sector. Overall, nutrient inputs in the agriculture sector also include biosolids and inorganic fertilizer, which are irrelevant to this panel's work and thus not discussed here. The only currently simulated source of animal nutrients is from their manure. The panel's recommendations may allow the CBP to simulate an explicit source of nutrients from routine animal mortalities, though the overall amount of those nutrients is expected to be dwarfed by other agriculture sector nutrient sources. Note: For this report it is important to understand that "barnyard" represents all non-pasture portions of livestock or poultry lifecycles for model purposes.

When a best management practice is applied in the Watershed Model, it can reduce loads in a number of general ways, which are described in full within the Model Documentation (Chapter 6), and also summarized in the *Quick Reference Guide for BMPs*, starting on page 17 (https://www.chesapeakebay.net/documents/BMP-Guide_Full.pdf). This section will not describe how each type of BMP is simulated in the Model, but it is important to note that Animal BMPs can have ripple effects on subsequent model processes, such as the load available for land application to crop need. This panel is not tasked with investigating or recommending changes to any of those processes, though the panel's recommendations will likely interact with them. Furthermore, it is understood that adding a new load source for mortalities would violate the calibration rules and would need to wait for a future version of the model (i.e., "Phase 7"), which means that aspects of this report will not apply within Phase 6.

2.1 Summary of watershed animal populations over time

Nutrients from manure generation or animal carcasses from routine mortality are based on the overall animal population. Animal populations vary over time, and the AgWG is often discussing how to improve its animal population data. Currently animal data is primarily based on Census of Agriculture data, as well as annual NASS survey data and state data. The data source varies by animal type, but the focus of this report is not on animal population data, so the data currently within CAST offers a sufficient snapshot for readers of this report. The following two graphs, Figures B.2.2 and B.2.3, split the total animal populations into Livestock and Poultry categories from 1985 to 2019. The respective animal types within each category are seen in the legend for each chart. The graphs are in animal units, which gives a better sense of the relative scale between livestock and poultry categories. Note: The figures below include animal totals from both "permitted" and "non-permitted" load sources in CAST.

The charts below represent animal populations at the 64,000-mile watershed scale. Animal populations and manure is simulated at a county scale and there is wide variation in animal populations amongst the 188 counties that are partially or wholly within the watershed. The greatest animal populations are found in the Shenandoah Valley (including Rockingham County) in Virginia, southeastern Pennsylvania (including Lancaster County), and the Delmarva Peninsula.

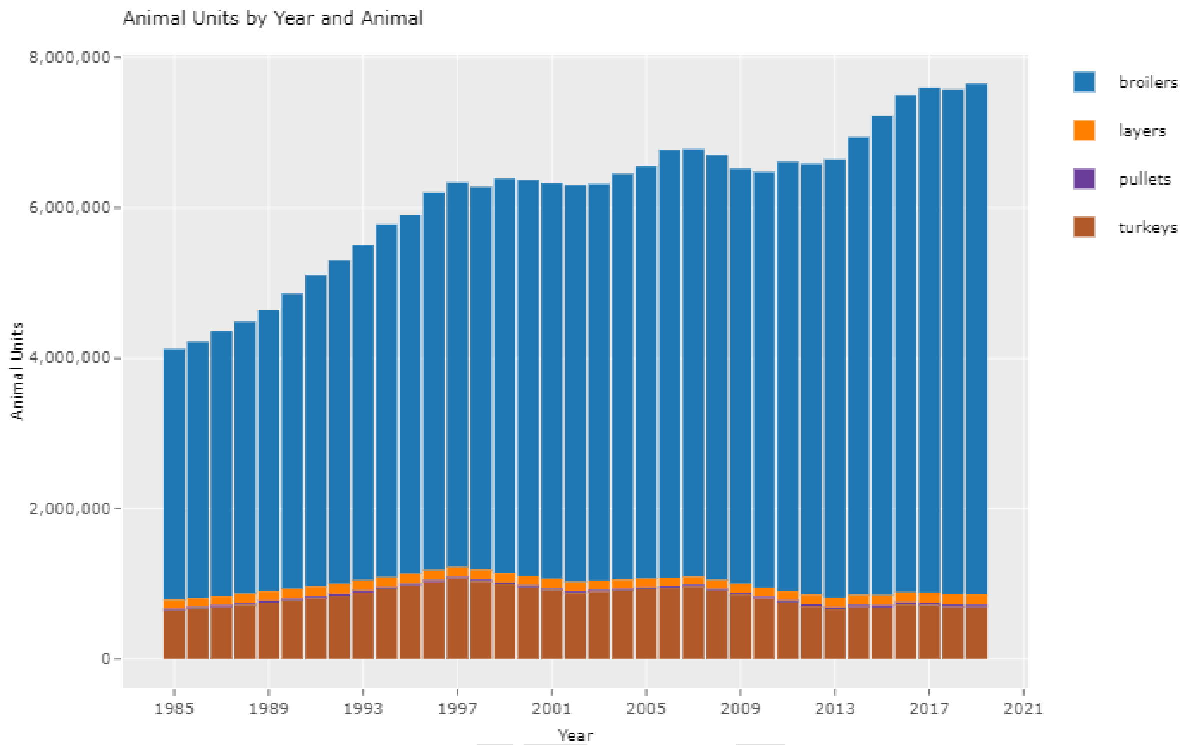

Figure B.2.2 Poultry total annual production (AU), Chesapeake Bay watershed, 1985-2019. Source: CAST trends over time, https://cast.chesapeakebay.net/TrendsOverTime/AnimalUnits

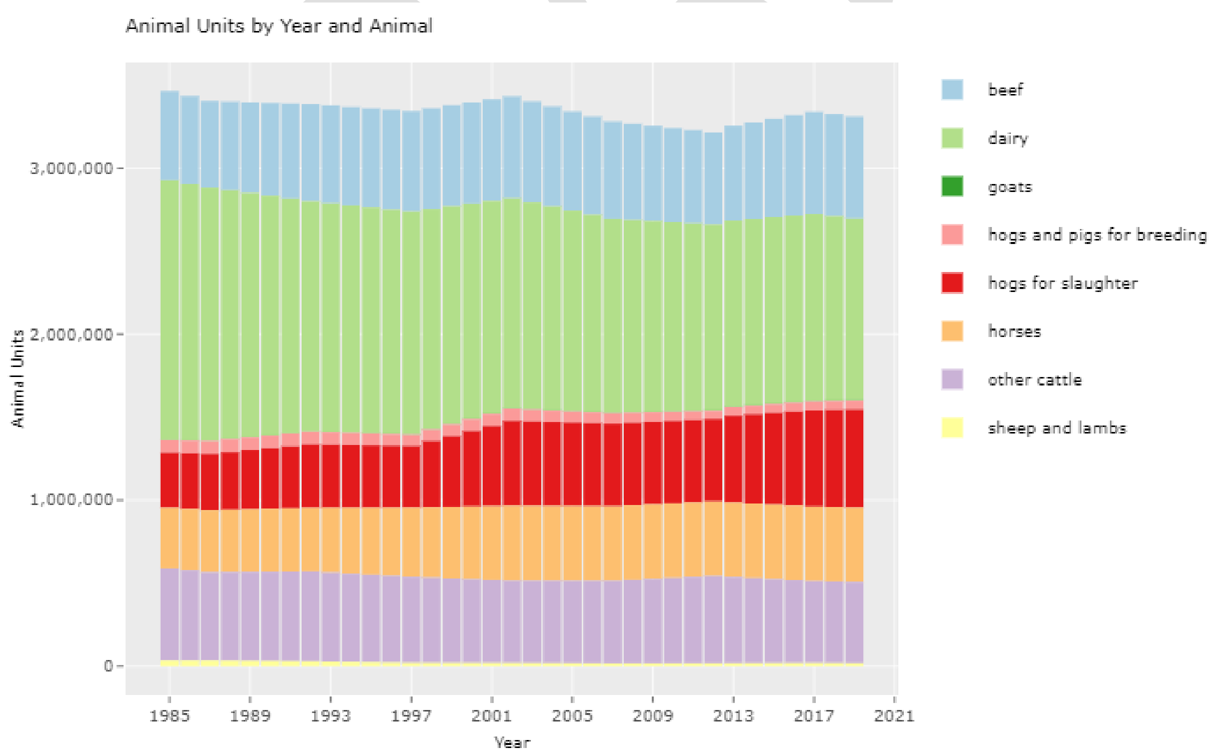

Figure B.2.3 Livestock total annual population (AU), Chesapeake Bay watershed, 1985-2019. Source: CAST, trends over time, https://cast.chesapeakebay.net/TrendsOverTime/AnimalUnits

Part I

Routine Mortality Production

1. Introduction

Unplanned death of livestock and poultry is a fact of life in animal agriculture. The loss of income and production capacity as well as the cost of carcass disposal can place a heavy burden on farmers. Mortalities are both a biosecurity and an environmental hazard. While this report focuses on the nutrient enrichment aspect of environmental pollution, the greatest hazard with mortalities may be the spread of disease by vectors and by direct contact with carcasses. Nuisance conditions associated with the disposal of mortalities also pose one of the greatest societal challenges of animal production.

1.1 Routine versus Catastrophic Mortalities

There are two types of mortalities in modern animal production: routine and catastrophic. Routine mortalities take place during the day-to-day operation of farms. Not all chicks, poults, pigs, calves and foals live to reach maturity, and mature animals die unexpectedly. Catastrophic death occurs because of one-time events such as fires, disease outbreaks, and weather-related incidents. Catastrophic losses might also occur as the result of purposeful depopulation of animals to contain the outbreak of disease. This report concentrates on routine mortalities of livestock and poultry. The first half of this report provides a method to quantify the routine mortalities experienced by animal operations and gives estimated numbers of moralities in typical agricultural production systems in the Chesapeake Bay Watershed. Many of the disposal methods covered in the second half of this report may be used on both routine and catastrophic mortalities.

1.2 Quantification of Routine Mortalities

A summary of the findings of this expert panel is given in Table I.1.1, reported on an animal unit (AU) basis. Estimating the number and weight of routine mortalities has been a vexing problem for farmers, and uncertainty in rate of mortalities produced has stifled the development of mortality disposal methods. In the past, estimates have generally taken the form of "estimated death rate of animals times the average weight of animals equals the rate of mortality production on a weight basis". The problem with this technique is it is an over-simplification of actual production systems. The death rate of animals is rarely constant. Death rate depends greatly on the age, size, and environmental conditions of the animals. Furthermore, most meat production systems involve young and juvenile animals that are constantly growing. Average death rate rarely occurs when animals are at their average weight. Death more commonly occurs when animals are very young or approaching maturity.

Table I.1.1. Summary of expert panel findings, estimated weight of mortality nutrients produced by farm on an AU (1,000 liveweight) basis.

Type of Farm	Characteristic Animal(s)	Weight of Mortality Nutrients Produced per Farm (lbs AU^{-1} $year^{-1}$)	
		TN	TP
Poultry			
Broiler	6 lb. Market Birds	1.8	0.25
Layer	Laying Hens	2.2	0.40
Tom Turkey	48 lb. Market Toms	2.5	0.33
Hen Turkey	25 lb. Market Hens	2.5	0.32
Swine	270 lb. Market Hog	1.5	0.34
Cattle			
Cow-Calf Herd	Mother Cow	0.65	0.19
Cattle Feedlot	Heifer and Steer Capacity	0.47	0.14
Dairy	Mature Cows (Milking and Dry)	1.9	0.57
Equidae	1,150 lb. Horse	0.34	0.12

The approach taken by this expert panel was to look at death at animal production systems for poultry (broilers, layers, and turkeys), swine, cattle (dairy and beef), and equidae (horses, donkeys and mules) as reported in the scientific and industry literature. Death was taken as an episodic event, and the weight of a given animal taken at the time of death was used as the weight of carcasses. Individual carcass weights were accumulated over a growing period (as in the case of broiler production), or over a multi-year cycle (as in the cases of laying hens), or a combination of the average annual death rates of breeding stock and the growth cycle of young stock (as in beef cow-calf herds). Values were then annualized by multiplying by the average number of growth cycles per year (6.1 flocks per year for 6-pound broilers for instance) or dividing by years in a multi-year production cycle (80 week laying period for hens). Weight of nutrients contained in mortalities was estimated by multiplying weight of mortalities by carcass composition. In some cases, such as broilers where it is known that the nutrient composition of flesh and feathers changes with age, the changing nutrient composition was taken into account during the accumulation of mortalities. Production of mortality nutrients was normalized for different production systems by dividing the average annual carcass nutrient weights by a characteristic animal for the system. These characteristic animals were chosen so that mortalities may be calculated using numbers provided by the USDA-NASS census of agriculture (mother cows for beef cow-calf operations), values used by the Chesapeake Bay Program (hogs for slaughter for swine), and populations reported by various trade organizations (horse population data). Data is provided on both a per-head and per-liveweight (AU) basis. Fall back numbers (values to be used in the absence of more identifying information for a farm or jurisdiction) for the general animal groups investigated by the expert panel are given in the summary table (Table I.1.1). More detailed information for individual production systems can be found in the chapters within Part I of this report.

1.3 Relative Mass of Nutrients from Routine Mortalities

The nutrients contained in mortalities are a minor component of the water pollution potential of animal production. The percentage of nitrogen and phosphorus contributed by mortalities to the combined mass of manure and mortality nutrients for the animal groups investigated by this expert panel is given in Table I.1.2. Greater detail is provided in the chapters within Part I of this report. Although the relative amount of waterborne nutrients contributed by mortalities to the Chesapeake Bay watershed may be small, this is not to say that mortality nutrients may not play a greater role in local water pollution. Also, the biosecurity hazard posed by inappropriately disposed carcasses may outweigh that of manure by several orders of magnitude.

Table I.1.2. Percentage of manure and mortality nitrogen and phosphorus contributed by mortalities for typical animal operations in the Chesapeake Bay Watershed.

Type of Farm	**Percentage of Farm Nutrients (Manure plus Mortalities) Originating with Mortalities**	
	TN	**TP**
Poultry		
Broiler	1.3 - 2.4	0.65 – 1.2
Layer	0.70	0.40
Turkey	4.0	2.0
Swine	3.2	3.8
Cattle		
Cow-Calf Herd	0.45	0.58
Cattle Feedlot	0.26 – 0.32	0.45 – 0.75
Dairy	0.55 – 0.65	0.93 – 1.2
Equidae	0.30 - 0.52	0.51 – 1.5

2. Poultry

2.1 Definitions

Broiler: A meat chicken of either sex bred and grown to market weights of 2 to 10 pounds. Broilers weighing more than 6 pounds are often referred to as **Roasters.**

Chick: A meat-type chicken of either sex from day old to the end of brooding.

DELMARVA: The peninsula of land where Delaware (3 counties), Maryland (9 counties), and Virginia (2 counties) converge. This area is situated between the Atlantic Ocean and the Chesapeake Bay, which is also referred to as the "Eastern Shore."

Layer: A female chicken (hen) kept solely for egg production for human consumption.

Mortality: On-farm death losses.

Poult: A meat-type turkey of either sex from day old to the end of brooding.

Pullet: A female chicken that has not yet started to lay eggs for human consumption.

Turkey: A meat-type turkey grown for human consumption. **Hen turkeys** are females grown to 12-16 pounds market weight. **Heavy hens** are females grown to 18 to 25 pounds market weight. **Tom turkeys** are males grown to 42-48 pounds market weight.

2.2 Broilers

2.2.a Broilers in the Watershed

The annual production of broilers in the six states making up the Chesapeake Bay watershed is nearly seven billion pounds (USDA-NASS, 2018). Table I.2.1 lists the total annual production of broilers, the average weight at finishing, and the average grow-out period of broilers in the states comprising the Chesapeake Bay Region. The numbers in Table I.2.1 represent the total of all production in the state listed, not only the portion of the state within the watershed. Production of broilers in the part of New York within the watershed is miniscule (Hawkins et al, 2016). The areas of highest broiler production are the Delmarva Peninsula, the Shenandoah Valley of Virginia, and Lancaster County, Pennsylvania.

Table I.2.1. Broiler production in the Chesapeake Bay Region (from USDA-NASS, 2018).

	Annual Production (Million Pounds)	Number of Birds Raised (Millions)	Average Market Weight (lbs)	Average Length of Grow-out[1] (days)
Delaware	1,900	260	7.2	47
Maryland	1,800	310	6.0	41
Pennsylvania	1,000	185	5.6	39
Virginia	1,600	280	5.8	40
West Virginia	340	86	3.9	31
Total of 5 States	**6,700**	**1,121**	**6.0**[2]	**41**[2]

[1]Based on growth rate of common genetic lines (Aviagen 2019, Cobb-Vantress, 2018).
[2]Weighted average based production capacity in each state.

Almost all broiler production in the watershed is through vertical integration, with large companies (the integrator) suppling chicks to contract growers who raise birds to market weight. Birds are then picked up by the integrator for slaughter. Market weights range from four to eight pounds; however, contract growers generally refer to pick-up times (for instance: five-, six-, and seven-week birds) rather than market weights.

All broilers within the watershed are raised in confinement. The newest confinement buildings are tunnel ventilated with between 25,000 and 50,000 birds raised under roof (Figures I.2.1, I.2.2 and I.2.3). On the Eastern Shore of Maryland and Delaware, farms have manure storage sheds capable of holding up to 180 days' worth of litter and cake production. Most of these sheds store cake (the wet crusted manure caked under feeders and waterers). Total litter removal occurs every three to four years on average, the bulk of which is transported off the farm of origin. The predominant mortality disposal method is on-farm composting, with freezer storage and transport to rendering facilities becoming more common on the Eastern Shore.

2.2.b Nutrients Contained in Broiler Mortalities

Growth Rate of Broilers

Three recent sources were found of typical growth pattern of broilers. Two sources were from common genetic lines of broiler chickens: Cobb 500 (Cobb-Vantress, 2018) and Ross 308 (Aviagen, 2019). The third was a refereed journal article describing the mortality and composition of male broilers (Caldas et al., 2019). The average growth pattern based on these three sources is shown in Figure I.2.4. The three sources are in very close agreement up to six weeks (42 days) of growth or approximately 6.4 pounds live weight. There is more uncertainty in live weight of birds after six weeks of age as indicated by the confidence interval shown in Figure I.2.4. The major source of uncertainty was the slower growth of the male broilers described in Caldas et al (2019) after five weeks of age. The average growth curve shown in Figure I.2.4 was used in all further calculations.

It should be noted that modern broilers grow much quicker than in previous years. In the 1980s, broilers reached four pounds in seven weeks (MWPS, 1980). Today's birds grow to eight pounds in seven weeks (Figure I.2.4).

Figure I.2.1. Typical layout of a broiler farm in the Chesapeake Bay Watershed (Chip West).

Figure I.2.2. Tunnel Ventilated Broiler Houses (Bud Malone).

Figure I.2.3. Interior of Broiler House – Birds near Market Weight (Poultryventilation.com).

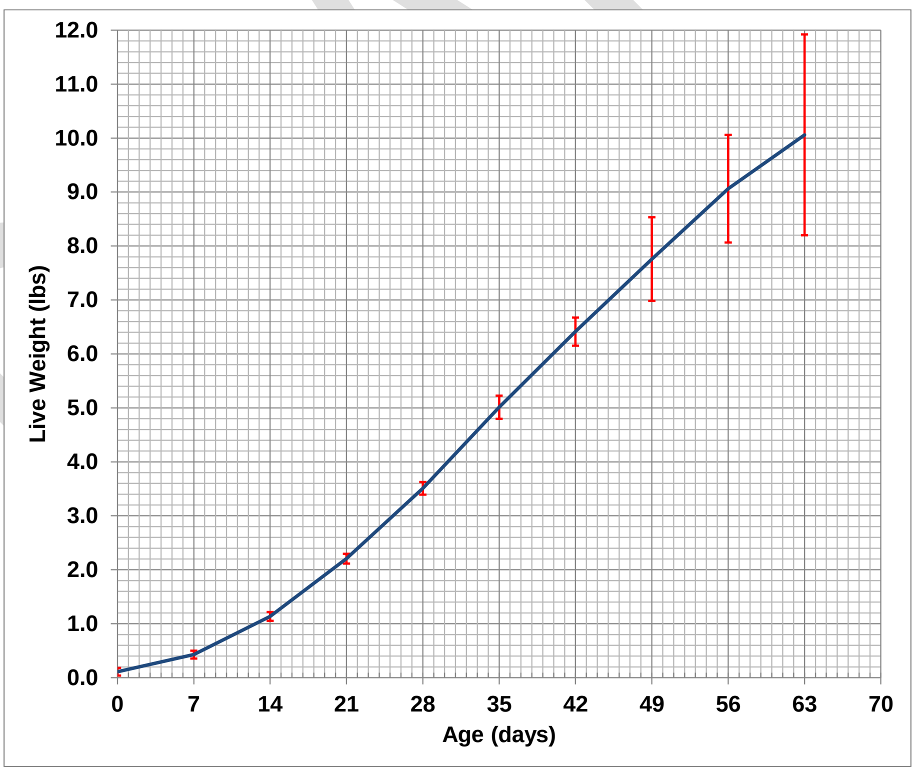

Figure I.2.4. Growth pattern of modern broilers based on average of Cobb 500 (Cobb-Vantress, 2018), Ross 308 (Aviagen, 2019), Caldas et al. (2019); error bars indicate 95% confidence interval.

Mortalities

Broilers do not die all at the same time nor at a constant rate. Weekly mortalities collected from a flock of 1,000 birds are shown in Figure I.2.5. The values labelled "NRCS Delaware" are based on statistical values used to size refrigerators for carcass storage. Those labelled "industry" were provided by industry sources in the Delmarva region (G.W. Malone, personal communication, 2019). Mortality is greatest during the first week that chicks are placed in buildings. The chief cause of mortality is the combined effects of stresses from hatching, transport, placement, house environmental conditions, and the rapid transition from using yolk nutrients to in-house feed and water sources. Uncertainty in chick mortality is indicated by the range of data between the two sources. Mortality decreases as the birds grow, reaching a minimum in both quantity and uncertainty at 28 to 42 days of age. Death rates increase after 42 days as the larger birds suffer greater stresses associated with increased bird density, lower air quality and litter conditions.

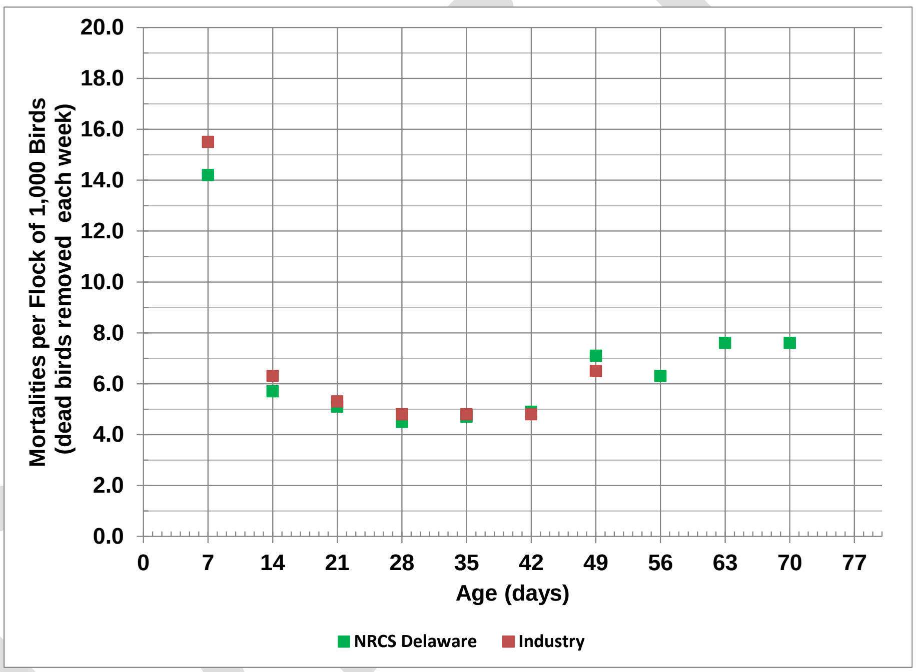

Figure I.2.5. Average weekly death loss of broilers (Malone, personal communication 2019).

Mass of dead birds collected per week was calculated by multiplying number of birds collected per week (Figure I.2.5) times live weight of birds (Figure I.2.4). Pounds of dead birds collected each week versus age for a flock of 1,000 birds is given in Figure I.2.6. Mass of mortalities calculated in this manner fits an exponential function with high correlation (Figure I.2.6).

Carcass Composition

Data on nitrogen composition of live broilers was found in four sources as shown in Table I.2.2. Average whole-body nitrogen content averaged over all four sources was 2.8% on an "as is" basis. Only two journal articles providing phosphorus composition of broiler carcasses were found. Average phosphorus composition of whole broilers based on these two sources was 0.375%.

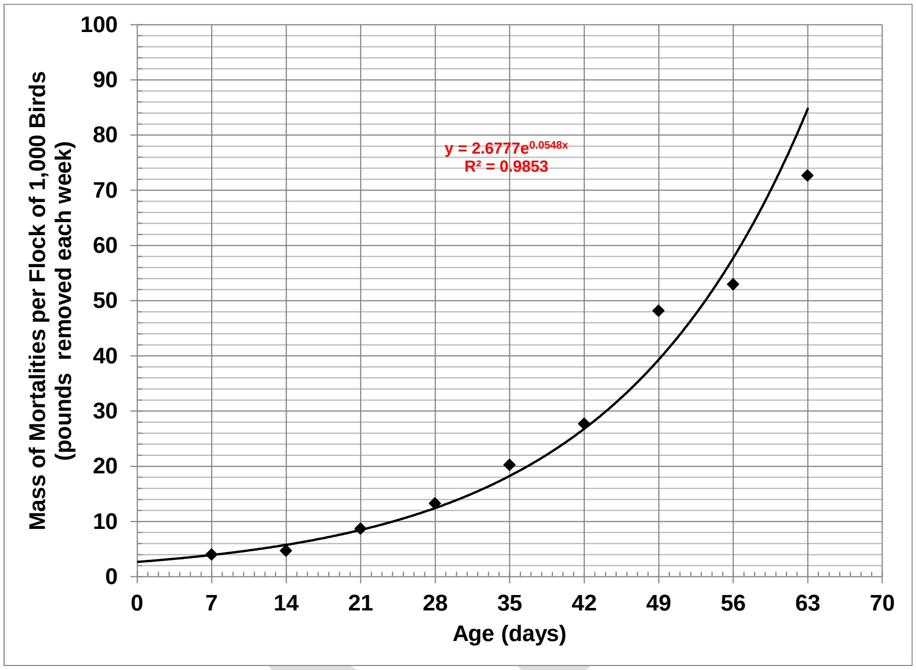

Figure I.2.6. Calculated mass of broiler mortalities collected each week.

Table I.2.2. Total nitrogen and phosphorus composition of broiler carcasses on an "as is" basis.

Literature Source	**Elemental Composition (% wet weight)**	
	N	**P**
Caldas et al., 2019	2.83	0.37
Fekete et al., 2019	2.66	
Lomax et al., 1991	2.84	0.38
Vandepopuliere, 1990	2.96	
Average	**2.82**	**0.375**

Caldas et al. (2019) found that nitrogen and phosphorus composition was not constant throughout the life of a male broiler but varied with age (Figure I.2.7). Phosphorus composition remains fairly constant once the basic skeletal structure of the bird is set. The increase in percent nitrogen composition after 20 days of age is attributed primarily to the growth of feathers. Nitrogen content of female birds may be higher than the values shown in Figure I.2.7; because females are likely to have a higher percentage of feathers by mass.

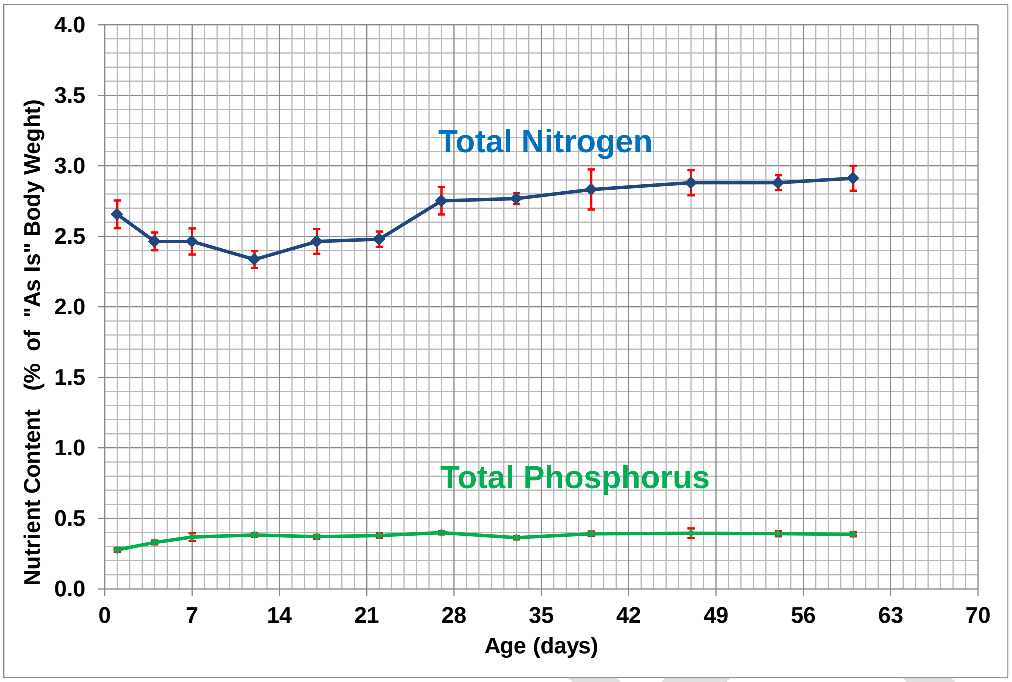

Figure I.2.7. Total nitrogen and phosphorus composition of male broiler carcasses versus age of birds (from Caldas et al., 2019). Error bars indicate 95% confidence interval.

Mass of N and P Available from Broiler Mortalities

Combining the data of Figures I.2.6 and I.2.7 gives the mass of nitrogen and phosphorus available for collection each week for a flock of 1,000 birds. This data is presented in Figure I.2.8. Adding the mass collected in the current week to that collected in previous weeks gives the cumulative mass of nutrients collected up to a certain age of birds (Figure I.2.9.). Since the growth pattern of birds is known (Figure I.2.4), we can also plot cumulative mass of nutrients against the market weight of birds (Figure I.2.10). Mass of mortalities collected and the nutrients contained in carcasses collected over the grow-out of a flock of 1,000 birds is tabulated for market weights of four, six, and eight pounds in Table I.2.3.

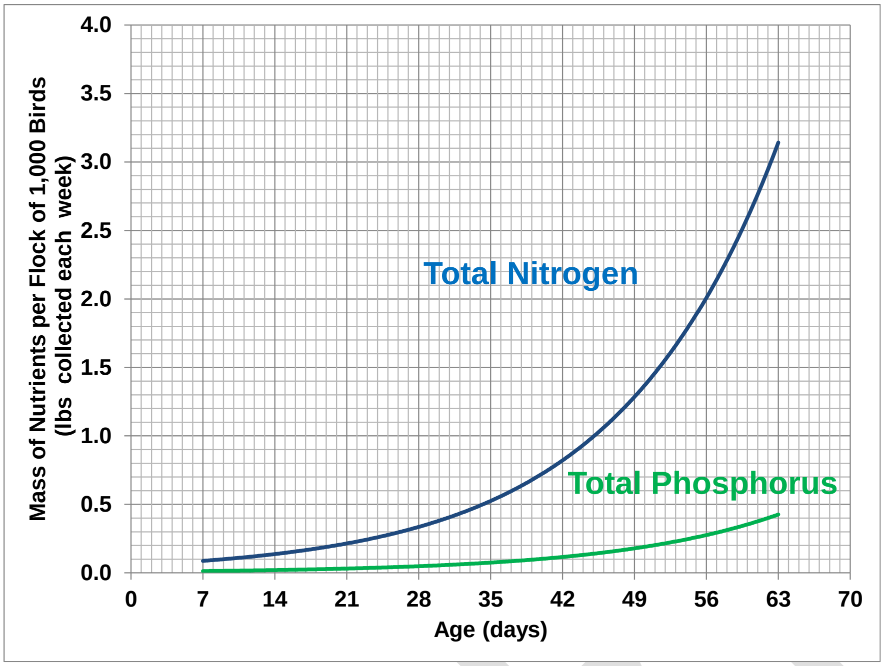

Figure I.2.8. Mass of total nitrogen and phosphorus contained in broiler mortalities collected each week from a flock of 1,000 birds versus age of birds.

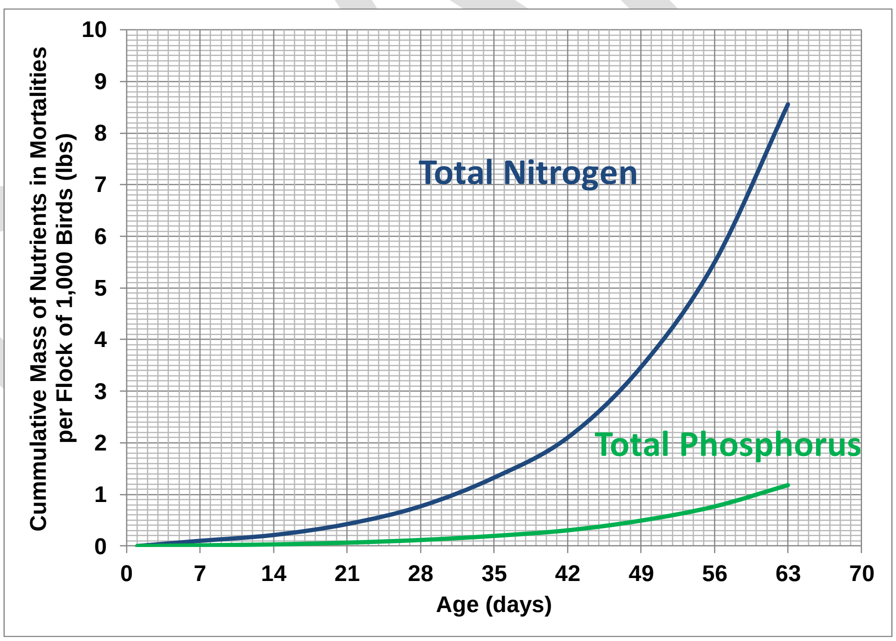

Figure I.2.9. Cumulative mass of total nitrogen and phosphorus collected with broiler mortalities from a flock of 1,000 broilers versus age of birds.

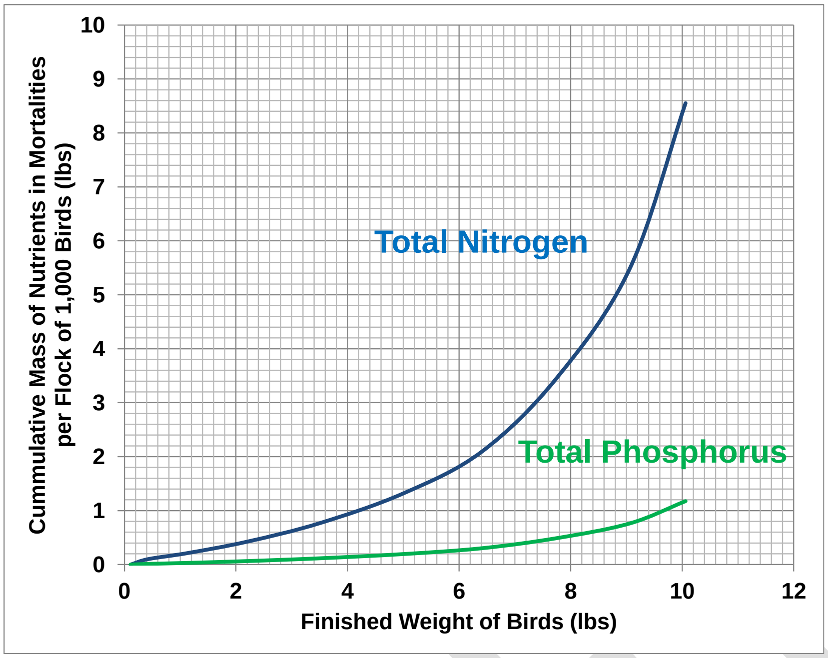

Figure I.2.10. Cumulative mass of nitrogen and phosphorus contained in broiler carcasses produced during the grow-out of a flock of 1,000 birds to various market weights.

Table I.2.3. Mass of broiler mortalities and nutrients contained in carcasses produced during the grow-out of a 1,000 bird flock.

Finished Weight (lb)	Mass of Mortalities and Nutrients collected (lbs)		
	Mortalities	Total N	Total P
4	37	1.0	0.15
6	70	1.8	0.25
8	135	3.8	0.55

2.2.c Annual Mass of Nutrients Contained in Broiler Mortalities

Assuming a broiler will grow to four pounds in 32 days, and given an average 18-day turnaround between flocks, 7.3 flocks of four-pound birds can be grown in a broiler house in one year. Likewise, 6.1 flocks of six-pound birds, and 5.2 flocks of eight-pound birds can be raised each year. Table I.2.4 shows the total mass of mortalities collected each year, and the mass of nutrients contained in those mortalities for a flock of 1,000 birds. Also, mass collected per Animal Unit (1,000 pounds liveweight = 1 AU) based on the estimated flocks per year at each market weight is given in Table I.2.4. The value used to calculate animal unit is mass of birds at the end of the grow-out cycle (i.e. the market weight of birds removed from the house).

Table I.2.4. Expected annual mass of mortalities and nutrients contained in carcasses from a 1,000 bird and one AU (1,000 lbs. liveweight) flock of broilers at various market weights.

		Per 1,000 Birds (lbs $year^{-1}$)			Per 1 AU (lbs $year^{-1}$)		
Market Weight (lb)	**Flocks per year**	**Mortalities**	**Total N**	**Total P**	**Mortalities**	**Total N**	**Total P**
4	7.3	270	7.3	1.1	68	1.8	0.28
6	6.1	430	11	1.5	72	1.8	0.25
8	5.2	700	20	2.9	88	2.5	0.36

2.2.d Comparison of Results to the Simpson-Weammert Report

Felton et al. (2009) reported on the estimated mass of mortality nutrients in the Chesapeake Bay Watershed as part of the more comprehensive Simpson-Wemmmert report defining nitrogen, phosphorus and sediment delivery by best management practices. Felton et al. (2009) calculated the mass of mortalities and nutrients from broilers based on an average market weight of five pounds. They assumed a 5% death loss of broilers, with all deaths occurring when broilers were in the 70% percentile of body weight (3.5 pounds). They also assumed a body composition of 2.9% nitrogen and 0.46% phosphorus at the time of death. The mass of mortalities and nutrients estimated in this report are compared to estimates of Felton et al. (2009) for a flock of 1,000 broilers at a five-pound market weight in Table I.2.5. **The estimates of Felton et al. (2009) overestimate the mass of mortalities and nutrients calculated by the methods used in this report by a factor of 3 to 4.** The discrepancy with the Simpson-Weammert values lies in the way in which Felton et al. (2009) estimated weight of birds at time of death. On-farm mortality data (Figure I.2.5) shows that not only did Felton et al. (2009) overestimate overall flock mortality in the first 35 days of broiler growth (5% versus 3.4%), but the majority of deaths occurred when birds were substantially lighter than 3.5 lbs.

Table I.2.5. Estimated mass of broiler mortalities and nutrients contained in carcasses during the grow-out of a 1,000 bird flock to five-pound market weight.

	Mass of Mortalities and Nutrients Collected (lbs)		
	Mortalities	**Total N**	**Total P**
This report	51	1.3	0.20
Felton et al. (2009)	175	5.1	0.80

2.2.e Comparison of Broiler Mortality Nutrients to Excreted Manure Nutrients

Comparison of nutrients contained in carcasses to nutrient excreted by birds is a true “apples to apples” comparison. Excreted nutrients are the nutrients leaving the birds, before bedding, ammonia volatilization, loss of litter in handling, and a multitude of other factors reduce nutrient concentration in collected manure. Likewise, the nutrients contained in carcasses calculated by the method outlined in this report are nutrients contained in the bird’s body right as it died, before losses from decay, storage, and treatment diminish its mass. Estimates using current formulas for excreted nutrients, which are based on nutrient intake, are highly dependent on assumptions of diet and cultural practices, and should be thought of as rough averages with a high degree of variability - just as this report has highlighted the variability of estimating the mass of carcass nutrients.

A comparison of the mass of nutrients contained in mortalities based on the methods used in this report to the mass of nutrients in excreted manure during the grow-out of the same flock of 1,000 birds at various market weights is provided in Table I.2.6. The American Society of Agricultural and Biological Engineers Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005) and the USDA-NRCS *Agricultural Waste Management Field Handbook* (USDA-NRCS, 2008) were used to calculate excreted manure values. Table I.2.6 shows that if carcass nutrients are combined with excreted nutrients, depending on the finished weight of broilers, **between 1.3 and 2.4% of the nitrogen produced on broiler farms originates with mortalities**. Likewise, **between 0.65 and 1.2% of the phosphorus produced on broiler farms comes from mortalities.** The ASABE standard (ASABE, 2005) estimates the mass of total nitrogen and phosphorus excreted during the growth of poultry raised for meat. These values are based on a mass balance of food intake, nutrients accumulated in the body, nutrients respired, and nutrients excreted. Total nitrogen excreted is 0.12 pounds of TN per finished bird. Total phosphorus excreted is 0.035 pounds of TP per finished bird. The *USDA NRCS Agricultural Waste Management Field Handbook* (USDA-NRCS, 2008) assumes finished weight of broilers in the ASABE standard is 6.0 pounds, and provides a proportional method of calculating nutrients excreted at other finishing weights. Furthermore, all birds in a flock of 1,000 do not live to harvest date. From Figure I.2.5, the cumulative death loss of a flock of 4-pound broilers (raised for 32 days) is 30 birds. Therefore, the mass of excreted nitrogen estimated from a nominal flock of 1,000 birds raised to 4 pounds is: 970 finished birds X (4 lbs./6 lbs.) X 0.12 pounds TN per finished bird = 78 pounds TN. Similarly, the mass of phosphorus excreted by a nominal flock of 1,000 4-pound broilers is 23 pounds.

Table I.2.6. Comparison of mass of nutrients contained in mortalities from a flock of 1,000 broilers to the estimated mass of nutrients contained in excreted manure (ASABE, 2005; USDA-NRCS, 2008) by the same flock raised to various market weights.

Market Weight (lb.)	Nutrients Contained in Mortalities (lbs. per 1,000 birds)		Nutrients Contained in Excreted Manure (lbs. per 1,000 birds)	
	TN	TP	TN	TP
4	1.0	0.15	78	23
6	1.8	0.25	120	34
8	3.8	0.55	152	44

2.3 Layers

2.3.a Layers in the Watershed

Total egg production in the Chesapeake Bay Watershed was nearly 10 billion eggs per year in 2017 (USDA-NASS, 2018). Table I.2.7 lists egg production and estimated number of hens by state. It should be noted that the values given in Table I.2.7 are for the entire state, not just the portion of the state within the Chesapeake Bay Watershed. Egg production in Delaware was too small to be listed individually by USDA-NASS (2018). Egg production in New York state was relatively large (1.8 billion eggs per year), but egg production in New York is located entirely outside of the Watershed (Hawkins et al., 2016); whereas, most of the egg production in Pennsylvania, Maryland, Virginia, and West Virginia is located within the watershed. Lancaster County, Pennsylvania has the highest egg production in the watershed, with 61% of all Pennsylvania production taking place in Lancaster County (Hawkins et al., 2016).

Table I.2.7. Egg production and laying hens housed within the Chesapeake Bay Watershed in 2017 (USDA-NASS, 2018).

	Egg Production (Million eggs yr^{-1})	Estimated[1] Number of Hens (Millions)
Maryland	830	2.7
Pennsylvania	8,200	27.0
Virginia	690	2.3
West Virginia	270	0.89
Total of 4 States	**9,990**	**33.0**

[1]Based on 303 eggs hen^{-1} yr^{-1} (Hyline International, 2019)

Almost all layers raised in the Watershed are housed in large confinement buildings (Figure I.2.11), most commonly in cages (although some farms sell niche market eggs from free-housed hens). The most common manure handling system for layers is a two-level, high-rise house. Caged birds are housed in the upper level of the high-rise house (Figure I.2.12). Manure is dried and stored in the lower level. The second most common system for storing laying hen manure is a pit under a slatted floor. Slatted floor houses handle manure from both caged and free hens. Slatted floors are replacing many older shallow pit, conveyer, and scraper systems (Hawkins et al., 2016).

Figure I.2.11. Laying hen farm in Pennsylvania (Phil Clauer, Pennsylvania State University).

Figure I.2.12. Caged layer production (Phil Clauer, Pennsylvania State University)

Young hens (pullets) are placed in the layer houses at about 18 weeks of age. They are housed on the farm for 80 to 100 weeks of age, giving between one and one-and-a-half years of egg production. At the end of their productive life, the entire house of hens is removed for slaughter and replaced with a new batch of pullets.

2.3.b Nutrients Contained in Layer Mortalities

Live Weight of Hens

At 18 weeks, a pullet is sexually mature and able to produce eggs; however, she does not reach full weight until approximately 44 weeks of age. To estimate the growth pattern of laying hens, three popular lines of birds were randomly selected: W36, W80, and Hyline Brown (Hyline International, 2019). These lines include two white egg birds (W36, W80) and one brown egg bird (Hyline Brown), and are representative of the hens found in Lancaster County, PA (Paul Patterson, personal communication, 2019). The growth pattern of the three lines is shown in Figure I.2.13. As can be seen , birds continue to grow throughout their life, but most growth occurs within the first seven weeks after they are placed in the house. Figure I.2.13 also shows that brown egg hens (Hyline Brown) are generally larger than the white egg hens (W36, W80). This difference appears to hold for all genetic lines (Hyline International, 2019). The ratio of two white egg to one brown egg genetic lines was chosen to represent the average of the population of laying hens across the watershed.

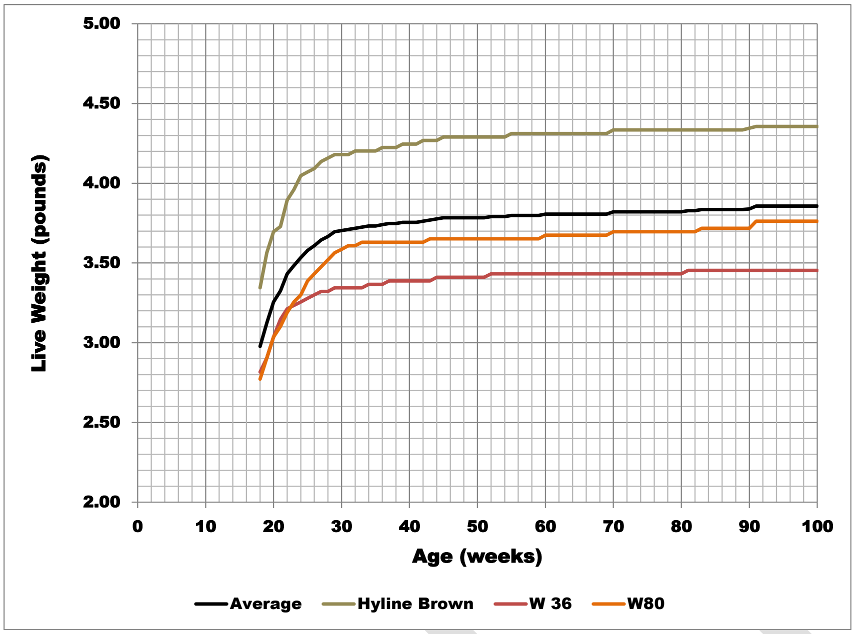

Figure I.2.13. Growth pattern of three common layer genetic lines (Hyline International, 2019).

Hen Mortalities

Figure I.2.14 shows the cumulative mortality of hens taken from the same genetic lines plotted in Figure I.2.13. Cumulative mortality is the number of dead birds removed from a house up to the day of record. All three genetic lines show different patterns of cumulative mortality; however, there does not appear to be a great difference between brown and white egg hens based on the three lines chosen. On average, mortality rate is one dead hen per week from of a flock of 1,000 birds throughout the egg laying period.

The cumulative mass of mortalities collected over the egg laying period is shown in Figure I.2.15. This pattern was calculated by multiplying average bird liveweight shown in Figure I.2.13 by the cumulative mortalities shown in Figure I.2.14. A linear interpolation of the curve gives an average death loss of 4.1 pounds per week, or slightly more than one hen per flock of 1,000 each week. The expected mass of mortalities collected from a flock of 1,000 hens over a 72-day laying period (week 90) is approximately 295 pounds. Averaging this over a 52-week year gives an annual mass of 210 pounds.

Carcass Composition

Only one replicated study giving mass of nutrients contained in laying hen carcasses was found. Haque et al. (1991) determined the nutrient content of whole ground hens to be 3.97% TN and 0.70% TP on an "as is" (wet liveweight) basis. These values are higher than those for the male broilers measured by Caldas et al. (2019)(2.9% TN and 0.40% TP), but this is consistent with the fact that laying hens have a higher percentage of bones and feathers per body weight than broilers (G.W. Malone, personal communication, 2019).

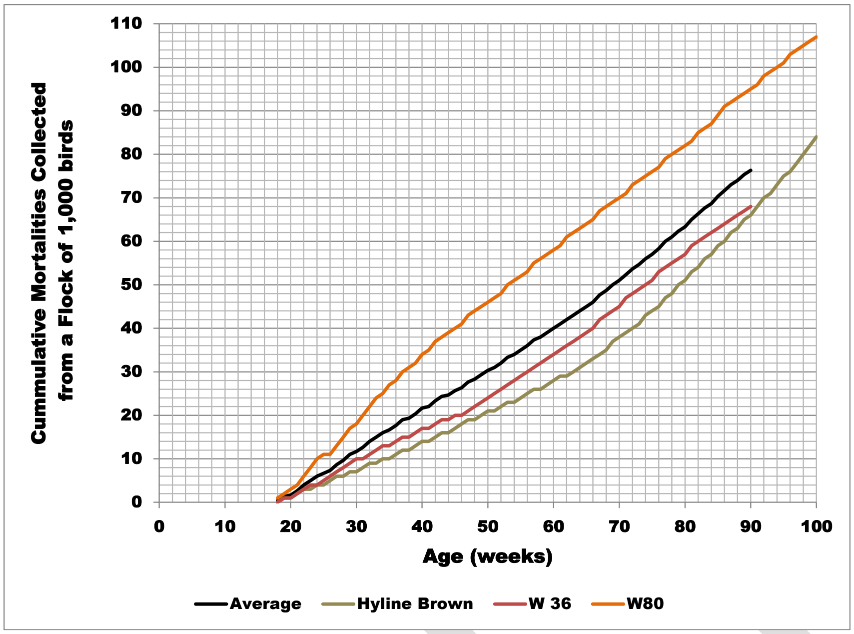

Figure I.2.14. Mortality patterns of three common layer genetic lines (Hyline International, 2019).

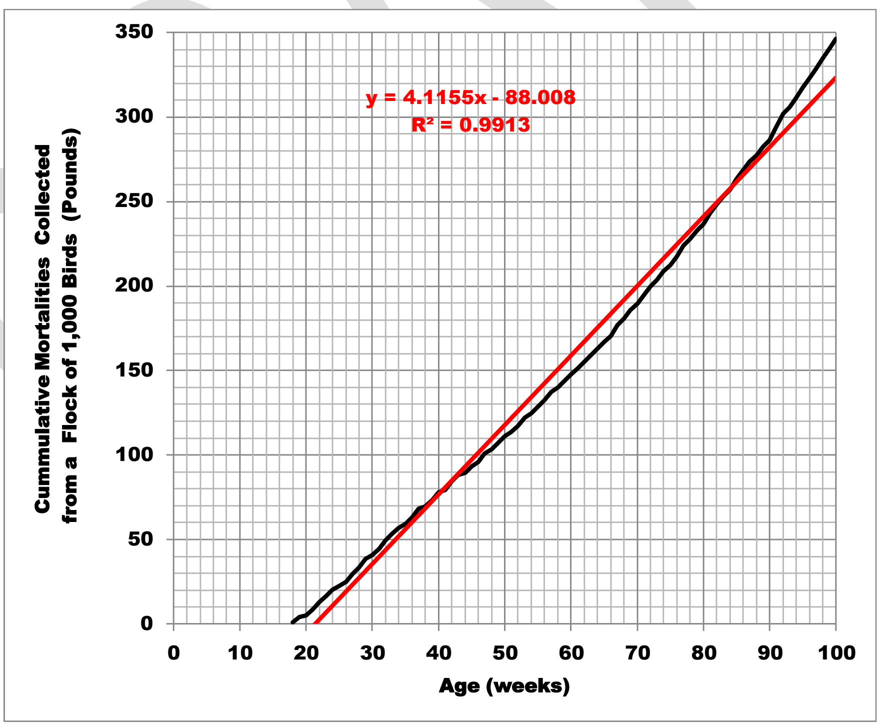

Figure I.2.15. Cumulative mass of mortalities collected during the egg laying period for a flock of 1,000 hens.

2.3.c Annual Mass of Nutrients Contained in Laying Hen Mortalities

Annual mass of nitrogen and phosphorus contained in the mortalities for a flock of 1,000 laying hens and per 1,000 pound animal units is given in Table I.2.8. Given an annual production of mortalities of 210 pounds per 1,000 birds, and a whole body nutrient composition of 3.97% TN and 0.70% TP, the expected mass of nutrients contained in the carcasses from a laying hen flock of 1,000 birds is 8.3 pounds of nitrogen and 1.5 pounds of phosphorus per year. Since the average weight of a hen at 44 weeks is 3.8 pounds, the annual mass of mortality nutrient production per 1,000 pounds liveweight (animal unit (AU) of laying hens is 2.2 pounds TN and 0.40 pounds TP.

Table I.2.8. Expected annual mass of mortalities produced and nutrients contained in carcasses for a 1,000 bird flock and one AU (1,000 lbs liveweight) of laying hens.

Per 1,000 Bird Flock (lbs year^{-1})			Per 1 AU (lbs year^{-1})		
Mortalities	**Total N**	**Total P**	**Mortalities**	**Total N**	**Total P**
210	8.3	1.5	55	2.2	0.40

2.3.d Comparison of Results to the Simpson-Weammert Report

Felton et al. (2009) calculated the mass of mortalities and nutrients from layers in the Chesapeake Bay watershed based on an average live weight of five pounds. They assumed a 5% death loss of birds during a 72-week placement in houses; this results in an annualized death loss of 3.6%. All deaths were assumed to occur when the birds were in the 70% percentile of body weight (3.5 pounds). They also assumed a body composition of 2.9% nitrogen and 0.46% phosphorus at time of death. The mass of mortalities and nutrients estimated in this report are compared to estimates of Felton et al. (2009) for a flock of 1,000 layers in Table I.2.9. **The estimates of Felton et al. (2009) slightly overestimate the mass of mortalities and underestimate the nutrients contained in mortalities compared to the methods used in this report.** The discrepancy in mortality mass occurs because Felton et al. (2009) used a single body mass at time of death (3.5 lbs); whereas, in this report body mass at time of death ranged from 3.0 to 3.85 pounds. Estimated mass of nutrients contained in mortalities are lower in the Felton et al. (2009) estimation, because they assumed a lower carcass nutrient concentration (2.9% N and 0.46% P, versus 3.97% N and 0.70% P).

Table I.2.9. Annual mass of mortalities and nutrients contained in carcasses by a 1,000 bird flock of layers.

	Mass of Carcasses and Nutrients collected (lbs)		
	Mortalities	**Total N**	**Total P**
This report	210	8.3	1.5
Felton et al. (2009)	250	6.9	1.2

2.3.e Comparison of Layer Mortality Nutrients to Excreted Manure Nutrients

Table I.2.10 gives a comparison of the mass of nutrients contained in mortalities produced from a flock of 1,000 laying hens in one year to the mass of nutrients excreted by the same flock in a year. The American Society of Agricultural and Biological Engineers Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005) and the USDA-NRCS *Agricultural Waste Management Field Handbook* (USDA-NRCS, 2008) were used to calculate excreted manure values. Based on the data contained in Table I.2.10, if carcass nutrients are compared with excreted nutrients, **less than 0.70% of the nitrogen**

and less than 0.40% of the phosphorus produced on laying hen farms originates from mortalities. ASABE standards (2005) and USDA-NRCS guidelines (2008) estimate 0.0035 pounds of total nitrogen and 0.0011 pounds of total phosphorus are excreted by a laying hen each day, regardless of the weight of the hen. Assuming the cumulative mortalities for a flock of 1,000 birds over a 90-week laying period is 70 birds (Figure I.2.14), then the average number of birds housed over any 52-week period is 965. Mass of nitrogen excreted per year of a nominal flock of 1,000 hens is 965 hens X 0.0035 lbs. TN per hen per day X 365 days per year = 1,233 lbs TN. Likewise, the mass of phosphorus excreted by a flock of 1,000 is 387 lbs. TP per year (Table I.2.10).

Table I.2.10. Comparison of mass of nutrients contained in mortalities from a flock of 1,000 laying hens to the estimated mass of nutrients contained in manure excreted (ASABE, 2005; USDA-NRCS, 2008) by the same flock.

Nutrients Contained in Mortalities (lbs per 1,000 birds per year)		Nutrients Contained in Excreted Manure (lbs per 1,000 birds per year)	
TN	TP	TN	TP
8.3	1.5	1,200	390

2.4 Turkeys

2.4.a Turkeys in the Watershed

Total weight of turkeys raised for meat in the Chesapeake Bay Watershed was 875 million pounds in 2017 (USDA-NASS, 2018). This is considerably less than the 6.7 billion pounds of broilers raised during the same time period (Table I.2.1); however, turkey farms are concentrated in a few key areas. Production of turkeys is confined to three states – Pennsylvania, Virginia, and West Virginia (Table I.2.11), and production in those states is entirely within the Chesapeake Bay Watershed (Hawkins et al, 2016). Hawkins et al. (2016) indicated that half of the turkeys raised in the watershed are located in the Shenandoah Valley of Virginia.

Table I.2.11. Turkey production and number of turkeys raised in key states of the Chesapeake Bay Watershed in 2017 (USDA-NASS 2018).

	Annual Production (Million pounds yr^{-1})	Number of Birds Raised (Million yr^{-1})
Pennsylvania	205	7.5
Virginia	560	17
West Virginia	110	3.7
Total of 3 States	**875**	**28.2**

Turkey production is similar to broiler production in that young birds (poults) are supplied by integrators to contract growers who raise the birds to market weight. A difference with broilers, however, is turkeys are segregated by sex. Females (hens) are smaller and raised to a market size of 18 to 25 pounds in 12 to 16 weeks (Figure I.2.16); whereas, males (toms) are raised to a market weight of 42 to 48 pounds in 20 to 22 weeks (G.W. Malone, personal communication, 2019).

Figure I.2.16. Meat type turkeys (Deposit Photos).

Turkey housing (Figure I.2.17) is similar to broiler houses. Hatched birds are generally kept at a hatchery for the first days of life and are then transported in paper lined cages to brooder houses (Gatton et al., 2006). Ogejo et al. (2016) described three distinct types of turkey grow-out systems: one-stage houses, two-stage houses, and all-in-all-out houses.

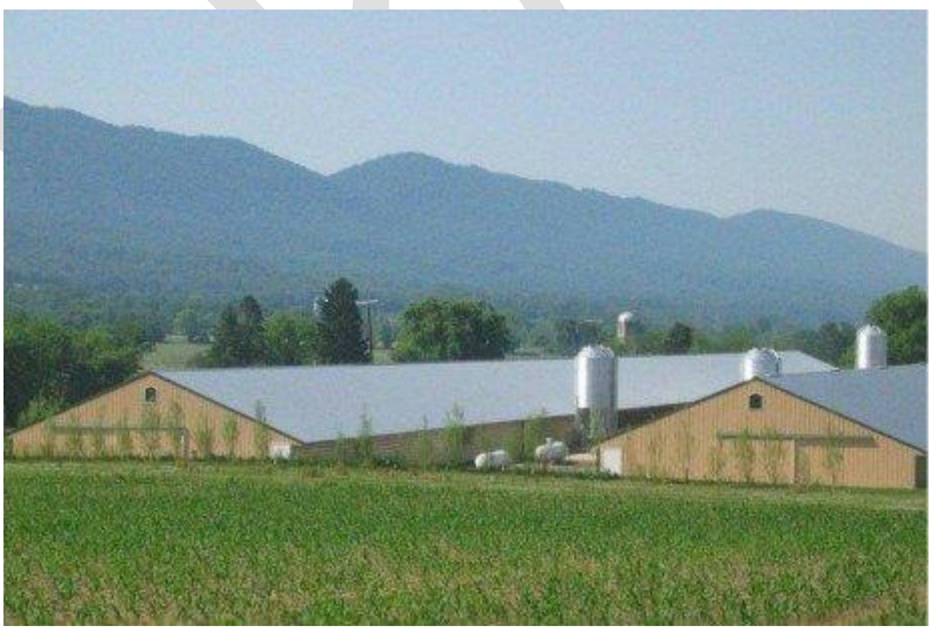

Figure I.2.17. A Pennsylvania turkey farm (Phil Clauer, Pennsylvania State University).

One-stage turkey houses are either brooder or grow-out houses. **Brooder houses** receive poults from the hatchery and grow those birds for 6 to 8 weeks. Birds are then moved to a **grow-out house** for another 6 to 14 weeks depending on gender and desired market weight. Brooder and grow-out houses may be located on the same farm, or birds may move from farm to farm. All litter is cleaned out of brooder houses after each flock and replaced with new bedding. Litter management of grow-out houses may be either partial reuse or multiuse.

With **partial litter reuse**, some crusted litter is removed from the house between flocks, and a total clean-out occurs after raising several flocks on the litter. Five to seven flocks are raised on litter before topping off with fresh bedding; litter is never completely cleaned out of a house under multiuse litter management.

In **two-stage turkey houses**, brooding and grow-out take place in the same house. Poults are started in the brood end of the house for 6 to 8 weeks, then moved to the other end of the house to be grown to market weight. Once a batch of brooders are moved, the brood area is cleaned and prepared to receive another starter flock. This results in two flocks of turkeys of different ages occupying opposite ends of the house. Litter removed from the brooding area is spread on the grower section of the house. Fresh bedding is spread in the brooder end, and litter is typically managed in the grow-out end using partial reuse.

Single flocks of turkeys are raised in the same **all-in-all-out turkey house** from brooding to harvest. Poults are started in a small section of the house. Flock space is expanded as the birds grow until the flock occupies the entire house. All-in-all-out houses use either partial reuse or multi-use litter handling.

For the remainder of this section, we will discuss mortalities occurring with a flock of turkeys from poult to market weight; i.e., mortalities encountered with a two-stage or an all-in-all-out house. Bear in mind that the amount of mortalities experienced by a particular farm may be vastly different than those on another. For instance, mortalities from a one-stage brooding house may be easily disposed of in a small composter, whereas a much larger unit is required to handle mortalities from a one-stage grow-out building. Viewing mortalities through the life cycle of the bird provides an accurate estimate of mortalities produced, and the nutrients contained in carcasses, relative to the total number of turkeys produced in a jurisdiction.

2.4.b Nutrients Contained in Turkey Mortalities

Growth Rate of Turkeys

Three sources were used to determine the average growth rate of turkeys. The Nicholas Select (Aviagen Turkeys, 2020) and Hybrid Converter (Hybrid Turkeys, 2020) represent whole frozen turkey genetic lines. The Hybrid XL (Hybrid Turkeys, 2020) is a line bred for the further processing market. The average liveweight of these three lines versus bird age is plotted in Figure I.2.18. Figure I.2.18 shows the marked difference in growth patterns of male and female turkeys.

Turkey Mortalities

There is also a difference in death rate between sexes in turkeys. Based on numbers provided by an industry source who chose not to be identified (G.W. Malone, personal communication, 2019), overall death loss in toms is approximately 15%, and death loss in hens ranges between 5 and 7% depending on market weight (Table I.2.12). Using the growth curves in Figure I.2.18 and the mortality patterns suggested in Table I.2.12, average mass of mortalities collected each week for a flock of 1,000 toms is plotted in Figure I.2.19. Average weekly mass of mortalities for a flock of 1,000 hens is shown in Figure

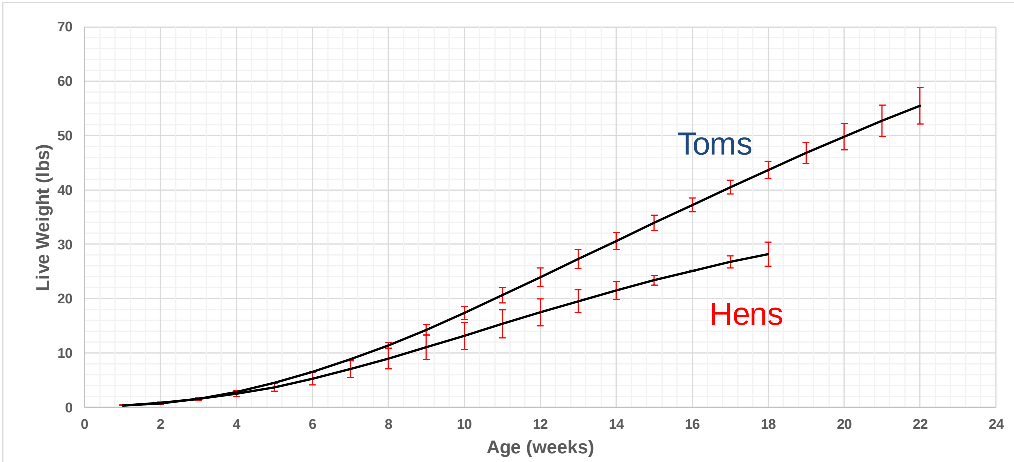

Figure I.2.18. Growth pattern of male (toms) and female (hens) turkeys based on average performance goals of Hybrid Converter, Hybrid XL (Hybrid Turkeys, 2020) and Nicholas Select (Aviagen Turkeys, 2020) genetic lines; error bars indicate 95% confidence interval.

Table I.2.12. Industry provided growth and mortality numbers for turkeys.

	Males (Toms)	Females (Hens)	
Market Weight (lbs)	42 - 48	18	25
Time to Reach Market Weight (weeks)	20 - 22	12	16
Mortality in First 7 to 10 Days (%)	2 - 3	1	1
Mortality in Last 2 to 3 Weeks (%)	1 - 2	0.5	0.5
Overall Mortality (%)	15	5	7

I.2.20. Cumulative mass of death losses is given for toms in Figure I.2.21 and for hens in Figure I.2.22. Cumulative mass of dead birds based on market weight of turkey toms and hens is given in Figure I.2.23.

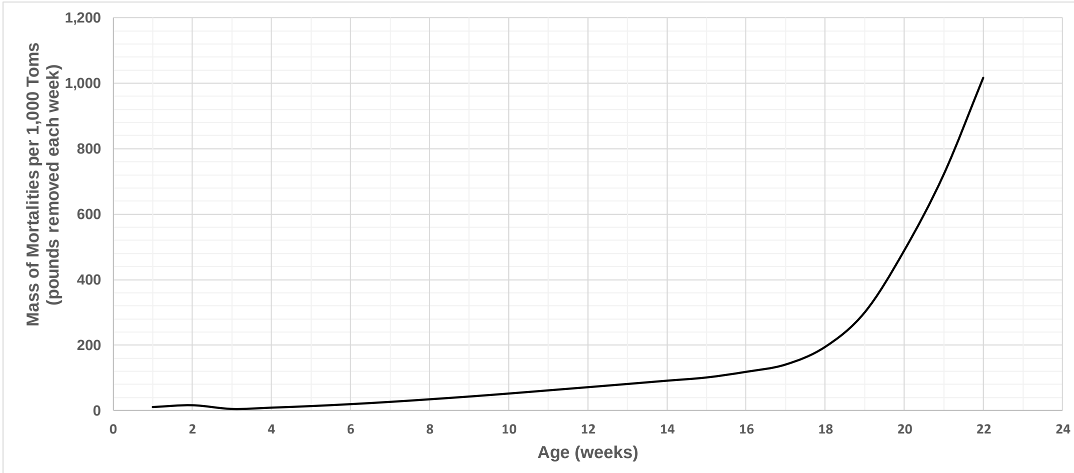

Figure I.2.19. Mass of dead birds collected each week from a flock of 1,000 tom turkeys based on the mortality pattern shown in Table I.2.12, multiplied by the average growth pattern shown in Figure I.2.18.

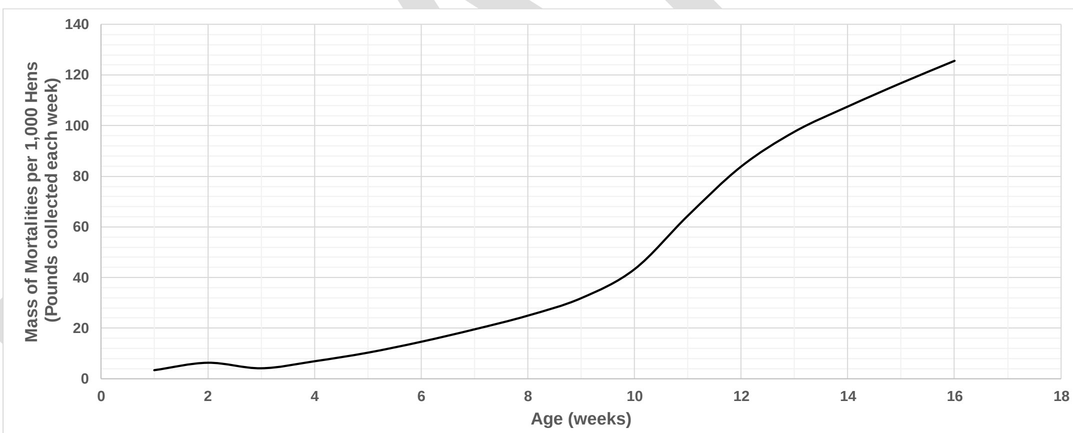

Figure I.2.20. Mass of dead birds collected each week from a flock of 1,000 turkey hens based on the mortality pattern shown in Table I.2.12, multiplied by the average growth pattern shown in Figure I.2.18.

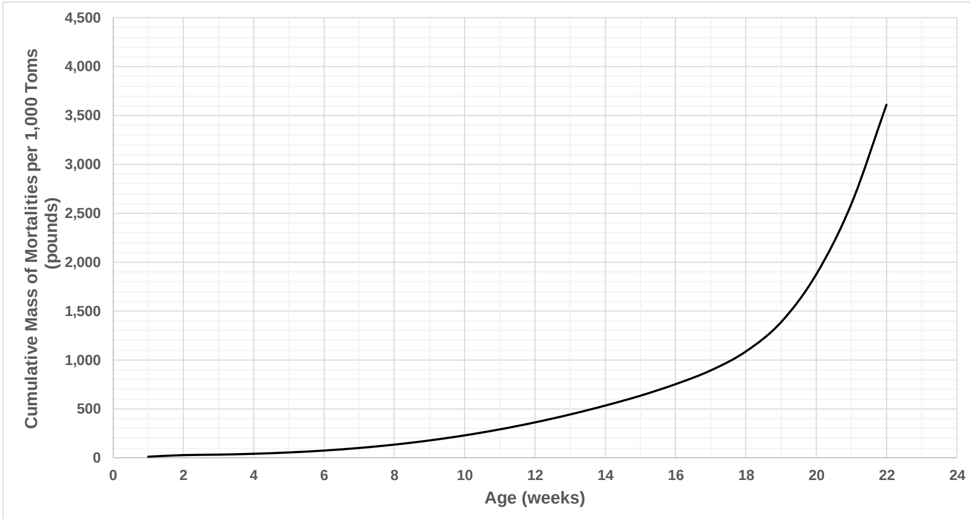

Figure I.2.21. Cumulative mass of dead birds collected from a flock of 1,000 tom turkeys (Based on data of Figure I.2.19).

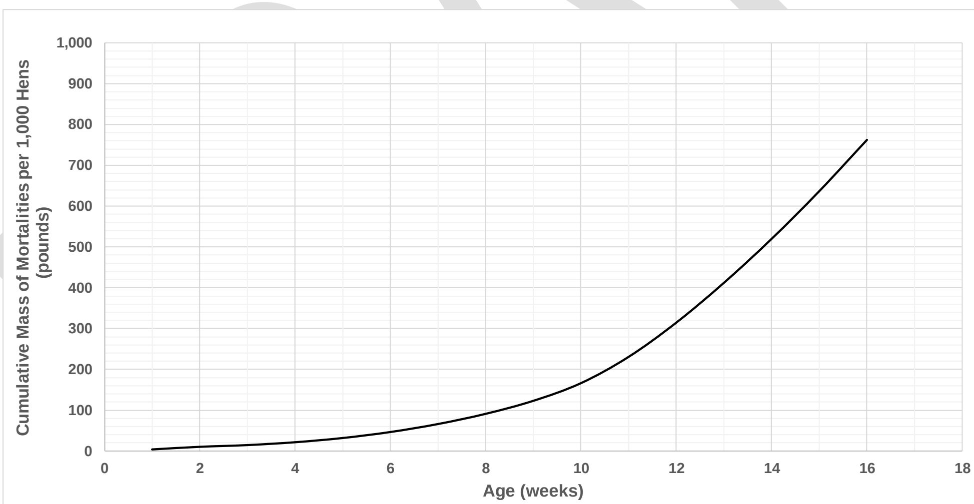

Figure I.2.22. Cumulative mass of dead birds collected from a flock of 1,000 turkey hens (based on data of Figure I.2.20).

Figure I.2.23. Cumulative mass of mortalities collected from a flock of 1,000 turkey toms and hens versus common market weights (based on data of Figures I.2.18, I.2.21, and I.2.22).

Carcass Composition

Only one literature source was found reporting the nitrogen composition of turkey carcasses. Li et al. (2009) determined that the nitrogen composition of tom turkey carcasses ranged between 2.46 and 2.93 percent total nitrogen, and generally increased with age of birds. They did not measure nitrogen content of hens. No literature values were found for the phosphorus content of turkey carcasses.

Mass of N and P in Carcasses From 1,000 Bird Flock

Using the literature value (Li et al., 2009) for nitrogen carcasses for tom turkeys to represent both sexes (2.46% TN first 7 weeks, 2.93% TN thereafter for toms; 2.46% TN first five weeks, and 2.93% TN thereafter for hens), and assuming the phosphorus content of turkey carcasses is similar to broilers (0.375% regardless of sex or age), cumulative mass of total nitrogen and phosphorus contained in turkey carcasses is graphed versus market weight in Figure I.2.24. Expected mass of mortalities and nutrients contained in mortalities at common market weights for both sexes of turkeys is given in Table I.2.13.

2.4.c Annual Mass of N and P from Turkey Carcasses

Ogejo et al. (2016) state that the number of flocks a farm raises per year varies with market conditions. However, one can assume the maximum number of flocks per year based on the time to grow to a certain market weight plus an 18-day turn-around between flocks. For example, using the growth curve of Figure I.2.18, 16 weeks are required, on average, to raise a 25-pound turkey hen. Adding the 18-day turn-around time gives 130 days per flock, or 2.8 flocks per year. Annual mass of mortalities and nutrients contained in mortalities per 1,000 bird capacity and AU are given in Table I.2.14.

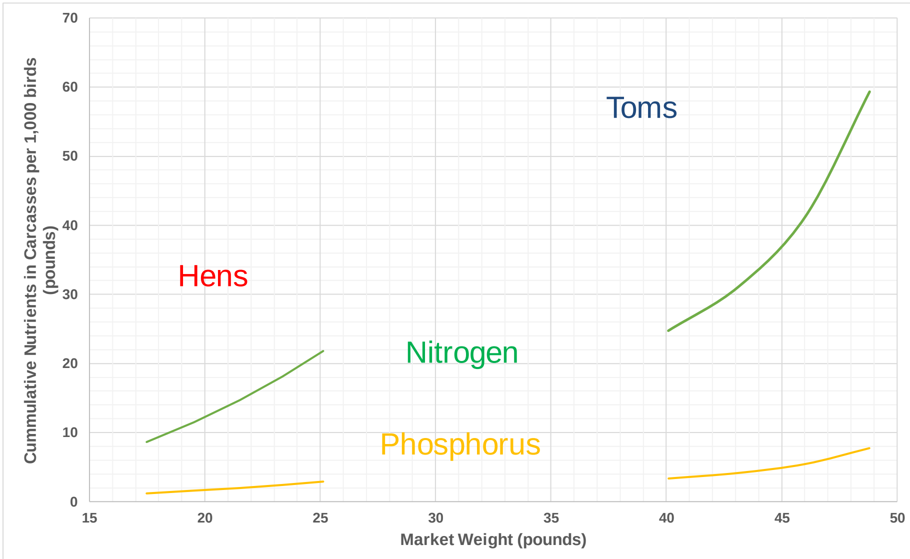

Figure I.2.24. Cumulative mass of total nitrogen and phosphorus contained in the carcasses produced from a flock of 1,000 birds based on market weight.

Table I.2.13. Estimated mass of mortalities and nutrients contained in carcasses during the grow-out of a 1,000 bird flock of turkeys.

Sex	Market Weight (lbs)	Mortalities (lbs)	Total Nitrogen (lbs)	Total Phosphorus (lbs)
Males (toms)	42	1,000	29	4.0
	44	1,200	34	4.4
	46	1,400	41	5.4
	48	1,700	50	6.5
Females (hens)	19	380	11	1.4
	21	480	14	1.8
	23	600	18	2.3
	25	760	22	2.9

Table I.2.14. Expected annual mass of mortalities produced and nutrients contained in carcasses for a 1,000 bird flock and one animal unit (AU = 1,000 lbs liveweight) of turkeys.

			Per 1,000 bird Flock (lbs year^{-1})			Per Animal Unit (lbs year^{-1})		
Sex	Market Weight (lbs)	Flocks per year	Mortalities	TN	TP	Mortalities	TN	TP
Toms	42	2.7	2,700	78	11	64	1.9	0.26
	44	2.6	3,100	88	11.5	70	2.0	0.26
	46	2.5	3,500	100	13.5	76	2.2	0.29
	48	2.4	4,100	120	16	85	2.5	0.33
Hens	19	3.3	1,250	36	4.6	65	1.9	0.24
	21	3.1	1,500	43	5.6	71	2.0	0.27
	23	3.0	1,800	54	6.9	78	2.3	0.30
	25	2.8	2,100	62	8.1	84	2.5	0.32

2.4.d Comparison of Results to the Simpson-Weammert Report

Felton et al. (2009) calculated the mass of turkey mortalities in the Chesapeake Bay watershed based on an average finished live weight of 24 pounds for toms and 15 pounds for hens. They assumed a 9% death loss for toms and 5% for hens. All deaths were assumed to occur when birds were in the 70% percentile of body weight (17 pound toms and 10 pound hens). Felton et al. (2009) did not report nutrient concentration of turkeys. The mass of mortalities estimated in this report are compared to estimates of Felton et al. (2009) for a flock of 1,000 turkey toms and hen in Table I.2.15. **Felton et al. (2009) underestimate the mass of mortalities from a flock of turkeys compared to the methods used in this report.** The discrepancy in the values lies in the market weights chosen by Felton et al. (2009), and the overall death losses experienced by both toms and hens. Based on the growth patterns of modern turkey breeds (Figure I.2.18), it would only take 11 weeks to reach the 24- and 15-pound market weights chosen by Felton et al. (2009). If raised for 11 weeks, death loss and mass of mortalities collected from modern birds would be much less than that estimated by Felton et al. (2009); however, since the estimates in this report are from the birds raised to higher market weights, both the death loss and body weight at time of death are higher than those assumed by Felton et al. (2009).

Table I.2.15. Comparison of mass of mortalities produced during the grow-out of a 1,000-bird flock of turkeys based on the method described in this report and the method of Felton et al (2009).

	Based on the method of this report		Based on the method of Felton et al.	
	Market Weight (lbs)	Mass of Mortalities (lbs)	Market Weight (lbs)	Mass of Mortalities (lbs)
Toms	48	1,700	24	1,500
Hens	25	760	15	500

2.4.e Comparison of Turkey Mortality Nutrients to Excreted Manure Nutrients

Table I.2.16 compares the nutrients contained in turkey carcasses to the mass excreted from a flock of 1,000 toms and hens. The American Society of Agricultural and Biological Engineers Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005) and the USDA-NRCS *Agricultural Waste Management Field Handbook* (USDA-NRCS, 2008) were used to calculate excreted manure values. Based on the data contained in Table I.2.16, if carcass nutrients are combined with excreted nutrients, **approximately 4% of the nitrogen and 2% of the phosphorus produced on both tom and hen farms originate from mortalities**. The ASABE standard (2005) estimates the mass of nitrogen excreted by turkeys to be 1.2 pounds TN per finished tom and 0.57 pounds TN per finished hen. Phosphorus excretion is estimated at 0.36 pounds TP per finished tom and 0.15 pounds TP per finished hen. USDA-NRCS Guidelines (2008) assume market weight of toms to be 48 pounds and hens to be 25 pounds. Number of live turkeys contributing to excreted manure values in Table I.2.16 was estimated to be 893 toms and 935 hens.

Table I.2.16. Comparison of mass of nutrients contained in mortalities from a flock of 1,000 turkeys to the estimated mass of nutrients contained in manure excreted by the same flock (ASABE, 2005; USDA-NRCS, 2018).

	Nutrients Contained in Mortalities (lbs per 1,000 birds)		Nutrients Contained in Excreted Manure (lbs per 1,000 birds)	
	TN	**TP**	**TN**	**TP**
Toms **48 lbs market weight**	50	6.5	1,100	320
Hens **25 lbs market weight**	22	2.9	530	150

2.5 Assumed Values of Mortality Masses and Carcass Nutrients for Watershed

Without any further defining information, the values given in Table I.2.17 should be used for mass of mortalities and nutrients produced annually per 1,000 bird flock and AU of finished birds. For broilers, the numbers given in Table I.2.17 are for a six-pound market weight (the average for the states in the watershed, Table I.2.1). Laying hen population within a jurisdiction is assumed to remain stable; therefore, the values in Table I.2.17 can be used for a base population within a one-county jurisdiction. The values for turkey hens and toms in Table I.2.17 are based on the largest market size for each sex. If the sex of turkeys is not known for a particular jurisdiction, values for AU can be used interchangeably for both sexes.

Table 17. Assumed annual mass of mortalities and nutrients contained in mortalities produced by all types of poultry production systems.

	Annual Mortalities and Nutrients Produced per Flocks of 1,000 Birds (lbs year^{-1})			Annual Mortalities and Nutrients Produced per AU (lbs year^{-1})		
	Mortalities	*TN*	*TP*	*Mortalities*	*TN*	*TP*
Broilers	430	11	1.5	72	1.8	0.25
Layers	210	8.3	1.5	55	2.2	0.40
Turkey toms	4,100	120	16.0	85	2.5	0.33
Turkey hens	2,100	62	8.1	84	2.5	0.32

2.6 Future Research Needs

2.6.a Types of Farms Not Covered in This Report

This report does not include mortality nutrient estimates for pullet and breeder farms for broiler, layer, and turkey production. These farms may produce a significant amount of mortalities. Immature and mature breeding stocks are grown on these farms to produce eggs that hatch into the birds covered in this report and/or future breeding animals. These farms were not included in the report, because sufficient data was not available from USDA-NASS (2017) to assess their presence in the watershed. Some breeder farms supplying eggs to the watershed may not exist within the boundaries of the Chesapeake Bay Watershed. It is quite possible, for instance, that broiler eggs supplied to Delmarva hatcheries are produced from broiler breeder hens and pullets grown in other states, such as North Carolina.

2.6.b Need for On-farm Data Collection

Although we are confident in the data produced in this report, the values were primarily produced through unpublished industry estimations of death losses and information provided by breeders. Research should be undertaken to determine the actual mass of mortalities produced on farms under the cultural practices used in the watershed.

2.6.c Need for data on Whole Carcass Nutrient Content

No data for whole carcass nutrient content of turkey hens either living or dead were found during the literature review conducted for this report. Data on laying hen carcasses was also limited. Even though more literature was found on broiler carcasses, only two sources were found providing phosphorus content of carcasses.

2.7 References

ASABE Standards. (2005). 384.2 Manure Production and Characteristics. St Joseph, MI: ASABE.

Aviagen. (2019). Ross 308/Ross 308 FF Broiler: Performance Objectives. 0419-ANNR 107. Retrieved from http://en.aviagen.com/tech-center/download/13/Ross308-308FF-BroilerPO2019-EN.pdf

Aviagen Turkeys. (2020). Nicholas Select: Commercial Performance Objectives. Retrieved from https://www.aviagenturkeys.us/uploads/2015/11/13/nicholas_comm_perf_obj_select_2015.pdf

Caldas, J.V., Boonsinchai, N., Wang, J., England, J.A., & Coon, C.N. (2019). The dynamics of body composition and body energy content in broilers. *Poultry Science* (98)2:866-877. https://doi.org/10.3382/ps/pey422

Cobb-Vantress. (2018). Cobb 500: Broiler Performance & Nutrition Supplement. L-2114-08 EN: August 2018. Retrieved from https://cobbstorage.blob.core.windows.net/guides/70dec630-0abf-11e9-9c88-c51e407c53ab

Fekete, D., Hannahs, A., Luu, J., & Pegnato, P. (2019) [Unpublished Manuscript]. University of Maryland.

Felton, G., Timmons, J., & Ogejo, J.A.. (2009). Mortality composting, definition and nutrient and sediment reduction effectiveness estimates, pp 393-412, In Simpson, T. and J. Weammert. *Final Report, Developing Best Management Practices and Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay Watershed*. College Park, MD: Univ. of MD Mid Atlantic Water Program.

Gatton, H., Weaver, M.J., Novak, C.L., & Nessler, S.E.. (2006). *Crop Profile for Turkey in Virginia.* Blacksburg, VA: Virginia Polytechnic and State University.

Haque, A.K.M.A, Lyons, J.J., & Vandepopuliere, J.M.. (1991). Extrusion processing of broiler starter diets containing ground whole hens, poultry byproduct meal, feather meal, or ground feathers. *Poultry Science*. 70:234-240.

Hawkins, S., Hamilton, D., Mcintosh, B., Moyle, J., Risse, M., & Vanderstampen, P. (2016). *Animal Waste Systems, Recommendations from the BMP Expert Panel for the Animal Waste Management Systems in the Phase 6 Watershed Model.* Annapolis, MD: Chesapeake Bay Program.

Hybrid Turkeys. (2020). Performance Goals: Hybrid Converter and Hybrid XL. Retrieved fromhttps://www.hybridturkeys.com/en/product/

Hyline International. (2019). *Commercial Management Guides for Hyline W38, Hyline W80 and Hyline Brown.* Retrieved from https://www.hyline.com/aspx/products/productinformation.aspx

Li, H., Xin, H., Burns, R.T., Hoff, S.J., Harmon, J.D., Jacobson, L.D., Noll, S., & Koziel, J.A.. (2009). Can mass balance be trusted in estimating N loss for meat-poultry housing? ASABE Paper No. 09-6323. St. Joseph, MI: ASABE.

Lomax, K.M., Malone, G.W., & Saylor, W.W.. (1991). Acid preservation for poultry carcass utilization. ASAE Paper No. 91-4051. St Joseph, MI: ASABE.

Midwest Plan Service (MWPS). (1980). *Structures and Environment Handbook, MWPS-1, 10th ed.* Ames, IA: Midwest Plan Service.

Ogejo, J.A., Kristoff, J., Shifflett, A., Sexton, T., Long, B., & Dubin, M.. (2016). *Final Report for Turkey Litter Generation and Nutrient Content for Use in Phase 6.0 Chesapeake Bay Program Watershed Model.* Annapolis, MD: Chesapeake Bay Program.

USDA-NASS. (2018). *Poultry – Production and Value, April 2018*. Washington, DC: United States Department of Agriculture, National Agricultural Statistics Service.

USDA-NRCS. (2008). *Part 651, Agricultural Waste Management Field Handbook, Chapter 4: Agricultural Waste Characteristics.* Washington DC: United States Depart of Agricultural, Natural Resources Conservation Service.

Vanderpopuliere, J.M. (1990). Carcass preservation systems – extrusion. Proceedings of the National Poultry Waste Management Symposium. Raleigh, NC. ISBNT 0-9627682-6-2. pp 64-68.

3. Swine

3.1 Definitions

Barrow: A castrated male pig or hog.

Boar: An intact, sexually mature male hog used for breeding purposes.

Breeder Farm: A farm whose main purpose is production of male or female breeding stock. A breeder farm that produces primarily replacement gilts for sale (or distribution to meat producing farms in vertical integration) is called a **multiplier farm** or **multiplier unit**. A breeder farm that raises replacement boars is called a **Boar Farm**. Boar farms may also produce semen for artificial insemination and conduct boar performance testing.

Farrow: The act of giving birth for swine. Farms with the term farrow in their descriptive title are farms where sows are bred to produce piglets that typically enter the food supply chain. A group of piglets born at the same time is called a **litter**. Sows and their litters are often counted as single unit whether they are housed in farrowing crates or open pens.

Farrow-to-Finish Farm: A farm in which all phases of production (breeding, gestation, farrowing, nursery, growing, finishing) are housed at the same location or under the same management. A self-contained or **Closed Herd** farrow-to-finish farm also raises its own replacement gilts, and occasionally boars.

Farrow-to-Feeder Farm: A farm whose purpose is the production of feeder hogs. Gestation, farrowing, and nursery units are located at the same location.

Farrow-to-Wean Farm: a farm that produces weaned pigs to be moved to off-site nurseries or sold to wean-to-finish farms.

Feeder Pig: A pig raised for meat production weighing approximately 55 pounds.

Finisher Farm: A farm or production unit whose purpose is to raise pigs to market weight, around 270 pounds or more. This is the final production phase before harvest of a hog for human consumption. Contemporary finishing farms receive **Feeder Pigs** from a **Nursery.**

Finishing: The final phase of meat production. **Finishing hogs**, or **Finishers,** are generally larger than 120 pounds on average. Fat deposition becomes a major component of weight gain during finishing.

Gilt: A female hog weighing more than 50 pounds that has not been bred, or a bred female that has never farrowed a litter in the past. Once a female farrows her first litter her status moves from gilt to sow.

Grower: A term not frequently used in modern swine farming meaning a swine animal raised for meat production (usually a barrow or gilt) weighing between 50 and 120 pounds.

Hog: a swine animal weighing more than 120 pounds

Market Hog: A hog that leaves the finisher destined for harvest at a processing plant.

Nursery: A farm or production unit whose purpose is to raise weaned pigs to feeder pigs in isolation. A nursery often serves a single farrow-to-wean farm and one that does is called an **Off-Site Nursery.**

Pig: A swine animal weighing less than 120 pounds.

Piglet: A newly born pig.

Porcine: Adjective referring to swine, hogs, or pigs.

Sow: A female pig that has already delivered its first litter of piglets. Sows typically weigh 450 to 500 pounds.

Sow Farm: A farm or production unit whose purpose is to produce pigs that are transported to Finisher Farms. Sows farms can be further divided between Farrow-to-Wean and Farrow-to-Feeder farms.

Swine: Domesticated animals of the genus *Sus scrofa domesticus*.

Weaning: The act of removing a piglet from its mother's milk and converting it to a solid diet. Newly weaned young pigs are sometimes called **Shoats** but are more commonly referred to as **Weaned Pigs or Nursery Pigs**.

Wean-to-Finish Farm: A farm whose purpose is production of market hogs. Pigs are purchased or brought to the farm after weaning.

3.2 Swine in the Watershed

Swine production in the Chesapeake Bay Watershed is described on a state-by-state basis in Table I.3.1. Pennsylvania has by far the largest swine production in the Chesapeake Bay Watershed, and Hawkins et al. (2016) estimated that 42% of all non-breeding inventory of hogs and pigs in Pennsylvania were located in Lancaster and Lebanon Counties. Figure I.3.1 shows a traditional hog farm in Lancaster County. Hawkins et al. (2016) stated that no pigs were raised in any Delaware counties that had more than 50% of its land area located within the watershed. Swine production in New York is much higher than is shown in Table I.3.1, but most of New York's swine production is located outside the watershed (Hawkins et al., 2016).

Table I.3.1. 2017 estimated swine inventory and sales in counties with more than fifty percent of their land area within the Chesapeake Bay Watershed, by state (USDA-NASS, 2019; Hawkins et al., 2016).

	Total Hogs and Pigs Inventory	Hogs and Pigs Sold per Year
Maryland	18,000	63,000
New York	2,900	11,000
Pennsylvania	1,100,000	4,800,000
Virginia	110,000	280,000
West Virginia	1,800	3,500
Total Watershed	**1,232,700**	**5,157,500**

3.2.a Animal Life Cycles and Types of Farms

Hog production is difficult to quantify using the USDA-NASS (2019) values of Hog and Pig Inventory and Hog and Pigs sold. The primary difficulty lies in the fact that the instantaneous inventory of hogs and pigs at any one time depends on the life cycles of breeding and non-breeding stock, which are not necessarily in sync with the calendar year.

Sows and boars live for multiple years, growing to breeding age in roughly six months to a year. Depending on intensity of production, sows may be bred to have between two and two-and-a-half litters per year (Pork Checkoff, 2019). Figure I.3.2 shows a modern swine farrowing building with sows and pigs housed in farrowing crates. Nationally, the replacement rate of sows (or the fraction of gestating sows replaced by new gilts) is 45%, meaning an individual sow will remain in production approximately two years and eleven weeks (Global Ag Media, 2010). Artificial insemination is widely

Figure I.3.1. Aerial view of Jeff and Sue Frey swine farm in Lancaster County, PA; 2012 Pork Industry Environmental Stewards (National Hog Farmer).

Figure I.3.2. Interior of a farrowing building with several sows and piglets in farrowing crates (Thepigsite.com Global Ag Media).

practiced by hog farms in the watershed. Using artificial insemination, the number of boars required per farm is greatly reduced. With artificial insemination (even if semen is collected from boars housed on the farm) the ratio of sows to boars is 1:100. Using natural "hand mating", sow-to-boar ratio is approximately 1:20 (Estienne et al., 2016).

The growth of market hogs is broken into five phases: farrowing, weaning, nursery (15 to 55 pounds), growing (55 to 120 pounds), and finishing (120 to 250-280 pounds). The entire life of a market hog from birth to slaughter lasts roughly six months. These days, piglets are weaned early at about three weeks. They spend roughly seven weeks in a nursery and become 55-pound feeder pigs. Feeder pigs are fed to market size over the span of sixteen to seventeen weeks (Estienne et al., 2016; Pork Checkoff, 2019). Often the growing and finishing phases are housed continuously in one facility.

Different parts of hog production can take place at several different locations, and farms are named based on what productions units are located on the farm. The entire breeding and feeding cycles are housed in one location on farrow-to-finish farms. Sow breeding and gestation, grow-out of replacement gilts, farrowing of baby piglets, and weaning take place on farrow-to-wean farms. Sometimes, grow-out of replacement gilts takes place on a special production unit called a multiplier or an isolation unit. The main product of farrow-to-wean farms are weaned pigs. A sow farm that also contains an on-site nursery is called a farrow-to-feeder farm.

Weaned pigs are raised to feeder pigs in nurseries. The interior of a nursery building is shown in Figure I.3.3. Most typically, nursery pigs are grown in an all-in-all-out fashion – weaned pigs arrive as a group, grow together, and leave in the same group. Empty all-in-all-out nurseries are completely cleaned and disinfected between groups. An off-site nursery will grow 6 to 8 groups, or turns, per year. In modern commercial production, a sow farm supplies pigs to a designated nursery in a scheme referred to as the sow farm's 'production flow'. This single sourcing philosophy greatly benefits animal health because animals are not introduced to disease challenges that may exist in other sow production flows. In turn, benefits are realized in production efficiencies, feed efficiencies, and decreased mortalities. Similarly, nursery pigs are moved to designated locations for finishing (Estienne et al., 2016).

Finisher farms produce market hogs from weaned or feeder pigs. A typical finisher facility is shown in Figure I.3.4. In the Chesapeake Bay Watershed, market hogs average 270 pounds (Etienne et al., 2016). A farm that receives weaned pigs from a farrow-to-wean farm is called a wean-to-finish farm. Finisher farms receiving feeder pigs from off-site nurseries or farrow-to-feeder farms are called a feeder-to-finish farms. Finisher farms are usually operated in an all-in-all-out fashion, with wean-to-finish farms having an average of 2.1 turns per year, and feeder-to-finish farms having 2.7 turns per year.

Types of farms within the state of Pennsylvania in 2017 are shown in Table I.3.2. The table lists number of farms and inventory housed on each type of farm segregated by size of farm. The distribution of farm types within Pennsylvania is taken to be representative of the entire watershed. Although small swine farms (less than 100 total hog and pig inventory) are greatest in number, more hogs are housed on farms with more than 1,000 animals in total inventory. Relatively few animals are housed on farrow-to-finish farms -- less than 8% of the total hog and pig inventory in Pennsylvania was housed on a farrow-to-finish farms in 2017. Multi-site production dominates swine farming in the watershed, particularly among larger farms. The most common combination of farms is farrow-to-wean, off-site-nursery, and finisher. Vertically integrated companies use multi-site production in complexes centered regionally around feed mills, with contract growers operating most production units.

Figure I.3.3. Chris Hoffman, 2019-2020 National Pork Board's America's Pig Farmer of the Year, in the nursery of his Pennsylvania hog farm (Farmanddairy.com).

Figure I.3.4. Interior of a finisher building (National Hog Farmer).

Table I.3.2. Hogs and pigs in Pennsylvania, inventory by type of operation, 2017 (From USDA-NASS, 2019).

Size of Individual Farm (Inventory)	Farrow-to-Wean		Farrow-to-Finish		Finish Only		Farrow-to-Feeder		Off-Site Nursery		Other	
	Number of Farms	**Total Inventory on Farm Type**	**Number of Farms**	**Total Inventory on Farm Type**	**Number of Farms**	**Total Inventory on Farm Type**	**Number of Farms**	**Total Inventory on Farm Type**	**Number of Farms**	**Total Inventory on Farm Type**	**Number of Farms**	**Total Inventory on Farm Type**
1 to 24	173	1,588	481	3,243	898	4,450	189	1,519	18	56	278	1,039
25 to 49	16	582	61	2,036	23	768	30	961	3	118	11	348
50 to 99	16	851	53	3,528	25	1,661	9	602	-	-	3	215
100 to 199	1	-	25	3,420	11	1,384	11	-	-	-	-	-
200 to 499	8	-	9	2,734	48	14,879	6	1,892	1	-	2	-
500 to 999	6	4,791	17	12,438	39	28,114	5	3,310	2	-	1	-
1,000 to 1,999	5	8,019	6	9,287	48	60,916	5	-	7	8,121	1	-
2,000 to 4,999	14	38,290	8	27,040	113	336,530	8	28,400	19	67,017	5	16,800
5,000 or more	14	176,793	4	29,531	34	276,420	2	-	3	21,388	2	-
Total	**253**	**234,039**	**664**	**93,237**	**1,239**	**725,122**	**265**	**56,898**	**53**	**98,233**	**303**	**31,739**

3.2.b Total Hogs and Pig Inventory

Inventory is the total number of animals housed on a farm or living within a political or natural boundary at one time. It is difficult to describe swine production systems (and in particular the number and mass of mortalities produced on a farm) based solely on inventory. One needs to understand the different groupings of animals found on various production units to determine mortality number and mass. Table I.3.3 gives the average number of each type of animal in a total inventory for a farrow-to-finish operation. The operation shown has a total of 1,150 sows in inventory, and is expected to produce 25,000 market hogs each year. These numbers are roughly equivalent to the Chesapeake Bay Program's population values of 1,150 hogs and pigs for breeding and 25,000 hogs for slaughter. The inventory shown was calculated using industry average values for litters per year, pigs born per litter, turns per year in nursery and finisher given in this section -- plus mortality values given in the following section. This table can be used to determine breakdown of groupings for other types of farms. To determine inventory for a farrow-to-wean farm, for instance, sum gestating sows, boars, gilts, sows with litters, and piglets in litters. Off-site nurseries and grow-finish farms have inventory equal to the head space available in barns, or the "number housed" value in Table I.3.3. Farrow-to-finish inventory can be used to estimate total numbers in each animal group for an entire state or watershed -- provided animals do not move across state or watershed boundaries during their lifetime. To estimate number of animals in each age or production group within a state, multiply total hogs and pigs inventory in Table I.3.1 by "percentage of total housed" for the group in Table I.3.3.

Table I.3.3. Approximate instantaneous inventory for a closed-herd, farrow-to-finish farm using artificial insemination with 1,150 sows in breeding and producing 25,000 market hogs (6,750 AUs) annually.

	Number Housed	Percentage of Total Housed	Liveweight (AUs)	Percentage of Total Liveweight
Gestating Sows	990	5.87	446	24.70
Boars	12	0.07	8.4	0.47
Gilts	115	0.68	34.5	1.91
Sows with Litters	160	0.95	72	3.99
Piglets in Litters	2,000	11.85	15	0.83
Nursery Pigs	3,900	23.11	130	7.20
Finisher Pigs and Hogs	9,700	57.47	1,100	60.90
Total	**16,877**		**1,805.9**	

3.2.c Hog Production – Hogs and Pigs Sold

Another complicating factor in understanding the number of hogs in the watershed is the use of hog and pig sales as a metric. The term "Hog and Pigs Sold" does not state exactly what is being sold. This term should not be taken to mean finished hogs marketed. A hog or a pig can be "sold" at any time in its breeding or growing cycle. In fact, a single hog can be sold several times: as a weaned pig, a feeder pig, and as a market hog. Breeding stock (replacement gilts, replacement boars, and sows destined for slaughter) can all be sold at some point in their life. The Chesapeake Bay Program's population value of "hogs for slaughter" is roughly equivalent to the annual number of hogs marketed in an equivalent farrow-to-finish farm.

3.2.d Type of Producer

Animals may be owned by individual family farms, by an integrator (vertically integrated, sometimes publicly owned corporations), and every permutation in between. A common form of ownership is "contract growing" where an independent contractor raises or grows animals owned by another individual or corporation. Table I.3.4 lists number of farms and inventory for the three most common ownership classes in Pennsylvania. As shown in Table I.3.4, small farms owned by an independent grower were the most common type of producer in Pennsylvania in 2017; however, most of the inventory was housed on relatively large farms (inventory greater than 2,000) and raised by contract growers.

Table I.3.4. Hogs and pigs in Pennsylvania, inventory by type of producer, 2017 (From USDA-NASS, 2019).

Size of Individual Farm (Inventory)	Independent Grower		Integrator or Contractor		Contract Grower	
	Number of Farms	Total Inventory on Farm Type	Number of Farms	Total Inventory on Farm Type	Number of Farms	Total Inventory on Farm Type
1 to 24	2,037	11,895	-	-	-	-
25 to 49	144	4,813	-	-	-	-
50 to 99	100	6,494	1	-	5	-
100 to 199	47	-	-	-	1	-
200 to 499	39	11,642	-	-	35	11,763
500 to 999	33	-	1	-	36	26,249
1,000 to 1,999	14	20,910	-	-	58	72,186
2,000 to 4,999	18	-	9	-	140	430,692
5,000 or more	16	102,131	9	160,862	34	265,139
Total	**2,448**	**242,997**	**20**	**189,832**	**309**	**806,472**

3.2.e Buildings and Management

Almost all swine production in the watershed takes place under roof in mechanically ventilated buildings with fully-slatted or partially-slatted floors. Most manure storage takes place in-building in deep pits. A few producers use shallow pits with manure flushed to outdoor storage ponds. Very little swine manure is stored and treated in lagoons in the watershed. There are a few anaerobic digesters. Older buildings are ventilated with a combination of cross or ridge and pit ventilation. Newer buildings are usually ventilated with a tunnel ventilation.

3.3 Nutrients Contained in Swine Mortalities

3.3.a Growth Rate of Hogs

Growth from farrowing to market weight is not linear. A representative growth curve (Figure I.3.5) was documented in *MWPS-8, Swine Housing and Equipment Handbook* (MWPS, 1983). At the time *MWPS-8* was published, the market weight of hogs averaged 230 pounds, compared to the most recent reported national average market weight of 280 pounds (USDA-AMS, 2019). In addition to larger carcass size, the time for hogs to grow to today's market weight has been shortened. In 1983, it took an average of 30 weeks for a hog to grow to the 230 market weight (MWPS, 1983); today's hogs reach 280 pounds in six months or 26 weeks (Pork Checkoff, 2019). Assuming today's faster growing pigs follow a similar "S" shape growth curve to that documented in MWPS (1983), a growth curve was devised for an average market weight of 280 pounds (Figure I.3.5) over a 26-week period. The average growth curve based on Pork Checkoff (2019) data shown in Figure I.3.5 was used in all further calculations.

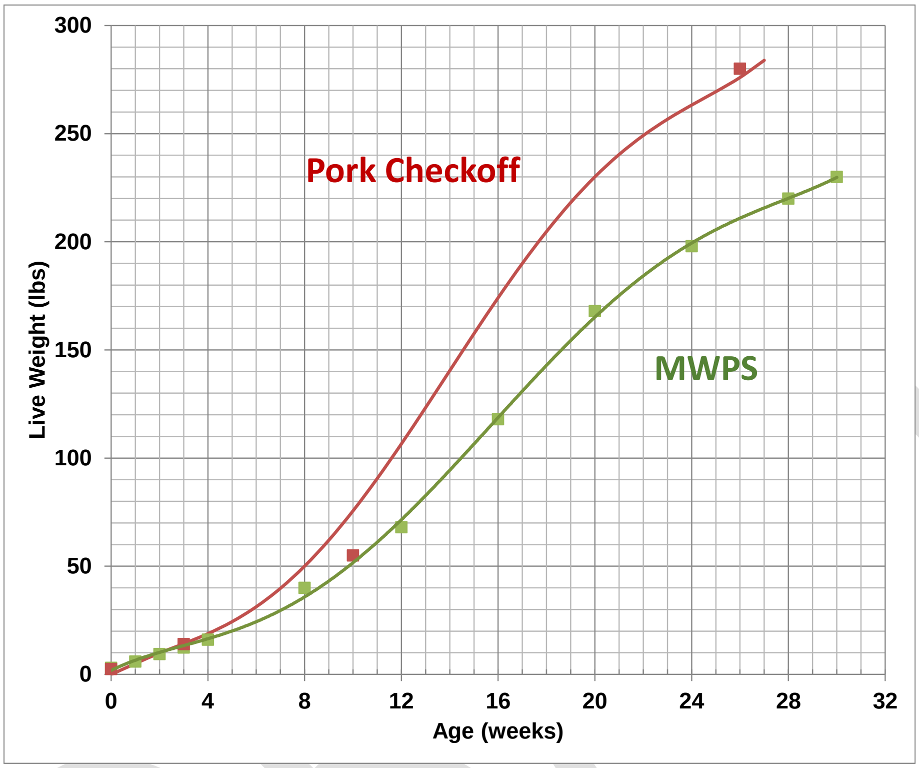

Figure I.3.5. Growth curve for swine fitted to data of MWPS (1983) and Pork Checkoff (2019).

3.3.b Mortalities

Few studies report death loss on sow farms in the Chesapeake Bay Watershed. However, it can be assumed that mortality rates reported from the following studies can be transferred to similar production systems in the Watershed.

Management and productivity of U.S. swine operations located in 13 states (The only watershed state included in the study was Pennsylvania) were estimated In the USDA National Animal Health Monitoring System (NAHMS) Swine 2012 study (USDA APHIS, 2012a). The Swine 2012 study was conducted on operations that had 100 or more swine in total inventory. The reported overall piglets born per litter was 11.3, of which 10.3 were born alive, and 9.3 were weaned. In addition, 3.6% of the piglets that entered nursery phase died, and 4.1% of the piglets that entered the grower/finisher phase died. For the wean-to-finish operation, 1.4% of wean-to-finish pigs died before the split, while nearly two-thirds of the deaths were attributed to respiratory problems. Overall, 4.2% of pigs in the wean-to-finish phase died after the split, and almost 60% of the deaths after the split were attributed to respiratory problems.

In contrast to the larger farms, the USDA NAHMS study for small-enterprise swine operations targeted operations with fewer than 100 pigs (USDA APHIS, 2012b). .. Overall, the study found that 7.8% of breeding animals (sows, gilts, and boars) died from June 2011, to May 2012. Within the same period, the percentage of pigs that died were 7.8% and 3.4% for pre-weaned and weaned pigs, respectively.

Maes et al. (2001) investigated mortality in 14 swine complexes, including 146 closeouts comprising 1,345,127 pigs. Overall mortality during the entire grow-finish period was expressed as deaths per 1,000 pig weeks. Weekly mortality was reported as the number of pigs that died during a week divided by the average inventory of pigs during that week. Mean overall weekly mortality during the 4 year study period (1996-2000) was 3.23 per 1,000 pigs. Mortality increased steadily from 2.6 (1996) to 3.6 per 1,000 pigs (1999) (P<.001). Late mortality was consistently greater than early mortality (P<.001), and increased from 3.1 (1996) to 5.5 pigs per 1,000 pigs (1999) (P<.001). The study was conducted in a three-site production system consisting of one sow complex, five similar nursery complexes, and 14 grow-finish complexes. The grow-finish complex consisted of eight barns with a capacity of 1150 pigs per barn (9200 pigs per complex). The grow-finish facilities, built in 1994 to 1995, contained 46 pens per barn. At about 10 weeks of age, nursery pigs were moved into the finishing barns, with 25 to 26 pigs per pen, and an initial stocking density of approximately 0.641 m^2 per pig. Barrows and gilts were not housed separately. The barns were tunnel-ventilated (i.e., plastic ducts with a fan in one end of the barn) and had fully slatted concrete floors. Manure was flushed daily to a lagoon. Pigs were fed a corn-soybean feed (meal) ad libitum using a wet-dry feeding system. Six different feeding phases were used during the grow-finish period, with bacitracin added to all phases as a growth promotant.

Data was collected from one large swine system in the Midwest from March 2013 (before PEDv had been reported in the USA) to June 2014. The study was conducted to evaluate the impact of porcine epidemic diarrhea virus (PEDv) infection on growing pigs' performance (Alvarez et al., 2015b). All sows and boars were cross-bred commercial genetics. All pigs were vaccinated for Mycoplasma hyopneumoniae, porcine circovirus (PCV) and porcine reproductive and respiratory syndrome (PRRS). PCV was present in all farms while PRRS virus (PRRSv) was occasionally detected in a proportion. Mortality was determined as percentage dying divided by the total pigs started. Before the PEDv outbreak overall mean monthly mortality ranged between 4.3–4.8%. Analysis of the mortality of the first PED-positive batches on each flow revealed an increase in the mortality up to 14.9% in nursery and 15.5% in wean-to-finish (WF) operation.

In a similar study, mortality rates of 9 wean-to-finish farms in the Midwest region of the United States were studied to evaluate the association between Influenza A Virus (IAV) and PRRSV (Alvarez et al., 2015a). All farms were managed by one firm and were relatively similar to each other in terms of management practices. Performance records from all pig batches weaned into WF sites between June 2011 and April 2014 were included. A total of 185 batches of WF pigs in which the IAV status of the sow farm at weaning had been determined within one week before or after their weaning were initially selected. Mortality in those batches ranged between 0 and 25%. Mean mortality was higher in the IAV + batches (5.92%) compared to IAV − batches (5.21%), and in PRRSV + batches (6.68%) compared to PRRS − batches (5.43%), although differences were not statistically significant (P = 0.052 and P = 0.20 respectively). Mean mortality was also higher in batches weaned in winter (5.61%) compared to summer season (5.34%), but again differences were not significant (P = 0.46).

Another Midwest-based study of 1010 weaned pigs reared in one nursery in Iowa from weaning (17 ± 2 days) until 10 weeks of age evaluated the likelihood of survival and low growth during the nursery phase (Larriestra et al., 2006). Weaned pigs from two sow units of 2,500 sows per unit were included in this study. In both sow units, the preweaning mortality was approximately 14% and clinical coccidiosis was the major disease concern in the progeny. The nursery mortality rate was reported as 7.03%. In both farms, porcine reproductive and respiratory syndrome (PRRS) was endemic.

In a more recent study death loss was recorded from 870 farms over a 52-week time period; the study reported average death loss for the time period at 9%, with the removal rate at 45.8% (Ketchem et al., 2019).

Mortality rates of various operational phases were provided from 2012 to 2017 in the Pork Checkoff Industry Productivity Analysis report (Pork Checkoff, 2018). Table I.3.5 summarizes the average annual mortality rates and average rate for the entire period.

Table I.3.5. Data from the Pork Checkoff Productivity Analysis Report (Pork Checkoff, 2018).

	Year						**Overall**	
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**Average**	**Std**
Piglets Born Alive (number per litter)	12.3	12.4	12.3	12.1	12.4	12.6	**12.35**	**0.164**
Piglets Weaned (number per litter)	10.3	10.2	9.7	10.0	10.2	10.3	**10.1**	**0.232**
Pre-weaning Mortality (%)	15.5	17.3	20.5	17.4	17.3	17.8	**17.6**	**1.62**
Nursery Mortality (%)	3.80	3.87	5.47	5.22	4.58	4.77	**4.615**	**0.685**
Grow-Finisher Mortality (%)	5.03	5.04	5.78	5.53	5.34	5.19	**5.32**	**0.269**

Cumulative death loss during the growth of meat swine from birth to market based on the mortality values of Table I.3.5 and the number born dead from USDA-APHIS (2012a) are shown in Figure I.3.6. The values plotted are cumulative dead collected at the end of the week (week zero for pigs born dead) for a group of 1,000 pigs. The group size resets at each phase of production, i.e. 1,000 pigs are born alive, and 1,000 weaned pigs enter the nursery.

The cumulative mortality mass (Figure I.3.7) measured at the end of week was calculated by multiplying number of mortalities per week (Figure I.3.6) by liveweight during the week (Figure I.3.5). Mass of mortalities collected during each phase of growth was taken from Figure I.3.7 and tabulated in Table I.3.6.

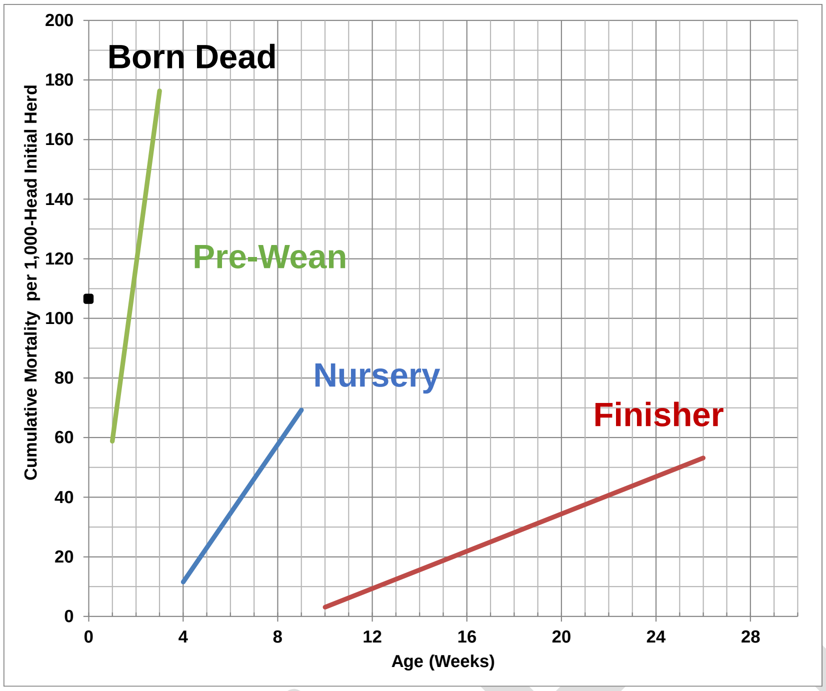

Figure I.3.6. Cumulative death loss measured at the end of each week during the three growth phases of production for groups of 1,000 animals (from Table I.3.5 and USDA-APHIS 2012a).

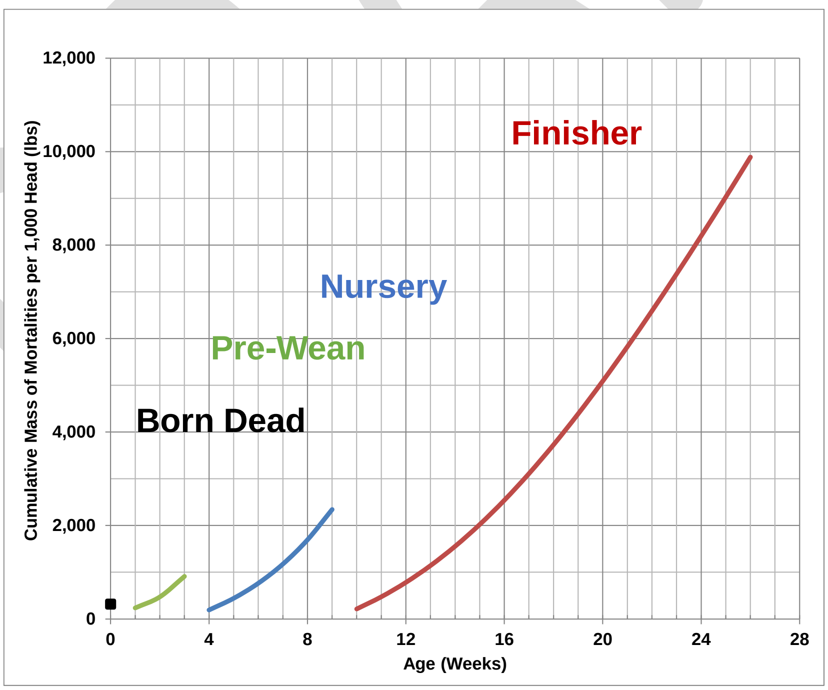

Figure I.3.7. Cumulative mass of mortalities measured at the end of each week during the three growth phases of production for groups of 1,000 animals (Figure I.3.5 multiplied by Figure I.3.6).

Table I.3.6. Mass of mortalities estimated for each phase of swine growth (group size at beginning of each phase equals 1,000 head).

	Mortality Mass Collected Over Entire Growth Phase (lbs. per 1,000 pigs)	Mortality Mass Collected Over Entire Growth Phase (lbs. per pig)
Piglets Born Dead	317	0.317
Pre-Wean	911	0.911
Nursery	2,340	2.34
Finisher	9,880	9.88

3.3.c Carcass Composition

Total body P content of cull sows was chemically determined in order to facilitate more accurate P mass balance calculations for swine breeding herd farms (May and Rozeboom, 2008). Fifteen sows were removed from a central Michigan swine breeding herd, following normal farm culling protocol, and slaughtered. Each sow's blood, viscera including digesta and carcass were individually processed and sampled such that each sow's individual components and each sow's total body content for protein, fat, ash, and nine minerals, including P, were analyzed. Average P content of the 15 cull sows was 0.563% P. A P mass balance model for an example 2,400-sow case farm using this value for cull sows, and those reported in the literature for other specific stages of production at the time when animals enter or depart the farm, were used to estimate annual accumulation of P_2O_5 in manure. The P mass balance model using stage-specific, chemically-determined values, estimated there would be 29,751-kg manure P_2O_5 accumulated annually by this farm, 9% to 31% greater than other estimates made using currently available methods.

A nutrient management plan developed using a mass balance model with stage-specific, chemically-determined total or whole body P requires a larger land base, but that estimation reduces the risks of P accumulating in the soil and future restrictions on the use of that land for manure applications because of high soil P levels. The data presented in May and Rosenboom (2008) provide a reasonable means to predict the amount of potential P from swine mortalities. The P ranges of values is between 3.76 $g\ kg^{-1}$ to 5.63 $g\ kg^{-1}$ of body weight.

The chemical whole-body composition of 20 Landrace × (Landrace × Large White) pigs of 20 kg liveweight was determined by Smits et al. (1988). Mean (± SD) body protein, lipid, ash, and water contents (%) were 15.9 ± 1.47, 14.2 ± 2.72, 3.7 ± 0.43, and 65.6 ± 2.61, respectively. These values agreed closely with mean estimates derived from a review of the world literature. Body lipid content (Coefficient Variation = 19.10%) was markedly more variable than the other chemical components. The TKN mass is then calculated using the reported mean body protein value of 15.9% in the literature (Smits et al., 1988), and a factor of 6.25 to convert protein to TKN value (Benedict ,1987). Following this procedure gives an average TN content per AU of 25.44 lbs.

3.4 Annual Mass of Nutrients Contained in Swine Mortalities

The annual mass of mortalities and nutrients contained in mortalities for a farrow-to-finish operation are given in Table I.3.7. These values were calculated using the instantaneous inventory of a farrow-to-finish operation (Table I.3.3), the annual death rate of breeding stock (7.8%), the average weight of breeding stock at time of death (sows = 450 lbs., gilts = 300 lbs., boars = 700 lbs.), and mass of mortalities per growth phase (Table I.3.6). Mass of mortalities for growing stock was determined using the number of animals entering the growth phase each year (not the number of animals leaving shown in Table I.3.7). For instance, we used 27,500 weaned pigs entering the nursery each year, and not the 26,000 pigs leaving the nursery each year (27,500 weaned pigs – 27,500 X 0.04615 death rate for nurseries = 25,808 ≈ 26,000 feeder pigs leaving). Nutrient mass was calculated using 0.0254 lbs. TN and 0.00563 lbs. TP per lbs. of carcass for all animals.

Table I.3.7. Expected annual mass of mortalities and nutrients contained in carcasses produced by a farrow-to-finish operation with a running average of 1,150 sows.

	Inventory	Number Leaving Phase Each Year	Animals Dying (Head yr^{-1})	Mortality Mass (lbs. yr^{-1})	Mass of TN (lbs. yr^{-1})	Mass of TP (lbs. yr^{-1})
Sows	1,150	-	90	40,000	1,025	227
Gilts	115	-	19	2,700	68	15
Boars	12	-	1	700	16	4
Pigs Born Dead	0	-	3,200	9,450	240	53
Weaned Pigs	2,000	27,500	9,500	30,000	770	170
Feeder Pigs	3,900	26,000	1,500	64,000	1,600	362
Finishers	9,700	25,000	1,400	260,000	6,600	1,500
Total	**16,877**			**406,900**	**10,340**	**2,292**
Per Sow				**350**	**9.0**	**2.0**
Per Sow AU				**790**	**20**	**4.4**
Per Finisher Sold				**16**	**0.42**	**0.092**
Per Finisher AU				**61**	**1.5**	**0.34**
Per Inventory Unit				**24**	**0.61**	**0.14**

Mass of mortalities produced on common types of swine farms in the watershed are tabulated in Tables I.3.8 and I.3.9. Mass of mortalities resulting from farms housing breeding stock is given in Table I.3.8. Mass of mortalities on farms housing non-breeding stock is given in Table I.3.9. The mortality weights were calculated using the inventory of the type of animals housed on the farm based on the inventory of a farrow-to-finish farm. Size of every farm given in Tables I.3.6, I.3.7, and I.3.8 are matched to production of a 1,150-sow farrow-to-finish unit. For instance, 27,500 weaned pigs are produced by 1,150 sows per year, assuming seven turns for an off-site nursery per year results in an inventory (or pig space) of 3,900 for that nursery (rounded to two significant figures).

Table I.3.8. Annual mass of mortalities and nutrients contained in mortalities produced on farms housing breeding stock (based on 1,150 sow farrow-to-finish farm producing 25,000 market hogs per year).

	Farrow-to-Finish			Farrow-to-Wean			Farrow-to-Feeder		
Total Inventory	17,000			3,300			7,200		
	Mortality Mass (lbs. yr^{-1})	Mass of TN (lbs. yr^{-1})	Mass of TP (lbs. yr^{-1})	Mortality Mass (lbs. yr^{-1})	Mass of TN (lbs. yr^{-1})	Mass of TP (lbs. yr^{-1})	Mortality Mass (lbs. yr^{-1})	Mass of TN (lbs. yr^{-1})	Mass of TP (lbs. yr^{-1})
Per Sow	350	9.0	2.0	73	1.85	0.41	130	3.3	0.72
Per Sow AU	790	20	4.4	160	4.1	0.91	290	7.3	1.6
Per Pigs or Hogs Leaving	16	0.42	0.092	3.0	0.077	0.017	5.6	0.14	0.032
Per Pig or Hog Leaving AU	61[1]	1.5[1]	0.34[1]	200[2]	5.1[2]	1.1[2]	100[3]	2.6[3]	0.58[3]
Per Inventory Unit	24	0.61	0.14	26	0.65	0.14	21	0.52	0.12

[1] Market Hog at 270 lbs.

[2] Weaned Pig at 15 lbs.

[3] Feeder Pig at 55 lbs.

Table I.3.9. Annual mass of mortalities and nutrients contained in mortalities produced on farms housing non-breeding swine production phases (based on 1,150 sow farrow-to-finish farm producing 25,000 market hogs per year).

	Off-Site Nursery			Wean-to-Finish			Grow-Finish		
Total Inventory	3,900			13,100			9,700		
Turns per year	7			2.1			2.7		
	Mortality Mass (lbs. yr^{-1})	Mass of TN (lbs. yr^{-1})	Mass of TP (lbs. yr^{-1})	Mortality Mass (lbs. yr^{-1})	Mass of TN (lbs. yr^{-1})	Mass of TP (lbs. yr^{-1})	Mortality Mass (lbs. yr^{-1})	Mass of TN (lbs. yr^{-1})	Mass of TP (lbs. yr^{-1})
Per Pigs or Hogs Leaving	2.5	0.062	0.014	13	0.33	0.073	10	0.265	0.059
Per Pig or Hog Leaving AU	45[1]	1.1[1]	0.25[1]	48[2]	1.2[2]	0.27[2]	39[2]	0.98[2]	0.22[2]
Per Inventory Unit	16	0.42	0.092	25	0.63	0.14	27	0.68	0.15

[1] Feeder Pig at 55 lbs.

[2] Market Hog at 270 lbs.

3.5 Comparison of Swine Mortality Nutrients to Excreted Manure Nutrients

Comparison of nutrients contained in carcasses to nutrient excreted by swine is a true “apples to apples” comparison. The nutrients contained in carcasses calculated by the method outlined in this report are nutrients contained in the animal’s body right exactly at the time of death - before losses from decay, storage, and treatment diminish its mass. Excreted manure nutrients are the nutrients leaving the animal - before weathering, ammonia volatilization, and a multitude of other factors diminishes its mass. Estimates using current formulas for excreted nutrients, which are based on nutrient intake, are highly dependent on assumptions of diet and management practices, and should be thought of as rough averages with a high degree of variability - just as this report has highlighted the variability of estimating the mass of carcass nutrients.

Table I.3.10 compares the mass of nutrients contained in mortalities based on the methods used in this report to the mass of nutrients excreted by the same 1,150 sow farrow-to-finish operation. The USDA-NRCS Waste Management Field Handbook (USDA-NRCS, 2008), which in turn is based on the American Society of Agricultural and Biological Engineers Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005), was used to calculate the excreted manure values. The ASABE standard (ASABE, 2005) estimates the mass of total nitrogen and phosphorus excreted by breeding stock per day. The nutrients excreted by pre-weaned pigs is considered to be part of the mother’s excreta. These values are based on a mass balance of food intake, nutrients accumulated in the body, nutrients respired, and nutrients excreted. Mass of nutrients produced by growing swine is also estimated by a mass balance, but is given on a per animal finished basis.

Table I.3.10 shows that, if carcass nutrients are combined with excreted nutrients, **approximately 3.2% of the nitrogen produced by a farrow-to-finish swine operation originates with mortalities**. Likewise, **3.8% of the phosphorus produced by a farrow-to-finish operation comes from mortalities.**

3.6 Future Research Needs

3.6.a Types of Farms Not Covered in This Report

This report does not provide per farm mortality data for operations providing breeding stock for multi-site production such as boar farms and multiplier farms. However, nutrients produced on these farms can be estimated by considering the units making up a full farrow-to-finish operation housed on the farm.

3.6.b Need For On-farm Data Collection

Although we are confident in the data produced in this report, the values were primarily produced through limited published data on mortalities, and personal communication with top researchers in this area. Research should be undertaken to determine the actual mass of mortalities produced on farms under the cultural practices used in the watershed.

3.6.c Need For Data on Whole Carcass Nutrient Content

Very limited data exists for whole carcass composition of swine.

Table I.3.10. Mass of as-excreted manure nutrients produced by a farrow-to-finish operation with a running average of 1,150 sows compared to nutrients contained in carcasses produced by the same operation.

	Inventory	Annual Production	Nutrients Excreted per Animal[1]		Annual Nutrient Excretion (lbs. yr^{-1})	
	Head	**Head yr^{-1}**	**TN**	**TP**	**TN**	**TP**
Gestating Sows	990	-	0.071 lbs. hd^{-1} d^{-1}	0.020 lbs. hd^{-1} d^{-1}	26,000	7,200
Lactating Sows with Litters	150	-	0.190 lbs. hd^{-1} d^{-1}	0.055 lbs. hd^{-1} d^{-1}	11,000	3,200
Boars	12	-	0.061 lbs. hd^{-1} d^{-1}	0.021 lbs. hd^{-1} d^{-1}	267	92
Replacement Gilts	115	520	10 lbs. hd^{-1}	1.7 lbs. hd^{-1}	5,200	880
Nursery Pigs	3,900	26,000	0.91 lbs. hd^{-1}	0.15 lbs. hd^{-1}	24,000	3,900
Finisher Hogs	9,700	25,000	10 lbs. hd^{-1}	1.7 lbs. hd^{-1}	250,000	42,500
				Total Manure Nutrients (lbs. yr^{-1})	**316,467**	**57,772**
				[2]Total Mortality Nutrients (lbs. yr^{-1})	**10,340**	**2,292**
				Total Nutrients (lbs. yr^{-1})	**326,807**	**60,064**
				Portion of Total Nutrients from Mortalities	**3.2 %**	**3.8 %**

[1]USDA-NRCS (2008)

[2]From Table 7

3.7 Assumed Values of Mortality Masses and Carcass Nutrients for Watershed

Without any further defining information, the values given in Table I.3.11 should be used for mass of routine mortalities and nutrients produced annually for swine with routine mortalities. If type of farm is known, the values given in Tables I.3.8 and I.3.9 should be used. The values given in Table I.3.11 are mortalities produced during all phases of hog production from farrow to finish. Weight of mortalities, total nitrogen, and phosphorus produced per year are given per inventory unit, which can be used to determine weights given state and county hog inventory in the USDA-NASS Census of Agriculture. Values are also given on a per animal and per AU basis for the Chesapeake Bay Program's units of Hogs and Pigs for Breeding and Hogs for Slaughter.

Table I.3.11. Assumed annual mass of mortalities and nutrients contained in mortalities produced by all types of swine farms.

	Per Animal Basis			Per Weight Basis		
	lbs. head^{-1} year^{-1}			lbs. AU^{-1} year^{-1}		
	Mortalities	TN	TP	Mortalities	TN	TP
Inventory	24	0.61	0.14	-	-	-
Hogs and Pigs for Breeding (Sows)	350	9.0	2.0	790	20	4.4
Hogs for Slaughter (Market Hogs)	16	0.42	0.092	61	1.5	0.34

3.8 References

Alvarez, J., Sarradell, J., Kerkaert, B., Bandyopadhyay, D., Torremorell, M., Morrison, R. & Perez, A.. (2015a). Association of the presence of influenza A virus and porcine reproductive and respiratory syndrome virus in sow farms with post-weaning mortality. *Preventive Veterinary Medicine* 121(3):240-245.

Alvarez, J., Sarradell, J., Morrison, R., & Perez, A.. (2015b). Impact of Porcine Epidemic Diarrhea on Performance of Growing Pigs. *PLOS ONE* 10(3):e0120532.

ASABE Standards. (2005). 384.2: Manure Production and Characteristics. St Joseph, MI: ASABE.

Benedict, R. C. (1987). Determination of nitrogen and protein content of meat and meat products. *Journal-Association of Official Analytical Chemists*, *70*(1), 69-74.

Etienne, M., Meinen, R., Kristoff, J., Sexton, T., Long, B., & Dubin, M. (2016). *Recommendations to Estimate Swine Nutrient Generation in the Phase 6 Chesapeake Bay Program Watershed Model.* Annapolis, MD: Chesapeake Bay Program.

Felton, G., Timmons, J., & Ogejo, J.A.. (2009). Mortality composting, definition and nutrient and nutrient sediment reduction effectiveness estimates, pp 393-412, In Simpson, T. and J. Weammert. *Final Report, Developing Best Management Practices and Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay Watershed*. College Park, MD: Univ. of MD Mid Atlantic Water Program.

Global Ag Media. (2006). *Basic Pig Husbandry – The Boar.* https://thepigsite.com Accessed July 28, 2020.

Global Ag Media. (2010). *Gilt management.* https://thepigsite.com Accessed July 28, 2020.

Hawkins, S., Hamilton, D., Mcintosh, B., Moyle, J., Risse, M., & Vanderstampen, P. (2016). *Animal Waste Systems, Recommendations from the BMP Expert Panel for the Animal Waste Management Systems in the Phase 6 Watershed Model.* Annapolis, MD: Chesapeake Bay Program.

Ketchem, R., Rix, M., &Duttlinger, V. (2019). Focus areas for improving sow mortality. *National Hog Farmer.* https://www.nationalhogfarmer.com/print/28839. Accessed September 13, 2019.

Larriestra, A. J., Wattanaphansak, S., Neumann, E. J., Bradford, J., Morrison, R. B., & Deen, J. (2006). Pig characteristics associated with mortality and light exit weight for the nursery phase. *The Canadian Veterinary Journal* 47(6):560-566.

Maes, D., Larriestra, A., Deen, J., & Morrison, R.. (2001). A retrospective study of mortality in grow-finish pigs in a multi-site production system. *Journal of Swine Health and Production* 9(6):267-276.

May, A. G.& Rozeboom, D. W.. (2008). Sow body composition for improved estimation of farm phosphorus mass balance. *Applied Engineering in Agriculture* 24(6):767-772.

MWPS. (1983). MWPS- 8: *Swine Housing and Equipment Handbook*. Ames, IA: Midwest Plan Service.

Pork Checkoff. (2018). *Checkoff's Pork Industry Productivity Analysis.* Des Moines, IA: National Pork Board. https://www.pork.org/facts/stats/industry-benchmarks/#AverageConventionalFinisherProductivity. Accessed October 1, 2019.

Pork Checkoff. (2019). *Life Cycle of a Market Pig*. Des Moines, IA: National Pork Board. https://www.porkcdn.com/sites/porkorg/library/2016/08/life_cycle_of_a_market_pig.jpg. Accessed October 1, 2019.

Smits, C. H. M., Moughan, P. J., & Smith, W. C.. (1988). Chemical whole-body composition of the 20 kg liveweight growing pig. *New Zealand Journal of Agricultural Research* 31(2):155-157.

USDA-AMS. (2019). *National Daily Hog and Pork Summary*. Washington, DC: United States Department of Agriculture, Agricultural Marketing Service. https://www.ams.usda.gov/mnreports/lsddhps.pdf. Accessed October 1, 2019.

USDA-APHIS. (2012a). S*wine 2012 Part I: Baseline Reference of Swine Health and Management in the United States, 2012*. Washington, DC: United States Department of Agriculture, Animal and Plant Health Inspection Service. https://www.aphis.usda.gov/animal_health/nahms/swine/downloads/swine2012/Swine2012_dr_PartI.pdf. Accessed June 25, 2019.

USDA-APHIS. (2012b). *Swine 2012: Reference of Management Practices on Small-enterprise Swine Operations in the United States, 2012.* Washington, DC: United States Department of Agriculture, Animal and Plant Health Inspection Service. https://www.aphis.usda.gov/animal_health/nahms/swine/downloads/swine2012/Swine2012_dr_KITI.pdf. Accessed June 25, 2019.

USDA-NASS. (2019). Census of Agriculture, 2017. Washington, DC: United States Department of Agriculture, National Agricultural Statistics Service. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/

USDA-NRCS. (2008). *Part 651, Agricultural Waste Management Field Handbook, Chapter 4: Agricultural Waste Characteristics.* Washington DC: United States Depart of Agricultural, Natural Resources Conservation Service.

4. **Cattle**

4.1 Definitions

AFO: An Animal Feeding Operation smaller than the **CAFO** threshold

Animal Unit (AU): commonly used unit representing 1,000 pounds of live animal weight

Beef Cattle: bovine intended for meat production

Bull: intact male bovine

CAFO: Confined Animal Feeding Operation, an **AFO** usually housing more than 1,000 animal units.

Calf: young bovine stock (plural: calves)

Carcass: a deceased animal; in the context of mortality management, it is the whole animal including head, hide, feet and internal organs; in the context of meat production, it is the de-hided, beheaded, eviscerated, and cleaned carcass prepared for butchering

Confinement: animal production system where animals are confined in pens or houses and feed is brought to the animals; animals do not gain a majority of nutritional needs from grazing or environmental sources; may be referred to as **AFO** or **CAFO**; does not apply to fenced pastures or grazing operations

Cow: mature female bovine having produced one or more calves

Cow-Calf Operation: cattle enterprise defined by pastured animals (cows) producing calves for annual sale to be finished elsewhere at a feedlot

Dairy Cattle: female bovine intended for milk production; may include male breeding stock for herd reproduction, e.g. dairy bulls

Feeder Cattle: cattle on delivered/provided feed intended for eventual meat production; may be referred to as **Cattle on Feed**

Feedlot: confinement operation usually associated with cattle for eventual meat production; may be roofed, but more commonly uncovered pens and lots; synonyms: feed yard, feeding operation

Head: colloquial unit representing one agricultural animal, not age specific, most common for stock such as cattle, pigs, and small ruminants (goats and sheep)

Heifer: immature female bovine, not yet having produced a calf; a heifer may be bred and is often referred to as a **First Calf Heifer** or **Bred Heifer**

Herd: a group of cattle

Ruminant: multi-stomached animal with a large main stomach (rumen) that microbially digests fiber; ex: cattle, sheep, goats, bison, yaks, and similar wildlife

Steer: castrated male bovine; most common animal for meat production

Stocker Cattle: heifers and steers fed on pasture in preparation for placement on a feedlot -- usually off the farm on which they were born and weaned.

Weaned/Weaning: animal removed from mother's milk and transitioned to eating solid feed exclusively

4.2 Beef Cattle (Cow-Calf)

4.2.a. Beef Cattle in the Watershed

Eastern beef production is characterized by relatively small cow-calf herds, where the herd is described by the number of mother cows. Cattle are raised on pasture with some supplemental hay feeding when conditions warrant (Figures I.4.1 and I.4.2). Cattle are on pasture greater than 95% of the time. Under ideal conditions, each cow will yield one calf per year to be sold by year's end. Some female calves will be retained to replace culled cows from the herd, maintaining the same general herd size.

Table I.4.1 lists numbers of mature beef cows living in each state making up the Chesapeake Bay Watershed. This list includes all cattle living in each state, not just those in the watershed, but gives a snapshot of the widespread presence of cow-calf herds in the watershed.

Table I.4.1. Beef cow population by state in 2017 (USDA-NASS, 2020).

	Number of Beef Cows
Delaware	2,400
Maryland	48,000
New York	110,000
Pennsylvania	220,000
Virginia	640,000
West Virginia	210,000
Total	**1,230,000**

4.2.b Nutrients Contained in Cow-Calf Mortalities

Weight and Growth of Cattle

Common Hereford/Angus cross cattle were used in all calculations for this report. Common weights at life stages are given in Table I.4.2. Weaning time and weight, as well as other management practices, vary from producer to producer. The weights given in Table I.4.2 are considered averages. As some finishing may occur on a cow-calf operation or a feeding site, the weight of a finished steer is also given.

Cow-Calf Herd Mortalities

Annual beef mortality rates are reported by USDA-APHIS (2010) based on herd size. There is little difference amongst herd sizes of 1-49, 50-99, and 100-199 mother cows. The average mortality rates for three life stages of calves are given in Table I.4.3. It was assumed that, under normal circumstances, mother cows do not die in herds, but are rather culled and replaced before dying.

Figure I.4.1. Beef cows on pasture in Virginia (USDA-NRCS).

Figure I.4.2. Steers on pasture in Virginia (USDA-NRCS).

Table I.4.2. Weight of Hereford/Angus cross beef cattle at different life stages (Greiner, 2005; Hamilton, 2011; C. Sanford Personal Communication, June, 2019).

Life Stage	Weight (lbs)
Calf at Birth	80.4
Calf at Weaning	458
Heifer	840
Finished Steer	1,100
Mature Mother Cow	1,400

Table I.4.3. Average annual mortality rates of immature beef cattle for herds 1-199 mother cows (USDA-APHIS, 2010).

	Annual Mortality (%)
Born Dead	3.03
Died before Weaning	3.83
Died after Weaning	1.73

Using a 50-cow herd as the reference size, the mortality rates of Table I.4.3 are translated to a head per year basis as shown in Table I.4.4. The total weight of mortality from each life stage is the product of the average weight of cattle in the stage times the average number dying each year in that life stage group. The total weight of mortalities produced each year in a reference herd of 50 cows is the total of weights from each life stage group. Dividing the total mortality weight by 50 yields an estimate of annual mortality on a per mature cow basis. Calculations are summarized in Table I.4.4. On average, 32.3 pounds of cattle carcasses are produced per cow each year. Figure I.4.3 highlights the annual weight of mortality relative to life stage. Despite the low mortality rate after weaning, this stage represents a significant contribution to the weight of mortality to be managed.

Table I.4.4. Annual weight of mortalities produced by a 50-cow, cow-calf herd.

	Head dying	Average Life Stage Weight (lbs.)	Weight of Mortalities (lbs. yr^{-1})
Born Dead	1.52	80.4	122
Died Before Weaning	1.92	269	516
Died After Weaning	0.865	1,130[1]	977
		TOTAL ANNUAL MORTALITY WEIGHT	**1,615**
		TOTAL ANNUAL MORTALITY WEIGHT per MATURE COW	**32.3**

[1]Calculated as the average of heifer, finished steer, and mature cow weights (Table I.4.2).

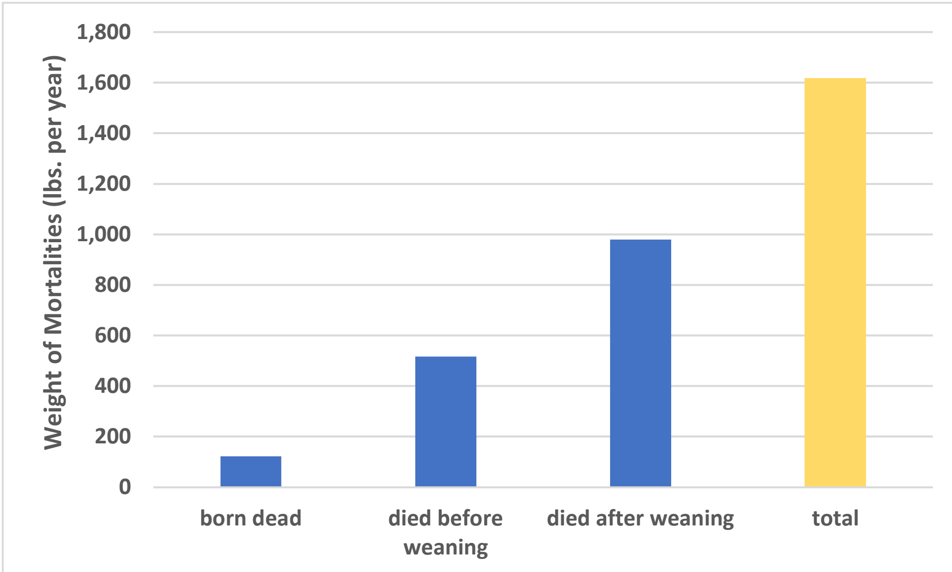

Figure I.4.3. Annual weight of beef mortalities at each growth stage for 50-cow cow-calf herd (from Table I.4.4).

Carcass Composition

Data on whole carcass composition in the literature is sparse, as whole dead cattle are seldom analyzed for this purpose. Even whole carcasses of calves are difficult to analyze, because, unlike poultry whose relatively small carcasses can be digested and rendered in a laboratory to fractionate and measure chemical and mineral components, cattle are large and exceedingly hard to digest whole.

Three estimates were used to determine the percent protein of whole cattle carcasses. Bonilla et al. (2011) estimated 18% protein. Rendering experts David Meeker and Janis Swan estimated 20% and 15% protein product rendered from a whole bovine carcass, respectively (D. Meeker and J. Swan, personal communication , 2019). Therefore, an average of 17.67% was used as the estimate of protein in a whole carcass. Benedict (1987) published the following equation to convert total protein to total nitrogen: *TKN (Total Kjeldahl Nitrogen) = TP (Total Protein) ÷ 6.25*. This equates to 28.27 pounds of N per 1,000 pounds of carcass weight, or 28.27 pounds of nitrogen per animal unit (AU).

Bonilla et al. (2011) also estimated whole bovine carcass ash at 4.56%, and Cohen (2009) estimated that bovine carcass ash is 18% phosphorus. The following equation was used to estimate the pounds of phosphorus in a 1000-pound bovine carcass: *0.0456 pounds ash per pound carcass X 0.18 pounds TP per pound ash X 1,000 pound carcass = 8.2 pounds of phosphorus.*

4.2.c Annual Mass of Nutrients Contained in Cow-Calf Mortalities

Combining the annual mortality values of Table I.4.4 with the estimated mass of nitrogen and phosphorus per cattle carcass, gives the estimated mass of nutrients contained in the carcasses produced by cow-calf herds per year. Estimates of mortalities produced and nutrients contained in mortalities on a per mother cow and per AU basis for cow-calf operations is given Table I.4.5, assuming 1,400 pounds per mother cow.

Table I.4.5. Estimated annual mass of mortalities and nutrients contained in carcasses from cow-calf herds.

Per Mother Cow (lbs. per year)			Per 1,000 pound AU (lbs. per year)		
Mortalities	**Total N**	**Total P**	**Mortalities**	**Total N**	**Total P**
32.3	0.905	0.265	23.1	0.646	0.189

4.2.d Comparison of Cow-Calf Mortality Nutrients to Excreted Manure Nutrients

Comparison of nutrients contained in mortalities to nutrient excreted by cattle is a true "apples to apples" comparison. The nutrients contained in mortalities calculated by the method outlined in this report are nutrients contained in the animal's body exactly at the time of death - before losses from decay, storage, and treatment diminish their mass. Excreted manure nutrients are the nutrients leaving the animal - before weathering, ammonia volatilization, and a multitude of other factors diminishes their mass on the pasture. Estimates using current formulas for excreted nutrients, which are based on nutrient intake, are highly dependent on assumptions of diet and cultural practices, and should be thought of as rough averages with a high degree of variability - just as this report has highlighted the variability of estimating the mass of carcass nutrients.

Table I.4.6 gives a comparison of the mass of nutrients contained in mortalities based on the methods used in this report to the mass of nutrients excreted by the same 50-cow, cow-calf herd. The American Society of Agricultural and Biological Engineers Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005) was used to calculate excreted manure values. Table I.4.6 shows that, if carcass nutrients are combined with excreted nutrients, **approximately 0.45% of the nitrogen produced by cow-calf herds originates with mortalities**. Likewise, **0.58% of the phosphorus produced by cow-calf herds comes from mortalities.** The ASABE standard (ASABE, 2005) estimates the mass of total nitrogen and phosphorus excreted by mature beef cows and growing calves (in confinement) per day. The nutrients excreted by un-weaned calves are considered to be part of the mother's excreta. These values are based on a mass balance of food intake, nutrients accumulated in the body, nutrients respired, and nutrients excreted. Total nitrogen excreted is 0.42 pounds of TN per cow per day, and 0.29 pounds of TN per growing calf per day. Total phosphorus excreted is 0.097 pounds of TP per cow per day and 0.055 per calf per day. Therefore, the mass of excreted nitrogen estimated from a 50-cow, cow-calf herd is: 50 cows X 0.42 lbs. TN per cow per day^{-1} X 365 days = 7,700 TN per year, plus 47 calves (after still born and pre-weaned death loss) X 0.29 lbs. TN per calf per day X 180 days (post weaning) = 2,450 lbs. TN per year, for a herd total of 10,150 lbs. TN per year. Dividing by 50 gives the per cow mass of TN excreted as 200 pounds per year. Similarly, the mass of phosphorus excreted by 50-cow, cow-calf herd is 45 pounds TP per cow per year.

Table I.4.6. Mass of nutrients contained in mortalities from a 50 cow, cow-calf herd compared to the estimated mass of nutrients contained in manure excreted (ASABE, 2005) by the same herd.

Nutrients Contained in Mortalities (lbs. per cow per year)		Nutrients Contained in Excreted Manure (lbs. per cow per year)	
TN	**TP**	**TN**	**TP**
0.905	0.265	200	45

4.3 Cattle on Feed

4.3.a Feeder Cattle in the Watershed

Although most beef production in the watershed is cow-calf herds, some cattle finishing facilities do exist in the watershed (Figure I.4.4). Table 1.4.7 gives the state-level numbers for cattle on feed in the watershed, along with a measure of the relative size of feeding facilities in each state. This list includes the feeding capacity of feed yards in each state, not just those in the watershed.

If one assumes one calf is born to each beef cow per year, comparing Tables I.4.1 and I.4.7 indicates that less 15% of the cattle born in the mid-Atlantic region are finished there. The majority of beef cattle are shipped west as stockers and finished in feedlots in the upper Midwest and southern plains. The only state with a sizeable cattle feeding enterprise is Pennsylvania, and Hawkins et al. (2016) indicate that cattle feeding is concentrated in Cumberland, Lancaster, and York Counties in Pennsylvania. Larger farms, those feeding more than 200 head, do so under roof, with manure being scraped and stored in dry stacks, or stored in-house as bedded pack solid manure or deep pit liquid manure. Few farms currently finish cattle in open lots. The majority of those farms feeding less than 100 head finish cattle on pasture (Hawkins et al, 2016).

Table I.4.7. Cattle on feed in states in the watershed and the relative size of feeding facility in each state (USDA-NASS, 2020).

	Cattle on Feed	Percentage of Farms in Each State Feeding the Indicated Number of Cattle (head capacity)					
		1-19	**20-50**	**50-100**	**100-200**	**200-500**	**500+**
Delaware	1,500	12.5	12.5	25	0	12.5	12.5
Maryland	11,000	32	37	18	7	3	3
New York	24,000	26	36	19	11	7	1
Pennsylvania	120,000	20	31	24	17	6	2
Virginia	20,000	5	40	34	14	6	1
West Virginia	2,800	5	25	30	15	15	10
Total	**178,500**	**20**	**33**	**23**	**15**	**6**	**2**

Figure I.4.4. Cattle on feed in Maryland (USDA-NRCS).

4.3.b Nutrients Contained in Cattle-on-Feed Mortalities

Body Weights and Growth Rate

Cattle are generally on feed in a confinement facility for around 120 days. For the purposes of calculating mortality, a linear growth curve is used with cattle entering the feeding program at 400 to 600 pounds and leaving at 1,000 to 1,200 pounds.

Confined Beef Mortalities

The most comprehensive study on beef feedlot mortalities was conducted by Vogel et al. (2015). The data reflected lots in the Midwest and Great Plains; however, the data are expansive and suitable for estimates in the Chesapeake Bay Watershed. Annual mortality rates for a given capacity of cattle on feed are shown in Table I.4.8. With milder weather and more controlled conditions (feeding under roof), the watershed's rates could be lower.

Table I.4.8. Average annual mortality rates for a cattle feeding facility (Vogel et al., 2015).

	Annual Mortality (%)
First 30 days	0.67
Mid-feeding	1.59
60 to 31 days pre-harvest	0.19
Final 30 days	0.23

Using a 100-head feeding operation as the reference size, the previous mortality rates are translated to head dying per year in Table I.4.9. The live body weights in Table I.4.9are based on common or anecdotal weights at entry (400-600 lbs.) and goals for finishing weight (1,000-1,200 lbs.) over a linear growth curve. The total weight of mortality from each life stage is the product of the live weight times the average head dying per year. The total annual mortality weight for this reference herd represents the relative contribution of each listed life stage and respective mortality rate. Dividing the total by 100 yields an estimate of annual confined beef mortality on a head basis; 18.24 pounds of annual mortality is predicted for each finished beef animal in confinement on an operation.

Table I.4.9. Annual mortalities in a cattle feeding operation with 100 head capacity.

	Head dying	Average Live Weight (lbs.)	Weight of Mortalities (lbs. yr^{-1})
First 30 days	0.67	500	335
Mid-feeding	1.58	690	1,090
60-31 days pre-harvest	0.18	875	160
Final 30 days	0.22	1,100	240
TOTAL ANNUAL MORTALITY WEIGHT			**1,825**
TOTAL ANNUAL MORTALITY WEIGHT per Head in Confinement			**18.25**

Annual weight of mortality relative to time in or stage of feeding is illustrated in Figure I.4.5. The greatest contribution to annual mortality, approximately 60%, is in the mid-feeding stage where animals average 690 pounds.

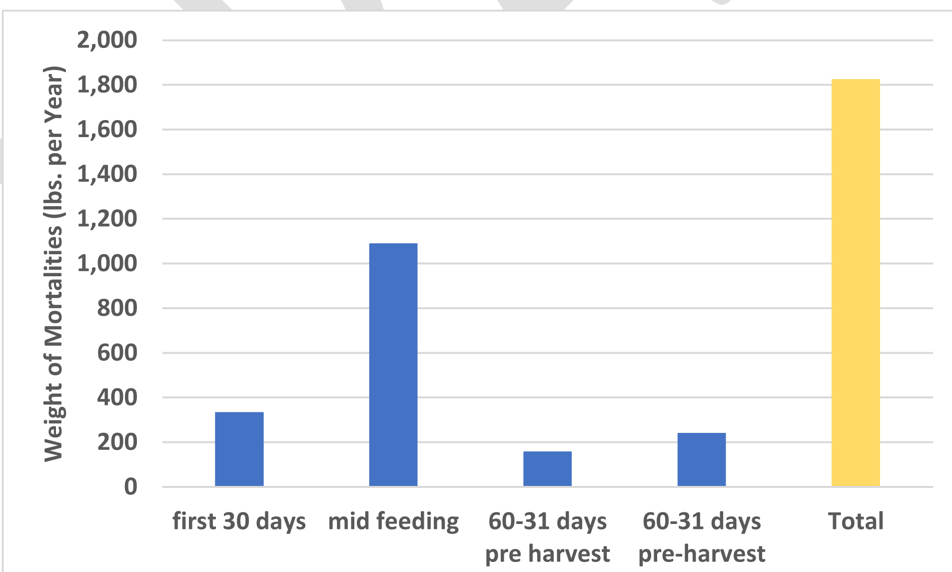

Figure I.4.5. Total annual weight of beef mortality at growth stage for a 100-head feedlot

Carcass Composition

Carcass nutrient composition specific to cattle on feed was not found in the literature. Therefore, the data of Bonilla et al. (2011), Meeker and Swan (D. Meeker and J. Swan, personal communication, 2019),Benedict (1987), and Cohen (2009) were used to estimate concentration of nutrients in finisher cattle carcasses.

4.3.c Annual Mass of Nutrients Contained in Cattle on Feed

Annual mass of total nitrogen and total phosphorus contained in carcasses produced in a feedlot with 100 head capacity was calculated by multiplying the data of Table I.4.9 by the estimates of cattle composition. Annual mass of nitrogen and phosphorus in carcasses of cattle on feed is given in Table I.4.10. Values per 1,000-pound AU were based on the weight of cattle upon finishing (1,100 lbs.).

Table I.4.10. Estimated annual mass of mortalities and nutrients contained in carcasses from a beef finishing operation with the capacity of 100 head.

Per Head (lbs. per year)			Per 1,000 pound AU (lbs. per year)		
Mortalities	**Total N**	**Total P**	**Mortalities**	**Total N**	**Total P**
18.25	0.52	0.15	16.5	0.47	0.14

4.3.d Comparison of Cattle on Feed Mortality Nutrients to Excreted Manure Nutrients

Table I.4.11 gives a comparison of the mass of nutrients contained in mortalities based on the methods used in this report to the mass of nutrients excreted by a feedlot with 100 head capacity. The American Society of Agricultural and Biological Engineer Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005) was used to calculate excreted manure values. Table I.4.11 shows that, if carcass nutrients are combined with excreted nutrients, **between 0.26 and 0.32 percent of the nitrogen produced by cattle on feed originates with mortalities, depending on diet**. Likewise, **between 0.45 and 0.74 percent of the phosphorus produced by cattle on feed comes from mortalities.** The ASABE standard (ASABE, 2005) estimates the mass of total nitrogen and phosphorus excreted by cattle on feed as they grow from 400 to 1,100 pounds. These values are based on a mass balance of food intake, nutrients accumulated in the body, nutrients respired, and nutrients excreted. Since cattle remain on feed for an average of 120 days, the maximum number of cattle that can pass through a feedlot of 100 head capacity in one year is 304; minus 2.65 head lost from mortalities, gives a number of approximately 300 head per year. Total nitrogen excreted is 53 pounds of TN per finisher fed on a diet without supplements. Nitrogen excretion increases to 75 lbs per finished animal for a diet of 25% distillers' grains, and 66 per finisher for a diet of 30% corn gluten. Total phosphorus excreted is 6.6 pounds of TP per finished animal without supplementation, 10 pounds per finished animal fed a diet of 25% distillers' grains, and 11 per finisher for a diet of 30% corn gluten. Therefore, the mass of excreted nitrogen estimated from a 100 head capacity feedlot without feed supplementation can be represented by 300 finishers per year X 53 lbs. TN per finisher = 16,000 pounds TN per year. Dividing by 100 gives the per head capacity mass of TN excreted as 160 pounds per year. Similarly, the mass of phosphorus excreted by a 100 head capacity feedlot feeding cattle without supplements is 20 pounds TP per head per year.

Table I.4.11. Nutrients contained in mortalities produced by a feedlot with 100 head capacity versus mass of nutrients excreted by the same feedlot based on three diets (ASABE, 2005).

	Total Nitrogen (lbs. $head^{-1}$ $year^{-1}$)	Total Phosphorus (lbs. $head^{-1}$ $year^{-1}$)
Contained in mortalities	0.52	0.15
Excreted by cattle fed a diet without supplements	160	20
Excreted by cattle fed a diet with 25% distillers' grain	230	30
Excreted by cattle fed a diet with 30% corn gluten	200	33

4.4 Dairy Cattle

4.4.a Dairy Cattle in the Watershed

The majority of dairy production (Figures I.4.6 and I.4.7) in the watershed is found in Pennsylvania, representing 73% of the dairy cows within counties with at least half their land mass within the Chesapeake Bay Watershed (Table I.4.12). The two counties in Pennsylvania with the greatest concentration of dairy production are Lancaster and Franklin. Nearly a fourth of Pennsylvania production is on dairy farms larger than 200 head, with some on dairy farms with greater than 500 head. The remainder are traditionally sized herds under 200 head, with some very small herds in Lancaster County (Hawkins, et al., 2016).

Table I.4.12. Estimated number of mature dairy cows residing in counties with land mass at least 50% within the Chesapeake Bay Watershed (USDA NASS, 2020; Hawkins et al., 2026).

	Number of Mature Dairy Cows
Delaware	1,800
Maryland	45,000
New York	44,000
Pennsylvania	400,000
Virginia	52,000
West Virginia	2,750
Total	**545,550**

4.4.b Nutrients Contained in Dairy Cattle Mortalities

Herd Characteristics and Body Weights

Using a 100-cow milking herd as a reference, a dairy farm will have around 50 female calves and 50 heifers in development. Heifers are bred at 15 months and give birth around 24 months (2 years) of age. Male calves are generally exported from the farm as soon as possible for development as lower grade beef cattle. A conventional dairy has heifers and dry cows on pasture, with the active milking herd in free-stall barns or alternative confinement for a 300-day lactation. Grazing dairies do not confine animals in housing. As management practices, regional differences, and herd genetics influence body weight at different life stages, body weights for life stages were estimated from several sources. The average weight for various life stages of dairy cattle is given in Table I.4.13.

Figure I.4.6. Dairy cattle on pasture in Virginia (USDA-NRCS).

Figure I.4.7. Dairy cattle in confinement in Maryland (USDA NRCS).

Table I.4.13. Average live weights of dairy cattle (Jones and Hendricks, 2016; Jones and Hendricks, 2017; USDA-APHIS, 2016; M. de Haro-Marti, personal communication 2019).

Life Stage	Average Weight (lbs.)
Pre-Weaned Calf	122.5
Weaned Heifers	555
Mature Cow	1,300

Mortalities

Annual dairy mortality rates are reported by USDA-APHIS (2014) across all eastern dairy herds sizes 30-500+ head. The average mortality rates for three life stages are given in Table I.4.14.

Table I.4.14. Mortality rates for dairy cattle (USDA-APHIS, 2014).

Life Stage	Annual Mortality (%)
Pre-Weaned Heifers	5.8
Weaned Heifers	1.8
Mature Cow	6.2

Table I.4.15 gives mortality weight for a 100-cow dairy. The mortality rates are translated to head died per year. The total weight of mortalities from each life stage is the product of the average weight of the stage, times the average head dying per year. The total annual mortality weight for this reference herd represents the relative contribution of each listed life stage and respective mortality rate. Dividing the total by 100 gives the annual dairy mortality on a per mature cow basis. For each mature dairy cow on a farm, 89.15 pounds of annual mortality could be predicted.

Table I.4.15. Annual mortality (head and weight) for a 100-cow dairy herd.

	Head dying	Life Stage Weight (lbs.)	Weight of Mortalities (lbs. yr^{-1})
Pre-weaned heifers	2.9	122.5	355
Weaned heifers	0.90	555	500
Cows	6.2	1,300	8,100
		TOTAL ANNUAL MORTALITY WEIGHT	**8,955**
		TOTAL ANNUAL MORTALITY WEIGHT/MATURE COW	**90**

Figure I.4.8highlights the annual weight of mortality relative to life stage. Despite nearly equal mortality rates for pre-weaned heifers and mature cows, pre-weaned calf inventory is half that of mature cows and body weights are significantly less. Weaned heifers have a higher average body weight moving through this phase towards breeding and maturity, but a very low mortality rate. Finally, the bulk of mortality weight on an annual basis is in the death of mature cows, due to the higher rate of mortality and the larger body weight.

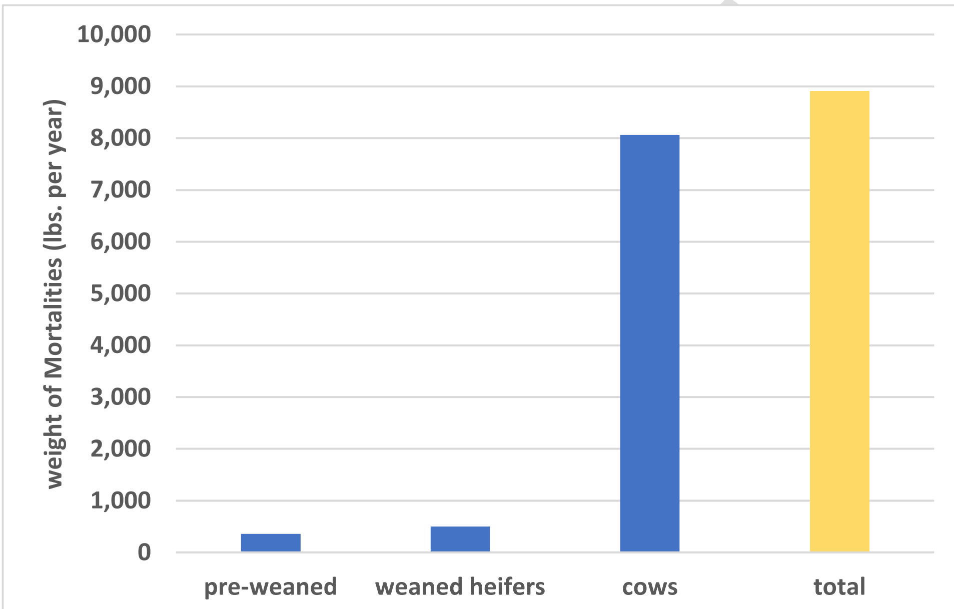

Figure I.4.8. Total annual weight of dairy mortality at growth stage for 100-cow herd.

Carcass Composition

Carcass nutrient composition specific to cattle on feed was not found in the literature. Therefore, the data of Bonilla et al. (2011), Meeker and Swan (personal communication, 2019), Benedict (1987), and Cohen (2009) were used to estimate concentration of nutrients in finisher cattle carcasses.

4.4.c Annual Mass of Nutrients Contained in Dairy Cattle Mortalities

Annual mass of total nitrogen and total phosphorus contained in carcasses produced in a 100-cow dairy herd was calculated by multiplying the data of Table I.4.15 by the estimates of cattle composition. Annual mass of nitrogen and phosphorus in carcasses per head of mature cows is given in Table I.4.16. Per animal unit values were based on the average weight of mature dairy cattle (1,300 lbs).

Table I.4.16. Estimated annual mass of mortalities and nutrients contained in carcasses from dairy herds.

Per Head (lbs. per year)			Per AU (lbs. per year)		
Mortalities	Total N	Total P	Mortalities	Total N	Total P
90	2.5	0.74	69	1.9	0.57

4.4.d Comparison of Dairy Mortality Nutrients to Excreted Manure Nutrients

Table I.4.17 gives a comparison of the mass of nutrients contained in mortalities based on the methods used in this report to the mass of nutrients excreted by a 100 head dairy herd. The American Society of Agricultural and Biological Engineer Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005) was used to calculate excreted manure values. Table I.4.17 shows that, if carcass nutrients are combined with excreted nutrients, **between 0.55 and 0.65 percent of the nitrogen produced by dairy cattle originates with mortalities, depending on milk production**. Likewise, **between 0.93 and 1.2 percent of the phosphorus produced by dairy cattle comes from mortalities.** The ASABE standard (ASABE, 2005) estimates the mass of total nitrogen and phosphorus excreted by dairy cattle on a pound per head per day basis. These values are based on a mass balance of food intake, nutrients accumulating in the body, nutrients respired, and nutrients excreted. For mature dairy cattle nitrogen and phosphorus excretion values are calculated on the basis of milk production, with 0.90 lbs. TN and 0.15 lbs. TP excreted per head per day with 15,000 lbs. milk per year production, and 1.11 lbs. TN and 0.21 lbs. TP excreted per head per day with 37,500 lbs. milk per year production. Milk-fed calves excrete 0.17 lbs. TN head^{-1} day^{-1}. Calves (average weight 330 lbs.) excrete 0.14 lbs. TN and 0.02 lbs. TP head^{-1} day^{-1}. Heifers (average weight 970) excrete 0.26 lbs.TN and 0.04 lbs. TP head^{-1} day^{-1}. Dry cows excrete 0.50 lbs. TN and 0.07 lbs. TP head^{-1} day^{-1}.

Table I.4.17. Nutrients contained in mortalities produced by a 100-cow dairy herd versus mass of nutrients excreted by the same herd at two levels of milk production (ASABE, 2005).

	Total Nitrogen (lbs. head^{-1} year^{-1})	Total Phosphorus (lbs. head^{-1} year^{-1})
Contained in mortalities	2.5	0.74
Excreted by cattle with a rolling herd average milk production of 15,000 lbs. head^{-1} year^{-1}	380	61
Excreted by cattle with a rolling herd average milk production of 37,500 lbs. head^{-1} year^{-1}	450	79

4.5 Future Research Needs

4.5.a Types of Farms Not Covered in This Report

Farms for small ruminants (goats, sheep) and exotic cattle, camelids, and other ruminants were not included in this report. These are niche enterprises, present in small numbers, often unaffiliated with producer groups, and poorly captured in agricultural census data.

Mortalities produced by veal feeding units were not investigated for this report due to lack of regional data, widely varying management practices and slaughter weights, and perceived low contribution to the overall mass of mortality across the watershed. However, it is an opportunity for future study and consideration. Veal production can often be associated with regions of dairy production, as a value-added enterprise utilizing dairy bull calves. Renaud, et al. (2018) reported that veal calves in Canada experienced an overall mortality rate of 7%, with 42% of deaths occurring within the first 21 days of arrival into the veal feeding program. Mean finish time in the Renaud, el al. (2018) study was 148 days; therefore, one could estimate that half of veal mortalities are in a weight range of 100 to 200 pounds body weight. Actual slaughter weights appear to vary widely, but the recent report from USDA-AMS (https://www.ams.usda.gov/mnreports/lswveal.pdf, accessed November, 2020) indicates an average slaughter weight of 232 pounds for the week of November 14, 2020.

4.5.b Need For On-farm Data Collection

Although we are confident in the data produced in this report, the values were primarily produced through limited published data on mortalities and personal communication with top researchers in this area. Research should be undertaken to determine the actual mass of mortalities produced on farms under the cultural practices used in the watershed.

4.5.c Need For Data on Whole Carcass Nutrient Content

Very limited data exists for whole carcass composition of any type of cattle.

4.6 Assumed Values of Mortality Masses and Carcass Nutrients for Watershed

Without any further defining information, the values given in Table I.4.18 should be used for mass of mortalities and nutrients produced annually per head and AU of defining head. For cow-calf herds the defining head is a mother cow. For cattle on feed the defining head is steer or heifer capacity. For dairy cattle, defining head is mature dairy cattle (lactating and dry).

Table I.4.18. Assumed annual mass of mortalities and nutrients contained in mortalities produced by all types of cattle production systems.

	Annual Mortalities and Nutrients Produced per Head (lbs. $year^{-1}$)			Annual Mortalities and Nutrients Produced per AU (lbs. $year^{-1}$)		
	Mortalities	**TN**	**TP**	**Mortalities**	**TN**	**TP**
Cow-Calf	32	0.905	0.265	23	0.65	0.19
Cattle on Feed	18	0.52	0.15	16.5	0.47	0.14
Dairy	90	2.5	0.74	69	1.9	0.57

4.7 REFERENCES

ASABE Standards. (2005). 384.2: Manure Production and Characteristics. St Joseph, MI: ASABE.

Benedict, R. C. (1987). Determination of nitrogen and protein content of meat and meat products. *Journal-Association of Official Analytical Chemists*, *70*(1), 69-74.

Bonilha, S. F. M., Tedeschi, L. O., Packer, I. U., Razook, A. G., Nardon, R. F., Figueiredo, L. A., & Alleoni, G. F. (2011). Chemical composition of whole body and carcass of Bos indicus and tropically adapted Bos taurus breeds. *Journal of animal science*, *89*(9), 2859-2866.

Cohen, Y. (2009). Phosphorus dissolution from ash of incinerated sewage sludge and animal carcasses using sulphuric acid. *Environmental technology*, *30*(11), 1215-1226.

Felton, G., Timmons, J., & Ogejo, J.A.. (2009). Mortality composting, definition and nutrient and nutrient sediment reduction effectiveness estimates, pp 393-412, In Simpson, T. and J. Weammert. F*inal Report, Developing Best Management Practices and Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay Watershed*. College Park, MD: Univ. of MD Mid Atlantic Water Program.

Greiner, S. P. (2005). Beef cattle breeds and biological types.

Hamilton, H. (2011). The Relationship Between Cow Size & Production, Beef Magazine Online Retrieved from https://www.beefmagazine.com/cow-calf/relationship-between-cow-size-production

Hawkins, S., Hamilton, D., Mcintosh, B., Moyle, J., Risse, M., & Vanderstampen, P. (2016). *Animal Waste Systems, Recommendations from the BMP Expert Panel for the Animal Waste Management Systems in the Phase 6 Watershed Model.* Annapolis, MD: Chesapeake Bay Program.

Jones, C. & Heinrichs, J. (2016). Early Weaning Strategies. *Penn State Extension, State College, PA.*

Jones, C. & Heinrichs, J. (2017). Growth Charts for Dairy Heifers. *Penn State Extension, State College, PA.*

Renaud, D.L., Duffield, T.F., LeBlanc, S.J., Ferguson, S., Haley, D.B., & Kelton, D.F. (2008). Risk factors associated with mortality at a milk-fed veal calf facility: A prospective cohort study. *Journal of Dairy Science,* 101 (3), 2659-2668.

USDA-APHIS (2010). Mortality of Calves and Cattle on U.S. Beef Cow-calf Operations: Info Sheet, 2010. Fort Collins, CO: USDA-APHIS.

USDA-APHIS. (2016). Dairy 2014: Health and Management Practices on US Dairy Operations, 2014. Report, 3, 62-77. Fort Collins, CO: USDA-APHIS,.

USDA-NRCS. (2008). *Part 651, Agricultural Waste Management Field Handbook, Chapter 4: Agricultural Waste Characteristics.* Washington DC: United States Depart of Agricultural, Natural Resources Conservation Service.

Vogel, G. J., Bokenkroger, C. D., Rutten-Ramos, S. C., & Bargen, J. L. (2015). A retrospective evaluation of animal mortality in US feedlots: rate, timing, and cause of death. *Bov. Pract*, *49*(2), 113-123.

5. **Equidae**

5.1 Definitions

Colt: intact male equid, less than four years of age

Dam: female parent of an equid

Donkey: domesticated animal of the species, *Equus assinus*. Donkeys have 62 chromosomes. The name Donkey is Interchangeable with **Ass**, but Ass usually refers to wild animals. Feral Asses in the US are called by their Spanish name, **Burro.**

Equid: animal of the family *Equidae*

Filly: intact female equid, less than four years of age

Foal: equid less than six months of age

Gelding: castrated horse or pony of any age

Horse: domesticated animal of the species, *Equus caballus*, greater than 14.2 hands in height at the withers. Horses have 64 chromosomes.

Jack: male donkey or mule

Jenny or Jennet: female donkey or mule

John: gelded male mule

Mare: intact female horse or pony, four years or older

Mule: a hybrid from a donkey sire and a horse dam, possessing 63 chromosomes -- generally cannot produce offspring.

Pony: domesticated animal of the species, *Equus caballus*, less than 14.2 hands high at the withers. Like horses, ponies have 64 chromosomes.

Sire: male parent of an equid

Stallion: intact male horse or pony four years or older

Weaning: the gradual replacement of mother's milk by another type of feed.

5.2 Equids in the Watershed

Horses, donkeys, and mules, unlike other livestock in the US, are bred for use and not for consumption. Because they are bred for a wide variety of purposes (e.g. work, racing, show, pleasure), there is great diversity in size and breed (Figures I.5.1 through I.5.6). A survey of baseline equine health and management conducted in 2015 collected equine data regionally across the United States (USDA-NASS, 2016). Four of the six Chesapeake Bay states (Delaware, Maryland, New York, Pennsylvania) were

Figure I.5.1. A team of draft horses stand at rest as an NRCS employee discusses conservation plans with an Amish farmer (Bob Nichols, USDA Natural Resources Conservation Service).

Figure I.5.2. Endurance race at the 2010 World Equestrian Games (Amanda Gumbert).

Figure I.5.3. Thoroughbred filly (University of Kentucky Agricultural Communications).

Figure I.5.4. Ponies in their shaggy winter coats (Amanda Gumbert).

Figure I.5.5. A donkey jenny and her foal enjoying a Delaware pasture (Alice Welch, USDA Natural Resources Conservation Service).

Figure I.5.6. A mule team pulls a canal barge in Bucks County, PA (ScenicBucksCounty.com).

included in the Northeast region. The top three types of equine operations in this region were farm/ranch (36.5%), a residence with equids for personal use (32.5%), and boarding stables/training facilities (16.2%). The Northeast region also had the highest percentage of draft horses nationwide (15.2%). Based on trends found in the Northeast, a typical operation with equids in the Chesapeake Bay watershed is a small (5-9 animals) farm/ranch or personal/recreational use facility (Figure I.5.7).

Figure I.5.7. Waredaca horse pasture in Montgomery County, Maryland (Will Parsons, Chesapeake Bay Program).

Table I.5.1. lists equid populations for the six states containing the Chesapeake Bay Watershed. The numbers in Table I.5.1 are for whole states, not the portion of the state in the watershed. Equine populations are challenging to innumerate in the Chesapeake Bay watershed, and numbers reported are variable. For example, the 2017 Census of Agriculture (USDA-NASS, 2017) reported a horse population of 88,343 in Pennsylvania, while the American Horse Council reported a horse population of 223,628 that same year (Smarsh, 2018). The American Horse Council estimates New York's horse population at 154,000 (AHCF, 2018), but USDA estimates 68,599 (USDA-NASS, 2017). The discrepancy in horse population numbers is likely attributed to accounting methodology. The USDA Census of Agriculture accounts for only horses on properties with $1,000 or more in agricultural products sold in the census year and does not account for operations with less than five animals. The USDA estimate (USDA-NASS, 2017) also excludes mules and donkeys. Horse population estimates conducted by groups such as the American Horse Council and state-specific equine commodity organizations include hobby farms, rescues and sanctuaries, boarding/riding facilities, and equine assisted therapy facilities. The majority of equids in Maryland are kept at facilities for personal use or at boarding/riding/training facilities, followed by racing facilities (MHIB, 2010).

Table I.5.1. Horse and pony population in the states containing the Chesapeake Bay Watershed based on USDA (USDA-NASS, 2019) and industry sources (MHIB, 2010; Rephann, 2011; AHCF, 2018; Pennsylvania Horse Council, 2019; Delaware Horse Properties, 2019; Smarsh, 2018; West Virginia Horse Properties, 2019).

	USDA Estimate[1]	Industry Estimate
Delaware	4,178	11,000
Maryland	27,635	79,100
New York	68,599	154,000
Pennsylvania	88,343	223,628
Virginia	65,588	215,000
West Virginia	23,472	43,000
Total	**277,815**	**725,728**

[1]Excludes mules and donkeys.

Lawful equine mortality disposal practices in the Chesapeake Bay watershed include burial, composting, landfilling, incineration, and rendering. Virginia has established a hierarchy for disposal, with rendering being the preferred disposal method, followed by composting. Not all landfills accept animal mortalities, and there is limited accounting of numbers accepted (G. Flory, personal communication, January 11, 2019). Rendering options are limited when euthanasia drugs are utilized to terminate the animal. Further, a concern of equine mortality disposal is that of secondary toxicosis associated with euthanasia drug residues remaining in the carcass following burial or composting. Payne et al. (2015) found sodium pentobarbital residue present in compost material and soil samples under composting treatment bins 367 days after death at concentrations of 25.15 mg/kg and 0.2 mg/kg, respectively, suggesting residues leached from the bins. Custom cremation is available in at least four states in the watershed. Pet crematories in Maryland, Virginia, New York, and Pennsylvania offer individual and/or group cremation with the option for horse owners to retrieve the cremains.

5.3 Nutrients Contained in Equine Carcasses

5.3.a Animal Growth Patterns

Equids grow rapidly during the first year of life, with the most intense period of growth occurring during the first three months (Kavazis and Ott, 2003). Full body weight is reached around 36-48 months of age (Figure I.5.8). Foals are weaned generally between 6-9 months of age. Equids are considered to have reached full height by age 2; muscling and bone development increases until full physical maturity is reached between 5-6 years old.

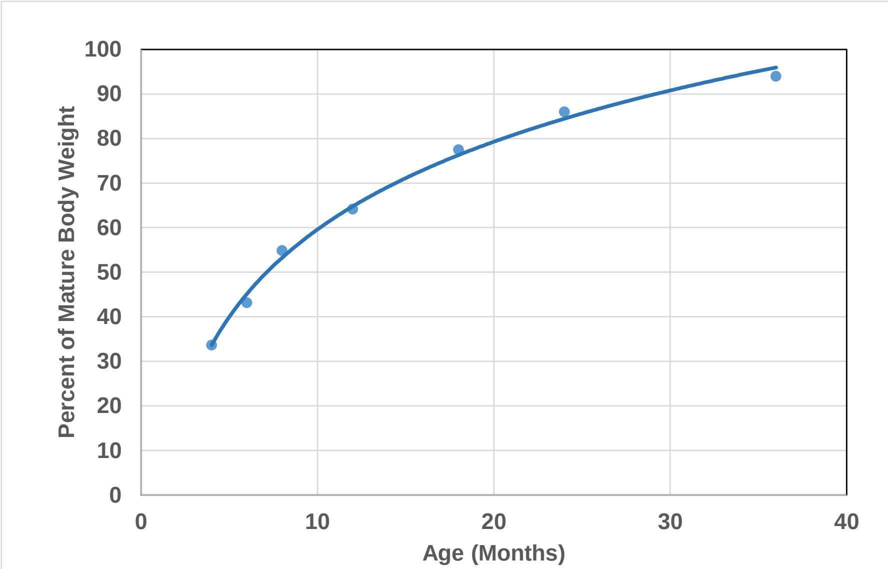

Figure I.5.8. Growth pattern of equids (NRC, 2007).

5.3.b Death Rate

The overall annual mortality rate of equids (including donkeys, mules, ponies, miniature horses, drafts, and full-size horses) in the United States is estimated at 1.4% (USDA-APHIS, 2017). The highest mortality rates occur in two seasons of life: 2.8% at less than six months of age, and 3.1% at 20+ years. Common causes of death for younger animals include injury, wounds, and trauma. Old age was the most common cause of death in animals greater than 20 years old. USDA-APHIS (2016) provided national and regional population distributions for equids (Table I.5.2). Within each population segment, the percentage of resident equids that died or were euthanized in the previous 12 months was estimated. Although regional differences occur in both population distributions and death rates, these differences were within the margin of error for the population sampled. The national average values for population distribution and death rate for population segments were used for all calculations in this report.

5.3.c Nutrient Composition

Data on whole carcass nutrient composition of equids is extremely limited, with most research studies focusing on body composition related to horse performance (Kearns et al., 2002). Lorenzo et al. (2013) reported the average body composition of the horse to be 69.6% muscle, 17.4% bone, and 10.4% fat (as a percentage of whole-body weight). Body fat appears to be the most variable tissue component, especially when comparing among breeds. A review of the literature by Kearns et al. (2002) reported a range in body fat of 5.1% for thoroughbreds (race breed) and up to 24.5% for Percherons (draft breed). Percent fat tends to increase with age (Lorenzo et al., 2014).

Grace et al. (1999) determined the phosphorus content of 5-month-old weaned foals to be 10.1 g/kg empty body weight, while Schryver et al. (1974) reported the P content to be 8 g/kg live full body weight of a young (24 months) horse. When converted to full body weight (assuming empty body weight equals 92% of full body weight (Schryver et al. 1974)), the phosphorus contents of foals and young horses were

Table I.5.2. Population distribution and death rates for equids (USDA-APHIS, 2016).

Age	Population Distribution (head per 100)	Annual Death Rate for Each Population Segment (%)	Number Dying Each Year in a Herd of 100 (head $year^{-1}$)
0 to 30 days	1.4	2.8	0.039
30 days to 6 months	2.9	2.8	0.081
6 months to year	2.1	1.2	0.025
1 to 5 years	16.5	0.5	0.083
5 to 20 years	65.6	0.8	0.525
20 to 29	9.9	3.1	0.307
30 or older	1.5	3.1	0.047
Totals	**99.9**		**1.11**

1.1% and 0.8%, respectively. Cooper et al. (2001) reported P content of quarter horse rib bone to range from 13.1% in animals 1 to 20 years old to 20.6% in pregnant mares of unreported age, though these values reflect individual bone biopsy analysis and no data was available to convert to a whole animal carcass basis. The full body phosphorus content of mature horses was not available in the literature; therefore, calculations for mature horses was based on 0.8% of full live body weight.

The calculated masses of total nitrogen (TN) and total phosphorus (TP) expected for a young animal (0-6 months of age) and a mature animal (greater than 3 years) are shown in Table I.5.3. Values are reported on a pound per animal unit (AU) basis. One animal unit is equal to 1,000 pounds liveweight. Nitrogen content was calculated from protein content using the equation: *Total nitrogen = Total protein/6.25* (Benedict, 1987), utilizing protein percentage values reported by Lorenzo et al. (2014). Total nitrogen values are reported as the sum of muscle and bone protein, assuming muscle is 21.66% protein (Lorenzo et al., 2013) and bone is 30% protein on a mass basis. Fat content is not reflected in the nutrient calculations as it is assumed that fat contains no protein or mineral.

Table I.5.3. Mass of nutrients in equid bodies.

	Mass of Nutrient (lbs. AU^{-1})	
	TN	**TP**
Young animal (0 to 6 months old)	32	11
Mature animal (more than 36 months old)	32	8
Overall average	32	9.5

5.4 Estimated Annual Mass of Nutrients Contained in Mortalities from Equine Herds

What follows is a method to calculate the mass of mortalities produced by a population of equids and the nutrients contained in those mortalities. Population generally refers to equids living in a census designated entity such as a state or county. Death loss on individual farms is an episodic event. A farm may suffer no loss for many years, and suddenly be faced with the dilemma of disposing of a 2,000-pound draft horse.

The population distribution shown in Table I.5.2 is further expanded in Table I.5.4 to align with the growth pattern shown in Figure I.5.8. The assumption was made that each population segment could be broken down evenly. For instance, there are 2.9 animals in the 30 days to 6 months group in Table I.5.2. This was broken down into equal portions of 0.58 head for each month of age. The data from Figure I.5.8 was used to determine the weight of each animal in each population group, assuming a mature weight of 1,000 pounds (Table I.5.4). Total weight of animals in each population group was determined by multiplying number of animals in each group by the estimated weight of the individual animal. Summing group weights gives the weight of the entire population (or herd).

Table I.5.4. Expanded population distribution and weights of animals assuming 1,000-lb mature weight.

Age	Population Distribution (head)	Fraction of Mature Weight (From Figure I.5.8)	Weight of Animal (lbs.)	Weight in Each Population Group (lbs.)
0 to 1 month	1.4	0.300	300	420
1 to 4 months	1.75	0.350	350	613
4 to 5 months	0.58	0.370	370	214
5 to 6 months	0.58	0.426	426	247
6 to 8 months	0.7	0.495	495	346
8 months to year	1.4	0.596	596	835
1 year to 18 months	2.75	0.711	711	1,956
18 months to 2 years	2.75	0.807	807	2,218
2 to 4 years	5.5	0.908	908	4,993
4 to 5 years	5.5	1.000	1,000	5,500
5 to 20 years	65.6	1.000	1,000	65,600
20 to 29 years	9.9	1.000	1,000	9,900
30 and older	1.5	1.000	1,000	1,500
Total Animals	**99.91**	**Total Weight of Herd (lbs.)**		**94,342**

Likewise, the number of animals expected to die during the course of a year in each of the expanded population distribution groups is determined by multiplying the population of the group by the death rate for the group (Table I.5.5). Weight of mortalities in each group is the number expected to die multiplied by weight of individual animals. Summing the weight of mortalities of each group gives the annual weight of mortalities produced by the entire herd (Table I.5.5). Dividing the weight of mortalities produced by the herd by the number of animals in the herd gives the weight of mortalities per head. Dividing the weight of mortalities produced by the herd by the total liveweight of the herd (Table I.5.4) gives annual weight of mortalities per pound of liveweight. Multiplying annual weight of mortalities per pound of liveweight times 1,000 gives annual weight of mortalities per herd weight in units of AU.

Table I.5.5. Weight of mortalities and nutrients contained in mortalities for a population of equids with a mature weight of 1,000 pounds.

Age	Number Dying in Each Group per Year (head yr^{-1})	Weight of Animal (lbs.)	Weight of Mortalities in Each Group (lbs. yr^{-1})	Weight Fraction of Nutrients (lb. nutrient per lb. carcass)		Nutrients contained in mortalities (lbs. yr^{-1})	
				TN	TP	TN	TP
0 to 1 month	0.039	300	11.8	0.032	0.0110	0.38	0.129
1 to 4 months	0.049	350	17.2	0.032	0.0110	0.55	0.189
4 to 5 months	0.016	370	6.0	0.032	0.0110	0.19	0.066
5 to 6 months	0.016	426	6.9	0.032	0.0110	0.22	0.076
6 to 8 months	0.008	495	4.2	0.032	0.0109	0.13	0.045
8 months to year	0.017	596	10.0	0.032	0.0106	0.32	0.106
1 year to 18 months	0.014	711	9.8	0.032	0.0101	0.31	0.099
18 months to 2 years	0.014	807	11.1	0.032	0.0089	0.35	0.099
2 to 4 years	0.028	908	25.0	0.032	0.0086	0.80	0.215
4 to 5 years	0.028	1,000	27.5	0.032	0.0080	0.88	0.220
5 to 20 years	0.525	1,000	524.8	0.032	0.0080	16.79	4.198
20 to 29 years	0.307	1,000	306.9	0.032	0.0080	9.82	2.455
30 and older	0.047	1,000	46.5	0.032	0.0800	1.49	3.720
Totals for the Entire Herd			**1,007.5**			**32.24**	**11.62**
Weight of Mortalities per Head (lbs. yr^{-1})			**10.1**	**Weight per Head (lbs. yr^{-1})**		**0.32**	**0.12**
Weight of Mortalities per Herd Weight (lbs. AU^{-1} yr^{-1})			**10.7**	**Weight per Herd Weight (lbs. AU^{-1} yr^{-1})**		**0.34**	**0.12**

The literature (Grace et al., 1999; Schryver et al, 1974) shows that nutrient concentration per pound of carcass weight is not constant throughout the life of a horse. The mass fraction of phosphorus drops from 0.011 pounds TP per pound of carcass for young animals to 0.008 pounds TP per pound of carcass for horses five years and older (Table I.5.5). Multiplying the weight fraction of nutrients per carcass by weight of mortalities in each population group gives the annual weight of nutrients contained in mortalities produced by each group. Summing the weight of nutrients in mortalities for each group gives the weight of nutrients produced by the herd. Dividing the annual weight of nutrients produced by the herd by number of animals in the herd gives the annual weight of nutrients produced per head. Dividing the annual weight of nutrients produced by the herd by herd weight (Table I.5.4), and multiplying by 1,000 gives annual weight of nutrients per herd weight in units of AU.

The mass of mortalities per AU is constant at 10.7 pounds per year. The mass of nutrients contained in carcasses is also constant at 0.34 pounds TN and 0.12 pounds TP per AU per year. To find the values for different breeds of equids, one must go through the process outlined above using the mature weight for each breed. Weights of mortalities and nutrients contained in carcasses produced per head per year are given for several breeds of horses and donkeys in Table I.5.6. Mature weight of mules can be estimated by averaging the weight of the parents. Draft mules usually have a mammoth jack as a sire and a draft horse as a dam. Saddle mules are usually a cross between a mammoth jack and a saddle horse mare.

Table I.5.6. Annual weight of mortalities and nutrients contained in mortalities per head for several breeds of horses and donkeys (NRC, 2007; NMDA, 2020; OSU-ANSI, 2020)

Breed	Breed Type	Mature Weight (lbs)	Weight of Mortalities per Head (lbs yr^{-1})	Weight of Nutrient per Head (lbs. yr^{-1})	
				TN	TP
Belgian	Draft	1,899	19.2	0.61	0.22
Hanoverian	Warm blood	1,276	12.9	0.41	0.15
Thoroughbred	Race	1,276	12.9	0.41	0.15
Standardbred	Race	1,100	11.1	0.35	0.13
Quarter Horse	Light	1,221	12.3	0.39	0.14
Arabian	Light	1,001	10.1	0.32	0.12
Morgan	Light	999	10.1	0.32	0.12
Pony	Pony	429	4.3	0.14	0.050
Miniature	Donkey	275	2.8	0.089	0.032
Standard	Donkey	500	5.0	0.16	0.058
Mammoth	Donkey	950	9.6	0.31	0.11
Average of All Equids		**983**	**9.9**	**0.32**	**0.11**
Average of Horses		**1,150**	**11.6**	**0.37**	**0.13**

5.5 Comparison of Equid Mortality Nutrients to Excreted Manure Nutrients

Comparison of nutrients contained in mortalities to nutrient excreted by equids is a true "apples to apples" comparison. The nutrients contained in mortalities calculated by the method outlined in this report are nutrients contained in the animal's body exactly at the time of death - before losses from decay, storage, and disposal method diminish their weight. Excreted manure nutrients are nutrients leaving the animal - before weathering, ammonia volatilization, and a multitude of other factors diminishes their weight on the pasture. Estimates using formulas for excreted nutrients, which are based on nutrient intake, are highly dependent on assumptions of diet and cultural practices, and should be thought of as rough averages with a high degree of variability - just as this report has highlighted the variability of estimating the mass of mortality nutrients.

Table I.5.7 compares the mass of nutrients contained in mortalities based on the methods used in this report to the mass of nutrients excreted by the same 100-head herd with a mature weight of 1,000 pounds. The *USDA-NRCS Waste Management Field Handbook* (USDA-NRCS, 2008), which in turn is based on the American Society of Agricultural and Biological Engineer Standard 384.2 *Manure Production and Characteristics* (ASABE, 2005), was used to calculate excreted manure values. The ASABE standard (ASABE, 2005) estimates the mass of total nitrogen and phosphorus excreted by horses per day. These values are based on a mass balance of food intake, nutrients accumulating in the body, nutrients respired, and nutrients excreted. NRCS (2008) further divides excreted values based on the activity level of horses. Sedentary horses, horses that are not receiving any imposed exercise, are expected to excrete 0.18 pounds of TN and 0.026 pounds of TP per AU per day. Exercised horses excrete 0.31 pounds of TN and 0.066 pounds of TP per AU per day. Table I.5.7 shows that, if carcass nutrients are combined with excreted nutrients, **approximately 0.52% of the nitrogen and 1.3% of the phosphorus produced by stables housing sedentary horses originate from mortalities**. Likewise, **0.30% of the nitrogen and 0.51% of the phosphorus from training stables and working horse farms originate from mortalities.**

Table I.5.7. Nutrients contained in mortalities produced by a 100-head herd of equids with 1,000 pounds mature weight versus the mass of nutrients excreted by the same herd at two levels of activity (ASABE, 2005; NRCS, 2008).

	Total Nitrogen ($lbs.\ head^{-1}\ year^{-1}$)	**Total Phosphorus ($lbs.\ head^{-1}\ year^{-1}$)**
Contained in Mortalities	32	12
Excreted by Sedentary Equids	6,198	895
Excreted by Exercised Equids	10,675	2,273

5.6 Future Research Needs

Future work should include development of practical and specific guidance for end-of-life decision-making and disposal options for equid owners in the Chesapeake Bay watershed. Nationwide, only 59.8% of equid operations have an end-of-life plan, with equine boarding or stabling operations having a higher percentage of plans in place as compared to farms/ranches/residences with personal use equids (USDA, 2016).

5.7 Assumed Values of Mortality Masses and Carcass Nutrients for Watershed

Without any further defining information, the values given in Table I.5.8 should be used for mass of mortalities and nutrients contained in mortalities produced annually per head and per AU. The values given in Table I.5.8 are for an average horse weighing 1,150 pounds at maturity - assuming in most jurisdictions the population of horses greatly outnumbers the population of donkeys and mules. If the composition of an equid population is known - for instance, the population contains 50% quarter horses, 40% thoroughbreds, 8% draft horses and 2% standard donkeys - the average for the entire population can be estimated using the breed values of Table I.5.6 proportionally (i.e., 0.5 X 0.39 + 0.4 X 0.41 + 0.08 X 0.61 + 0.02 X 0.16 = 0.41 pounds TN per head per year.)

Table I.5.8. Assumed annual mass of mortalities and nutrients contained in mortalities produced by equids.

Annual Mortalities and Nutrients Produced per Head (pounds year^{-1})			Annual Mortalities and Nutrients Produced per AU (pounds year^{-1})		
Mortalities	**TN**	**TP**	**Mortalities**	**TN**	**TP**
11.6	0.37	0.13	10.7	0.34	0.12

5.8 References

American Horse Council Foundation. (2018). *Economic Impact of the Horse Industry in New York*. American Horse Council, Washington, DC.

ASABE Standards. (2005). 384.2: Manure Production and Characteristics. St Joseph, MI: ASABE.

Benedict, R.C. (1987). *Determination of nitrogen and protein content of meat and meat products*. Journal of the Association of Official Analytical Chemists. 70(1), 69-74.

Cooper, S.R., Topliff, D.R., Freeman, D.W., Collier, M.A., & Balch, O.K. (2001). Evaluation of Bone Mineral content in Equine Cadavers and Pregnant Mares. *Journal of Equine Veterinary Science*. 21, 450-453.

Delaware Horse Properties. (2019). Retrieved from https://www.horseproperties.net/state/delaware, accessed October 11, 2019.

Grace, N.D., Pearce, S.G., Firth, E.C., & Fennessy, P.F. (1999). Content and Distribution of Macro- and Micro-elements in the Body of Pasture-fed Young Horses. *Australian Veterinary Journal*. 77 (3), 172-176.

Kavazis, A.N. & Ott, E.A.. (2003). Growth Rates in Thoroughbred Horses Raised in Florida. *Journal of Equine Veterinary Science.* 23 (8), 353-357.

Kearns, C.F., McKeever, K.H., & Abe, T. (2002). Overview of Horse Body Composition and Muscle Architecture: Implications for Performance. *The Veterinary Journal*, 162, 224-234.

Lorenzo, J.M., Pateiro, M., & Franco, D. (2013). Influence of Muscle Type on Physicochemical and Sensory Properties of Foal Meat. *Meat Science*. 94, 77-83.

Lorenzo, J.M., Sarries, M.V., Tateo, A., Polidori, P., Franco, D., & Lanza, M. (2014). Carcass Characteristics, Meat Quality, and Nutritional Value of Horsemeat: A Review. *Meat Science*. 96, 1478-1488.

Maryland Horse Industry Board. (2010). *2010 Maryland Equine Census.* Retrieved from https://mda.maryland.gov/horseboard/pdf/2010_equine_census.pdf.

National Miniature Donkey Association (NMDA). 2020. *Donkey Facts*. Retrieved from https://www.nmdaasset.com/

National Research Council of the National Academies (NRC). (2007). *Nutrient Requirements of Horses,* Sixth revised edition. Washington, DC: The National Academies Press.

Oklahoma State University Department of Animal Science (OSU-ANSI) 2020. *Breeds of Livestock.* Retrieved from http://afs.okstate.edu/breeds.

Rephann, T.J. (2011). *The Economic Impact of the Horse Industry in Virginia*. Charlottesville, VA: University of Virginia.

Schryver, H.F., Hints, H.F., Lowe, J.E., Hintz, R.L., Harper, R.B., & Reid, J.T. (1974). Mineral Composition of the Whole Body, Liver and Bone of Young Horses. *The Journal of Nutrition,* 104, 126-136.

Smarsh, D. (2018) *Pennsylvania is a Top Ten Horse State*. Retrieved from https://extension.psu.edu/pennsylvania-is-a-top-ten-horse-state.

U.S. Department of Agriculture (USDA-APHIS). (2016). *Equine 2015 Baseline Reference of Equine Health and Management in the United States*, 2015 (Report No 718.1216). Retrieved from https://www.aphis.usda.gov/animal_health/nahms/equine/downloads/equine15/Eq2015_Rept1.pdf.

U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS). 2017. *APHIS Info sheet: Equine Mortality in the United States, 2015*. Retrieved from: https://www.aphis.usda.gov/animal_health/nahms/equine/downloads/equine15/Equine15_is_Mortality.pdf

U.S. Department of Agriculture National Agricultural Statistics Service (USDA-NASS). (2017). Retrieved from https://www.nass.usda.gov/index.php.

USDA-NRCS. (2008). *Part 651, Agricultural Waste Management Field Handbook, Chapter 4: Agricultural Waste Characteristics.* Washington DC: United States Depart of Agricultural, Natural Resources Conservation Service.

West Virginia Horse Properties. (2019) Retrieved from https://www.horseproperties.net/state/west-virginia, accessed October 11, 2019.

Part II

Disposal Methods

1. Introduction

1.1 Concept of Nutrient Movement from Disposal Methods

Routine Mortality Disposal is a best management practice for livestock operations. Within that practice there are several methods of mortality disposal. This expert panel investigated five methods of livestock and poultry mortality disposal: burial, composting, incineration, landfilling, and rendering. Mortality disposal methods can be viewed as a treatment process, and as stated in Hamilton et al. (2016), treatment processes do not remove nutrients from a waste stream. Disposal methods change the form of nutrients (such as protein nitrogen to ammonia nitrogen), and transfer nutrients from animal carcasses to various environmental media such as air, water, and soil. Figure II.1.1 illustrates the concept of nutrient transfer during routine mortality disposal.

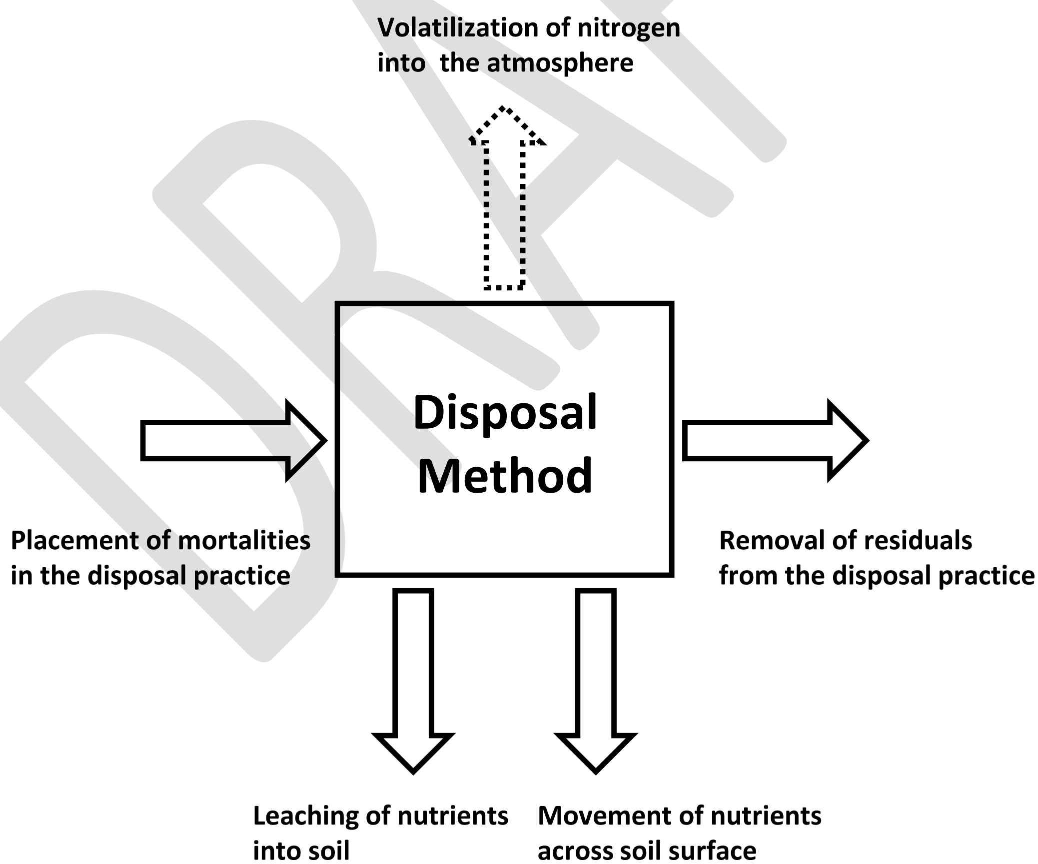

Figure II.1.1. Transfer of nutrients by a disposal method to various environmental media.

For the purposes of this report, the expert panel simplified the transfer scheme of Figure II.1.1 to only consider those pathways that are either inputs to the Chesapeake Bay Model or measurable during verification of a disposal method. Figure II.1.2 illustrates this simplified scheme. The arrows shown in Figure II.1.2 indicate movement of nutrients into environmental media and removal from the practice as useful end products. As you will see in the following chapters, diagrams drawn for each practice will not be identical. Some practices will have some arrows missing. For instance, it is not expected that residuals will be removed from a burial site; therefore, the arrow for removal of residuals will be missing from the burial process diagram. Likewise, thermochemical processes (incineration) take place within a watertight vessel; therefore, movement from the method does not occur except by reuse of end product and atmospheric emission -- although transfer to water resources may occur through improper disposal of ash or char.

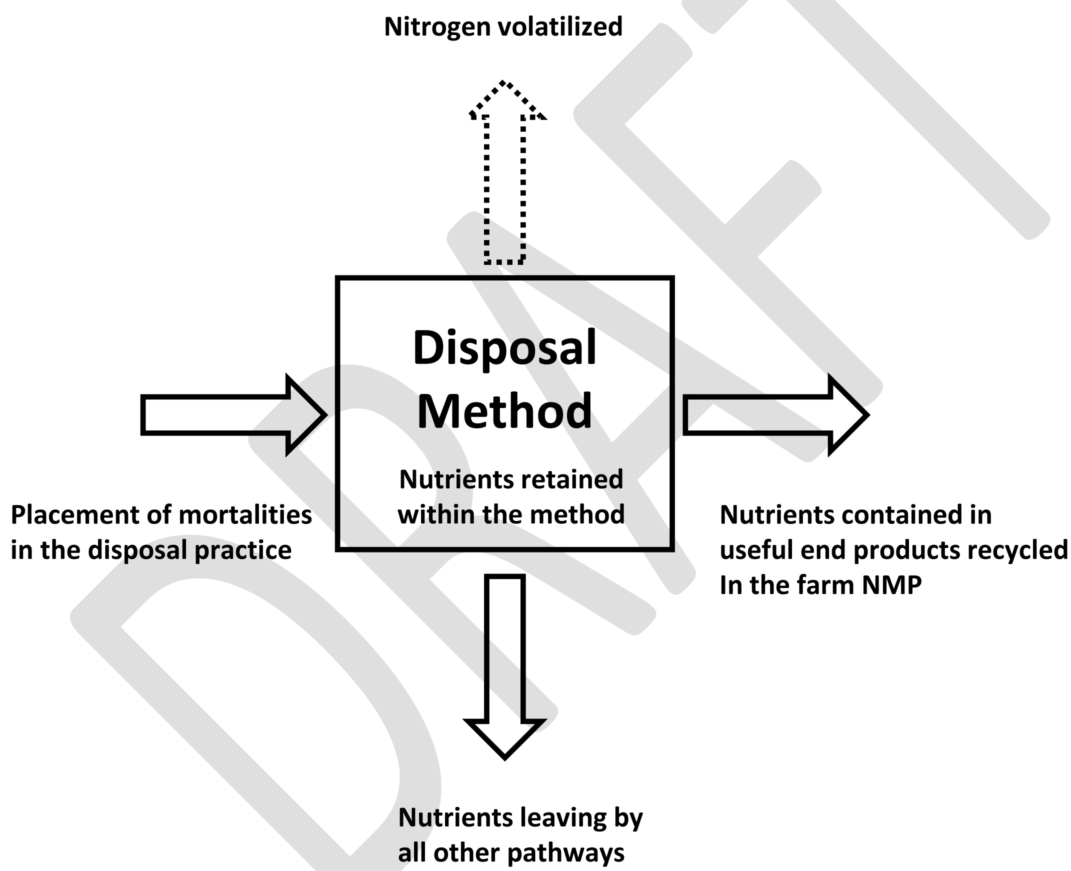

Figure II.1.2. Potential movement of nutrients during implementation of a disposal method.

Also, similar to Hamilton et al. (2016), the Expert Panel chose the concept of nutrient transfer efficiency to express the mass of nutrients leaving by various routes:

$$\text{Mass Transfer Efficiency} = \frac{(\text{Mass of Nutrients Indicated by Arrow Leaving the Method})}{(\text{Mass of Nutrients Entering the Method})}$$

With disposal methods, mass transfer efficiency is expressed as the percentage of nutrients leaving by a particular pathway. For example, for mass of total nitrogen (TN) emitted to the atmosphere:

$$\text{Percent TN Volatilized} = \frac{(\text{Mass of Nitrogen Leaving the Method via Volatilization})}{(\text{Mass of Nitrogen Contained in a Carcass Placed in the Method })} \text{ X } 100$$

1.2 Potential Movement of Nutrients within Methods

Estimated movement of carcass nutrients for each of the disposal methods will be discussed in the following chapters. Table II.1.1 lists the fallback (that is, estimates for a standard method without knowing all of the production and environmental factors pertaining to the method) percentages of nutrients exiting the method as shown in Figure II.1.2 for all of the disposal methods examined by this expert panel.

1.2.a. Nutrients Recycled in a Nutrient Management Plan (NMP)

As shown in Table II.1.1. only composting and incineration provide end-products that can be used on-farm and recycled in a nutrient management plan. Rendering produces a useful product (feed meal) but nutrients are not used on the farm in a land application system. Feed meal nutrients "disappear" from the Chesapeake Bay Model when carcasses are taken to a rendering plant, and could reappear as manure nutrients if the meal is fed within the watershed. Nutrients are retained within burial pits and landfills, and therefore, are not useful in any way to the producer.

1.2.b. Atmospheric Emissions

Both composting and incineration emit nitrogen to the atmosphere. Type of nitrogen emitted is discussed in the individual method chapters. Composting emits more nitrogen with more frequent turning or aggressive aeration of piles. Nitrogen from incineration will shift from emitted to useful end product with lowering incineration temperature. Minute amounts of nitrogen may be emitted from burial pits and landfills and is related to quality of cover. The rendering process may emit some nitrogen, but these emissions are covered by industrial air permits and, therefore, are not counted as agricultural emissions in the Chesapeake Bay Model. Farm incinerators generally do not have air control permits. Atmospheric emissions may occur from all methods if the carcasses are not refrigerated or disposed of quickly after death.

Table II.1.1. Potential movement of nutrients during implementation of a disposal method, fallback values.

	Mass Percentage of Carcass Nutrients Exiting the Method (%)				
	Nutrients recycled with end products in the farm nutrient management plan		Nutrients emitted to the atmosphere	Nutrients leaving the method by all other pathways	
Disposal Method	**TN**	**TP**	**TN**	**TN**	**TP**
Burial	0	0	0	15	5
Composting	80	100	10	10	0
Incineration	25	100	75	0	0
Landfilling	0	0	0	0	0
Rendering	0	0	0	0	0

1.2.c. All Other Pathways of Nutrient Movement

Some nutrients are leached from burial pits, but there is limited data presented in the literature. Little nutrients leave burial by overland flow due to proper placement and isolation of the pit. Some leaching and runoff of nutrients may occur with composting, but may be minimized by correct pile construction, placement of compost piles on constructed pads, and placement under roof. Nutrients do not leave incinerators except as volatilized nitrogen and useful end product; however, nutrient leaching and runoff may occur if the ash produced during incineration is not stored or handled properly. Leaching of nutrients from landfills is prevented by design, and point source discharge of nutrients from rendering plants is controlled through NPDES permits.

1.3 Other Considerations with Disposal Methods

The panel did not attempt to judge the superiority of one method over the others. In fact, movement of nutrients may not be the primary criteria by which disposal methods are judged. Biosecurity and removal of nuisance conditions from mortality disposal have the greatest value to society. Individual farmers are likely to place greatest emphasis on biosecurity, ease of operation, ability to use end products on-farm, and the existence of outside networks aiding in operation of a method. Each method has benefits and drawbacks that increase or decrease its likelihood of adoption.

1.3.a. Burial

A properly constructed burial pit is ideal for out of sight, out of mind management. Biosecurity and nuisance control are very high if carcasses are buried quickly. The major drawback to this method is land used for burial pits is tied up indefinitely. Recovery of materials from a burial pit is not recommended due to biosecurity concerns. Also, many farms may not have land suitable for burial. Equipment required for burial of large animals may also deter many from using this method. Poorly constructed burial pits can be a major environmental hazard, resulting in groundwater pollution in sandy soils with high water tables or areas underlain by karst geology.

1.3.b. Composting

Composting has the highest potential for on-farm recycling of nutrients of all the methods the expert panel examined. Creating high quality compost with adequate pathogen reduction requires a high level of knowledge, skill and labor commitment on the part of the farmer, however. Land requirement is lower than burial in that the same area may be used to compost many carcasses. Cost of equipment and/or buildings required to properly compost may be high for some farmers. The biosecurity cost of improper composting cannot be understated. Pathogens may be spread by scavengers or by land application of poorly composted material.

1.3.c. Incineration

Recycling of nutrients is also possible through incineration of carcasses. Of the methods this expert panel examined, incineration has the highest potential for control of pathogens when done properly. A fairly high level of skill is needed to properly incinerate carcasses. Poorly ashed carcasses can be a source of pathogens. The greatest drawback for incineration is the equipment needed to incinerate large carcasses. Atmospheric emission of particulates and volatile organic compounds may be a concern if a properly sized afterburner is not used with incineration. Also, a considerable amount of fossil fuel must be used to properly incinerate mortalities, resulting in release of greenhouse gases.

1.3.d. Rendering and Landfilling

Rendering and landfilling appear to be the ideal solution for livestock and poultry farmers: someone comes to the farm, takes the mortalities, and troubles disappear. The greatest drawbacks to landfilling are finding a landfill willing to take carcasses, a trucker willing to haul mortalities to the landfill, and the costs associated with these activities. To make rendering a viable disposal option a strong network for carcass collection and a sufficient number of rendering plants willing and able to receive farm mortalities is an absolute requirement. The greatest environmental and biosecurity hazards associated with landfilling and rendering are the storage, timely collection, and transportation of carcasses. These methods, particularly for smaller carcasses, are greatly improved if refrigerated storage containers are deployed on-farm.

2. Burial

2.1 Definitions

Burial in the context of normal livestock mortality is defined as the act of placing a dead animal below the ground surface for disposal. Burial involves excavation of a pit or hole, depositing the animal in the pit, and capping or covering the animal with material from excavation. The excavated pit may be constructed using more than one method dependent on the equipment and manpower available. Excavation may be in the form of a vertical hole, a trench or a pit. Excavation may vary in depth, and pits are generally unlined. After burial, the animal carcass will undergo decomposition. Decomposition rate will vary based on burial depth, soil texture, temperature, moisture and drainage conditions. As the carcass breaks down components of the animal will migrate into the surrounding soil. Some substances will be lost to air and water, some will be transformed, and some will become immobile. There is the possibility of some contamination of soil, groundwater and surface water within 1 – 2 m of the pit (Freeman et. al, 2003).

2.2 Movement of Nutrients

Figure II.2.1 is a schematic of the movement of nutrients based on the definition of burial. The greatest transfer of nutrients into the environment during burial is through leaching of nitrogen into the soil - although some volatilization of nitrogen occurs and there is the possibility of surface water contamination close to the pit. Much of the nutrients contained in carcasses remain interred in the pit with the decomposing carcass. Since the intention of burial is for the remains to never be removed from the pit, no nutrients exit with byproducts to be recycled in an NMP. Estimated losses to the environment are given in Table II.2.1.

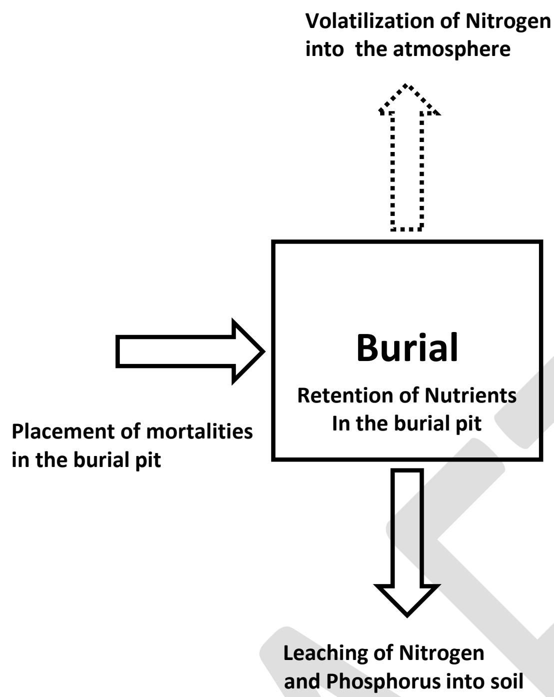

Figure II.2.1. Movement of nutrients using burial.

Table II.2.1. Estimated percentage of mortality nutrients transformed to useful end products and transferred to surrounding environment using the burial method of mortality disposal, assuming burial is conducted according to the Pennsylvania Domestic Animal Law (Williams, 2015).

	TN	TP
Mortality nutrients recycled with end products in the farm nutrient management plan (% of nutrients entering)	0	0
Mortality nutrients emitted to the atmosphere (% of nutrients entering)	0	0
Mortality nutrients leaving the method by all other pathways (% of nutrients entering)	15	5

2.3 Description of the Burial Method

Construction of the pit should comply with state and local regulations. A site should be selected where there are desirable soils, free of rocks and tree roots, as close to animal(s) as possible, but away from sensitive areas and concentrated surface water runoff. Use of the site will be limited for any purposes that will disturb the burial pit for some time. The bottom of the pit should be a minimum of 2 ft. above seasonal high water table, rock or highly permeable soils.

Other specifications for utilizing the burial method include the following:

- Excavate a hole or pit above ground water, deep enough to place animal and cover with a minimum of 2 feet of cap material.
- If desired, a layer of dry carbon material such as sawdust can be added to the bottom of the pit to retain leachate.
- Consolidate or pack the excavated material over the animal and mound the cap to shed runoff around the burial site and reduce infiltration Cap material should have lower permeability to protect the burial from infiltration of rainfall.

2.4 How Burial is Used with Different Animal Types

For small animals, more than one animal may be placed in the same excavation. Typically, with routine mortality, carcasses are be layered in daily until the excavation is at capacity. Smaller animals will have a smaller "footprint" and require less area for burial. Historically in the Delmarva area burial pits for poultry were constructed of a pit with a metal cover or lid for access. Loading rates were approximately 15 – 25 kg of dead birds per pit. Because of the high water-table, many of these pits were constructed into the water table (Ritter and Chirnside, 1995).

Larger animals are generally buried individually. Large animal carcass placement can be limited by the equipment and manpower available. Moving large carcasses can be awkward at least and difficult at worst. Ideally, producers need a tractor that can lift the carcass, a person to operate the tractor, and a person to assist with placement of the carcass.

2.5 Estimated Nutrient Mass (N and P) Lost along Pathways

Generally, the nutrient content of the animal (aside from that which may leach) remains buried, but may change form dependent on exposure to water or air. Research on burial has focused on leaching and groundwater as the pathway for nutrient movement. The research found as a result of this project focused on the nutrient content of the leachate as opposed to the carcass itself.

2.5.a Leaching

Ritter and Chirnside (1995) found that ammonia contamination was the greatest concern around poultry disposal pits, and measured ammonia concentrations greater than the EPA drinking water standard of 10 mg L^{-1} for nitrate in groundwater around half of the pits they evaluated. Although there is no standard for ammonia, ammonia at any concentration is not desirable in groundwater or drinking water. Pratt and Fonstad (2009) tested leachate from burial of three species (bovine, swine, poultry). Livestock mortality leachate on average contained concentrations of 12,600 mg L^{-1} NH_4-N, 1,500 mg L^{-1} total phosphorus, and 2,300 mg L^{-1} potassium. One pit for each species was assessed for leachate chemistry. For the first two months after burial, livestock leachate ammonium concentrations for each species were at their lowest at approximately 5,000 mg L^{-1}. The concentrations tended to increase between 4 and 9 months. At two years, bovine ammonium concentration was at 19,200 mg L^{-1}, swine ammonium concentration was 16,300 mg L^{-1}, and poultry was 10,100 mg L^{-1}. Phosphorus concentrations ranged from 1,200 mg L^{-1} (bovine) to 1,800 mg L^{-1} (poultry). Phosphorus concentrations fluctuated in the first 5 months and then levelled after 5 months. Potassium concentrations also did not fluctuate much during the two-year period.

Table II.2.2 Average mortality leachate concentrations per species over 25 months (Pratt and Fonstad, 2009).

	Poultry	**Swine**	**Bovine**	**Average**
Mass of Carcasses in Pit (kg)	1,300	5,900	3,920	1,300
Leachate pH	6.5	6.7	6.9	6.7
Analyte Concentration (mg L^{-1})				
Biocarbonate	39,133	48,467	50,733	46,100
Chloride	2,570	2,380	2,813	2,600
Total Alkalininity	22,500	39,700	41,600	34,600
NH_3-N	10,400	13,300	14,100	12,600
NO_3+NO_2-N	2.3	3.1	3.8	3.1
Inorganic Carbon	7,697	9,533	9,947	9,100
Organic carbon	79,000	65,000	68,000	71,000
Aluminum	0.50	0.50	0.50	0.50
Calcium	81	48	36	60
Copper	0.90	1.70	0.60	1.10
Iron	18	19	18	20
Magnesium	79	17	18	40
Manganese	0.50	0.10	0.10	0.20
Phosphorus	1,927	1,513	1,150	1,500
Potassium	2,400	2,400	2,000	2,300
Silicon, soluble	20	24	26	20
Sodium	1,600	1,700	2,000	1,800
Sulfate	3,970	3,900	2,900	3,600
Sulfur	1,300	1,297	963	1,200
Zinc	2.20	1.80	1.70	1.90

Pratt and Fonstad (2018) noted that livestock mortality leachate had ammonium concentrations 2 to 4 times higher than hog manure, and had much higher concentrations of phosphorus and potassium as compared to manure storages, lagoons, and landfills, with the highest concentrations exceeding drinking water standards by over 400 times. Alkalinity in livestock mortality leachate is 60 times higher than drinking water standards and exceeds the concentrations in hog manure and landfill leachate by 20,000 mg L^{-1}. Many other constituents found in livestock mortality leachate also greatly exceed the concentrations found in manure storages and landfills including sodium, sulfate, phosphorus, potassium, and chloride.

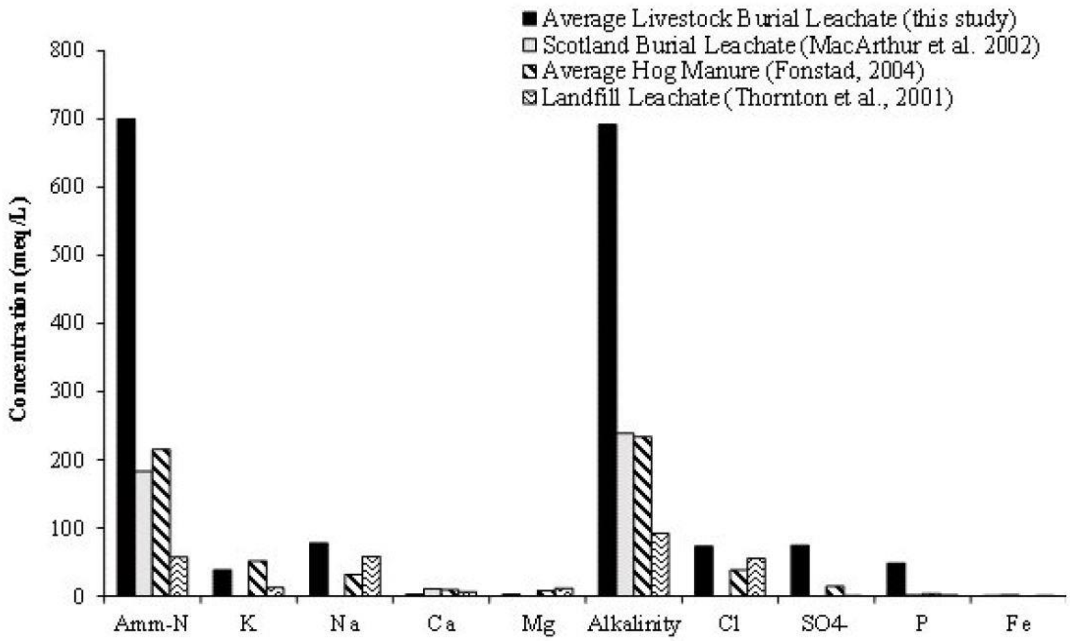

Figure II.2.2. Leachate from livestock burial pits to landfill leachate and swine lagoon effluent (Figure 3 in Pratt and Fonstad, 2018).

Yuan et al. (2013) reported much lower total phosphorus concentrations in burial pit leachate than Pratt and Fonstad (2009). Yuan reported estimated total mass of contaminants with mean concentration 4.1 g Kg^{-1} TKN and 3.71 g Kg^{-1} TP. Carcasses in the Yuan et al. (2013) study were surrounded by soil, mimicking actual on-farm conditions, unlike the Pratt and Fonstad (2009) study in which whole-carcass leachate was collected without soil interaction. Soil adsorption likely resulted in lower phosphorus concentrations in the Yuan et al. (2013) study and provides further justification for proper soil contact with animal carcasses upon burial.

Munro (2001) provided an estimate of leachate release per animal. Munro estimated that 50% of the total available fluid volume would “leak out” in the first week following death and the remainder would drain in the next two months (Table II.2.3). Assuming the majority of leachate will be released in the first two months after burial, and using the leachate volume from Munro (2001) and the concentrations found by Pratt and Fonstad (2009), an estimate of the quantity of nutrient per animal can be developed. The mass of nutrients leaching from a burial pit two months postmortem is given in Table II.2.4.

Table II.2.3. Estimated volume of leachate produced from burial pits in the first two months after Burial (Munro, 2001)

Species	Weight	1 week postmortem (L)	2 months postmortem (L)
Cattle - Adult	500-600 Kg	80	160
Cattle - Calf		10	20
Pig - Adult	170 Kg	6	12
Pig – Grower/Finisher	80 Kg	3	6
Pig - Piglet	12 Kg	0.4	0.8

Table II.2.4. Calculated weight of nutrients per animal leaving a burial pit as leachate two months postmortem based on the data of Pratt and Fonstad (2009) and Munro (2001).

Species – Life Stage	Weight of Animal (lbs.)	NH_3-N (lbs.)	TP (lbs.)
Cattle - Adult	1100-1300	4.97	0.41
Cattle - Calf		0.62	0.05
Pig - Adult	375	0.35	0.04
Pig - Grower/Finisher	176	0.18	0.02
Pig - Piglets	26	0.02	0.003

2.5.b Runoff

When the burial is properly constructed and surface water is diverted, surface water nutrient loss should be negligible.

2.5.c Nitrogen Volatilization

Gaseous products are generated in decomposing carcasses. Munro (2001) estimated that gas produced would be 10% N_2, 35% CH_4, and 45% CO_2. The majority of the gas is given off immediately after deposition when the stomach contents decompose. If properly constructed with a 2 ft minimum cap, loss to the atmosphere is minimized.

2.6 Other Important Considerations with Burial

2.6.a Short term effects

Burial should be performed as quickly as possible to prevent contact with other animals to minimize biosecurity issues. The carcass will start to decompose and bloat, making movement of the carcass more difficult. After placement in the burial pit the carcass should be lanced to allow for the release of gas. If the animal bloats, the excavation will have to be larger to accommodate the bloated carcass. State-specific rules and regulations generally state that burial should occur in the first 48 hours after death. Odor and risk of surface runoff of carcass leachate during rainfall events will increase with time. As a process, burial can be performed quickly if equipment and manpower are available. Once burial is performed properly it requires no other time from the producer. Odor dissipates quickly once the carcass is covered.

2.6.b Long term effects

Decomposition in burial is a long-term process that is site dependent and varies in length of time. The burial site is not available for use for any purposes that disturb the site. Burial can prevent other uses of the site for years. The remaining nutrients from the carcass will create a hotspot at the burial location. Yuan et al. (2013) reported substantial leachate production after 370 days (approximately 12 months) of decomposition, with the majority of leachate produced between 370 and 540 days.

2.6.c Equipment Availability

If hand tools are used, excavation will be limited to the extent possible. Where tractors or powered equipment are used, augers or backhoes can dig deeper and move more material faster with less human effort. Tractors make movement of the carcasses easier. A loader or bucket can be used to carry carcasses to the burial location. Large animals can be lifted and placed into the excavation. If the equipment is not large enough to lift the carcass, the carcass can be drug and pulled into place.

2.6.d Pharmaceuticals Used in Euthanasia

There is concern about the persistence of Phenobarbital or other drugs in euthanasia of animals. The concern is tied to drugs showing up in other products and places as a result of the disposal method. Because of this concern other methods of disposal such as rendering may not be available to producers or landowners when an animal is euthanized in this manner. Burial may be their only option of disposal.

2.6.e Biosecurity

If the carcass is not buried deep enough or covered sufficiently, scavengers will dig down to a carcass, unearthing it and allowing other vectors to feed off the remains. This poses a biosecurity as well as an odor issue. Odor will draw vectors to the carcass increasing the biosecurity hazard. Burial is preferable as a method to many producers because the mortality remains on site, which prevents transfer of disease between facilities.

2.6.f Closure

If the area of burial must be reclaimed, any remains should be excavated and disposed of properly in another location. The abandoned pit should be pumped out and filled to minimize impact on ground water (Ritter et al., 1995).

References

Freeman, R. & Fleming, R. (2003). *Water quality impacts of burying livestock mortalities*. Livestock Mortality Recycling Project Steering Committee presentation. Ridgetown College, University of Guelph.

Munro, R. (2001). *Decomposition of farm animals corpses in mass burial sites*. Veterinary Laboratories Agency, United Kingdom.

Nutsch, A. and Spire, M. (2004). *Carcass Disposal: A comprehensive review. Chapter 1, Burial*. National Agricultural Biosecurity Center Consortium. Kansas State University.

Pratt, D. and Fonstad, T. (2009). *Livestock mortalities burial leachate chemistry after two years of decomposition*. ASABE Paper No. 095705. St. Joseph, MI: ASABE..

Pratt, D. and Fonstad, T. (2018). Speciation of geochemical Implications of burial leachate. *Transactions of ASABE,* 61(2): 559-570.

Ritter, W.F., & Chirnside, A.E.M. (1995). Impact of dead bird disposal pits on ground-water quality on the Delmarva Peninsula. *Bioresource Technology,* (53) 104-111.

Williams, C.J. (2015). Poultry and Livestock Mortality Disposal in Pennsylvania. *Penn State Extension, State College, PA*. https://extension.psu.edu/livestock-and-poultry-mortality-disposal-in-pennsylvania

Yuan, Q,, Snow, D. & Bartelt-Hunt, S. (2013). Potential water quality impacts originating from land burial of cattle carcasses. *Science of the Total Environment*, (456-457) 246-253.

3. Composting

3.1 Definitions

Composting: an aerobic biological process able to stabilize organic material including animal tissue. For proper composting to occur, dry carbon-rich material must be added to mortalities to control moisture released from the carcasses and supply a carbon source for the microbes. Composting of mortalities consists of two phases: active composting (110ºF-160ºF), and curing (ambient to 110ºF). Additional water is generally not needed during the active phase of composting due to the high moisture content of carcasses.

Static Piles and Windrows: Sometimes called **Passive Piles**, static piles consist of mortalities placed on a bed of carbon-rich material and covered with additional carbon-rich material. Windrows are elongated piles (Figure II.3.1). Heat generated during the composting process rises and draws air into the pile. Piles are turned infrequently, if at all.

Turned Windrow Composter: Rows of mortalities are placed on a bed of carbon-rich material and covered with the same material. Aeration is through turning (Figure II.3.2). Turning is based on time and temperature, with the first turning coming after carcasses have disintegrated.

Static Aerated Windrow Composter: Similar to the passive windrow with the exception that oxygen is added through forced aeration (Figure II.3.3). Aeration may be either positive (blowing air into the windrow) or negative (removing air from the windrow). Negative pressure aeration requires biofiltration to remove odors.

Bin System: A passive composting system housed in a bin usually constructed of treated lumber atop a concrete slab. Most bin composters are constructed with a roof covering the bins. A common configuration is the “three bin system” (Figure II.3.4). The system is sized so that initial breakdown of the carcass takes place in one bin, the compost is mixed and aerated by moving the material to a second bin, and the compost is moved to a third bin after a second cooling. Curing usually takes place in a passive windrow or larger fourth bin. Bin systems are generally loaded by layering carcasses between carbon-rich material.

Tunnel Composter: A version of the bin system in which the bins are elongated to form long piles supported by concrete or treated lumber walls (Figure II.3.5). Aeration may be accomplished by augers,

Figure II.3.1. Static piles placed inside a poultry building (Mark Hutchinson).

Figure II.3.2. Turned windrow mortality composter (Mark Hutchinson).

Figure II.3.3. Negatively aerated compost pile with biofiltration (Washington State University).

Figure II.3.4. "Three Bin" mortality composter (Langston University).

Figure II.3.5. Tunnel composter treating broiler mortalities on the eastern shore of Maryland (Amanda Gumbert)

Figure II.3.6. Ecodrum™ rotating drum mortality composter (Mark Hutchinson).

turning, or forced aeration systems, but generally material is mixed and aerated by moving from one tunnel to another.

Rotating Drum Composter: A type of **In-Vessel Composter** in which mortalities and carbon-rich materials are loaded at one end of the tilted, rotating drum (Figure II.3.6). Aeration is accomplished by turning the bin several times a day. Material flows by gravity, sometimes with the aid of paddles. Given the cost of the system, rotating drums are primarily used for active composting. Curing takes place in passive windrow or a bin system.

3.2 Movement of Nutrients

Figure II.3.7 is a schematic of the movement of nutrients from compost mortality disposal. There is a large variability in the nitrogen loss from carcass compost piles. This variation is caused primarily by co-composting materials added to piles to aid in composting rather than the carcasses themselves. Nutrient movement also differs between types of composters and management. Piles and windrows constructed on natural earth have the potential to leach nutrients into groundwater. By design, there is no leaching of nutrients to ground or surface water from properly managed rotating drums, bins, and tunnels constructed on concrete pads; however, leaching and runoff may occur if curing takes place in open windrows constructed on natural earth. Although runoff from unroofed composters may cause nutrients to move into surface water, most farms are equipped with runoff retention basins with retained water used for moisture control. There is very little information in the literature to quantify nitrogen emissions from mortality composting. Glanville et al. (2006) estimated the total loss of nitrogen (both leaching and volatilization) during composting to be between 10 and 40%. Very little phosphorus is lost from composting systems apart from removal as useful end products. Table II.3.1 provides estimated movement of nutrients using composting to dispose of carcasses. Nutrient movement shown in Table II.3.1 is based on a static pile with little or no turning. Material removed from the pile is screened for bones and mixed with farmstead manure before spreading according to a Nutrient Management Plan.

3.3 Description of the Composting Method

3.3.a Mortality Composting Practices

Composting is a managed aerobic degradation process with an end product that is beneficial as a soil amendment. Composting carcasses requires specific management of pile moisture and structure and cover material. Composting has become widely accepted as a means to manage both routine and catastrophic mortality. It is an accepted USDA-APHIS practice. Composting is often preferred over other disposal options because it can be completed on site with minimal effort, is cost effective, and environmentally sustainable.

The Animal and Plant Health Inspection Service (USDA-APHIS, 2021) developed a matrix to determine carcass management options. Composting is listed as an approved method for routine and catastrophic events as well as foreign animal disease outbreaks, but was scored lower than several other options. After two significant national Foreign Animal Disease (FAD) events and flooding in several states, composting is often the first option for carcass management if at all possible. Composting has become a widely acceptable management practice as an alternative to less environmentally and economically sustainable practices such as burial, landfilling, and incineration.

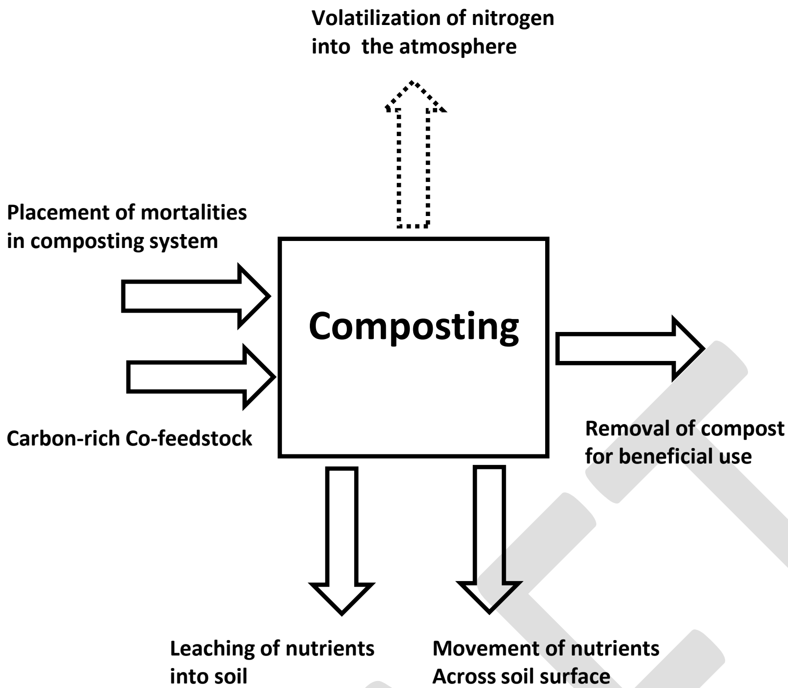

Figure II.3.7. Potential movement of nutrients during composting.

Table II.3.1. Estimated percentage of mortality nutrients transformed to useful end products and transferred to surrounding environment using the composting method of mortality disposal, following the best management practices for carcass composting (Seekins, 2011).

	TN	TP
Mortality nutrients recycled with end products in the farm nutrient management plan (% of nutrients entering)	80	100
Mortality nutrients emitted to the atmosphere (% of nutrients entering)	10	0
Mortality nutrients leaving the method by all other pathways (% of nutrients entering)	10	0

There is very little capital investment required to implement a compost program for carcass management. Most farm operations already have the infrastructure, land, co-composting materials, and material handling equipment necessary for composting. Composting on site reduces handling and transportation costs. Finished compost has value as a soil amendment which may be used in crop production systems.

3.3.b Composting Process Factors

To properly compost, certain environmental conditions must be established in the compost pile or windrow. The conditions (in order of importance) are moisture, porosity, and C:N ratio. Appropriate environment conditions and pile structure enhance the opportunity for microbial activity (Table II.3.2).

Table II.3.2. Environmental conditions necessary for proper composting.

Compost Characteristics Parameters	Acceptable Range
Moisture Content	40 - 60 %
Bulk Density	800 - 1,000 lbs. cubic yard^{-1}
Initial C:N ratio	25 - 40

There are two primary phases of animal tissue composting: active composting and curing. During active composting the carcass disintegrates and becomes more or less congruent with the carbon-rich material in the compost pile. The major groups of compost organisms are fungi, bacteria, and actinomycetes. Each group of organisms has specific functions in the decomposition process. The presence or absence and location of specific groups are indications of properly functioning compost. Thermophilic (110ºF-160ºF) organisms are dominant during the active phases; mesophilic (50ºF-110ºF) organisms are dominant during compost curing.

3.3.b Compost Methodologies

Three general methods of composting (windrow, bin, in-vessel) are used in the management of animal carcasses and tissue. The use of outside windrow composting for carcass management is now a routine practice for many large livestock farms. Poultry and swine farms also use bin as well as rotating drum composters for smaller carcasses and tissue. Each method requires knowledge of how the system works within the basic composting principles. Operators must be able to troubleshoot the system for timely and proper composting. Poor management of any of the systems can lead to negative environmental impacts including leaching and odors. All methods can be used for routine, catastrophic, and Foreign Animal Disease (FAD) events. Within each method there are variations.

Windrow Composting

Windrow composting is typically done in long trapezoidal rows 8-12 feet wide and 6-12 feet tall. This method can be conducted outside or inside of a building. Outside windrow systems are common for routine mortality management. They can be used with all poultry and livestock with no limits on space or equipment. Environmental features must be considered when locating an outside windrow compost system. Outside composting normally does not impede any other farm operations. Biosecurity could be a concern during a FAD event. Inside composting is commonly used with turkeys and broilers during a disease event using static aerated windrows. Inside windrow composting reduces the risk of airborne pathogen transmission. The size of the building limits composting capacity. Operation of equipment inside buildings for windrow construction, turning and cleanout can also be a limiting factor. Inside composting may also limit the farm's ability to restock.

Static windrows are commonly used for livestock or poultry mortality management. The soft tissue needs to remain covered (bio-filter) to deter vectors and reduce potential odors. During the turning process, soft tissue has the potential to be exposed and needs to be recovered. This process is time consuming and may add an extra expense for cover material. However, turning accelerates the composting process by redistributing the moisture and food sources and aerating the piles. As Seekins et al. (2015) noted, pile structure is important in the upward movement of nutrients in a carcass compost pile. The redistribution of nutrients has the potential to put soluble nutrients in the bottom of the pile, the nutrients are then susceptible to leaching.

Bin Composting

Covered bins are constructed to hold daily routine mortalities for up to 180 days (typically). The systems have primary bins to start the composting process followed by secondary bins to serve as turning. Tunnels are elongated bins with ends open for loading mortalities and unloading. Tunnels are sometimes aerated through augers, turners, or forced air, but are generally aerated by moving material from a primary tunnel to several secondary tunnels.

In-Vessel Composting

There are a wide variety of in-vessel compost systems available for managing carcasses and animal tissue with rotating drums being the most common. Advantages of in-vessel composting are accelerated decomposition, odor control and less carbon input. These systems have less potential leachate to be discharged to the environment. With most of these systems, the operator is able to control the composting variables, specifically aeration. A major disadvantage for these systems is the limited throughput. These mechanical systems are designed to handle an average death rate on a farm. Most of these systems have no surge capacity. In most situations, in-vessel composting is used for the active stage of composting, with curing taking place in a bin or windrow system. A second disadvantage is that these are mechanical systems. Operators need a secondary management plan in the event of mechanical failure. These systems require considerable infrastructure and capital investment.

3.4 Estimated Nutrient (N and P) Lost along Pathways

3.4.a. Leaching

Kalbasi et al. (2005) stated, “Due to the high moisture content of carcasses … and effects of precipitation on the exposed compost pile, (open air composting) may produce a considerable quantity of leachate. This leachate may run off or percolate the soil and contaminate the surface or groundwater.” This statement has been disproven by numerous research projects in a variety of conditions (Glanville et al. (2006); King (2014); Sanders et al. (2010); Hutchinson and Seekins (2021)).

Nitrogen is the nutrient most likely to be lost by leaching. Glanville et al. (2006, 2009), King (2014), and Sanders et al. (2010) examined the potential nutrient loss from leachate during composting and concluded that composting reduces the potential pollution risk to soil and groundwater when compared to burial. However, results were dependent on the type of co-composting material used during the process. Glanville et al. (2006), Gilroyed et al. (2016), and Hutchinson and Seekins (2021) all found that co-composting material, not the carcasses, significantly influenced leachate and air emission quality and quantity.

Glanville et al. (2006, 2009) found large differences in leachate from three different co-composting materials : silage, ground cornstalks, and yard waste compost. Corn stalks generated the most leachate while yard waste compost generated none. Leachate was collected in two areas just below the cover material and below the carcasses. They found the porosity of the co-composting material affected leachate volumes and nitrogen concentrations below the carcass. Corn stalk piles, which are highly porous, allowed greater amounts of N and ammonium to move downward through the pile. Yard waste compost was found to be an inadequate co-composting material because of poor porosity but did control leachate (Glanville 2003). Finer textured material captures leachate within the pile and repels rain water around the pile (King et al., 2014).

Hutchinson and Seekins (2021) constructed six compost piles on an undisturbed grass field with horse stall bedding and waste dairy feed. Carcasses were added to three of the piles. Pre- and post-composting soil samples at depths of 13 cm and 26 cm were analyzed for total nitrogen, nitrate, and ammonium. There was no statistical difference in any soil nitrogen level between the piles with and without a carcass. However, there was a statistical difference in all nitrogen species in the pre- and post-composting soil samples. This indicates that the carcass was not a major contributor to soil nitrogen under these conditions.

Glanville et al. (2006) took before and after soil samples from the locations in the field where compost piles were built. Leachate depth ranged from 3.8 to 28.5 mm, with the largest volumes coming from under piles containing corn silage. The least amount of leachate came using cornstalks as a carbon-rich co-composting material. Even the highest volume, however, was only a tiny fraction of the total precipitation received during the trial periods. This indicates that over 90% of the rainfall received was retained or shed from the pile. Nitrate nitrogen (NO_3-N) concentrations in the leachate ranged from 38.9 mg L^{-1} to 267.5 mg L^{-1}. The highest nitrate concentrations were found under the piles constructed with straw/cattle manure mix, and the lowest concentrations from the piles made up of corn silage. Ground cornstalks had an intermediate concentration in both trials: NH_4-N concentrations ranged from 186 mg L^{-1} to 1,361.7 mg L^{-1}. The highest concentrations were found under the straw/cattle manure mix, while the lowest were associated with the corn silage piles. They estimated that the nitrogen losses (both leaching and volatilization) amounted to between 10% and 40% of the total N in the piles depending on which co-composting material was used.

Glanville et al. (2006) concluded that in comparison to burial, which would place 100% of the nutrients from the carcasses close to the groundwater, the groundwater pollution potential was much lower for composting. Nitrogen leaching potential is highly dependent on co-composting material C:N. Expected nitrogen leaching is greater for low C:N materials such as poultry litter. Co-composting materials with a high C:N (e.g. wood shavings) would be expected to retain more N in the compost system. Hutchinson and Seekins (2021) found that there was no significant N contribution from carcasses to the soil profile when horse stall cleanings and waste dairy feed was used as a co-compost material.

There is limited information on phosphorus in carcass leachate in the literature. Phosphorus is not highly mobile in compost; therefore, a significant portion remains in the compost until field applied. Leachate from a platform interface study in Michigan had a total nutrient load of 8.7, 1.9 and 7.2% of N, P, K, respectively, of the estimated initial nutrients from carcass compost (Sanders et al., 2010). Morris, et al. (1996) found a total load of 6.5g and 10.1g of P in effluent from uncovered swine mortality compost bins. This is compared to straw piles that had total load levels of 34.9g and 64.4g. These levels of P loading are below annual crop removal for corn silage. Sanders et al. (2010) found that there was greater leachate loss on sandy loam soils than clay loam soils. This result is expected because of the larger macropores in sandy soil. Therefore, site selection and/or modifications are important prior to developing a compost location.

3.4.b. Runoff

Sanders et al. (2012) estimated the total P in runoff and infiltrating the soil from a 25-year, 24-hour storm event on a hypothetical uncovered mortality composting facility for a 1,000-cow dairy with 5% annual mortality (Table II.3.3). Given the assumption that fresh sawdust contributes no P to the system, then the carcasses contributed 3.14 lbs. of P in runoff and leachate. This indicates that the majority of P comes from carbon sources and bulking agents used in construction of the compost pile. Morris (1996) also observed levels of N, P, K, Mg, and Ca in the leachate of compost was substantially lower than what was found for cattle manure on 21 area farms in Ontario.

Table II.3.3. Mass of TP in runoff and leachate leaving an uncovered composting facility during a 25-yr, 24-hr rainfall event; the facility treated mortalities from a 1,000-cow dairy with a 5% annual mortality rate (Sanders et al., 2012).

Amendment	TP in runoff (lbs.)	TP infiltrating into soil (lbs.)
Fresh Saw dust	0.38	2.76
Corn Silage	23.68	592.26
Grass Clippings	2.46	61.50
Reused finished compost	0.39	4.46
Bovine manure pack	2.08	52.02
25% Bovine manure pack, 75% sawdust	0.61	15.40

3.4.c. Nitrogen Volatilization

There are very limited studies on air emissions from carcass composting. Nitrogen volatilization losses are influenced by the type of carbon-rich materials and bulking agents added to mortalities. Xu et al., (2007) found that the carcasses themselves contributed very little to atmospheric emissions when nutrient dense co-composting materials are used; however, these co-composting materials being low in carbon are only a portion of the entire mixture used to compost carcasses. Hamilton et al. (2016) found that nitrogen volatilization losses from manure composting ranged from 10 to 25%. In most cases, manure compost will be mixed more aggressively than mortality compost, particularly in the early hot composting phase; therefore, it is assumed nitrogen volatilization losses for mortality compost will be at the low end of the range. Rozeboom et al. (2012) compared ground carcasses with whole carcasses and found no significant differences in ammonia emissions between them. Seekins et al. (2015) found that nitrogen moved upwards in the compost pile and remained in the upper third of the pile when using a horse bedding, waste feed, and wood chip mixture. Ammonium was draw up through the compost windrow by the warm moist air. As the ammonium comes in contact with oxygen, it is converted to nitrate and adsorbs onto organic cover material therefore limiting volatilization.

3.4.d Nutrients in the End Product

Glanville (2006) estimated that 10-40% of the total N was lost to leachate or volatilization during the compost process. Using the values for mass of nitrogen per mass of body tissue for animal species given in Part I of this document, Table II.3.4 shows the amount of land needed to spread the nutrients from a one AU (1,000 pound) mortality at 100 pounds total N and 45 pounds P_2O_5 per acre per year. Table II.3.5 gives the estimated land needed to spread composted mortalities for various production schemes given in Part I of this document at 100 pounds total N and 45 pounds P_2O_5 per acre per year. Tables II.3.4 and II.3.5 show that phosphorus is usually the limiting element in land application of mortality compost, especially if mature animals are housed in the production system. However, total acreage needed for spreading depends on nutrients added with co-composting materials.

Table II.3.4. Land needed to spread mortality compost made from 1 AU (1,000 pounds live weight) carcass(s), assuming 100 pounds total nitrogen, 45 pounds P_2O_5 per acre per year application rate.

	Nitrogen in Body Tissue	Phosphorus in Body Tissue	Total N in 1 AU of Tissue	Total P in 1 AU of Tissue	Low N losses – 10%		High N Loses – 40%			
					TN in Compost	Land Needed	TN in Compost	Land Needed	P_2O_5 in Compost	Land Needed
	(%)	(%)	(lbs.)	(lbs.)	(lbs.)	(Acres)	(lbs.)	(Acres)	(lbs.)	(acres)
Broilers	2.82	0.375	28.2	3.75	25.3	**0.25**	16.9	**0.17**	8.25	**0.18**
Laying Hens	3.97	0.70	39.7	7.00	35.7	**0.36**	23.8	**0.34**	15.5	**0.39**
Tom Turkeys	2.93	0.375	29.3	3.75	26.3	**0.26**	17.6	**0.18**	8.25	**0.18**
Hogs	2.54	0.56	25.4	5.60	22.8	**0.23**	15.2	**0.15**	12.4	**0.28**
Cattle	2.83	0.82	28.3	8.20	25.5	**0.26**	17.0	**0.17**	18.1	**0.40**
Equid	3.20	0.95	32.0	9.50	28.8	**0.29**	19.2	**0.19**	20.9	**0.52**

Table II.3.5. Land needed to spread mortality compost for typical production systems, assuming 100 pounds total nitrogen and 45 Pounds P_2O_5 per acre per year application rate.

	Mortalities Collected	Mortality TN Collected	Mortality TP Collected	Low N losses – 10%		High N Loses – 40%		P_2O_5 in Compost	Land Needed
				TN in Compost	Land Needed	TN in Compost	Land Needed		
	(lbs. $Year^{-1}$)	(lbs. $Year^{-1}$)	(lbs. $Year^{-1}$)	(lbs. $Year^{-1}$)	(Acres)	(lbs. $Year^{-1}$)	(Acres)	(lbs. $Year^{-1}$)	(Acres)
Broilers 25,000 Bird Flock 6 lb. Birds	11,000	275	37.5	250	**2.5**	165	**1.65**	83	**1.8**
Market Hogs 1,000 Head Barn 270 lb. Hogs	16,000	420	92	380	**3.8**	250	**2.5**	200	**4.5**
Dairy Cattle 200 Milkers Holsteins	18,000	500	150	450	**4.5**	300	**3.0**	330	**7.4**
Horses 1,000 Head Herd Quarter Horses	12,000	390	140	350	**3.5**	230	**2.3**	310	**6.9**

3.5 Other Important Considerations with Composting

At the end of the compost process, the producer has a valuable soil amendment. Producers have often raised concerns about the large bones and nutrients tied up in the soil. Bones become brittle during the compost process but do not completely decompose. Large bones from older animals that are well ossified are more difficult to compost and may require several passes through the compost process. These bones can also be screened out or run through a grinder. Nutrient tie up has not been documented with the use of animal carcass compost. In many areas, nutrients need to be exported, especially phosphorus. Compost has the potential to concentrate nutrients that can be used in the landscape and home horticulture industry. The mushroom industry is a large consumer of compost but are prohibited from using mortality compost in their production systems.

3.6 References

Glanville, T.D., Richard T.L., Harmon, J.D., Reynolds, D.L., Sadaka, S.S., & Akins, S. (2003). Environmental impact and biosecurity of composting for emergency disposal of livestock mortalities. Paper No. 032262. St. Joseph, MI: ASABE.

Glanville, T. D., Ahn, H.K., Richard, T.L., Harmon, J.D., Reynolds, D.L. & Akins, S. (2006). Environmental impact of emergency livestock mortality composting - leachate release and soil contamination. Paper Number 064049. St. Joseph, MI: ASABE.

Glanville, T. D., Ahn, H.K., Richard, T.L., Shiers, L.E., & Harmon, J.D.. (2009). Soil contamination caused by emergency bio-reduction of catastrophic livestock mortalities. *Water, Air, Soil Pollution* 198:285-295.

Gilroyed, B.H., Conrad, C., Hao, X., McAllister, T., Stanford, K., & Reuter, T. (2016). Composting for biocontained cattle mortality disposal and associated greenhouse gas and leachate emissions. *Journal of Environmental Quality*, 45:646-656.

Hamilton, D.W., Cantrell, K., Chastain, J., Ludwig, A., Meinen, R., Ogejo, J., & Porter, J. (2016). *Manure Treatment Technologies, Recommendations from the Manure Treatment Technologies Expert Panel to the Chesapeake Bay Program's Water Quality Goal Implementation Team to Define Manure Treatment Technologies as a Best Management Practice.* Annapolis, MD. Chesapeake Bay Program.

Hutchinson, M.L. & Seekins, W. (2021). Large animal carcass mortality composting: impact on soil nutrients. *Compost Science & Utilization*.

Kalbasi, A., Mukhtar, S., Hawkins, S.E., & Auvermann, B.W. (2005). Carcass composting for management of farm mortalities: a review. *Compost Science & Utilization*, 13(3), 180-193.

King, M.A., MacDonald, G., Hutchinson, M., & Seekins, B. (2014). A comparison of the quantity and quality of leachate generated by five compost feedstocks exposed to simulated rainfall. *J. of Solid Waste Technology and Management*, 40 (1), 58-69.

Morris, J., O'Connor, T., & Kains, F. (1996). The effect of sawdust and straw on composting swine carcasses. *Ontario Swine Research Review*, 71-74.

Rozeboom, D., Fogiel, A., Lui, Z., & Powers, W. (2012). *Air emissions from in vessel rotating drum and open static compost of swine carcasses whole and ground*. 4th International Symposium on Managing Animal Mortality, Products, By Products and Associated Health Risk. Dearborn, MI.

Sanders, J.O., Rozeboom, D.W., Loudon, T.L., Northcutt, W.J., & Person, H.L. (2010). Quantifying nutrients in effluent from uncovered, intact mature bovine carcass compost piles subjected to storm events. *Compost Science & Utilization,* 18(4) 216-231.

Seekins W. (2011). Best Management Practices for Animal Carcass Composting. Augusta, ME: Maine Department of Agriculture, Food, and Rural Resources.

Seekins, W., Hutchinson, M., King, M., and MacDonald, G. (2015). Pile structure in large animal carcass compost piles: zone differences in physical and chemical characteristics. *Compost Science & Utilization,* 23, 67-83.

USDA APHIS. (2021). Carcass Management Dashboard https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/emergency-management/carcass-management

Xu, S., Hao, X., Stanford, K., McAllister, T., Larney, F.J. and Wang, J. (2007). Greenhouse gas emissions during co-composting of cattle mortalities with manure. *Nutrient Cycling in Agroecosystems*, *78*(2), 177-187.

4. Incineration

4.1 Definitions

Incineration*:* The burning or thermochemical conversion of mortalities to produce a gaseous and solid byproduct. Three types of thermochemical conversion may be used to dispose of livestock and poultry mortalities: combustion, gasification, and pyrolysis. Most mortality incinerators employ a hybrid of methods.

Combustion*:* Thermochemical conversion of organic material with a stochiometric excess of oxygen at temperatures between 1,500 and 3,000°F (815-1,650°C). The products of combustion are heat, carbon dioxide, water vapor, and ash.

Gasification*:* Thermochemical conversion of organic material in an oxygen-starved environment at temperatures between 1,400 and 2,700°F (760-1,480°C). The products of gasification are syngas and char or ash. Trace amounts of liquid and tar may also be produced during gasification. Syngas is a mixture of carbon monoxide, hydrogen, methane, and other light-weight hydrocarbons. In the context of mortality incineration, syngas produced by gasification is generally ignited with excess oxygen to produce carbon dioxide and water vapor.

Pyrolysis: Thermochemical conversion of organic material in an oxygen-free environment at temperatures between 575 and 1,475°F (300-800°C). The products of pyrolysis are syngas, a liquid product (bio-oil) and solid residue (bio-char). Fast pyrolysis, which occurs at higher operating temperature with a reaction time lasting seconds, results in a greater amount of bio-oil and a lesser amount of bio-char being produced. Slow pyrolysis, occurring at lower temperatures and reaction times lasting hours or days, produces almost no bio-oil and is mostly used to produce bio-char. To be considered bio-char, a char product must contain at least 10% organic carbon.

4.2 Movement of Nutrients

Figure II.4.1 is a schematic of the movement of nutrients from combustion-based incineration. Since incineration takes place in a sealed container, no movement of nutrients into or across the soil takes place. Some volatilization of nitrogen occurs during incineration. Assuming thermochemical conversion of mortalities is similar to that of manure (Hamilton et al., 2016), roughly 75% of the total nitrogen in livestock and poultry mortalities is volatilized during incineration and 25% remains with ash. One hundred percent of phosphorus contained in carcasses is transferred to ash. Table II.4.1 provides estimated losses of total nitrogen and total phosphorus to the environment by various pathways assuming mortality incineration most closely resembles fast pyrolysis of manure (Hamilton et al., 2016) based on temperature in the primary retort or primary combustion chamber. The possibility of either

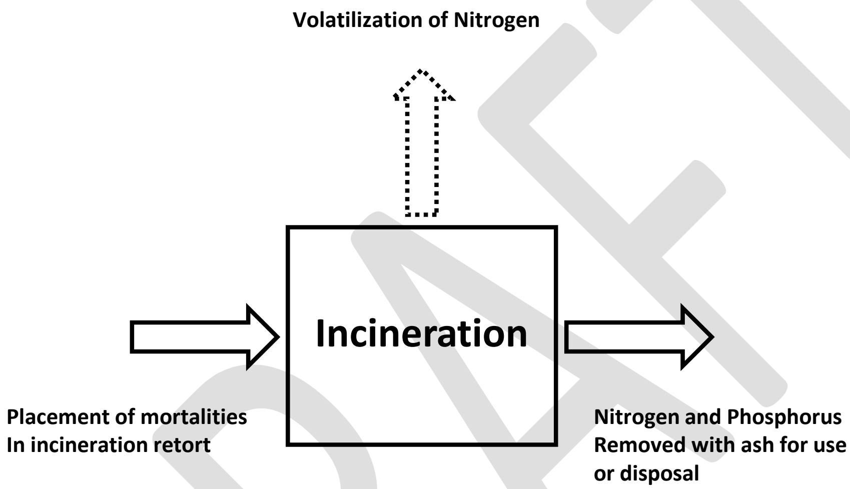

Figure II.4.1. Movement of nutrients during incineration.

Table II.4.1. Estimated percentage of mortality nutrients transformed to useful end products or transferred to the surrounding environment using the incineration method of mortality disposal, assuming incineration is conducted at a temperature similar to fast pyrolysis of manure (Hamilton et al, 2016).

	TN	TP
Mortality nutrients recycled with end products in the farm nutrient management plan (% of nutrients entering)	25	100
Mortality nutrients emitted to the atmosphere (% of nutrients entering)	75	0
Mortality nutrients leaving the method by all other pathways (% of nutrients entering)	0	0

nitrogen or phosphorus being transferred to water bodies may also occur if ash is mishandled during storage and land application.

4.3 Description of the Incineration Method

Mortality incineration does not fit easily into any of the thermochemical processes outlined in the definitions section. Based on operating temperature, air intake, and burner arrangement, most commercially available incinerators act as hybrid between the pyrolysis, gasification, and combustion processes.

Figure II.4.2 shows a popular model of on-farm incinerator. Animals are placed in the large metal-firebrick lined chamber (retort). The burner unit attached to the retort shoots flame into the chamber, heating the retort and burning the carcass. The burner is thermostatically controlled. When the retort temperature reaches 1,400^{o}F, the burner shuts down and air is forced into the chamber so that the carcass continues to burn (R and K Incinerators Inc, 2020). The forced air and 1,400^{o}F burn temperature make the process in the retort similar to low-temperature combustion. Most of the soft tissue volatilizes into particulates and shorter chained organic compounds. A second flame travelling through the afterburner (horizontal chamber attached to the vertical flue) burns particulates and gases before they pass out of the incinerator. Afterburner temperatures range between 735 and 1,600^{o}F (R and K Incinerators Inc, 2020). The afterburner is critical in ensuring complete burning of particulates, reducing odors, and meeting local air quality standards.

Gasification of mortalities has been investigated by a number of researchers (Brookes, 2009; Lemeiux et al., 2009; Porter, 2009). The BGP (Brookes Gasification Process) is the most commonly used gasification system. Figure II.4.3 is a schematic of the BGP for mortality incineration. Mortalities pass through a pre-breaker that breaks the body into large pieces, followed by a finer that more fully masticates the carcass. The accumulator consolidates the material for auguring into the pre-heated primary combustion chamber or retort. Volatile gases and particles rise out of the primary chamber by a tortuous path where they are met by a downward pointing flame which also pulls combustion air into the gasifier. Combustion takes place in the secondary combustion chamber and combustion gases rise up through an exhaust stack. Minimum temperature of the secondary combustion chamber is 1,560 ^{o}F. Heat is transferred upward to the primary combustion chamber through an uninsulated hearth separating the chambers. Design temperature of the primary chamber is 840 ^{o}F or greater, but care must be taken so that large loads of moist material do not cause the temperature to drop in the primary chamber. Masticated carcass material is conveyed through the primary chamber with a drag chain atop the hearth. Organic matter volatilizes as the heated material is conveyed through the chamber, and ash is collected at the far end by a cross auger.

Figure II.4.2. Commonly used on-farm incineration unit sized to handle up to 1,200 pounds of mortalities (R&K Incinerator Inc, 2020).

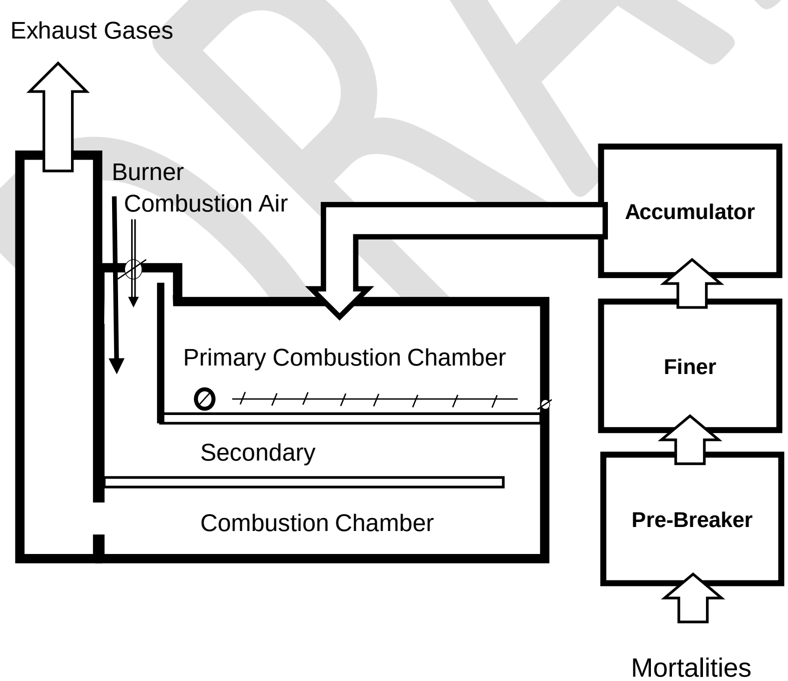

Figure II.4.3. Schematic of Brooks Gasification Process (BGP) for mortalities as modified by the US-EPA National Homeland Security Research Center (Brookes, 2009; Lemieux and Serre, 2016).

Perhaps the greatest hinderance to incineration of mortalities is the high moisture content of animal carcasses. Whereas biomass materials generally undergo a desiccation process to remove moisture before conversion by gasification and pyrolysis (Hamilton et al., 2016), mortalities are introduced to the retort “as is”. Lemieux and Serre (2016) reported a temperature drop as great as 328 ^{o}F as wet, masticated mortalities are introduced into the primary combustion chamber of the BGP gasifier, followed by flash combustion at 1,850^{o}F. More external fuel is used to keep a constant, high temperature during incineration of livestock and poultry mortalities compared to thermochemical conversion of dry feedstocks. European sources (https://www.funeralnatural.net/articulos/la-cremacion-y-la-calidad-del-aire) indicate that in cremation of human remains, of the estimated 880 pounds of CO_2 emitted into the atmosphere, only 59 pounds originate with the cadaver.

4.4 How Incineration is Used for Various Animal Types

The same basic type of incinerator is used for disposal of all animal types; the main difference between species is size of the incinerator. Several smaller animals (poultry, piglets) are placed in the incinerator at one time until the rated capacity is reached. Incineration is generally done one carcass at a time for larger animals, and incinerator capacity is determined by the largest carcass anticipated.

4.5 Estimated Nutrient Mass (N and P) Lost along Pathways

It is assumed that all of the phosphorus contained in mortalities exits the incineration process in the form of ash.

Incineration used for mortality disposal most closely resembles pyrolysis based on the temperature range (750^{o}F to 1,100^{o}F) found in the chamber where disintegration of the body occurs. As stated earlier in this report, retort temperature of the most common on-farm incinerators is limited to a maximum of 1,400^{o}F (R and K Incinerators Inc, 2020). Although temperature of the primary combustion chamber of BGP gasifier may range between 512^{o}F to 1,850^{o}F due to fluctuations in wet mass loading, the design lower operating temperature of this gasifier is 840^{o}F, which is below the operating range of dry biomass gasifiers (1,400 to 2,700^{o}F). More thorough ashing of carcasses occurs in mortality incineration compared to pyrolysis, because oxygen is not limited in the process. Cantrell et al. (2012) showed that temperature had a greater impact on nitrogen retention in pyrolysis compared to source of biomass.

Given the temperature range of mortality incineration, and the fact that carcasses are incinerated over the course of hours rather than days, we assume that nutrient retention in ash most closely resembles that of fast pyrolysis. Hamilton et al. (2016) gave a fast pyrolysis of manure a defined nitrogen volatilization efficiency of 75% and a nitrogen separation efficiency (analogous to byproducts with potential to be used in agricultural land application in this report) of 25%.

Limited data exists for composition of nitrogen emissions from incineration of animal mortalities. The Farm Manure-to-Energy Initiative (Hamilton et al., 2016) reported on a limited number of air emission tests conducted on gasification and combustion systems for poultry litter. Di-nitrogen gas (N_2) accounted for 90% of all nitrogen emissions from combustion systems and 96% of nitrogen emissions from gasifiers. Results show that ammonia emissions were less than 0.05% for all operations. Nitrogen oxides varied from 2.5 to 5.2% for combustion and 0.6% from gasification. The European Environmental Agency (Trozzi et al., 2019) gives a NOx emission factor of 0.825 kg per human body for crematories; however, it was not determined whether the source of NOx emission is the nitrogen contained in bodies, caskets, or through high-temperature oxidation of atmospheric nitrogen. US-EPA (1999) states that “concentration of thermal NO_X (NO_x created from atmospheric nitrogen during combustion) is controlled by nitrogen and oxygen molar concentrations and the temperature of combustion. Combustion at temperatures well below 2,370 °C (1,300 °F) forms much lower concentrations of thermal NOx"; therefore, it is assumed that mortality incineration will result in lower NOx emissions than other, drier biomass.

4.6 References

Brookes, D. (2009). Thermodynamic and design concepts behind the transportable bio-mass gasifier. In *Proc. 3rd Int. Symp. on Management of Animal Carcasses, Tissue and Related Byproducts*. Orono, ME: University of Maine Cooperative Extension.

Cantrell, K.B., Hunt, P.G., Uchimiya, M., Novak, J.M., & Ro, K.S. (2012). Impact of pyrolysis temperature and manure source on the physicochemical characteristics of biochar. *Bioresource Technology,* 107, 419-428.

Hamilton, D.W., Cantrell, K., Chastain, J., Ludwig, A., Meinen, R., Ogejo, J., Porter, J. (2016). *Manure Treatment Technologies, Recommendations from the Manure Treatment Technologies Expert Panel to the Chesapeake Bay Program's Water Quality Goal Implementation Team to define Manure Treatment Technologies as a Best Management Practice.* Annapolis, MD. Chesapeake Bay Program.

Lemieux, P., Brookes, D., Howard, J., and McKinney, J. (2009). Transportable gasifier for animal carcasses In *Proc. 3rd Int. Symp. on Management of Animal Carcasses, Tissue and Related Byproducts*. Orono, ME: University of Maine Cooperative Extension.Lemieux, P. & Serre, S. (2016). *Progress Report: Transportable Gasifier for On-Farm Disposal of Animal Mortalities*. Research Triangle Park, NC: US-EPA National Homeland Security Research Center.

Porter, J. (2009). Gasification of animal mortalities - The North Carolina experience. In *Proc. 3rd Int. Symp. on Management of Animal Carcasses, Tissue and Related Byproducts*. Orono, ME: University of Maine Cooperative Extension.R and K Incerator Inc. (2020). Burn-EZ Website, http://burnez.com/. Accessed November 25, 2020.

Trozzi, C., Keunen, J., Deslauriers, M., Niemi, D.R., Woodfield, M., & Hjelgaard, K. (2019). *EMEP/EEA Air Pollution Emission Inventory Guidebook, Chapter 5.C.1.b.v Cremation*. Copenhagen, Denmark: European Environment Agency.

US-EPA (1999). *Nitrogen Oxides Why and How They are Controlled, EPA-456/F-99-006R*. Research Triangle Park, NC: United States Environmental Protection Agency, Clean Air Technology Center.

5. Rendering and Landfilling

5.1 Definitions

Landfilling: Municipal or private landfills are sometimes an option to dispose of animal carcasses, but there is a lot of variability in the willingness or policies that determine whether an operator – or contractor – can dispose of their mortalities at a landfill or transfer facility. The extent of the use of landfills for animal mortality disposal in the Chesapeake Bay watershed is not known. Indeed, variability in record keeping would make it difficult to estimate the extent of landfill disposal for animal mortalities even if the panel had made such an investigation one of its key points of focus.

Rendering: Rendering of animal mortalities recycles carcasses into three potentially marketable products: carcass meal, melted fat or tallow, and water. Rendering is a well-established industry that follows rigorous requirements and quality control practices to ensure the safety of their products in whatever marketable form they take and regardless of whether they use animal carcasses or other feedstocks. The process involves numerous physical and chemical transformations, such as the application of heat, extracting moisture, and fat separation.

5.2 Movement of Nutrients

5.2.a Rendering Facilities

For purposes of this report, it is understood that rendering facilities, like other industrial operations with large amounts of water use and disposal, are regulated under the Clean Water Act and subject to applicable federal, state and local laws and regulations. Therefore, any disposal of nutrients back into the watershed would be captured as part of the monitoring reports submitted by the facility to regulators. Additionally, any marketed products (meal, fat, tallow, etc.) are irrelevant for the Watershed Model and its inputs. The transformation of any nitrogen into air emissions from animal carcasses is assumed to be below negligible. Altogether, the panel assumes that any nutrient load associated with animal carcasses transferred to a rendering facility are either transformed into products that are removed from the system, or become a portion of the point source load. Therefore, their previous load as part of agriculture or the feedspace load source is reduced to zero. This avoids potential for double counting the nutrient load and follows the same logic applied to instances where loads are transferred outside the watershed or into landfills and zeroed out from the original load source. Table II.5.1 gives the mass of mortality nutrients transported to the watershed environment by the rendering process through the pathways shown in Figure II.1.2

Table II.5.1. Estimated percentage of mortality nutrients transformed to useful end products and transferred to surrounding environment using the rendering method of mortality disposal.

	TN	TP
Mortality nutrients recycled with end products in the farm nutrient management plan (% of nutrients entering)	0	0
Mortality nutrients emitted to the atmosphere (% of nutrients entering)	0	0
Mortality nutrients leaving the method by all other pathways (% of nutrients entering)	0	0

5.2.b. Landfills

It is known that public- and privately-owned landfills for municipal solid waste are designed with clay and synthetically lined areas that collect leachate and recover gases. Therefore, the transfer of nutrients into a landfill within the Watershed Model conceptually eliminates them from the system as if they were removed from the watershed entirely, i.e., a 100% reduction of TN and TP. The panel is confident enough with that conceptual logic to apply it to animal mortalities and therefore recommends that verified transfer of animal mortalities to a landfill reduces the load of those nutrients to zero from the original load source. The panel acknowledges, however, that the record keeping may be problematic for jurisdictions to know the number or total tonnage of routine animal mortalities disposed in landfills on a county- or state-wide annual basis. Table II.5.2 gives the mass of mortality nutrients transported to the watershed environment from landfills through the pathways shown in Figure II.1.2

5.4. How Landfilling and Rendering are Used for Various Animal Types

The specific method of rendering or placing a carcass in a landfill varies little between animal types. Size of animal, however, plays a large role in how carcasses are stored and transported. Large animals (e.g. mature swine, horses, and cattle) are handled on an individual animal basis. Some large carcasses, particularly swine, may be stored temporarily on-farm in refrigerated or un-refrigerated containers; however, most carcass are removed from the farm and taken to the rendering facility or landfill on the day of death. Small animals (e.g. piglets, poultry) are delivered to the facilities in mass, and may be stored for a considerable amount of time on-farm in refrigerated containers.

Table II.5.2. Estimated percentage of mortality nutrients transformed to useful end products and transferred to surrounding environment using the landfilling method of mortality disposal

	TN	TP
Mortality nutrients recycled with end products in the farm nutrient management plan (% of nutrients entering)	0	0
Mortality nutrients emitted to the atmosphere (% of nutrients entering)	0	0
Mortality nutrients leaving the method by all other pathways (% of nutrients entering)	0	0

5.6 Important Considerations with Rendering

Rendering of animal carcasses will only be available in areas where a rendering plant is capable of accepting and rendering the mortalities. The ability to transport and render carcasses will vary by the animal size and the operation's proximity to a rendering facility, which often coincide with areas that have a tradition of extensive animal production. Panel members communicated with rendering industry representatives, but were unable to obtain regional data for summary in this report. There are approximately 300 rendering facilities across North America that recycle a tremendous amount of inedible byproducts from the animal industry, transforming it into other products for the industry or other markets (Meeker and Hamilton, 2006).

The panel understands that some cost-shared practices such as poultry freezers are closely associated with rendering, as they enable a farmer to safely collect and store their mortalities until the rendering company or a third party transfers the frozen or refrigerated mortalities to the processing facility. While freezing or refrigerated storage is less common for larger animal carcasses, it may still be an applicable storage technique under the right circumstances to enable economical use of rendering as a disposal option. Through panel members' discussions with local farmers and operators in Maryland, the panel was led to believe that when state cost-share funds are used to install freezers on a poultry operation there must be an agreement in place between the farmer and a rendering facility or contractor to collect and process the stored mortalities. Assuming such agreements are standard for mortality freezers, the panel recommends that states can track and report the implementation of mortality freezers as the mortality rendering BMP, which zeroes out the assumed nutrient load from the animal mortalities. However, the jurisdictions must have procedures in place to verify that the freezers were indeed utilized for mortality management on an active operation for the reported number (or percentage) of animals associated with that freezer. If a jurisdiction has the ability to track and report the number of animals or tonnage of animal mortalities – and ideally, animal type – transferred from watershed farmers to rendering facilities, that may be the most effective method for tracking and reporting the animal rendering BMP.

Regardless of tracking or reporting method, the panel acknowledges the benefit of rendering from economic and environmental perspectives. Despite a lack, or complete absence, of specific literature on the water quality benefits of rendering, the panel is reasonably confident that it can recommend a 100% reduction of both TN and TP for animal carcasses that are rendered, based strictly on the panel's conceptual understanding of how point source loads are simulated and how the transferred mortalities are therefore removed entirely from the original load source.

5.7 References

Meeker, D.L. and Hamilton, C.R. (2006). An overview of the rendering industry. In D.L. Meeker (Ed.), *Essential rendering: All about the animal by-products industry* (pp.1-16). North American Renderers Association. https://nara.org/wp-content/uploads/2019/10/essential_rendering_book3.pdf