Appendix G

Northeast Lakeshore TMDL

Total Maximum Daily Loads for Total Phosphorus and Total Suspended Solids

Estimation of manure and associated phosphate spreading for the development of a SWAT watershed model

Estimation of manure and associated phosphate spreading for the development of a SWAT watershed model

Wisconsin Department of Natural Resources, Bureau of Water Quality

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1. Introduction

1.1. Background

The NE Lakeshore TMDL study area has a high percentage of agricultural land devoted to dairy production. According to the Wiscland2 (Wiscland) landcover dataset, 34% of all land in the NE

Lakeshore TMDL area is under a dairy rotation, with additional agricultural land supporting dairy production. A dairy rotation refers to agricultural fields where crops such as corn grain, corn silage, and hay are grown in approximately five to eight-year sequences and primarily used to meet the feed requirements of dairy cattle. Areas under a dairy rotation typically receive manure applications during certain years of the rotation sequence to return nutrients such as nitrogen and phosphorus to the soil.

Given the density of dairy production operations and associated manure spreading in the NE Lakeshore TMDL area, the Wisconsin Department of Natural Resources (WDNR) pursued an effort to estimate manure and associated phosphate spreading at different locations in the study area. All references to the methods and results of this effort are hereafter referred to as the 'WNDR manure analysis' or simply, 'WNDR analysis'. The manure and associated phosphate from the WDNR analysis were used as an input to the SWAT (Soil and Water Assessment Tool) watershed model being developed in support of the NE Lakeshore TMDL. The agriculture sector typically utilizes the terms phosphorus, phosphate, and P2O5 interchangeably. As such, for consistency, the manure phosphorus results from the WDNR manure analysis are expressed as phosphate and will hereafter be referred to as P2O5.

The high occurrence of confined animal feeding operations (CAFOs) permitted through the Wisconsin Pollutant Discharge Elimination System (WPDES) in the NE Lakeshore basin allowed the WDNR to develop a method for estimating manure spreading rates and associated P2O5 in the NE Lakeshore basin. Cattle numbers and spreading locations reported by WPDES permitted CAFOs assisted with quantifying manure and associated P2O5 spreading amounts in the NE Lakeshore basin. Additionally, the manure and associated P2O5 spreading amounts reported by CAFOs in their Nutrient Management Plans and Annual Reports were used to independently verify the manure and associated P2O5 spreading results calculated with the WDNR manure spreading analysis.

1.2. Objective

The primary objective of the WDNR manure analysis was to calculate the yearly mass of manure-derived phosphate, expressed as P2O5, applied per subbasin per year. The yearly subbasin manure P2O5 amounts were then used as an input for the SWAT watershed model being developed in support of the NE Lakeshore TMDL.

1.3 Limitations

The WDNR analysis directly accounts for manure and associated P2O5 from cattle sources only. In reality, manure pits may include P2O5 contributions from feed leachate runoff and offsite sources; however, these situations are difficult to quantify and are likely to be outweighed by cattle source contributions. Nevertheless, P2O5 contributions from non-manure sources to manure pits were indirectly accounted for in the WDNR analysis through adjustment of the manure P2O5 concentration based on review of manure P2O5 concentrations reported in CAFO's Nutrient Management Plans.

The spreading rates and distribution of manure and associated P2O5 among subbasins was primarily based on locations of fields with dairy crop rotations, as identified by the Wiscland dataset. It is recognized that not all cattle manure is applied to dairy fields, for example, when it is sold to non-dairy farmers or applied to cash grain crops. However, the WDNR analysis primarily used the locations and acres of Wiscland dairy fields to calculate amounts and spreading rates of manure and associated P2O5, as dairy fields are the predominant agricultural land use consistently receiving manure in the NE Lakeshore basin.

1.4. Method overview

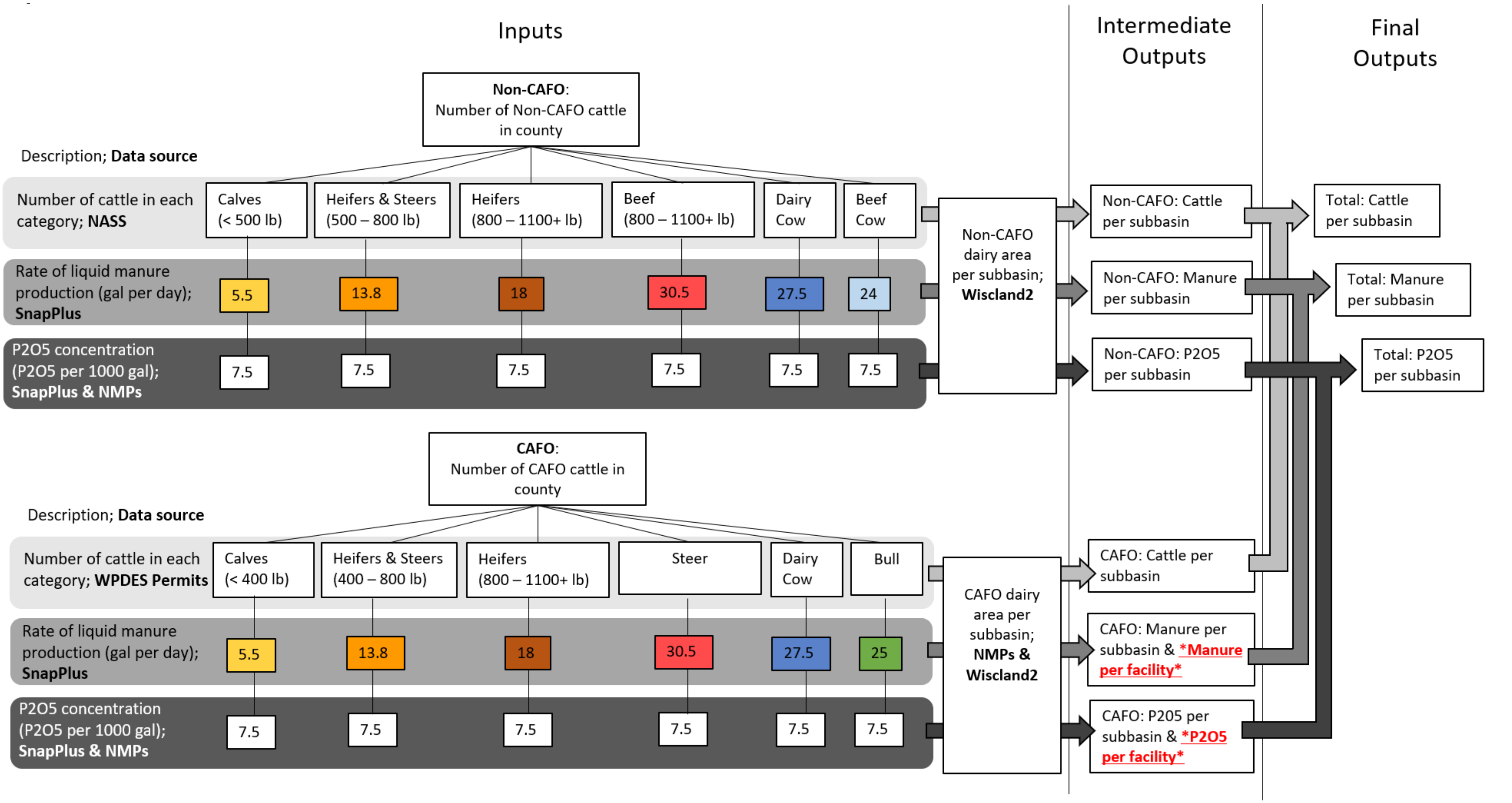
1.4.1. Manure and P2O5 amount per subbasin

Cattle inventories were used to calculate the manure volume and associated P2O5 mass per subbasin. This calculation was done by 1) calculating the number of CAFO and non-CAFO cattle for seven different cattle types in each county, 2) assigning each cattle type a unique manure production rate, 3) translating manure production rates into P2O5 production rates with a uniform P2O5 concentration, and 4) distributing the calculated masses of manure and phosphate among subbasins based on the occurrence of manure spreading locations in the subbasin. See Figure 1 for a diagram of this process.

1.4.2. Manure and P2O5 spreading rates per subbasin

The subbasin manure and associated P2O5 amounts calculated from the WDNR analysis were translated into three different spreading rates. Three different rates exist due to differences in the number of acres assumed to be receiving manure in each scenario. All three rates still sum to the same annual mass per subbasin. The purpose of the three different spreading rates was to translate the subbasin manure and associated P2O5 amounts into a more understandable form (rates) to verify the WDNR manure spreading analysis with agriculture professionals, compare results to values in CAFO Nutrient Management Plans, and share results with watershed planners and implementers. An overview of the three different rates is provided in section 2.4.2.

Figure 1. Summary of the WDNR manure analysis. ***Red*** outputs indicate values that were calculated with the WDNR manure analysis and compared to similar, but independent values, gathered from CAFO Nutrient Management Plans. See section 4.2.1. for results of comparisons.



2. WDNR manure analysis: Method

2.1. Step 1 - Cattle numbers and cattle types

2.1.1. CAFO cattle

CAFO cattle numbers and cattle types were gathered for each CAFO facility using the cattle numbers in their 2018 Annual Report. WPDES permitted CAFOs are required to enter cattle numbers for the follow cattle types:

- Calves (< 400 lb)
- Small Heifers (400 – 800 lb)
- Large Heifers (800 – 1200 lb)
- Dry and Milking Cows
- Steer
- Bull

2.1.2. Non-CAFO cattle

The number of cattle not associated with CAFOs (hereafter referred to as non-CAFO cattle) were only available at a countywide scale. Non-CAFO cattle numbers were calculated by subtracting the total number of cattle per county from the number of CAFO cattle per county (Figure 3). The number of cattle per county was obtained from the National Agricultural Statistics Service (NASS) 2017 Cattle Census using the NASS Quick Stats Database. Cattle types reported by NASS are not as specific as the cattle types in CAFO Annual Reports. Therefore, the NASS cattle types do not directly match the cattle types reported in the CAFO Annual Reports. The NASS cattle census reports the four following cattle types (NASS, General Explanation and Census of Agriculture Report Form, pg. 39):

- Calves (which includes beef and dairy calves, heifers, steers, and bulls)
    - Cattle on Feed (a subset of the calf category)
- Beef Cow
- Dry and Milking Cow

To assign representative manure production rates to non-CAFO cattle, the NASS calf category was divided into the cattle types similar to those in CAFO Annual Reports. The NASS calf category was divided into the following categories:

- Calves - dairy and beef (under 500 lb)
- Small heifer and steer (500 to 800 lb)
- Large dairy heifer and beef (800 to 1100 lb)
    - Large dairy heifer
    - Cattle on feed (beef) – this category was directly reported in the NASS cattle census

Cattle in the NASS calf category were assigned to sub-categories (as listed above) based on growth rates of dairy youngstock. A dairy youngstock will spend an average of 25% of its life as a calf (under 500 lb), 30% as a small heifer (500 – 800 lb) and 45% as a large heifer (800 – 1200 lb) (personal communication, Matt Akins, Dairy Specialist, UW Extension, Sept. 2019). Growth rates were assumed to be similar for both beef and dairy youngstock. Therefore, 25% of the NASS calf category was classified as beef and dairy calves (under 500 lb), 30% was classified as small heifers and steers (500 to 800 lb), and 45% was classified as large dairy heifers and beef (800 to 1100 lb). The large dairy heifer and beef category was further divided into large dairy heifers and cattle on feed (beef) by subtracting the cattle on feed category (as reported from the

NASS 2017 cattle census) from the large dairy heifer and beef category (45% of the NASS calf category). See Figure 2 for a diagram of how the NASS calf category was divided into specific cattle types.

Figure 2. Diagram of the approach used to divide the NASS calf category into specific cattle types. The color of the text boxes corresponds to the manure production rate that the category was assigned in Figure 1 and Table 1.

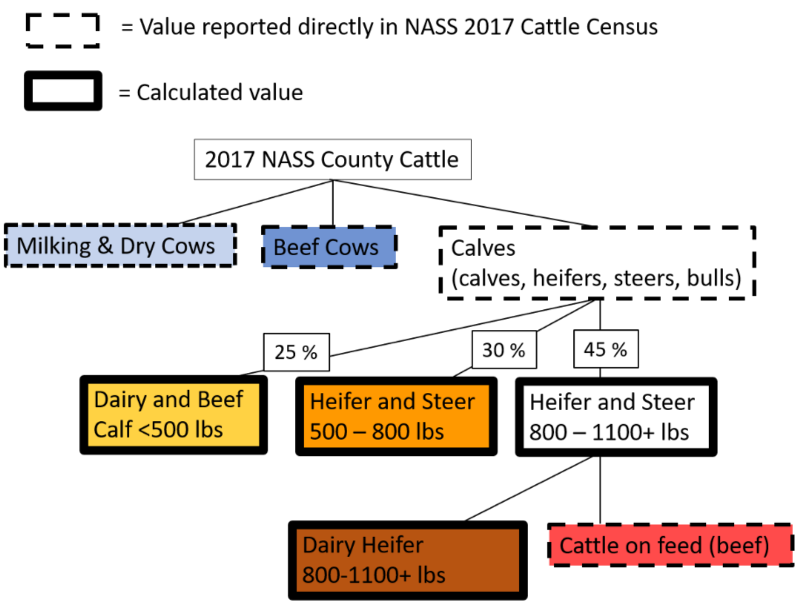
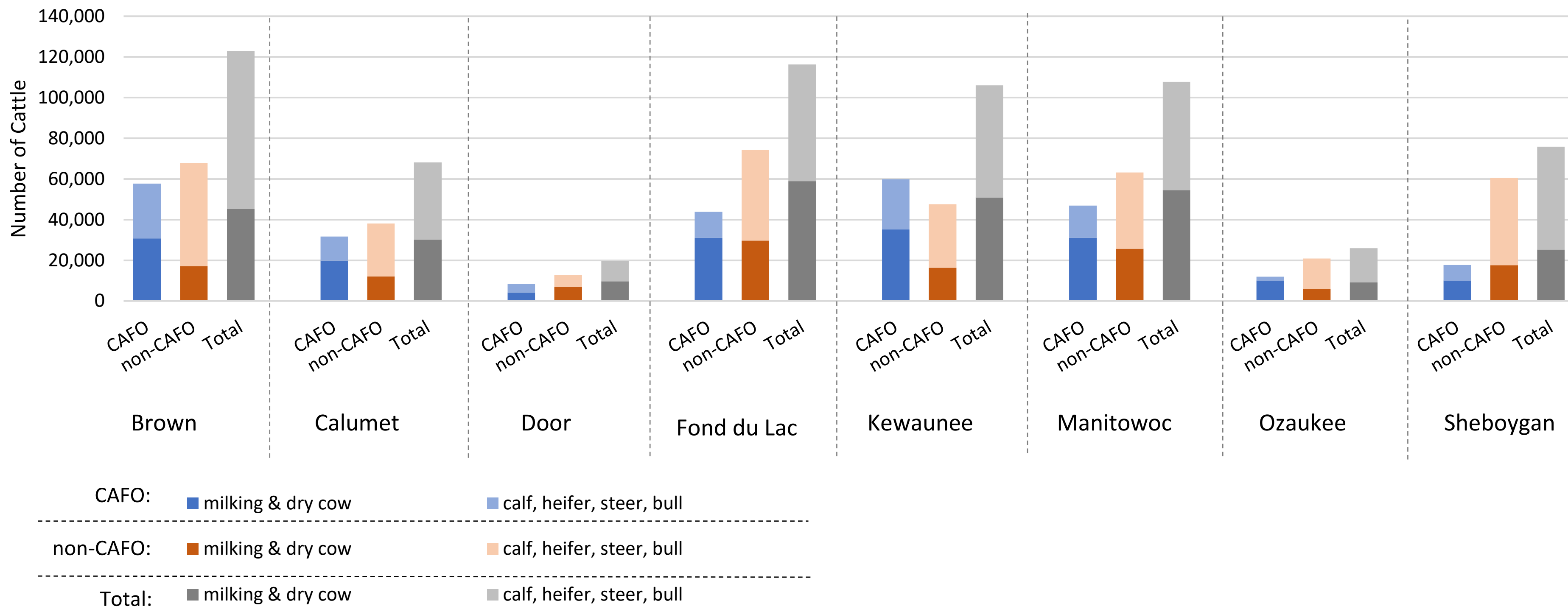


Figure 3. Countywide cattle numbers for CAFO facilities, non-CAFO facilities, and total (CAFO and non-CAFO). CAFO cattle numbers reflect numbers reported in each CAFO facility's 2018 Annual Report. Total countywide cattle numbers (grey) reflect the cattle numbers reported in the [2017 NASS cattle census](). Non-CAFO cattle numbers (blue) were calculated by subtracting the total countywide cattle numbers (grey) from the CAFO cattle numbers (orange).



2.2. Step 2 - Liquid manure production rates

Once countywide CAFO and non-CAFO cattle numbers were obtained for each cattle type, unique manure production rates were assigned to each CAFO and non-CAFO cattle category. Rates assigned for each cattle type are consistent with the rates reported in SnapPlus, which are summarized in the Midwest Plan Service (MWPS) publication number 18-1 “Manure Characteristics”. However, cattle types listed in SnapPlus/MWPS did not always share the same description as the cattle types in NASS (non-CAFO cattle) and Annual Reports (CAFO cattle). For example, SnapPlus/MWPS reports three liquid manure production rates for calves based on their weight. In cases where multiple SnapPlus/MWPS cattle types fit a NASS or Annual Report cattle description, the liquid manure production rates of the multiple SnapPlus/MWPS cattle types were averaged to assign one liquid manure production rate for the NASS and Annual Report cattle types. **Table 1** summarizes which SnapPlus/MWPS liquid manure production rates were assigned to the NASS and Annual Report cattle types. Note that all cattle types were assigned a manure production rate for liquid manure. Even though calves do not typically produce liquid manure, all liquid rates result in approximately equal nutrient content as their solid manure production rates (MWPS, Publication number 18-1 “Manure Characteristics”, 2000). Additionally, MWPS liquid manure production rates also include a dilution factor of 1.8 for dairy and 3.2 beef to account for dilution from urine and parlor wash water (Genskow and Larson, 2016, page 63). Dilution could be substantially different from operation to operation, and the dilution factor does not account for dilution from all possible sources such as feed leachate runoff, precipitation, or excess wash water.

Table 1. Liquid manure production rates from SnapPlus/MWPS and values used for the WDNR manure analysis. If more than one SnapPlus/MWPS rate applied to a non-CAFO and CAFO cattle type, then the SnapPlus rates were averaged for the WDNR manure analysis. Final liquid manure production rates used for the WDNR analysis are in the last column of the table. Colors correspond to the cattle types in figure 1 and figure 3. SnapPlus/MWPS rates in the first column of the table are based on manure production rates from the Midwest Plan Service publication number 18-1 “Manure Characteristics”.

SnapPlus/Midwest Planning Service (MWPS)		Non-CAFO Cattle – NASS 2017 Cattle Census	CAFO Cattle – Annual Report	Liquid manure production rate used for WDNR analysis
Cattle Type	**Rate (gal per day)**	**Cattle Type**	**Cattle Type**	**Rate (gal per day)**
Dairy Calf 150 lb	2.8	*Calf (beef and dairy under 500 lb)	Calf (under 400 lb)	5.5
Dairy Calf 250 lb	4.5			
Dairy Youngstock 500 lb	9.2			
Dairy Heifer 750 lb	13.8	*Dairy Heifer (500 - 800 lb)	Dairy Heifer (400 - 800 lb)	13.8
Dairy Heifer 1000 lb	18	*Dairy Heifer (800 - 1100+ lb)	Dairy Heifer (800 -1200 lb)	18
Dairy Lactating Cow 1000 lb	23	Dairy cow (milking and dry)	Dairy cow (milking and dry)	27.5
Dairy Lactating Cow 1200 lb	27.5			
Dairy Lactating Cow 1400 lb	32			
Beef Cow 1000 lb	24	Beef Cow 1000 lb	No data	24
Beef High Energy 1100 lb	30.5	Cattle on Feed	Steer	30.5
Beef Bull 1400 lb	25	No data	Bull	25

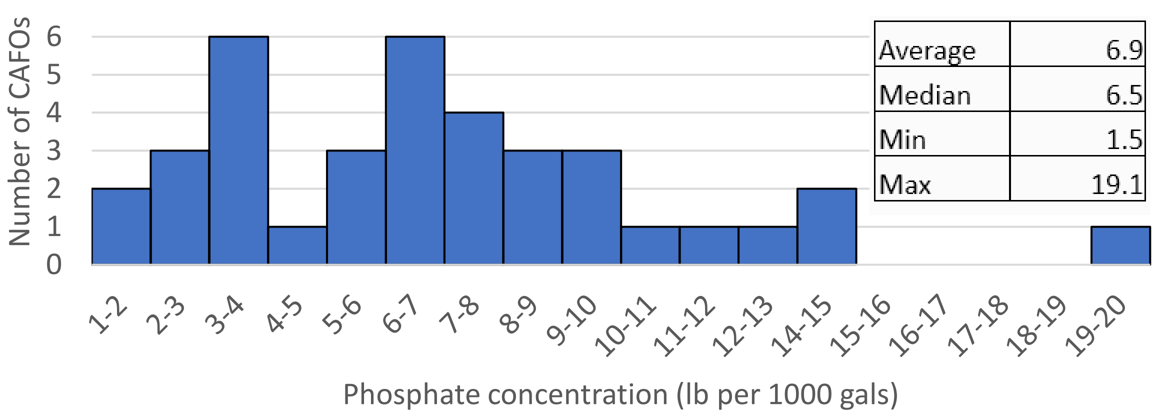
* Cattle counts for this category were not directly provided. Value was calculated as described in section 2.1.2 of this document.

2.3. Step 3 - Manure P2O5 concentration

For the analysis, all cattle types were assigned the same manure P2O5 concentration of 7.5 lb of P2O5 per 1000 gallons. However, because unique manure production rates were assigned to each cattle type (step 2), the daily mass of P2O5 still varied by cattle type.

SnapPlus uses a P2O5 concentration of 8 lb per 1000 gals for dairy slurry (4.1 – 11.0 % dry matter) (Laboski and Peters, 2012, Table 9.2). The WDNR analysis originally used a concentration of 8 lb per 1000 gals (rather than 7.5 lb per 1000 gal) to be consistent with SnapPlus. However, when initial P2O5 amounts and rates from the WDNR manure analysis were validated via comparison to P2O5 amounts and rates reported by CAFOs in their Nutrient Management Plans, it was found that a manure P2O5 concentration of 8 lb per 1000 gal resulted in the WDNR analysis overestimating the manure P2O5 amounts reported in CAFO's Nutrient Mangement Plans. Indeed, further analysis of 37 CAFO Nutrient Mangement Plans throughout the NE Lakeshore area indicated that CAFO manure had an average concentration of 6.9 lb P2O5 per 1000 gal (Figure 4), rather than 8 lb per 1000 gal (the statewide average used in SnapPlus). Therefore, the average manure P2O5 concentration of CAFO facilities in the NE Lakeshore TMDL is lower than the SnapPlus state average, indicating why the WDNR's initial P2O5 amounts and rates were overestimated. To correct this issue, it was not appropriate for the WDNR to re-run the analysis using manure P2O5 concentration of 6.9 lb per 1000 gal (the NEL CAFO average) because this represents the manure pit concentration that includes dilution from many possible sources and amounts such as rain water, feed lechate runoff, and offsite sources. In contrast, the WDNR manure analysis requires a manure P2O5 concentration that represents the liquid manure production rates described in section 2.2, which do not account for all sources of dilution. Therefore, to balance the observation of NE Lakeshore CAFOs having a lower average manure P2O5 concentration than the statewide average used for SnapPlus (8 lb per 1000 gals), but account for CAFO manure pits having a higher dilution factor than built into the SnapPlus manure production rates, the WDNR manure analysis used a P2O5 concentration of 7.5 lb per 1000 gallons. This resulted in a manure P2O5 concentration that is 0.5 less than used in SnapPlus and approximately 0.5 greater than the average concentration observed at CAFO facilities in the NE Lakeshore TMDL area.

Figure 4. Histogram of average yearly P2O5 concentration in manure (lb per 1000 gallons) from 37 CAFOs with production areas in the NE Lakeshore TMDL. Concentrations are based on information from one year per facility, year of data collection varied between 2014 and 2019. Concentrations were calculated by dividing total lb of manure P2O5 applied in year (source: mass balance report) by total manure produced in year (source: mass balance report).



2.4. Step 4 - Spatial distribution of manure and associated P2O5 across subbasins

2.4.1. Subbasin mass

TMDL subbasins serve as the primary watershed units used for TMDL development. During the TMDL development process, baseline loading conditions and TMDL allocations are calculated for each TMDL subbasin. Therefore, the WDNR manure analysis focused on estimating manure and associated P2O5 spreading at the subbasin scale.

2.4.1.1. Distribution of CAFO manure and associated P2O5

The manure mass and associated P2O5 calculated with the WDNR analysis for each CAFO was distributed among subbasins based on locations of spreadable acres reported in each CAFO's Nutrient Management Plan. Therefore, manure and associated P2O5 from CAFO sources could end up in a different county than the CAFO's production area. Additionally, the manure from a CAFO facility could be applied to a Wislcand land cover other than dairy. In the NE Lakeshore basin, 37% of CAFO spreading acres occurs on a Wiscland land cover other than dairy. Approximately 50% of these other land covers receiving manure were classified as cash grain, with the remainder of areas classified as continuous hay (15%), continuous corn (12%), and potato/vegetable (11%), and non-agricultural grasslands. Application of manure to areas classified as continuous hay, continuous corn, potato/vegetable, and grassland may not be reflective of actual practices due to areas being misclassified by Wiscland or having changed in land cover since the Wiscland dataset was developed.

2.4.1.2. Distribution of non-CAFO manure and associated P2O5

Countywide manure mass and associated P2O5 from non-CAFO sources was distributed among subbasins based on the presence of dairy fields in the subbasin, as reported by Wiscland (Figure 6). However, non-CAFO manure was only spread on dairy fields that were not already identified as being CAFO dairy fields. Additionally, non-CAFO manure and associated P2O5 were only distributed among dairy fields within the county they originated from, for example, all manure and associated P2O5 from non-CAFO cattle in Fond du Lac County, stayed in Fond du Lac County.

2.4.2. Subbasin spreading rates

While estimating yearly subbasin manure and associated P2O5 amounts was the main objective of the WDNR analysis, these amounts were translated into three different subbasin spreading rates to assist with interpreting the subbasin manure and P2O5 masses. Three different rates exist due to differences in the number of acres assumed to be receiving manure in each scenario. All three rates still sum to the same annual mass per subbasin. The three rates are referred to as 1) rate per spreadable acre, 2) rate per receiving acre, and 3) rate used in SWAT. Below is a description of the three spreading rates and the number of acres assumed to be receiving manure in each scenario.

1) Rate per spreadable acre

The 'spreadable acre rate' assumes that in a given year, manure and associated P2O5 is spread on 100% of the acres that the WDNR analysis identified as receiving manure. These acres were identified as the sum of Wiscland 2 dairy acres and non-Wiscland 2 dairy acres in CAFO Nutrient Management Plans. The 'spreadable acre rate' was calculated with equation 1.

Equation 1 $$\frac{\text{Subbasin manure or P2O5 amount}}{(\text{Wiscland dairy acres} + \text{CAFO spreadable acres})}$$

2) Rate per receiving acre

The ‘receiving acre rate’ assumes that in a given year, manure and associated P2O5 is spread on 50% of the spreadable acres that the WDNR analysis identified as receiving manure. This rate adjusts for the fact that alfalfa crops in dairy rotation are less likely to receive manure in a given year. The ‘receiving acre rate’ is most likely to reflect reality out of the three rates calculated.

Manure and associated P2O5 were assumed to be spread on 50% of the spreadable acres based on data from two sources. First, according to results of the agricultural survey, county conservationists in the NE Lakeshore TMDL area reported non-alfalfa crops growing in dairy rotations approximately 50% of the time (Table 1, NEL TMDL agricultural survey summary). Manure is less typically applied to alfalfa years of a dairy rotation; thus, about 50% of dairy fields would receive manure in a given year. Second, information in each CAFO’s 2018 Annual Report provided insight about the average percentage of acres receiving manure in a year. The 2018 Annual Reports indicated that CAFOs spread manure on approximately 50% of their spreadable acres per year, on average (Figure 5). Based on this information, the WDNR calculated manure and P2O5 ‘receiving rates’ with the assumption that 50% of the spreadable acres in a subbasin would receive manure per year. The ‘receiving acre rate’ was calculated with equation 2.

Equation 2 $$\frac{\text{Subbasin manure or P2O5 amount}}{(\text{Wiscland dairy acres} + \text{CAFO spreadable acres}) \times 0.5}$$

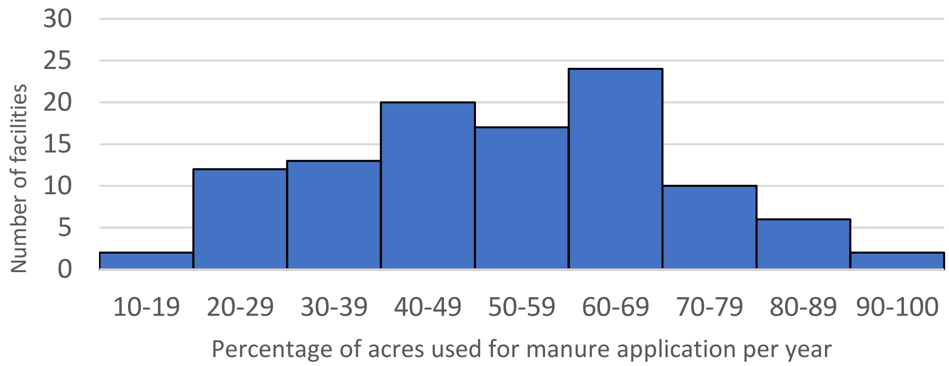
3) SWAT Rate

For SWAT watershed modeling, yearly P2O5 application rates were calculated by applying the total P2O5 amount per subbasin (according to the WDNR analysis) to only Wiscland dairy fields during the non-alfalfa and non-winter wheat years of the modeled dairy rotations. This assumption results in the watershed model applying P2O5 to approximately 50% of Wiscland dairy fields in a given year.

It is recognized that not all cattle manure is captured and applied to dairy fields, for example, when manure is purchased by non-dairy farmers or applied to cash grain crops; however, manure was only applied to dairy acres in the SWAT model, as dairy acres comprise the largest and most consistent land use receiving manure in the NE Lakeshore basin. Overall, the amount of P2O5 applied per subbasin is more important for model calibration than the spreading rate of P2O5 per subbasin. Therefore, the WDNR approached the manure spreading analysis with the goal of estimating the mass of manure P2O5 applied per subbasin, with less focus on the estimation of spreading rates. The ‘SWAT rate’ was calculated with equation 3.

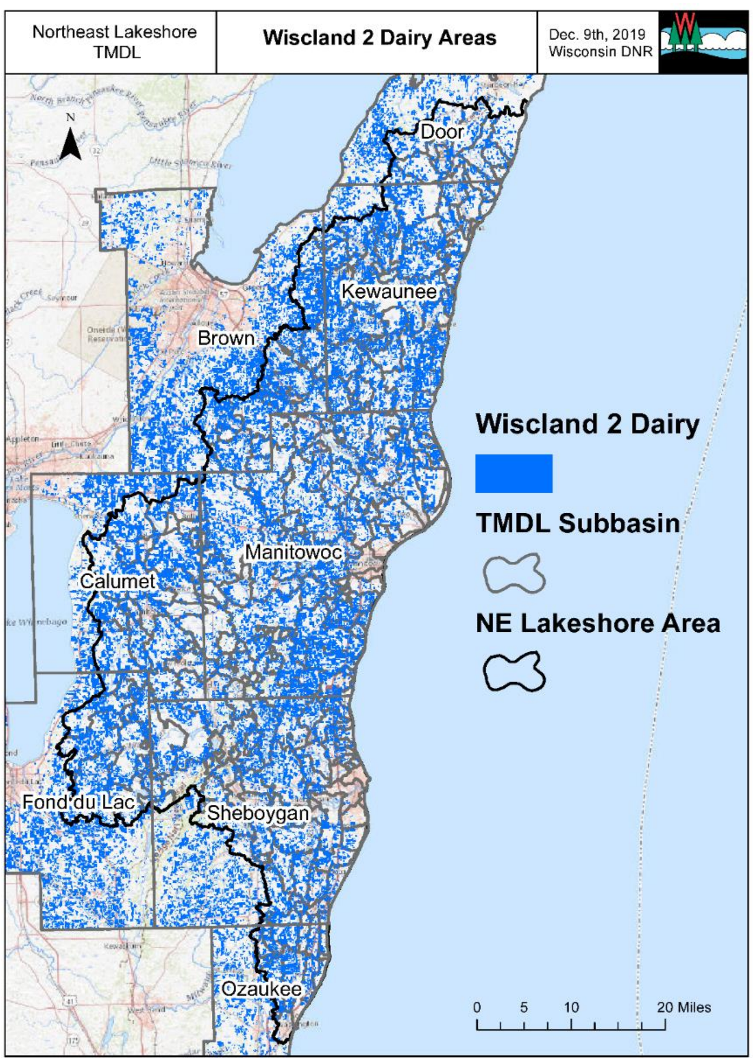
Equation 3 $$\frac{\text{Subbasin manure or P2O5 amount}}{(\text{Wiscland dairy acres}) \times 0.5}$$

Figure 5. Histogram of the percentage of acres receiving manure per year as reported by 106 CAFOs in the NE Lakeshore TMDL counties in their 2018 Annual Reports.



Avg	52.6
Median	53.6
Min	16.0
Max	100.0

Figure 6. Map of dairy fields as identified by the Wislcand 2 dataset. Dairy areas were identified using aerial imagery (USDA cropland data layer) from 2010- 2014 (Wiscland 2 Land Cover User Guide, 2016).



3. WDNR manure analysis: Results

3.1 Cattle counts and cattle density per subbasin

The subbasin cattle counts and rates are not representative of how many cattle are housed within each subbasin but rather the number of cattle whose manure is distributed into the subbasin based on the WDNR manure analysis. Additionally, cattle counts and rates represent the number of cattle and are not adjusted for animal units. A calf and cow both represent 1 unit.

The total cattle per subbasin ranged from 0 to approx. 10,000 with a subbasin average of 1,305 (Figure 8). Subbasin cattle densities ranged from 0 to 8.6 cattle per receiving acre and averaged 1.6 (Figure 7). Thirteen small subbasins (less than 750 acres) had no cattle because there was no Wiscland dairy acres or CAFO spreading locations in the subbasin.

Table 2. Summary statistics of cattle per subbasin and cattle density per subbasin according to the WDNR's manure analysis. See section 2.4.2 for a description of the three different densities.

		Cattle density (cattle/ac/year)		
	Cattle per subbasin per year	**Spreadable acre rate**	**Receiving acre rate**	**SWAT rate**
Average	1,305	0.8	1.6	2.0
Median	722	0.8	1.6	1.8
Min	0	0.0	0	0.0
Max	10,081	4.3	8.6	13.9

Figure 8. Map of total cattle per TMDL subbasin according to the WDNR manure analysis. Cattle counts are not reflective of animal units. Additionally, subbasin cattle counts do not reflect the number of cattle housed in the subbasin, rather, it reflects number of cattle distributed into the subbasin based on the WDNR manure analysis method.

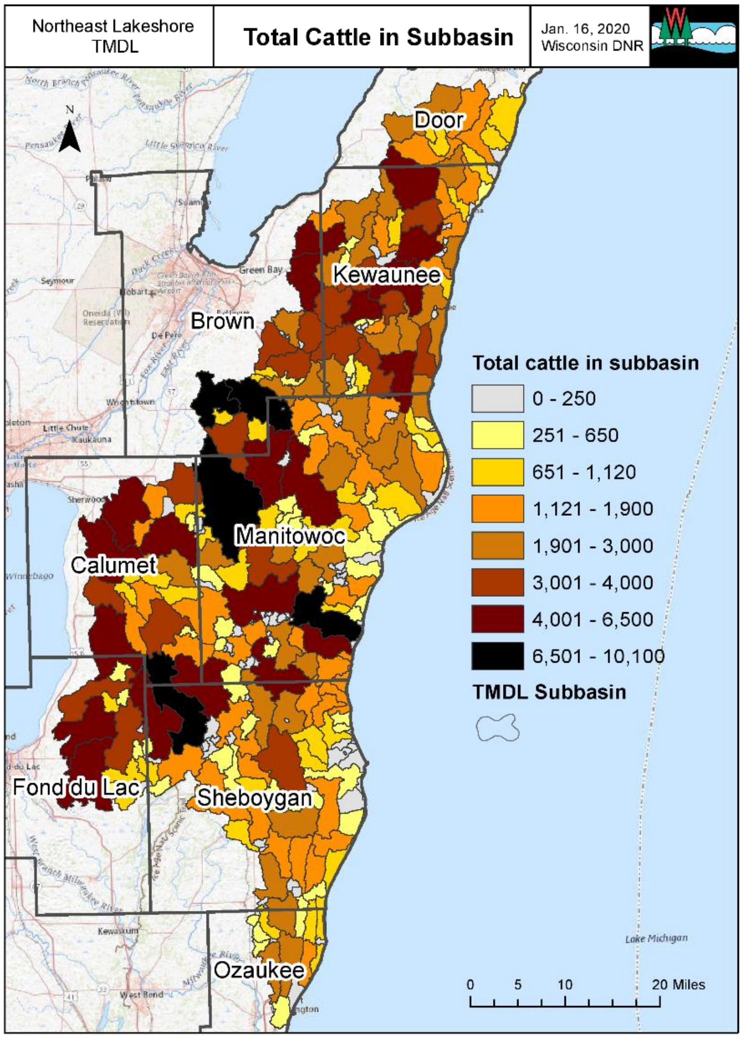
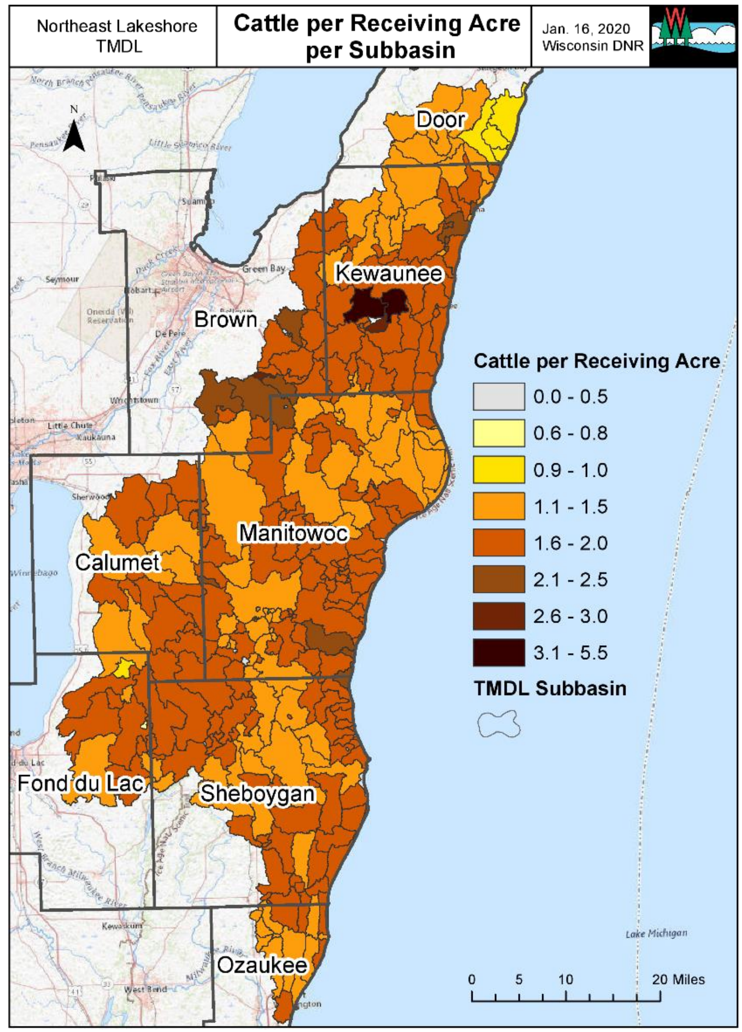


Figure 7. Map of cattle per receiving acre per subbasin per year according to the WDNR manure analysis. Densities are calculated using 50% of the total spreadable acres in a subbasin.



3.2 Liquid manure volumes and spreading rates per subbasin

The total manure volumes per subbasin ranged from 0 to approximately 80 million gallons per year with a subbasin average of 9.3 million gallons per year (Figure 9; Table 3). Subbasin manure spreading rates ranged from 0 to approx. 17,000 gal/receiving acre/year with an average near 10,500 gal/receiving ac/year (Figure 10; Table 3).Thirteen small subbasins (less than 750 acres) had no manure in the subbasin.

Table 3. Summary statistics of yearly manure volume per subbasin and manure spreading rate per subbasin according to the WDNR's manure analysis. See section 2.4.2 for a description of the three spreading rates.

		Liquid manure spreading rate (gal/ac/year)		
	Manure volume (gal) per subbasin per year	Spreadable acre rate	Receiving acre rate	SWAT rate
Average	9,391,699	5,270	10,540	14,314
Median	4,952,987	5,354	10,708	13.414
Min	0	0	0	0
Max	79,056,244	8,402	16,804	36,429

Figure 9. Map of total yearly manure volume (million gallons) applied per TMDL subbasin according to the WDNR manure analysis.

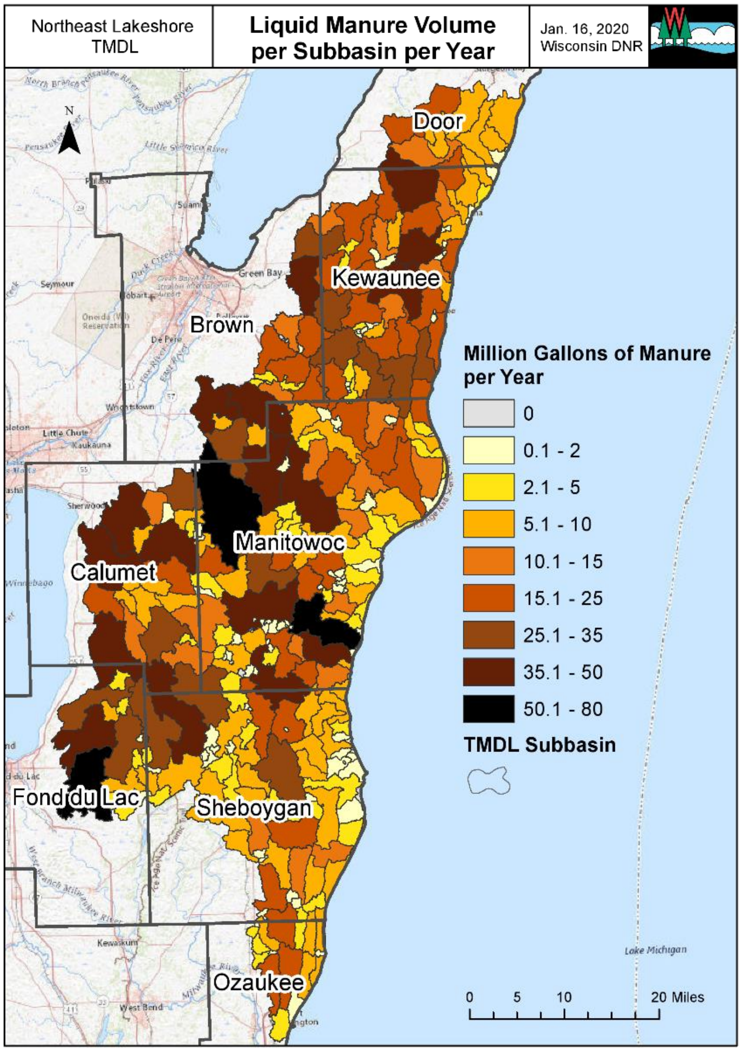
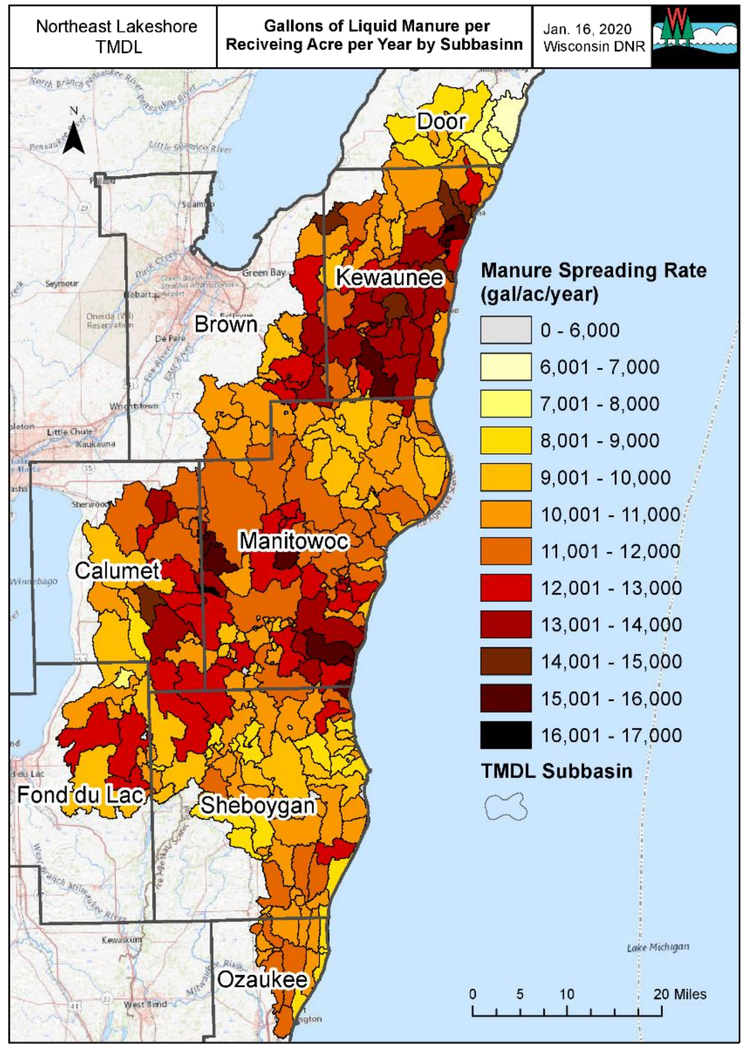


Figure 10. Map of manure spreading (gallons/receiving acre/yr) per subbasin according to the WDNR manure analysis. Rates reflect the assumption that 50% of the spreadable acres in a subbasin receive manure in a year.



3.3 Manure P2O5 mass and spreading rate per subbasin

The total P2O5 mass per subbasin ranged from 0 to approx. 600,000 pounds per year with a subbasin average near 70,000 pounds per year (Figure 12; Table 4). Subbasin P2O5 spreading rates ranged from 0 to 127 lb/receiving acre/year and averaged 85 lb/receiving ac/year (Figure 12; Table 4). Thirteen small subbasins (less than 750 acres) had no P2O5 in the subbasin.

Table 4. Summary statistics of yearly manure P2O5 mass per subbasin and manure P2O5 spreading rate per subbasin according to the WDNR's manure analysis. See section 2.4.2 for a description of the three spreading rates.

	Manure P2O5 mass (lb) per subbasin per year	Manure P2O5 spreading rate (lb P2O5/ac/year)		
		Spreadable acre rate	Receiving acre rate	SWAT rate
Average	70,438	43	85	107
Median	37,148	44	86	101
Min	0	0	0	0
Max	592,922	64	127	270

Figure 12. Map of total yearly phosphate (P2O5) mass (lb) applied per TMDL subbasin according to the WDNR manure analysis.

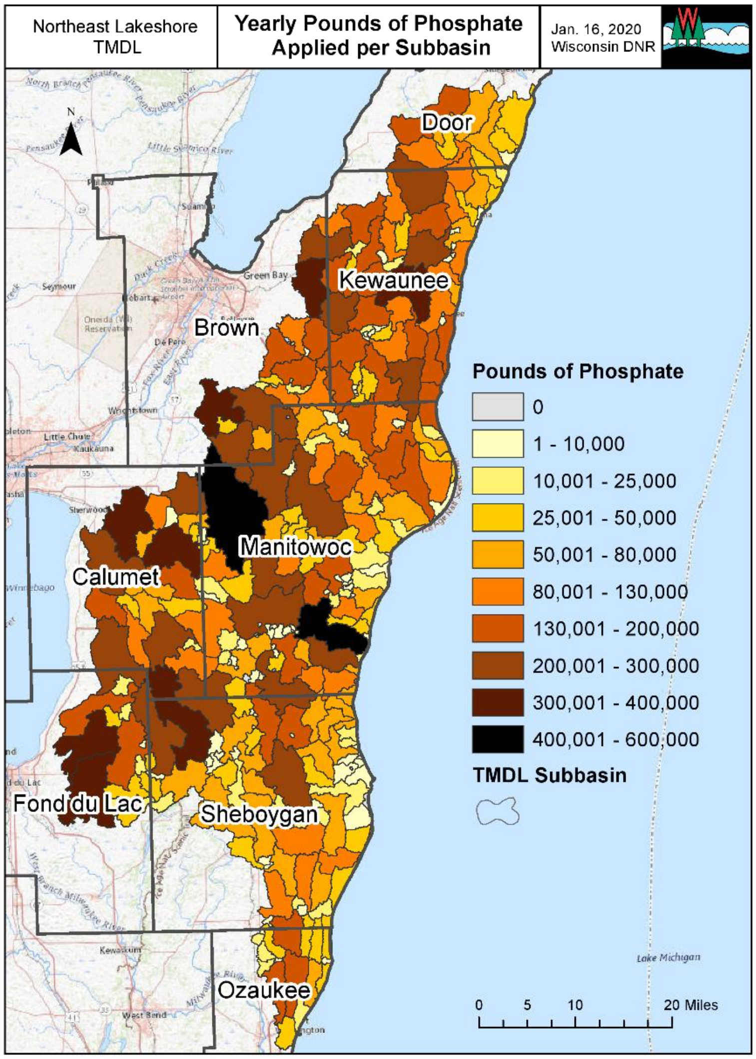
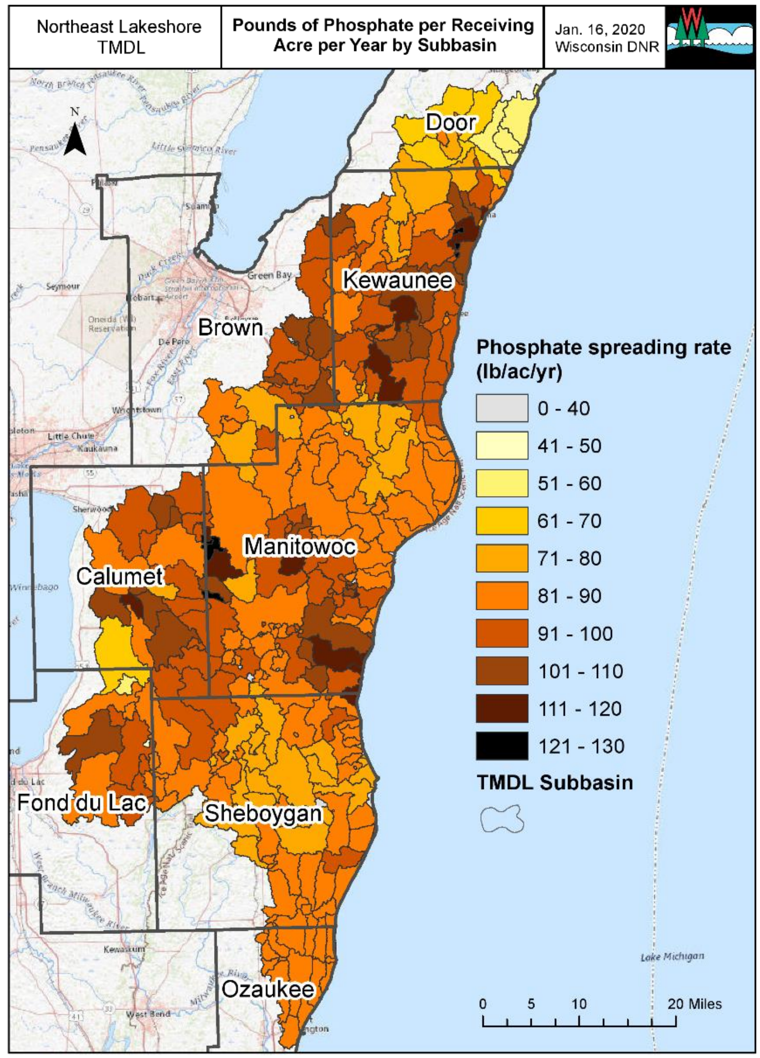


Figure 12. Map of phosphate (P2O5) spreading rate (lb/receiving acre/year) per subbasin according to the WDNR manure analysis. Rates reflect the assumption that 50% of the spreadable acres in a subbasin receive manure in a year.



4. Validation of WDNR analysis with CAFO reported values

4.1. Methods

This section outlines a comparison between CAFO results from the WDNR manure analysis and CAFO results reported in CAFO's Nutrient Management Plans and 2018 Annual Reports.

4.1.1. Comparison of WDNR CAFO results with CAFO reported values

While the main objective of the WDNR analysis was to estimate the mass of manure and associated P2O5 per subbasin per year, as shown in Section 3, the WDNR analysis also provided estimates of liquid manure and P2O5 amounts spread per CAFO facility. WDNR values of liquid manure and P2O5 produced per CAFO facility were compared with similar values reported in CAFO's Nutrient Management Plans and Annual Reports (Table 5). The comparisons are informative because they compare similar values that were calculated independently of one another. Therefore, comparison of WDNR manure and P2O5 CAFO estimates with CAFO reported manure and P2O5 provides a validation of the representativeness of the WDNR manure analysis method.

Table 5. Summary of the values calculated for individual CAFO facilities with the WDNR manure analysis and corresponding values reported in CAFO Nutrient Management Plans and Annual Reports. WDNR values and CAFO reported values in the same row were compared to provide insight into the representativeness of the WDNR manure analysis method.

CAFO value from WDNR manure analysis		**Value reported by CAFO**	
Value description	**Source**	**Value description**	**Source**
Gallons of liquid manure produced from cattle per CAFO facility per year	Value: WDNR analysis	Gallons of liquid manure spread per CAFO facility per year	Value: Annual Report (2018)
Gallons of liquid manure from cattle spread per ***spreadable*** acre per CAFO facility per year	Value: WDNR analysis Acres: Annual Report (2018)	Gallons of liquid manure per ***spreadable*** acre per CAFO facility per year	Value & Acres: Annual Report (2018)
Gallons of liquid manure from cattle spread per ***receiving*** acre per CAFO facility per year	Value: WDNR analysis Acres: Annual Report (2018)	Gallons of liquid manure per ***receiving*** acre per CAFO facility per year	Value & Acres: Annual Report (2018)
Pounds of P2O5 produced from cattle per CAFO facility per year	Value: WDNR analysis	Pounds of P2O5 (including P2O5 from liquid and solid sources, or received from offsite sources) spread per CAFO facility per year	Value: Mass Balance Report (2014 – 2018)
Pounds of P2O5 from cattle spread per ***spreadable*** acre per CAFO facility per year	Value: WDNR analysis Acres: Annual Report (2018)	Pounds of P2O5 (including P2O5 from liquid and solid sources, or received from offsite sources) per ***spreadable*** acre per CAFO facility per year	Value & Acres: Mass Balance Report (2014 – 2018)
Pounds of P2O5 from cattle spread per ***receiving*** acre per CAFO facility per year	Value: WDNR analysis Acres: Annual Report (2018)	Gallons of liquid manure (including P2O5 from liquid and solid sources, or received offsite) per ***receiving*** acre per CAFO facility per year	Value & Acres: Mass Balance Report (2014 – 2018)

4.1.2. Comparison of WDNR non-CAFO results with CAFO reported values

The WDNR's non-CAFO manure and P2O5 spreading rates were compared with similar values reported by CAFO facilities in their Mass Balance Reports and 2018 Annual Reports. This comparison verified that WDNR's non-CAFO results were in a realistic range. Table 6 summarizes the values that were compared.

Table 6. Summary of non-CAFO values calculated with the WDNR manure analysis and corresponding values gathered from CAFO Nutrient Management Plans and Annual Reports. WDNR values and CAFO reported values in the same row were compared to provide insight on the representativeness of the WNDR manure analysis method.

Non-CAFO value from WDNR manure analysis		Value reported by CAFO	
Value description	**Source**	**Value description**	**Source**
Gallons of liquid manure from cattle spread per ***spreadable*** acre per county	Value: WDNR analysis Acres: Wislcand2 dairy acres remaining after CAFO dairy acres were identified	Gallons of liquid manure per ***spreadable*** acre per CAFO facility per year	Value & Acres: Annual Report (2018)
Gallons of liquid manure from cattle spread per ***receiving*** acre per county	Value: WDNR analysis Acres: 50% of Wislcand2 dairy acres remaining after CAFO dairy acres were identified	Gallons of liquid manure per ***receiving*** acre per CAFO facility per year	Value & Acres: Annual Report (2018)
Pounds of P2O5 from cattle spread per ***spreadable*** acre per facility per year	Value: WDNR analysis Acres: Wislcand2 dairy acres remaining after CAFO dairy acres were identified	Pounds of P2O5 (including P2O5 from liquid and solid sources, or received from offsite sources) per ***spreadable*** acre per CAFO facility per year	Value & Acres: Mass Balance Report (2014 – 2018)
Pounds of P2O5 from cattle spread per ***receiving*** acre per county	Value: WDNR analysis Acres: 50% of Wislcand2 dairy acres remaining after CAFO dairy acres were identified	Gallons of liquid manure (including P2O5 from liquid and solid sources, or received from offsite sources) per ***receiving*** acre per CAFO facility per year	Value & Acres: Mass Balance Report (2014 – 2018)
Cattle per ***spreadable*** acre per county	Value: WDNR analysis Acres: Wislcand2 dairy acres remaining after CAFO dairy acres were identified	Cattle per ***spreadable*** acre per facility	Value & Acres: Annual Report (2018)
Cattle per ***receiving*** acre per county	Value: WDNR analysis Acres: 50% of Wislcand2 dairy acres remaining after CAFO dairy acres were identified	Cattle per ***receiving*** acre per facility	Value & Acres: Annual Report (2018)

4.1.3. Sources of CAFO reported values

4.1.3.1. Liquid Manure

Data about CAFO reported liquid manure was sourced from the 2018 Annual Reports.

Gallons of liquid manure spread in the 2018 crop year were gathered for all CAFOs with manure spreading fields in the NE Lakeshore TMDL counties, regardless if their production facility was within the NE Lakeshore TMDL area. So while there are 70 CAFOs with production facilities located within the TMDL study area, the annual reports for 106 CAFOs were used to inform the number of spreadable acres and the number of acres receiving manure. This acreage information was used to calculate unique 'CAFO reported' manure spreading rates for each facility.

4.1.3.2. P2O5 Mass

Data about CAFO reported P2O5 mass was sourced from the Nutrient Mass Balance Reports.

Nutrient Mass Balance Reports provide the yearly amount of P2O5 spread by a CAFO facility during a given number of years. The number of years reported varies by facility. Nutrient Mass Balance Reports collected for this analysis had a range of reported years between 2014 and 2024; however, only data from 2014 – 2018 was used because at the time the WDNR analysis was done, data from 2014 – 2018 represented the actual amounts of P2O5 applied (rather than estimated).

In SnapPlus, the yearly amount of applied P2O5 (reported in the Mass Balance Report) is typically calculated by operators or consultants entering records of spreading rate, acres applied, and nutrient content for all manure applications in a year. Yearly amounts of P2O5 reported in Mass Balance Reports represents P2O5 from both solid and liquid manure as well as P2O5 that was received from offsite sources. It is important to note that the yearly amounts of P2O5 reported in CAFO mass balance reports reflect the total plant *available* P2O5 and not the actual amount applied. The plant available P2O5 represents only 80% of the total P2O5 spread so the P2O5 amounts collected in the Mass Balance Reports were adjusted to represent 100% of the total P2O5 applied prior to comparing with the WDNR's P2O5 estimates.

While there are 70 CAFOs with production areas in the TMDL study area, Nutrient Mass Balance Reports were only available for 39 of these CAFOs. These 39 CAFOs encompass a range of CAFO sizes and locations, providing a representative sample of CAFOs in the NE Lakeshore TMDL area. Mass balance reports also provide information on the number of spreadable acres and the number of receiving acres for the years in the plan. Acres reported in the mass balance reports were used to calculate 'CAFO reported' P2O5 spreading rates for each facility.

4.2. Results

4.2.1. Comparison of WDNR CAFO results with CAFO reported values

While the main goal of the WDNR analysis was to estimate manure derived P2O5 applied per subbasin, comparison of CAFO reported values with the WDNR's CAFO results was useful for verifying the representativeness of the WDNR manure analysis. Table 7 summarizes results of the comparisons made between values from the WDNR manure method and CAFO reported values. Overall, WDNR's CAFO manure and associated P2O5 results were between 2% and 13% different than the corresponding value reported in the CAFO Nutrient Management Plan (Table 7). This indicates that the WDNR manure analysis is providing reasonable estimates of the total yearly P2O5 mass applied per subbasin.

Table 7. Summary of the comparison between CAFO facility values calculated with the WDNR manure analysis to similar, but independent, values reported directly by CAFOs in their Mass Balance Reports or Annual Reports.

Value	Method	Facilities in analysis	Facility Average	Percent difference in average	Facility Median	Percent difference in median	Facility Max	Facility Min	Countywide average for non-CAFOs (n=8)
Gallons of liquid manure produced per facility per year	WDNR analysis	106	20,844,722	10%	14,207,050	10%	97,156,156	4,643,530	-
	Annual Report	106	23,106,239		15,625,001		121,028,602	1,834,614	
Gallons of liquid manure per spreadable acre per year per facility	WDNR analysis	106	6,148	10%	5,908	5%	11,578	2,414	5,803
	Annual Report	106	6,787		6,387		18,970	944	
Gallons of liquid manure per receiving acre per year per facility	WDNR analysis	106	12,837	7%	11,657	7%	43,942	4,248	11,606*
	Annual Report	106	13,780		12,484		43,239	3,434	
Lb of P2O5 per facility per year	WDNR analysis	39	157,045	2%	107,436	6%	543,897	42,809	-
	Mass Balance Report	39	159,467		101,102		670,043	33,038	
Lb of P2O5 per spreadable acre per facility per year	WDNR analysis	39	48	8%	46	8%	87	25	44
	Mass Balance Report	39	52		50		103	20	
Lb of P2O5 per receiving acre per facility per year	WDNR analysis	39	105	13%	90	2%	257	51	88*
	Mass Balance Report	39	92		88		154	31	
Cattle per spreadable acre per year	WDNR analysis / Annual Report	106	0.8	-	0.7	-	6.4	0.2	0.8
Cattle per receiving acre per year	WDNR analysis / Annual Report	106	1.9	-	1.4	-	25	0.5	1.6*

*Non-CAFO rates assume that 50% of the spreadable acres are receiving manure in a given year.

4.2.1.1. Liquid manure comparisons

In general, the WDNR analysis underestimated the yearly volume of liquid manure produced at a CAFO facility. Both the average and median yearly manure production volumes calculated by the WDNR were lower than the average and median volumes reported in the CAFO's 2018 Annual Reports (Table 7). WDNR average and median yearly manure production volumes were approximately 10% different than the average and median yearly manure production volumes reported by CAFOs in their 2018 Annual Report (Table 7). The WDNR's underestimated values are most likely due to the additional dilution sources that are accounted for in the CAFO's reported volume, but not in the manure production rates used by the WDNR. The manure production rates used by the WDNR incorporated a dilution factor of 1.8, which is only meant to capture dilution from urine and some parlor wash water (Genskow and Larson, 2016, page 63). Similar patterns were also observed when adjusting yearly manure volumes into manure spreading rates (Table 7). The WDNR's average non-CAFO spreading rate (gal/spreadable acre/year) for all NE Lakeshore TMDL counties was about 1,000 gallons less than the average spreading rate (gal/spreadable acre/year) reported by CAFO facilities (Table 7).

Figure 13, Figure 14, and Figure 15 are supplementary to Table 7 and provide histograms to visualize the comparison of yearly liquid manure volumes and spreading rates calculated with the WDNR method to yearly liquid manure volumes and spreading rates gathered from CAFO's in their 2018 Annual Report. Overall, histograms show very similar distributions between the two methods. Additionally, Table 8. provides the yearly non-CAFO liquid manure spreading rates for each county in the NE Lakeshore TMDL area.

Figure 13. Comparison of the gallons of liquid manure produced per year per facility according to the WNDR analysis (top, dark blue) compared to the gallons of liquid manure produced per year per facility according to CAFO's 2018 Annual Reports (bottom, light blue). n = 106.

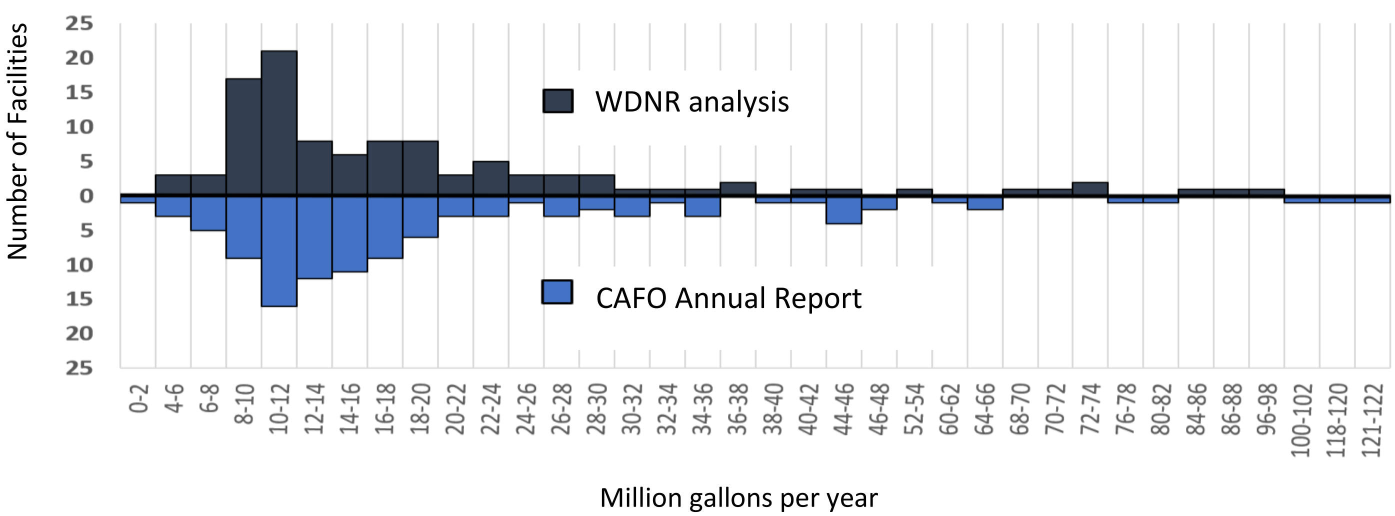


Figure 14. Comparison of the gallons of liquid manure per *spreadable* acre per facility per year according to the WNDR analysis (top, dark blue) compared to the gallons of liquid manure per *spreadable* acre per facility per year according to CAFO's 2018 Annual Reports (bottom, light blue). n = 106.

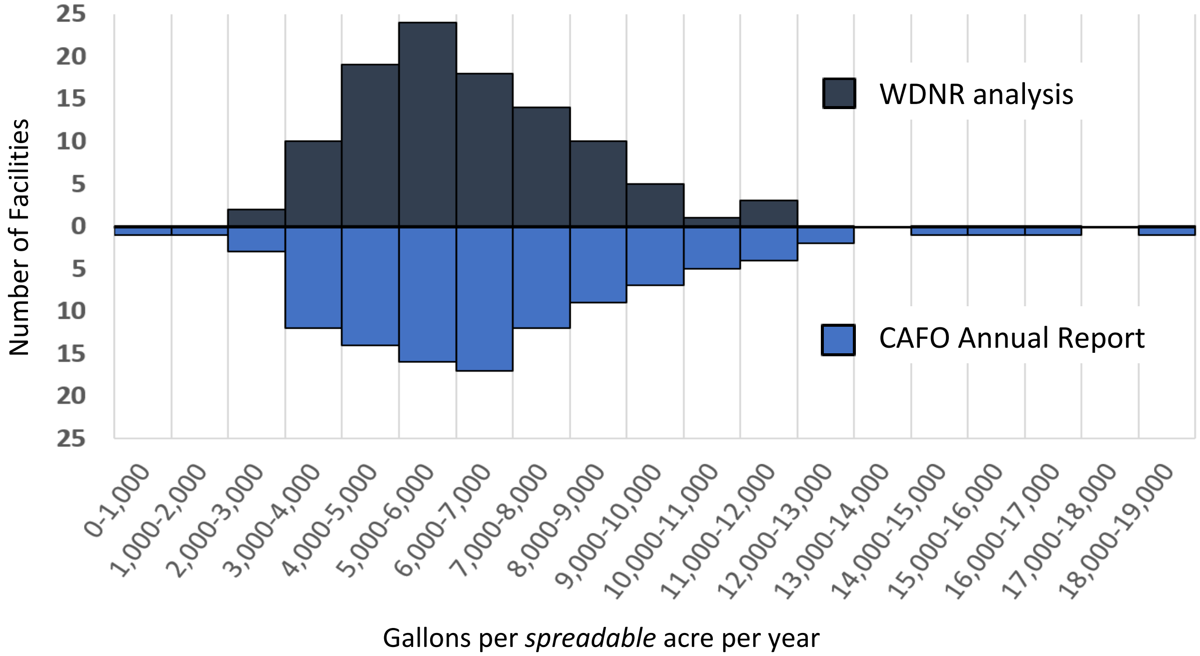


Figure 15. Comparison of the gallons of liquid manure per *receiving* acre per facility per year according to the WNDR analysis (top, dark blue) compared to the gallons of liquid manure per *receiving* acre per facility per year according to CAFO's 2018 Annual Reports (bottom, light blue). For both methods, receiving acres were calculated based on a unique receive acre percentage provided in each CAFO's 2018 Annual Report. n = 106.

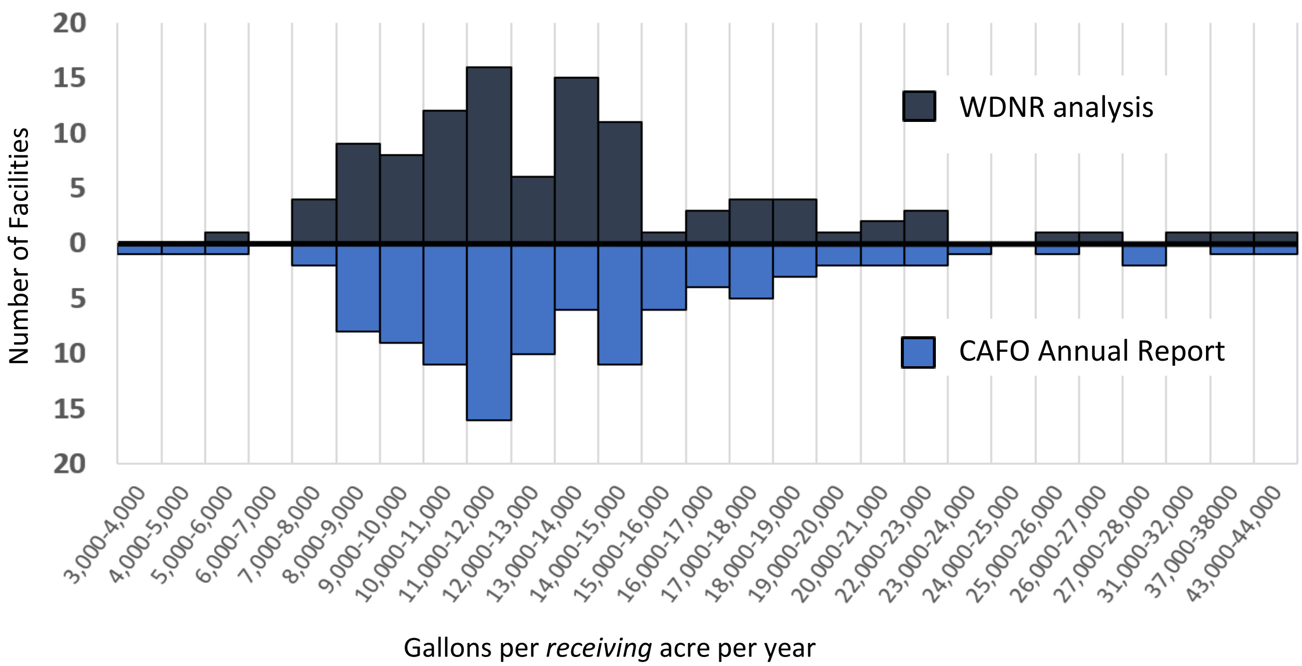


Table 8. Countywide non-CAFO manure spreading rates (gal per acre per year) from the WDNR analysis method.

County	Gal. of manure per *spreadable* acre per year	Gal. of manure per *receiving* acre per year [1]
BROWN	7,224	14,448
CALUMET	8,108	16,216
DOOR	2,541	5,082
FOND DU LAC	6,075	12,150
KEWAUNEE	5,943	11,886
MANITOWOC	5,751	11,502
SHEBOYGAN	5,357	10,714
OZAUKEE	5,422	10,844

(1) Rates per receiving acre assume that 50% of the spreadable acres are receiving manure in a given year

4.2.1.2.P2O5 comparisons

The average yearly P2O5 mass per facility calculated with the WDNR method was slightly less than the average P2O5 mass reported in CAFO Nutrient Management Plans. Averages were less than 2% different (Table 7). The median yearly P2O5 mass per facility calculated by the WDNR method was slightly greater than the median P2O5 mass reported in the CAFO Nutrient Management Plans, medians were approximately 6% different (Table 7). The average non-CAFO spreading rate (gal/spreadable acre/year) from the WDNR analysis for all counties in the NE Lakeshore TMDL was 8 lb per acre less than the average rate reported by CAFOs (Table 7).

Figure 16, Figure 17, and Figure 18 are supplementary to Table 7 and provide histograms to visualize the comparison of P2O5 mass and spreading rates calculated with the WDNR method to yearly P2O5 mass and spreading rates gathered from CAFO's Mass Balance Reports between 2014 and 2018. Overall, histograms show very similar distributions between the two methods. Additionally, Table 9 provides the yearly non-CAFO P2O5 spreading rates for each county in the NE Lakeshore TMDL area.

Figure 16. Comparison of the pounds of phosphate (P2O5) produced per year per facility according to the WNDR analysis (top, dark blue) compared to pounds of P2O5 produced per year per facility according to CAFO mass balance reports (2014 – 2018). n = 39.

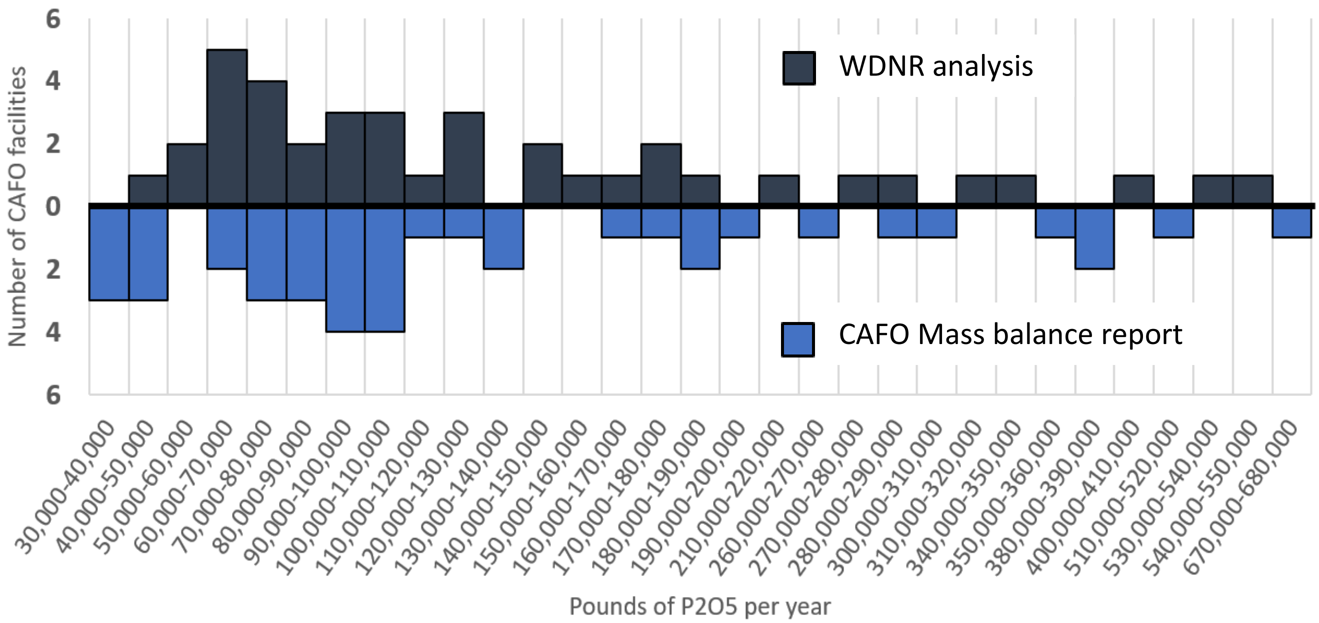


Figure 17. Comparison of the spreading rate of phosphate (P2O5) per *spreadable* acre per year per facility according to the WNDR analysis (top, dark blue) compared to the spreading rate of P2O5 per *spreadable* acre per year per facility according to CAFO mass balance reports (2014 – 2018). n = 39.

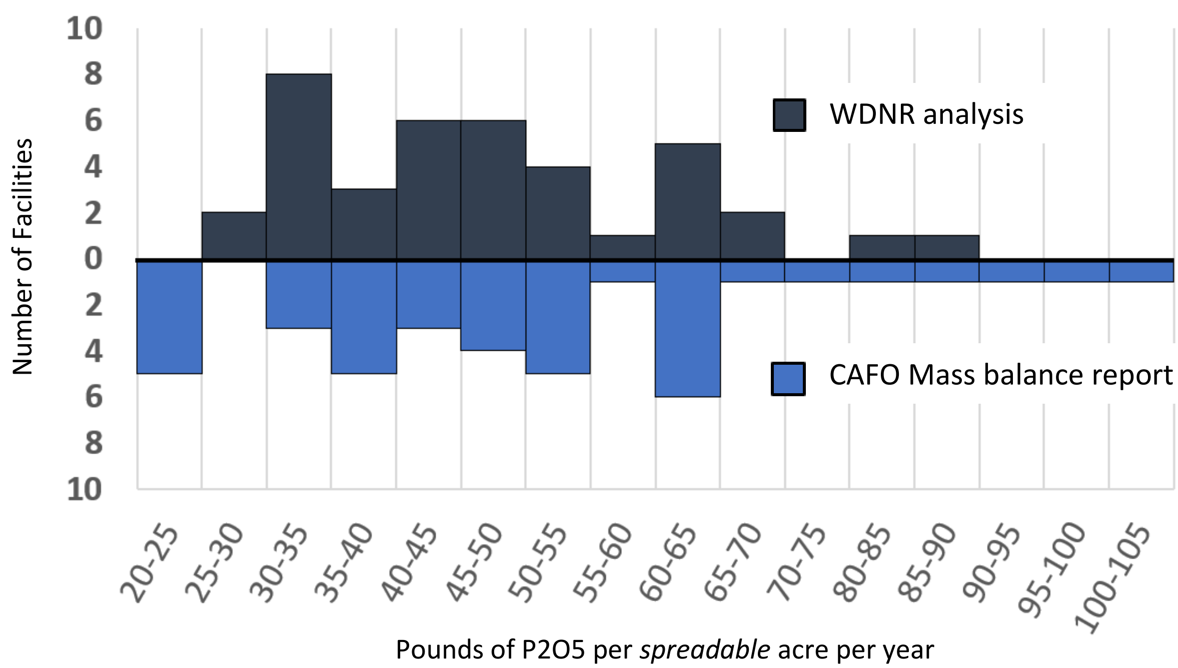


Figure 18. Comparison of the spreading rate of phosphate (P2O5) per *receiving* acre per year per facility according to the WNDR analysis (top, dark blue) compared to the spreading rate of P2O5 per receiving acre per year per facility according to CAFO mass balance reports (2014 – 2018). n = 39.

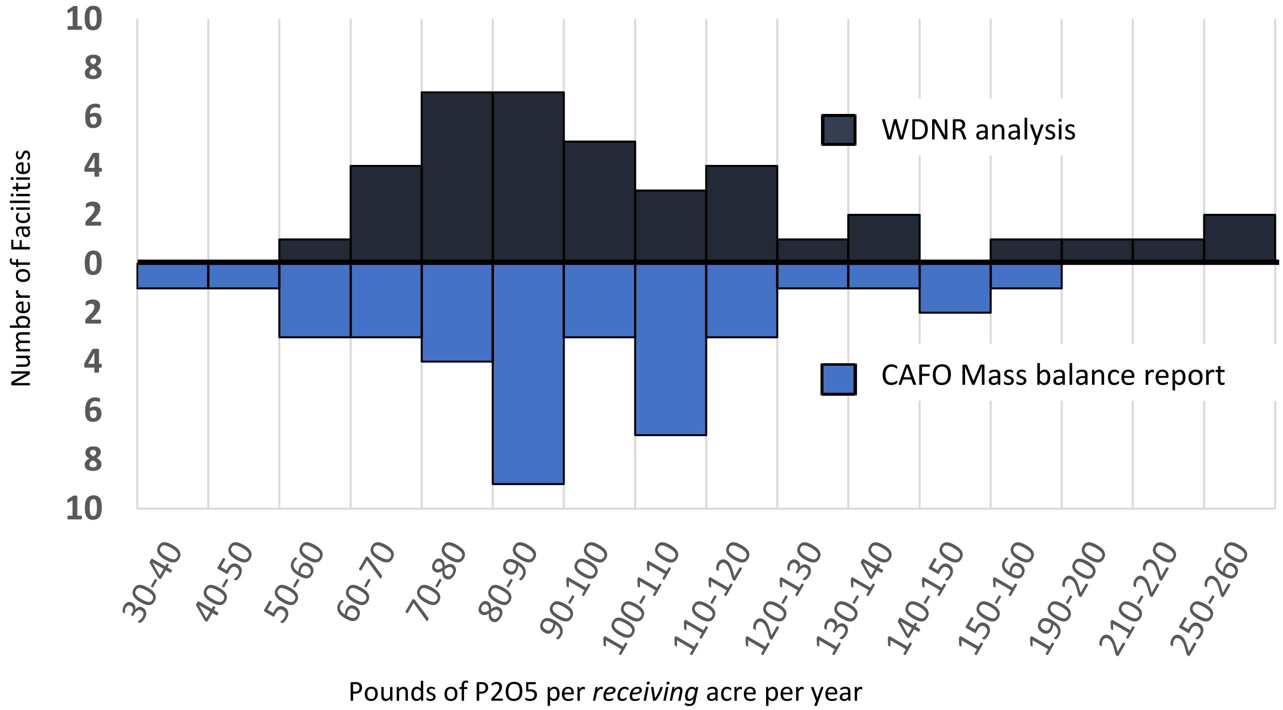


Table 9. Countywide non-CAFO P2O5 spreading rates (lb per acre per year) from the WDNR analysis method.

County	lb of P2O5 per spreadable acre per yr	lb of P2O5 per receiving acre per yr (1)
BROWN	54	108
CALUMET	61	102
DOOR	19	38
FOND DU LAC	46	92
KEWAUNEE	45	90
MANITOWOC	43	86
SHEBOYGAN	40	80
OZAUKEE	41	81

(1) Rates assume that 50% of the spreadable acres are receiving manure in a given year

4.2.1.3. Cattle Densities at CAFOs and Non-CAFOs

According to the 2018 Annual Reports submitted by CAFO facilities, CAFO cattle densities averaged 0.8 cattle per receiving acre and 1.9 cattle per spreadable acre (Table 7). Similarly, countywide non-CAFO cattle densities range 0.8 cattle per spreadable acre and 1.6 cattle per receiving acre (Table 7). Overall, the non-CAFO countywide cattle densities were similar to CAFOs, which indicates that the WDNR method resulted in a realistic ratio of cattle to acres for non-CAFO facilities.

Figure 19 and Figure 20 are supplementary to Table 7 and provide histograms to visualize the cattle densities of CAFO facilities. Additionally, Table **10** provides the countywide non-CAFO cattle densities for each county in the NE Lakeshore TMDL area.

Figure 19. CAFO cattle per *spreadable* acre per facility. Cattle numbers and spreadable acres were gathered from CAFO's 2018 Annual Report. Cattle numbers have not been adjusted to reflect animal units. n = 106.

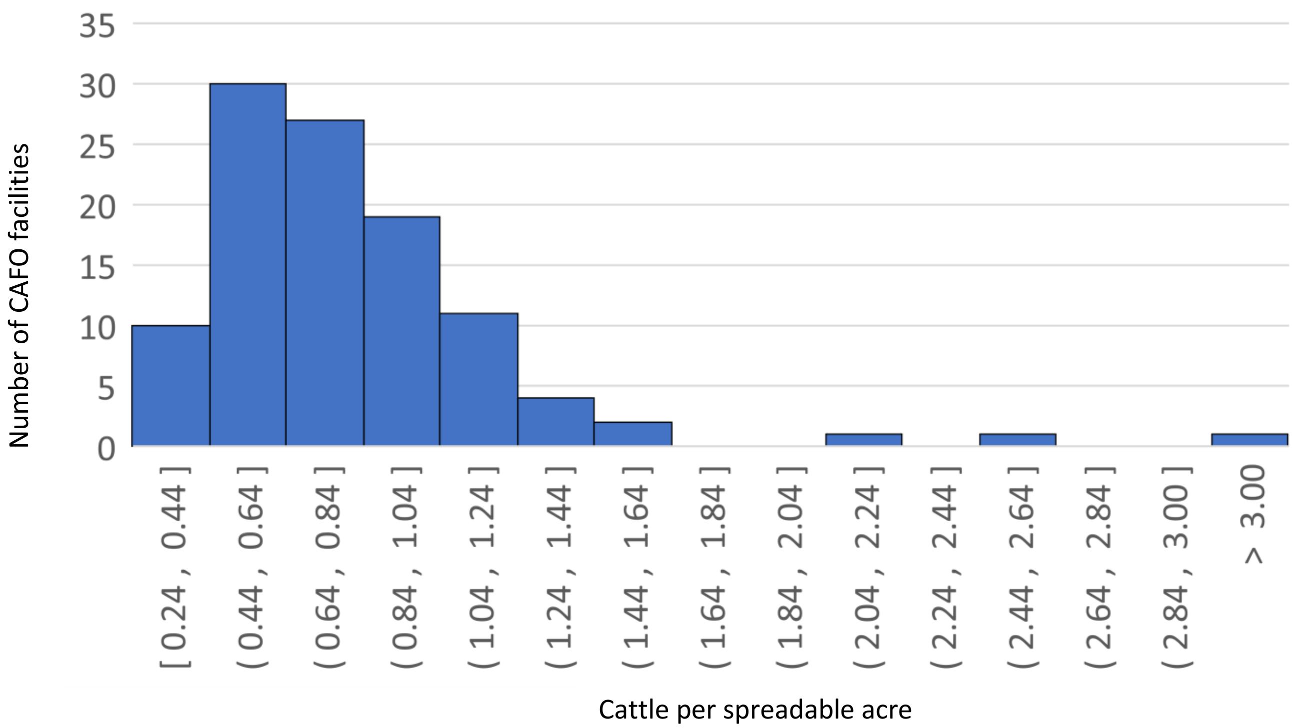


Figure 20. CAFO cattle per *receiving* acre per facility. Cattle numbers and receiving acres were gathered from CAFO's 2018 Annual Report. Cattle numbers have not been adjusted to reflect animal units. n = 106.

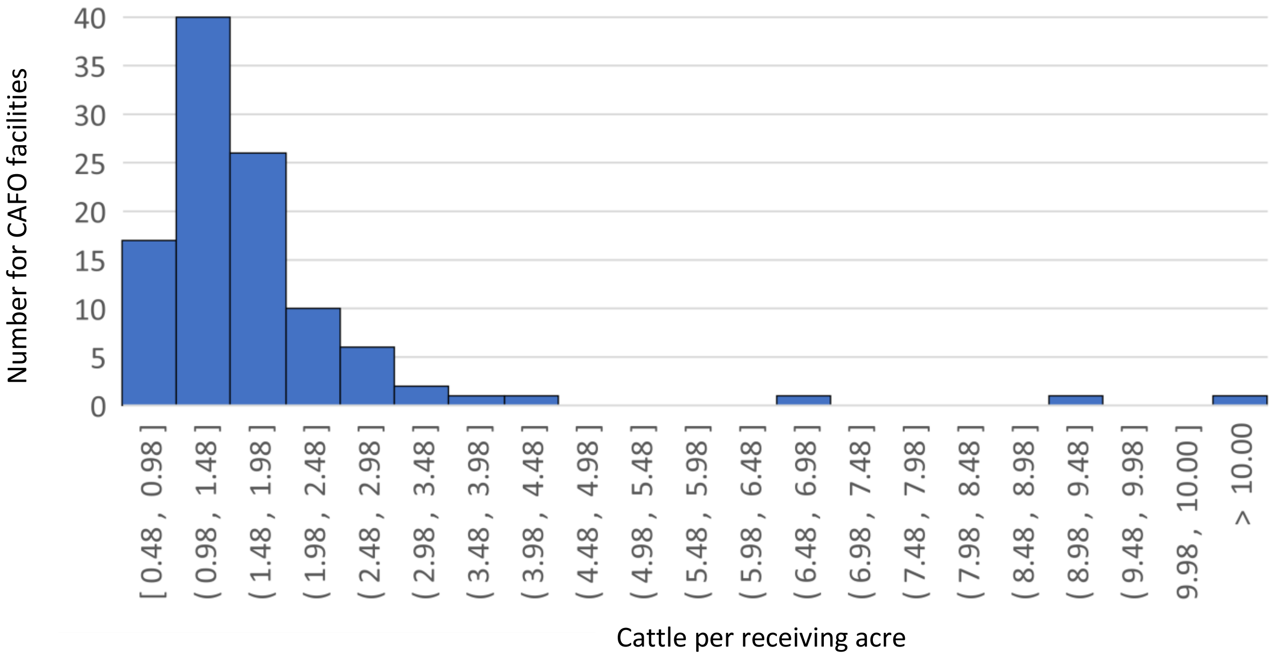


Table 10. Countywide non-CAFO cattle densities calculated from the WDNR analysis method.

County	Non-CAFO cattle per acre spreadable acre	Non-CAFO cattle per receiving acre [(1)]
BROWN	1.1	2.2
CALUMET	1.1	2.2
DOOR	0.3	0.6
FOND DU LAC	0.8	1.6
KEWAUNEE	0.8	1.6
MANITOWOC	0.8	1.6
SHEBOYGAN	0.8	1.6
OZAUKEE	0.8	1.6

[(1)] Rates assume that 50% of the spreadable acres are truly receiving manure in a given year

5. P2O5 Spreading Rates for the NE Lakeshore TMDL SWAT Model

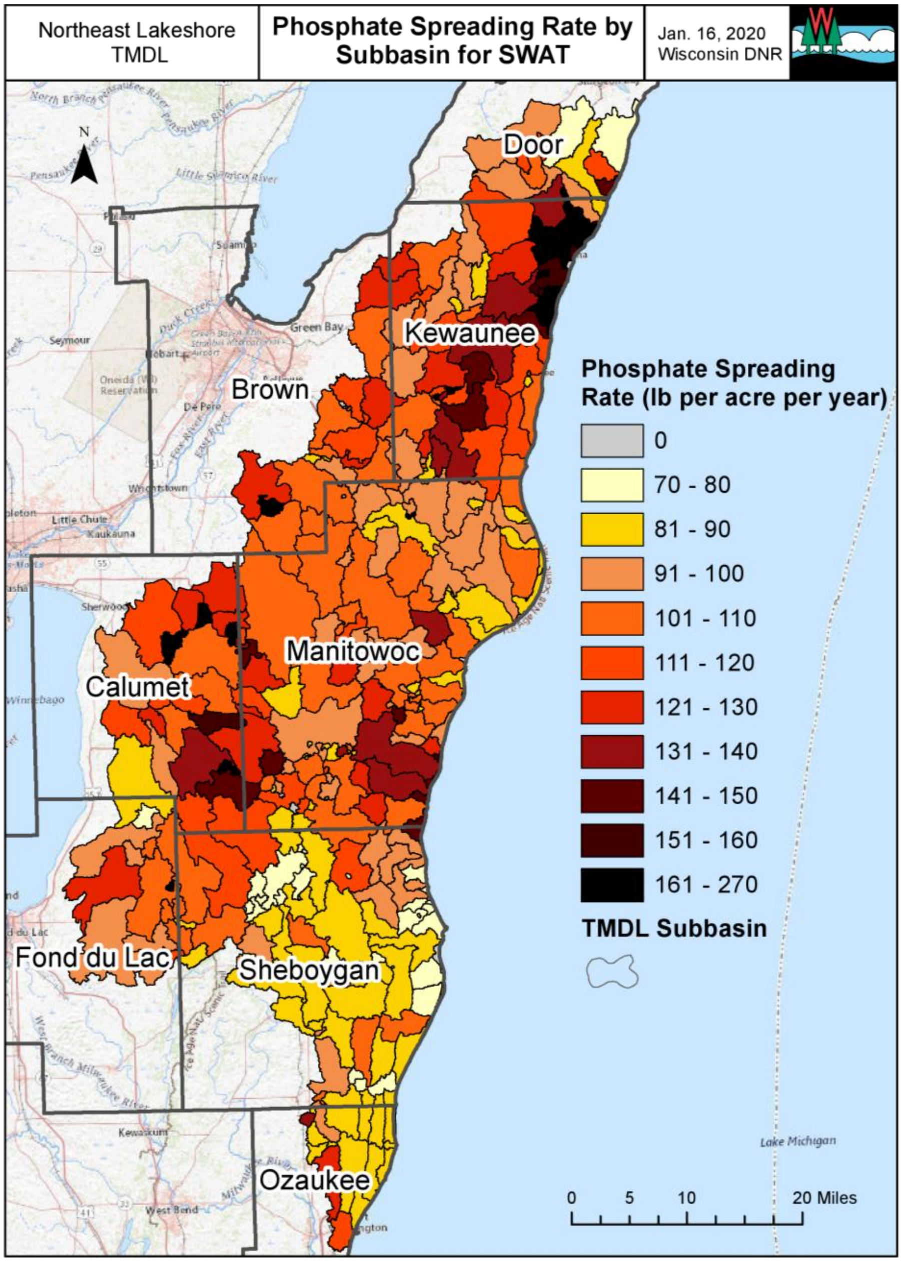
5.1 Methods

Results of the WDNR analysis provide estimates of P2O5 from manure sources by SWAT model subbasin (Section 3; Figure 12). These estimates will be used in the SWAT model and applied to Wiscland 2 dairy fields during the non-alfalfa and non-winter wheat years of the modeled dairy rotations. Due to differences in receiving acres (as described in section 2.4.2), the SWAT yearly manure and P2O5 spreading rates are slightly higher than the ‘spreadable rates’ and ‘available rates’ in Section 3; however, all rates result in the same amount of yearly P2O5 per subbasin.

5.2 Final input for the SWAT model

The subbasin P2O5 spreading rates for SWAT in Figure 21 represent the final rates proposed for input to the NE Lakeshore TMDL SWAT model. However, the SWAT P2O5 rates in Figure 21 represent annual rates and will be divided by two to account for a spring and fall application in SWAT. Additionally, P2O5 rates will be converted into phosphorus rates (rather than phosphate as P2O5) using a stochiometric conversion factor of 0.437. In the majority of subbasins, SWAT P2O5 yearly spreading rates ranged from 70 to 150 lb of P2O5 per acre per year, with a NEL basin average of 107 lb P2O5 per acre per year (Figure 21). Four percent of subbasins had a SWAT P2O5 spreading rate between 161 to 270 lb per year. Thirteen small subbasins (< 750 ac) had a P2O5 spreading rate of 0, meaning there was no Wiscland dairy acres in the subbasin.

Figure 21. Average annual phosphate (as P2O5) spreading rates (lb P2O5 per receiving acre per year) by TMDL subbasin for the NE Lakeshore TMDL SWAT model. Annual rates will be reduced by 50% in SWAT modeling to account for a spring and fall application.



5.3 Validation of SWAT P2O5 spreading rates

To check the SWAT P2O5 spreading rates, the WDNR calculated SWAT manure spreading rates using the same approach as the SWAT P2O5 spreading rates. This involved using 50% of the Wiscland dairy acres in a subbasin but excludes non-dairy spreading areas reported by CAFOs (equation 3). Then, the SWAT subbasin manure spreading rates were compared with the average HUC12 watershed manure spreading rates reported by County Land and Water Conservation Departments (LWCDs) in an agricultural questionnaire survey conducted for the development of the NE Lakeshore TMDL. The average SWAT county manure spreading rates calculated by the WDNR encompassed a similar range as those reported by the county LWCDs (Figure 22). The county average rates estimated for SWAT were 12% different than those reported by the county LWCDs, on average. The county LWCDs reported average HUC12 manure spreading rates ranging from 10,000 to 17,000 gal/ac/day (Figure 23), while the majority of SWAT subbasin spreading rates ranged between 9,000 to 20,000 gal/ac/day (Figure 24). Three percent of subbasins had WDNR spreading rates between 20,000 and 25,000. Overall, the average SWAT manure spreading rates calculated by the WDNR showed consistent trends with values reported in the county agricultural surveys. Note that counties with higher SWAT rates than reported by the county LWCDs can be attributed to the reality that not all manure is captured and applied to dairy fields.

Figure 22. Average HUC12 manure spreading rates reported from the county survey compared with average subbasin manure spreading rates calculated from the WDNR manure analysis. County average manure spreading rates from the WDNR analysis were calculated by area weighting spreading rates by subbasin. Error bars represent plus or minus one standard deviation. SWAT manure analysis rates assume manure is spread on 50% of the Wiscland 2 dairy acres.

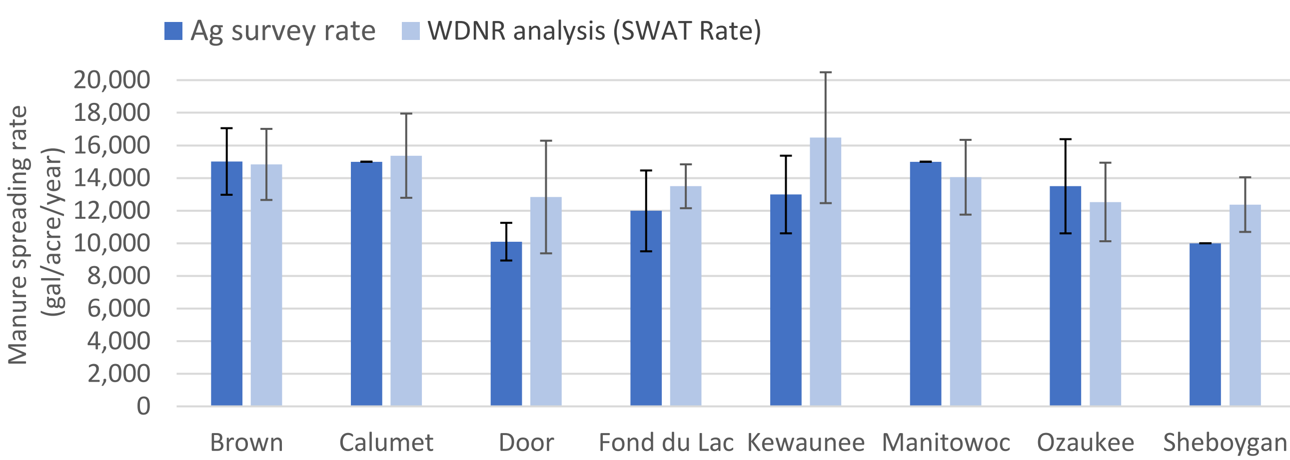


Figure 23. *Data source: County Agriculture Surveys.* Average liquid manure spreading rates (gallons per acre per year) by HUC12.

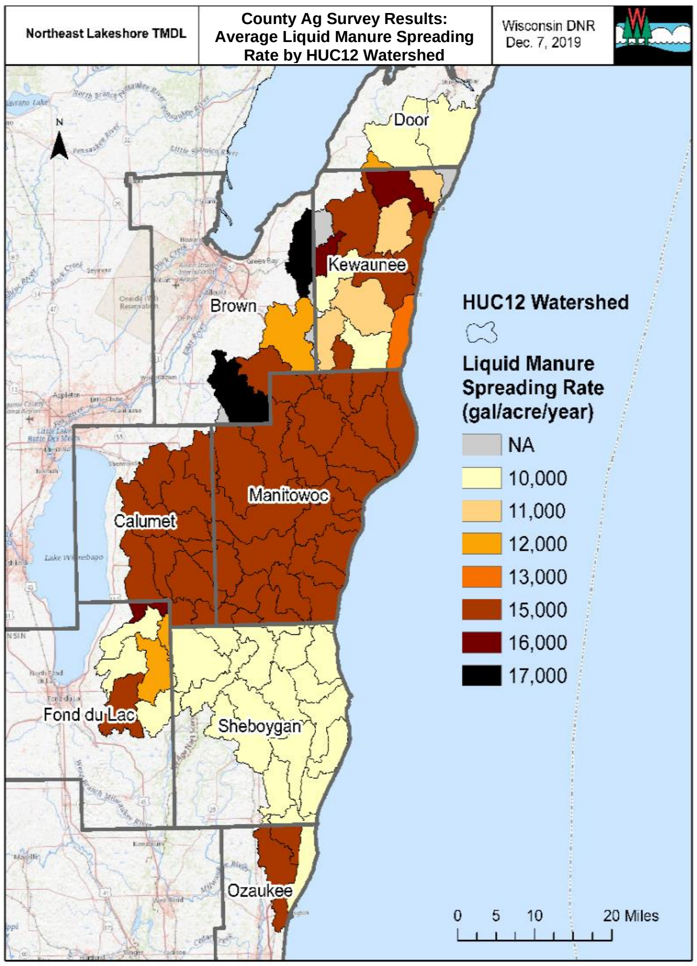
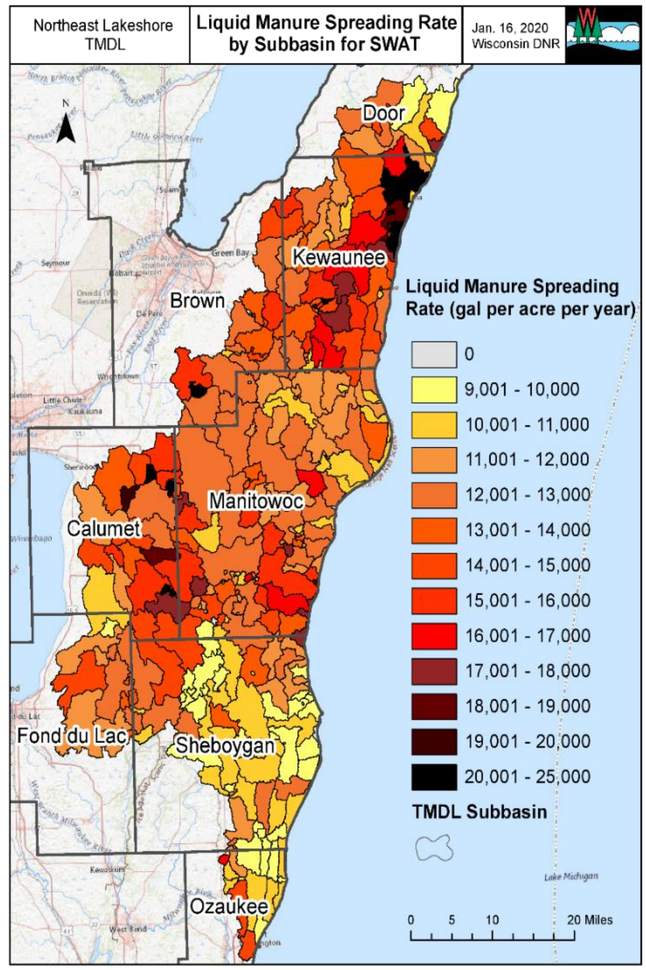


Figure 24. *Data source: WDNR analysis.* Average SWAT liquid manure spreading rates (gallons per acre per year) by TMDL subbasin.



6. References

Genskow, K.D. and Larson, R.A (eds.). 2016. Considerations for the Use of Manure Irrigation Practices: Report from the Wisconsin Manure Irrigation Workgroup. University of Wisconsin-Extension and UW-Madison College of Agricultural and Life Sciences, Environmental Resources Center. Publication Number ERC 001-16. https://fyi.extension.wisc.edu/manureirrigation/files/2017/04/Manure-Irrigation-Workgroup-Report-2016.pdf

Laboski, C.A.M and Peters, J.P. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. Table 9.2, page 75, of the UW extension document A8909. 2012 https://cdn.shopify.com/s/files/1/0145/8808/4272/files/A2809.pdf

Midwest Plan Service (MWPS). Publication number 18-1 "Manure Characteristics", Section 1. 2000. Published by Iowa State University.

Note: *MWPS Liquid manure rates can be viewed on the NRCS Wisconsin Conservation Planning Technical Note, 2016. Page 10*.
https://datcp.wi.gov/Documents/NM590TechNoteApp23.pdf

Natational Agricultural Static Service (NASS) 2017 Cattle Census, Quick Stats Tool. https://quickstats.nass.usda.gov/?source_desc=CENSUS

Natation Agricultural Static Service (NASS). General Explanation and Census of Agriculture Report Form (Appendix B). 2019. Page 39. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usappxb.pdf

WDNR and The CADMUS Group, LLC (2020). NE Lakeshore TMDL: Agriculture Practice Summary. https://dnr.wisconsin.gov/sites/default/files/topic/TMDLs/NEL_ag_survey_summary.pdf

Wiscland 2 Land Cover User Guide, 2016. Wisconsin Department of Natural Resources, University of Wisconsin-Madison, Wisconsin State Cartographer's Office. https://data-wi-dnr.opendata.arcgis.com/datasets/b6cff8bd00304b73bb1d32f7678ecf34