Appendix 3. Methods For Manure, Fertilizer, and Crop Removal Calculations

Manure phosphorus inputs for the Maumee watershed in Ohio were calculated from animal population inventories of the U.S. Department of Agriculture Census of Agriculture and permitted capacities from the Ohio Department of Agriculture Division of Livestock Environmental Permitting (ODA DLEP).

The procedures used for this analysis include:

- Section A3.1 – Prorating county-level animal population numbers from the Census of Agriculture to estimate the animals within the Maumee watershed,
- Section A3.2 - When the population was not disclosed by the Census of Agriculture, then permitted capacities from ODA DLEP were used,
- Section A3.3 - Calculating the phosphorus content of the animal manure using two recent, local datasets of manure analysis compiled by the ODA, and
- Section A3.4 - Estimating annual crop removal using average crop nutrient removal, yield goals, and relative crop planting distribution.

Similar methods have been used by Environmental Working Group (EWG, 2019), Ruddy et al. (2006), Mueller and Gronberg (2013), and Goolsby et al. (1999).

A3.1 Prorating county-level data from the Census of Agriculture

Census of Agriculture

The U.S. Department of Agriculture publishes the Census of Agriculture every five years (USDA, 2017). The most recent report, at the time of this analysis, was conducted in 2017 and published in 2019.

Discussion of livestock by type

This analysis used three categories of livestock and poultry from the Census of Agriculture:

1. Cattle and calves, which is divided into three subgroups: 1) beef cows, 2) milk cows, and 3) other cattle (which includes heifers that had not calved, steers, calves, and bulls)
2. Hogs and pigs
3. Poultry, which is divided into five subgroups: 1) layers, 2) pullets for laying flock replacement, 3) broilers and other meat-type chickens, 4) turkeys, and 5) ducks, geese, and other miscellaneous poultry

Most livestock in the region falls into these three categories. Therefore, other livestock types, such as sheep and horses, were not included. Similarly, the poultry subgroup of ducks, geese, and other miscellaneous poultry was not considered, as this population is comparatively very low. It is safe to assume that the relatively small numbers of these other livestock and poultry types in the region would not substantially alter the estimate of manure phosphorus produced.

Areal proration

The Census of Agriculture publishes results by county. To estimate the animals within the Maumee watershed the population was prorated by area. Table A3.1 below shows the percentages used for the calculations.

Table A1.1. Areas of Ohio counties within the Maumee watershed used to prorate animal numbers from the Census of Agriculture

County Name	Area (acres)	Area of County in Maumee Watershed (acres)	Percent of County in Maumee Watershed Rounded
Allen	258835.2	258323.6	100
Auglaize	256800	196779.8	77
Defiance	263142.4	263142.4	100
Fulton	260339.2	260339.2	100
Hancock	340064	250521.9	74
Hardin	300985.6	105822	35
Henry	266560	266560	100
Lucas	217894.4	177339	81
Mercer	296492.8	127877.8	43
Paulding	266406.4	266406.4	100
Putnam	309676.8	309676.8	100
Seneca	352377.6	5759.9	2
Shelby	261932.8	15972.3	6
Van Wert	262457.6	262457.6	100
Williams	269913.6	269913.6	100
Wood	395084.8	114908.5	29
Wyandot	259590.4	27368.9	11

A3.2 Permitted capacities from the Ohio Department of Agriculture Division of Livestock Environmental Permitting

Census of Agriculture data suppression

Not all animal numbers are published in the Census of Agriculture. If publishing data would identify an individual operation (for example, if there is only one producer of a particular species in a county), the Census does not publish the information. In such cases, the data are suppressed and shown as "(D)," meaning "withheld to avoid disclosing data for individual operations". Data suppression can cause a substantial number of animals to be unreported, particularly laying hens and pullets.

DLEP permit numbers

Table A3.2 shows the animal agriculture facilities permitted by ODA DLEP as of June 2022 with their permitted capacity. In cases where the Census suppressed data, ODA DLEP information was used to fill in the gap. All permitted facilities are required to have a permitted capacity. These capacities were used in cases where it was known that animal agriculture existed within a county, but the animal population was suppressed by the Census. These facilities were typically not populated to their full permitted capacity, therefore using the capacity will lead to an overestimate of animals.

Table A3.2. Confined Animal Feeding Facilities permitted by ODA DLEP in the Maumee watershed in Ohio with permitted capacity, June 2022.

Facility Name	Watershed	Animal 1 Species	Animal 1 Count	Animal 2 Species	Animal 2 Count
Bridgewater Dairy, LLC	04100003	Dairy	3,900		
Del-Rod Farms, LLC	04100003	Swine - over 55 lbs	5,000		
Grand Republic	04100003	Swine - over 55 lbs	7,350		
Heritage Family Farms, LLC	04100003	Swine - over 55 lbs	6,000		
Bowersock Pork	04100004	Swine - over 55 lbs	4,800	Beef	20
Heartland Dairy Holdings, LLC	04100004	Dairy	2,100		
KFS Farms, LLC	04100004	Swine - over 55 lbs	7,680	Beef	820
Liberty Egg Farms, Ltd.	04100004	Chickens-Layers	207,360		
Luginbill Swine Farm	04100004	Swine - over 55 lbs	7,200		
MVP Dairy	04100004	Dairy	4,500		
Pine Valley Ranch, LLC	04100004	Chickens-Layers	2,264,000		
R & S Farms Ag, LLC	04100004	Chickens-Layers	105,000		
Wilker Eggs and Grain Farm LLC	04100004	Chickens-Layers	317,151		
Wilker Family Farms	04100004	Chicken-Pullets	210,000		
Flat Land Dairy	04100005	Dairy	3,144		
Fox Tail	04100005	Swine - over 55 lbs	3,675		
Hicksville Farm	04100005	Beef	3,020		
Hillandale Farms	04100005	Chickens-Layers	4,011,864		
Pheasant Run	04100005	Swine - over 55 lbs	7,350		
Vissers Dairy	04100005	Dairy	1,600		
West Side Dairy	04100005	Dairy	1,400		
Bernath Farms 1 and 2	04100006	Swine - over 55 lbs	5,000		
Brown Swine Farm	04100006	Swine - over 55 lbs	4,800		
Crites Farms	04100006	Swine - over 55 lbs	4,800	Sheep	100
De Vries Dairy Ltd. North	04100006	Dairy	2,400		
Goebel Pork, LLC	04100006	Swine - over 55 lbs	4,550		
Nofziger Livestock	04100006	Swine - over 55 lbs	10,000		
PGC Chesterfield Hogs	04100006	Swine - over 55 lbs	4,800		
Planson Pork LLC	04100006	Swine - over 55 lbs	4,800		
VanderMade Dairy LLC	04100006	Dairy	1,800	Dairy	180
Zeedyk Swine Farm	04100006	Swine - over 55 lbs	6,000		
Bob Sinn Swine	04100007	Swine - over 55 lbs	9,600		
Bruce Rosswurm Swine Farm	04100007	Swine - over 55 lbs	9,600		
Canal Farm	04100007	Swine - over 55 lbs	3,582		
Convoy Dairy, LLC	04100007	Dairy	2,033	Slaughter-Feeder-Heifer	240
Creek View Farm	04100007	Swine - over 55 lbs	4,800		
Deer Run Farm	04100007	Swine - over 55 lbs	3,500		
Feather Ridge Farm	04100007	Chickens-Layers	183,288		
Gina Dairy LLC	04100007	Dairy	1,300	Slaughter-Feeder-Heifer	200
Happy Yolks, LLC	04100007	Chickens-Layers	404,616		
Harting Livestock LLC	04100007	Swine - over 55 lbs	14,000	Chickens-Layers	44,000
Hefner's Dola Swine Farm	04100007	Swine - over 55 lbs	4,200		

Facility Name	Watershed	Animal 1 Species	Animal 1 Count	Animal 2 Species	Animal 2 Count
Hillside Acres	04100007	Swine - over 55 lbs	13,600		
Jeff and Alan Ricker Swine	04100007	Swine - over 55 lbs	4,900	Turkey	36,000
Lamar Swine Farms LLC	04100007	Swine - over 55 lbs	9,600		
Miller City Dairy	04100007	Dairy	1,250	Slaughter-Feeder-Heifer	116
Oak Forest	04100007	Turkey	74,000		
Paulding Dairy	04100007	Dairy	5,501		
Pessefall Farms, LLC	04100007	Swine - over 55 lbs	5,200		
Profit Family Pork	04100007	Swine - over 55 lbs	9,600		
Riverbend Sow Complex	04100007	Swine - over 55 lbs	3,500		
RMK Farming, LLC	04100007	Swine - over 55 lbs	4,800		
Rose Grove Farm	04100007	Swine - over 55 lbs	3,611		
Schweinefarmen, LLC	04100007	Swine - over 55 lbs	4,800		
Sugar Lane Dairy, LLC	04100007	Dairy	3,820		
Sun Mountain Dairy LLC	04100007	Dairy	3,200	Slaughter-Feeder-Heifer	700
The Brick Farm Swine, LLC	04100007	Swine - over 55 lbs	6,000		
Tim Sinn Family Hog Farm	04100007	Swine - over 55 lbs	4,800		
Triple R Farms, Inc.	04100007	Swine - over 55 lbs	7,200		
Triple V Pork LLC	04100007	Swine - over 55 lbs	5,450		
Van Erk Dairy	04100007	Dairy	2,000		
Vandenhengel Pork, LLC	04100007	Swine - over 55 lbs	7,350		
White Oak Farm	04100007	Swine - over 55 lbs	2,776		
Wildcat Dairy	04100007	Dairy	1,102		
Willow Tree Swine, LLC	04100007	Swine - over 55 lbs	9,600		
Continental Dairy, LLC	04100008	Dairy	2,250		
Highslip Pork	04100008	Swine - over 55 lbs	4,200		
Vrieco Farms Ltd	04100008	Dairy	825		
Fenstermaker Farms, Inc.	04100009	Swine - over 55 lbs	6,780	Swine - under 55 lbs	2,400
Hertzfeld Poultry Farms, Inc.	04100009	Chickens-Layers	1,256,191		
KMLS Farms LLC	04100009	Swine - over 55 lbs	5,234	Swine - under 55 lbs	200
BB Land, LLC	04100010	Dairy	5,000		
Boyer Farms	04100010	Swine - over 55 lbs	4,800		
Reyskens Dairy LLC	04100010	Dairy	2,000		
Roger and Lori Rader Farms	04100010	Swine - over 55 lbs	4,000		

Animal units

The term animal unit is a unit of measurement used to standardize animals by size. For any animal feeding operation, animal units were calculated based the definition of a “large concentrated animal feeding operation” found in Ohio Revised Code 903.01(M). The animal unit conversion factors are listed in Table A3.3.

The Census does not provide the distribution animal maturity or size within a county. For this analysis, it was assumed that all livestock reported in the Census of Agriculture and in ODA DLEP permits were mature. For example, if 100,000 swine were reported in a county, then ODA assumed all 100,000 were over 55 pounds, used the 0.4 animal unit conversion, and arrived at total of 40,000 animal units.

This assumption will overestimate the amount of animal units, as surely some animals are not mature. (In this example, breeding sows and swine under 55 pounds). A similar assumption was made for poultry. For example, all turkeys reported by the Census were assumed to be seven pounds of more. Again, this assumption likely overestimates animal units, and some turkeys are less than seven pounds and would have a lower animal unit conversion factor.

Animal unit results

Table A3.3 shows the resulting estimate of animal units in the Maumee watershed in Ohio over the past four Censuses of Agriculture. In this Figure, animal types reported in the Census are consolidated into six general categories:

a. **Milk Cows** = Census Milk Cows
b. **Cattle Non-Milk Cows** = Census Cattle and Calves – Census Milk Cows
c. **Swine** = Census Hogs and Pigs
d. **Turkeys** = Census Turkeys
e. **Chicken Pullets** = Census Pullets
f. **Chickens Layers =** Combination of Census Layers and DLEP permitted layers

Animal units were rounded to the nearest thousand to reflect the reliability of previous estimates used in the calculation.

Table A3.3. Estimate of animal units in the Maumee watershed in Ohio 2002-2017, using a combination of Census of Agriculture and ODA DLEP permitting data.

Type	Population				Animal Unit Factor	Animal Units - Rounded			
	2002	2007	2012	2017		2002	2007	2012	2017
Milk Cows	1,748	46,917	41,360	50,428	1000/700	45,000	67,000	59,000	72,000
Cattle - Non-Milk Cows	93,937	116,808	136,115	136,326	1000/1000	94,000	117,000	136,000	136,000
Swine	343,616	511,073	624,004	801,232	1000/2500	137,000	204,000	250,000	320,000
Turkeys	459,391	532,019	606,203	811,309	1000/55,000	8,000	10,000	11,000	15,000
Chicken Pullets	626,671	793,607	680,464	1,125,498	1000/125,000	5,000	6,000	5,000	9,000
Chicken Layers	4,078,097	4,160,386	3,700,194	8,749,470	1000/82,000	50,000	51,000	45,000	107,000
					Total animal units:	339,000	455,000	506,000	659,000

A3.3 Manure phosphorus generated

The livestock population can be multiplied by an estimate of manure phosphorus produced by each animal to arrive at an estimate of the total manure phosphorus produced in the watershed. Of course, the estimate of manure phosphorus produced by each animal greatly influences the calculation. Past estimates of this nature have used "book values" such as the Mid-West Plan Service 2004 publication Livestock Waste Facilities Handbook (MWPS-18, 1993) or Ruddy et al. (2006). Manure nutrient content has changed over the past 20 years as livestock feed management evolved. To account for the change in manure composition, ODA did not use the Mid-West Plan Service or Ruddy et al. values. Instead, ODA used two recent datasets of manure analysis to estimate manure phosphorus produced by each animal type:

1. Permitted facilities are required to submit manure nutrient analysis and the amount of manure produced as a condition of a Permit-to-Operate issued by ODA DLEP. The most recent manure analyses for permitted

operations in the Maumee watershed in Ohio were compiled and averaged in 2021. These values are shown in the column labeled ODA DLEP in Table A3.3.

2. The Grand Lake St. Marys watershed is presently designated as a Watershed in Distress under Ohio Administrative Code 901:13-1-20. Non-permitted facilities in this watershed, which is adjacent to the Maumee watershed, are required to submit manure nutrient analysis and the volume of manure produced as part of a nutrient management plan. The most recent manure analyses for these non-permitted operations were compiled and averaged in 2021. A value for dairy cattle could not be calculated from the available data and therefore was omitted. These values are shown in the column labeled GLSM in Table A3.4.

A simple average of these two recent datasets, the column labeled ODA Average in Table A3.4, is ODA's best estimate of manure phosphorus concentrations and was used for further calculations.

Table A3.4. Comparison of manure phosphorus concentration estimates.

Estimated P in Manure (MT P per animal per year)					
	Ruddy et al. (2006)	**MWPS (2004)**	**ODA DLEP**	**GLSM**	**ODA Average (2021)**
Dairy Cow	0.01169	0.03219	0.02121	n/a	0.02121
Beef Cattle	0.01863	0.00723	0.00795	0.00843	0.00819
Finishing Hogs	0.00438	0.00362	0.00149	0.00124	0.00137
Layers	0.00022	0.00006	0.00015	0.00021	0.00018
Pullets and Broilers	0.00011	0.00010	0.00003	0.00004	0.00004
Tom Turkeys	0.00073	0.00054	0.00017	0.00073	0.00045

Lifecycle/days

Past estimates of manure phosphorus have considered the life cycle of the animal, specifically how many days the animal is in captivity. For example, Gronberg and Arnold (2017) used the equation:

Phosphorus in manure of an animal category = Census population of an animal category × phosphorus (kilograms per animal per day) × life cycle (days).

However, the Census does not provide information on the lifespan of reported animals. Therefore, periods of animal confinement were not considered for this estimate. It was assumed that all animals reported in the Census population and in ODA DLEP permits were confined for 365 days per year. This simplification likely leads to an overestimate of manure phosphorus produced, possibly greatest in animal species that typically have confinement periods of less than one year, such as slaughter cattle and turkeys.

Phosphorus generated by species

ODA used the average manure nutrient values from two recent datasets (ODA Average in A3.4) and multiplied by the population estimates from 2002, 2007, 2012, and 2017. The calculations described above finds approximately 5,300 metric tons of manure phosphorus were produced in the Maumee watershed in Ohio in 2017. Table A3.5 shows the manure phosphorus produced for other census years considered in this appendix. Total metric tons of phosphorus were rounded to the nearest thousand to reflect the reliability of previous estimates used in the calculation.

Table A3.5. ODA calculated metric tons of phosphrous produced in Ohio's portion of the Maumee watershed by livestock species in 2002, 2007, 2012, and 2017.

Type	Population				Estimated P in Manure in MT P/animal/year	Metric Tons P Generated per Year			
	2002	2007	2012	2017		2002	2007	2012	2017
Milk Cows	31,748	46,917	41,360	50,428	0.02121	673	995	877	1,069
Cattle - Non-Milk Cows	93,937	116,808	136,115	136,326	0.00819	769	957	1,115	1,117
Hogs	343,616	511,073	624,004	801,232	0.00137	470	699	853	1,096
Turkeys	459,391	532,019	606,203	811,309	0.00045	207	240	273	365
Chicken Pullets	626,671	793,607	680,464	1,125,498	0.00004	24	30	26	42
Chicken Layers	4,078,097	4,160,386	3,700,194	8,749,470	0.00018	733	748	666	1,574
					Total	2,900	3,700	3,800	5,300

A3.4 Estimate of crop removal/fertilizer need

Annual crop removal of phosphorus from the Maumee can also be estimated using the crop removal rates found in the most recent Tri-State Recommendations (Culman et al., 2020) multiplied by an assumed crop yield. For this estimate, it was assumed that the average yields were 180 bushel an acre for corn and 50 bushels an acre for soybeans. It is assumed that the 2.3 million acres of cropland in the Maumee watershed in Ohio were planted in an even 50/50 split of corn and soybeans (although cropping pattens do vary from year to year). Under these assumptions, crop removal is in approximately 23,500 metric tons of phosphorus per year.

$$Assumed\ average\ corn\ yield\ goal(180\ bu.ac) \times 0.35\ lbs\ P205\ lbs\ per\ bushel$$
$$= 63\ lbs\ P2O5\ removed\ per\ acre\ of\ corn$$

$$Assumed\ average\ soybean\ yield\ goal\ (50\ bu.ac) \times 0.8\ lbs\ P205\ lbs\ per\ bushel$$
$$= 40\ lbs\ P2O5\ removed\ per\ acre\ of\ soybean$$

$$Assumed\ 50{:}\ 50\ corn{:}\ soybean\ split\ in\ crop\ acerage\ \ \therefore 51.5\ lbs\ P2O5\ removed\ from\ average\ acre$$

$$51.5\ lbs\ P2O5\ \div 2.29\ (to\ account\ for\ mass\ of\ phosphorus\ in\ P2O5) = 22.5\ lbs\ P\ removed\ per\ acre\ per\ year$$

$$22.5\ lbs\ P * 2.3\ million\ cropland\ acres\ in\ Ohio\ in\ Maumee\ watershed$$
$$=\ 51{,}750{,}000\ lbs\ P\ removed\ from\ Ohio\ Maumee\ watershed\ per\ year$$

$$51{,}750{,}000\ lbs\ P\ removed\ from\ Ohio\ Maumee\ watershed\ per\ year$$
$$\div 2{,}205\ lbs\ per\ metric\ ton\ (unit\ converion)$$
$$= 23{,}469\ metric\ tons\ P\ removed\ from\ Ohio\ Maumee\ watershed\ per\ year$$

Manure's contribution to crop need

Combining the estimates of crop removal and manure phosphorus produces results in the final estimate that approximately 23 percent of the crop need is supplied by manure phosphorus in the Maumee watershed in Ohio.

$$\frac{5{,}300\ metric\ tons\ manure\ produced\ per\ year}{23{,}469\ metric\ tons\ P\ removed\ per\ year} = 22.6\%$$

Conservative assumptions are noted throughout this appendix that mention a likely overestimate of the amount of manure produced in the Maumee watershed.

A3.4 Trends in commercial fertilizer and manure phosphorus in the Maumee watershed in Ohio

ODA has estimated the amount of phosphorus applied within the Maumee basin in Ohio through commercial fertilizers and manure application combined. This amount was then compared to the amount of phosphorus removed through crop harvest. This section of Appendix 1 documents the data used, and analysis carried out to develop Figures 12, 13, and 14 in the PMR.

The procedures used for this analysis include:

- Compilation of data on fertilizer sales from 2008 to 2020 and proration of data to the area within the Maumee basin in Ohio.
- Estimation of manure production/application for 2002, 2007, 2012, and 2017 using data compiled by ODA.
- Calculation of annual crop removal using data from NASS and nutrient removal rates from the 2020 Tri-State Fertilizer Recommendations (Culman et al., 2020).

The following provides more detail for each of these steps.

Fertilizer sale/application

An estimate of phosphorus fertilizer application from 2007 to 2020 for the Maumee watershed in Ohio was calculated using data obtained from ODA Division of Plant Health. Fertilizer distributors are required to report annual fertilizer sales to the Division of Plant Health. These data are based on the location of sale and serve as a proxy for fertilizer application on a county or multi-county basis. The Division of Plant Health provided the raw fertilizer data, which was summarized to show annual tons of phosphorus (as P2O5) per county. See Table A3.6 for the results for years 2007, 2012, and 2017. These data were then prorated to the area within the Maumee basin in Ohio, according to Table A3.1.

Several public entities, including The Ohio State University, NUGIS, and the Fertilizer Institute have acquired these data, and have used them in conjunction with publicly available U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) data on crop production to carry out studies of fertilizer application and crop removal similar to this one.

Table A3.6. Fertilizer sales per county, before prorating, for years included in this anlaysis.

County	P2P05 fertilizer sales (metric tons)		
	2007	2012	2017
Allen	3,193	2,782	3,122
Auglaize	10,196	9,632	11,235
Defiance	5,794	3,288	4,413
Fulton	9,191	7,821	7,184

Hancock	7,151	8,401	7,736
Hardin	5,571	3,419	4,256
Henry	9,817	9,613	8,601
Lucas	5,139	3,795	7,745
Mercer	10,591	10,311	11,747
Paulding	4,962	3,353	3,409
Putnam	8,343	9,940	13,201
Van Wert	10,861	12,164	12,342
William	6,009	4,878	4,933
Wood	8,283	10,147	11,559
Total	**105,101**	**99,546**	**111,483**

Manure production/application

Manure production estimates were taken from ODA's assessment of livestock manure production in the Maumee basin in Ohio, explained above. For the purposes of this estimate it was assumed that all manure produced was applied within the basin. Manure production data points from three available years (2007, 2012, and 2017) were used to compare combined P2O5 from commercial fertilizers and manure application with P2O5 removed through crop harvest. Note: fertilizer data prior to 2006 was not available.

Crop removal

An estimate of nitrogen and phosphorus (P2O5) removed was made using agricultural data taken from the USDA-NASS, and the 2020 Tri-State Fertilizer Recommendations crop removal rates. Acres harvested and average yield for corn, soybeans, and wheat (grain only) were queried from the NASS database on a county basis. The total bushels produced per county was calculated, and the nutrients removed were calculated using the values provided in the 2020 Tri-State Fertilizer Recommendations (Figure 1 from Cullman et al., 2020). The following equation illustrates this exercise:

$$
\begin{aligned}
&P2O5\ removal\ in\ County\ in\ 2020 \\
&\quad = ((2020\ NASS\ acres\ corn\ harvested) * (2020\ NASS\ county\ average\ corn\ yield) \\
&\quad * (0.35\ lb\ P2O5\ removed\ per\ bushel)) \\
&\quad + \big((2020\ NASS\ acres\ soybeans\ harvested) * (2020\ NASS\ county\ average\ soybean\ yield) \\
&\quad * (0.80\ lb\ P2O5\ removed\ per\ bushel)\big) + ((2020\ NASS\ acres\ wheat\ harvested) \\
&\quad * (2020\ NASS\ county\ average\ wheat\ yield) * (0.50\ lb\ P2O5\ removed\ per\ bushel))
\end{aligned}
$$

These data were then prorated to the area within the Maumee basin in Ohio, according to Table A2.1. This estimate of crop removal is conservative, as it did not include nutrient removal from corn silage, hay, or vegetables. The resulting crop removal data was then plotted with the fertilizer and manure application data to assess the balance of nutrients added and removed from the soil annually.

A3.5 Works cited

Works cited are included in Appendix 8.