Evaluation of Manure Storage Capital Projects in the Yahara River Watershed

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Table of Contents

Executive Summary

As of 2012, there were more than 143,000 animal units in Dane County, with approximately 79,000 located on 291 operations. The greatest density of these animals, 80% or 63,000 animal units, reside in the Upper Yahara sub-watersheds located within Dane County. The high animal density in the Upper Yahara sub-watersheds leads to manure phosphorus applications which are greater than the phosphorus removed through crop uptake, Table ES.1, leading to increased phosphorus concentrations in soils. Unfortunately, this increase in soil phosphorus concentration leads to increased edge-of-field phosphorus losses in runoff events. Therefore, to reduce losses, the amount of phosphorus applied should be balanced with phosphorus crop uptake to avoid soil phosphorus buildup. In fields where phosphorus buildup has already occurred, phosphorus applications must be less than phosphorus crop uptake to reduce soil phosphorus concentrations.

Table Es.1: Ratio of manure phosphorus applied to phosphorus uptake by crops

Region	Ratio of phosphorus manure applied to phosphorus crop uptake	
	2012	2013
Dane County	0.94	0.66
Yahara River Watershed	1.04	0.74
Upper Yahara sub-watersheds (within Dane Co.)	1.95	1.35

*This analysis (1) excludes synthetic phosphorus fertilizers, and (2) assumes no movement of manure from or into each region.

One way to reduce phosphorus transport to surface waters is to reduce the amount of manure phosphorus applied in the winter, as application during frozen conditions can lead to increased phosphorus loading. Current manure production in the Upper Yahara sub-watershed study area was calculated to be 430 million gallons per year. In the study area, there are 80 manure storages with an approximate combined capacity of 162 million gallons, or 38% of the 430 million gallons produced annually. However, as manure storage is typically emptied every six months, the six-month capacity is closer to 76% of the manure production. This indicates that a minimum of 24% (or 106 million gallons per year) of manure in the study area is being applied throughout the year. Of the facilities in the study area, nearly 39% have existing manure storages. This indicates that approximately 16,700 animal units in the study area are located on a farm with no storage capacity. As farm size increases, the percentage of facilities that have existing manure storage increases. However, aside from the permitted facilities, there may not be six months of storage on these facilities, which could result in winter spreading. The largest number of animal units without storage are on facilities with 100-250 animal units, although there are also a number of facilities from 250-1,000 animals that do not have storage, Table ES.2.

Table ES.2: Manure storage by facility size in the Upper Yahara study area

Farm Size	Animal Units	Storage Capacity (Million Gallons)	Animal Units Located on Facilities with Storage	Animal Units Located on Facilities with Storage (%)
0-100	3,494	3	334	10
101-250	15,325	15	5,376	35
251-1,000	23,692	55	20,139	85
1,000+	20,599	89	20,599	100

An additional 53 million gallons of storage capacity would be needed at a minimum to avoid all winter manure applications. An evaluation of manure storage with maximum capital costs of $5 million highlights two northern regions in the eastern and western portion of the Upper Yahara sub-watersheds as the target areas for installation, Figure ES.1. The optimization targets small farms lacking manure storages in areas with sensitive fields. Building additional storage increases annual hauling costs for all of the scenarios investigated, but would reduce the year round application of un-stored manure (a portion of which is spread in the winter).

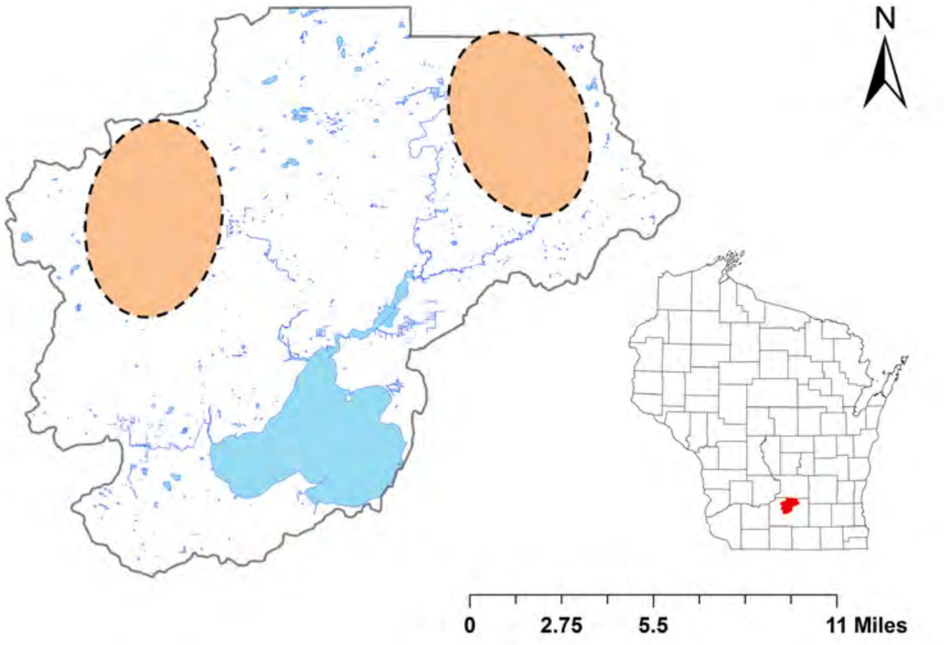


Figure ES.1: Manure storage optimization target manure storage locations (ovals represent target locations)

Contributing $5 million in capital costs to manure storage construction results in the installation of five manure storages during the optimization process, increasing capacity by 19 million gallons, or 36% of the un-stored manure produced in six months in the study area. Additional storage investment of $10 million further increases the manure storage capacity by constructing 10 manure storages in the study area, adding 38 million gallons, or 72%, of the un-stored manure produced in the study area. Examining a 20-year horizon, a 2% increase in manure production is expected from 430 to 439 million gallons per year, with a 15% decrease in cropland, from 60,000 acres to 51,000 acres, in the study area and a

2% increase in crop yield. This would require additional storage capacity of 4.5 million gallons but would also increase manure phosphorus application rates in the study area mainly due to the projected reduction in cropland.

Using Snap Plus, the estimated reduction in P Index loading ranges from 4,100 (low-erosion scenario) to 18,200 (high-erosion scenario) pounds per year with the installation of 19 million gallons of manure storage capacity at an estimated cost of $5 million. This results in an annual reduction of phosphorus transported to surface water of 0.22 to 0.96 pounds per thousand gallons of manure storage capacity installed. This indicates a capital cost of phosphorus reduction to the county of $18-$81 per pound of phosphorus reduced annually and an increase in hauling costs to producers of $93-$415 per pound of phosphorus transported to surface waters annually. However, it should be noted that the majority of the fields under the high-erosion scenario had calculated soil loss rates that greatly exceeded the Natural Resource Conservation Services tolerable soil loss rate (T). As many of the producers in the study area are participating in conservation efforts it is unlikely that the majority of the fields are managed with little consideration for soil loss as represented in the high-erosion scenario.

When examining the impact to phosphorus field loss, it is clear that introducing storages will initially reduce winter spreading, which will in turn reduce phosphorus losses. However, if the over application of manure phosphorus is not reduced then the gains made initially will be lost in 16-75 years due to an increase in soil phosphorus. Therefore, to maintain benefits manure phosphorus applications need to be reduced. If a portion of the manure phosphorus were removed from the watershed so that manure phosphorus applications were less than crop removal, runoff losses would gradually decline. In addition, as erosion is reduced due to conservation practices, losses from surface applications in the winter will make up a greater percentage of the remaining losses, increasing the importance of a reduction in winter manure spreading.

Exporting manure phosphorus from the study area (this study did not take into account any current exports) to redistribute in other locations that are phosphorus deficient is not typically economically feasible without densification. Therefore, further investigation into manure densification technologies for redistribution to reduce the volume and hauling costs associated with transport may be beneficial.

Outcomes by Objective

a. Assessment and quantification of the total amount of manure produced and total nutrients applied in the Yahara Watershed and how increasing storage capacity can impact water quality; include both current and future projections for total manure and facility locations [see objective b for future projections and objective c for facility locations];

   Outcome: Animal units in the Yahara Watershed total 79,303, Table ES.3, a majority of which (63,110 animal units) are located in the Upper Yahara study area, Table ES.4 & Figure ES.2. This results in an annual production of manure in the Yahara Watershed of 540 million gallons of manure containing 2.2 million pounds of phosphorus annually. In the Upper Yahara Watershed study area livestock produce a calculated 430 million gallons of manure per year containing 1.8 million pounds of phosphorus.

Table ES.3: Animal numbers in the Yahara Watershed

Animal Type	Operations	CAFOs	Animal Units	Phosphorus Produced (pounds/year)
Beef	90	1	11,155	400,600
Horses	2	-	115	600
Sheep	4	-	147	3,800
Hogs	9	-	1,383	17,900
Dairy	186	6	66,090	1,825,300
Total	291	7	79,303	2,248,200

Table ES.4: Animal numbers in the Upper Yahara Watershed

Animal Type	Operations	CAFOs	Animal Units	Phosphorus Produced (pounds/year)
Beef	54	1	7,793	279,900
Horses	1	-	61	300
Hogs	5	-	580	7,500
Dairy	148	5	54,342	1,500,800
Total	208	6	63,110	1,788,500

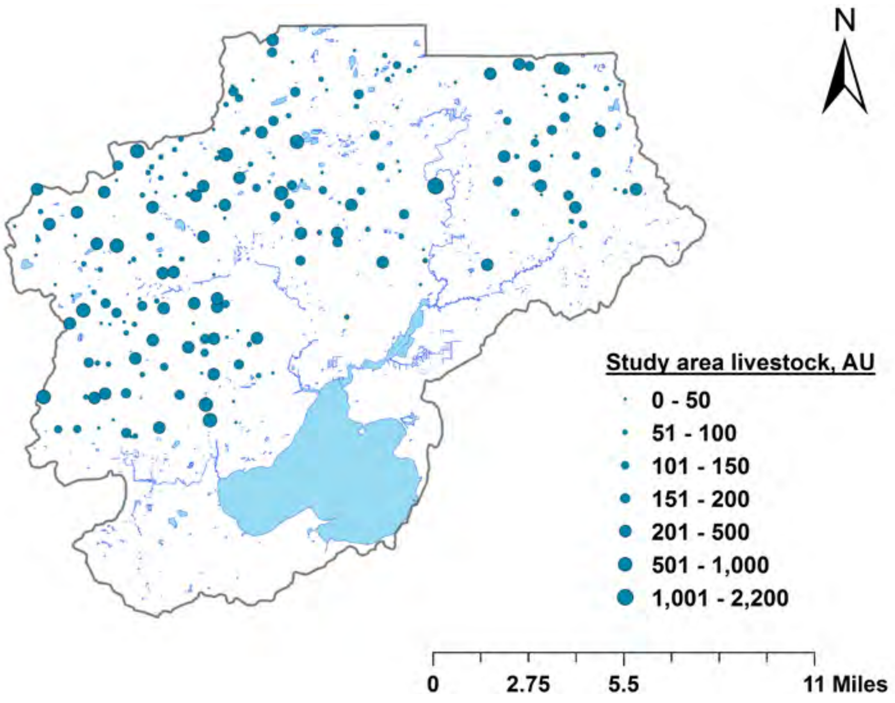


Figure ES.2: Livestock density in the Upper Yahara Sub-Watersheds

Using Snap Plus the estimated reduction in P Index loading ranges from 4,100 (low-erosion scenario) to 18,200 (high-erosion scenario) pounds per year with the installation of 19 million gallons of manure storage capacity, at an estimated cost of $5 million. This results in an annual reduction of phosphorus transported to surface water of 0.22 to 0.96 pounds per thousand gallons of manure storage capacity installed. This indicates a capital cost of phosphorus reduction to the county of $18-$81 per pound of phosphorus reduced annually and an increase in hauling costs to producers of $93-$415 per pound of phosphorus transported to surface waters annually. However, it should be noted that the majority of the fields under the high-erosion scenario had calculated soil loss rates that greatly exceeded the Natural Resource Conservation Services tolerable soil loss rate (T). As many of the producers in the study area are participating in conservation efforts it is unlikely that the majority of the fields are managed with little consideration for soil loss as represented in the high-erosion scenario.

b. Recommendations on the amount of storage needed in the county, how the location of collective or individual storage structures be can be optimized to facilitate a reduction in the importation and release of nutrients to the Yahara Watershed; both current and future need;

Outcome: Current manure production in the Upper Yahara sub-watershed study area was calculated to be 430 million gallons per year. In the study area, there are 80 manure storages with an approximate capacity of 162 million gallons, or 38% of the 430 million gallons produced annually. However, as manure storage is typically emptied every six months, the six-month capacity is closer to 76% of the manure production. This indicates that a minimum of 24% (or 106 million gallons per year) of manure in the study area is being applied throughout the year. Of the facilities in the study area, nearly 39% have existing manure storages. This indicates that approximately 16,700 animal units in the study area are located on a farm with no storage capacity. An additional 53 million gallons of storage capacity would be needed at a minimum to avoid all winter manure applications. The largest number of animal units without storage are on facilities with 100-250 animal units, although there are also a number of facilities from 250-1,000 animals that do not have storage. Therefore, it is recommended that facilities of this size be targeted for storage. Cost savings would be incurred for the construction of these facilities if more than one farm contributed manure to the storage, however this would increase the hauling costs for producers.

Examining a 20-year horizon, a 2% increase in manure production is expected from 430 to 439 million gallons per year with a 15% decrease in cropland from 60,000 acres to 51,000 acres in the study area, and a 2% increase in crop yield. This would require additional storage capacity of 4.5 million gallons but would also increase manure phosphorus application rates in the study area mainly due to the projected reduction in cropland.

c. Develop a strategy to identify storage locations that would have the greatest impact on water quality of the Yahara Lakes by reducing the necessity of winter spreading or other criteria;

Outcome: An optimization model was developed to assess ideal placement of manure storages based on the location of manure phosphorus production; location and capacity of manure storages; field capacity for phosphorus uptake; and location of fields that had characteristics that would lead to greater phosphorus manure runoff from winter spreading. The map below, Figure ES.3, outlines the targeted locations where storages will have the greatest impact.

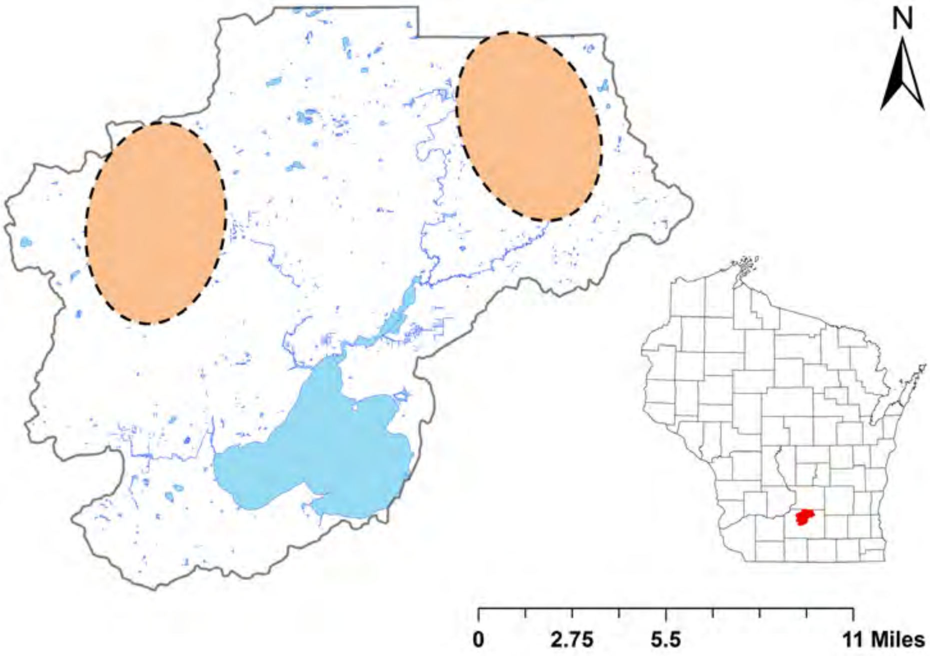


Figure ES.3: Manure storage optimization target manure storage locations (orange ovals represent target locations)

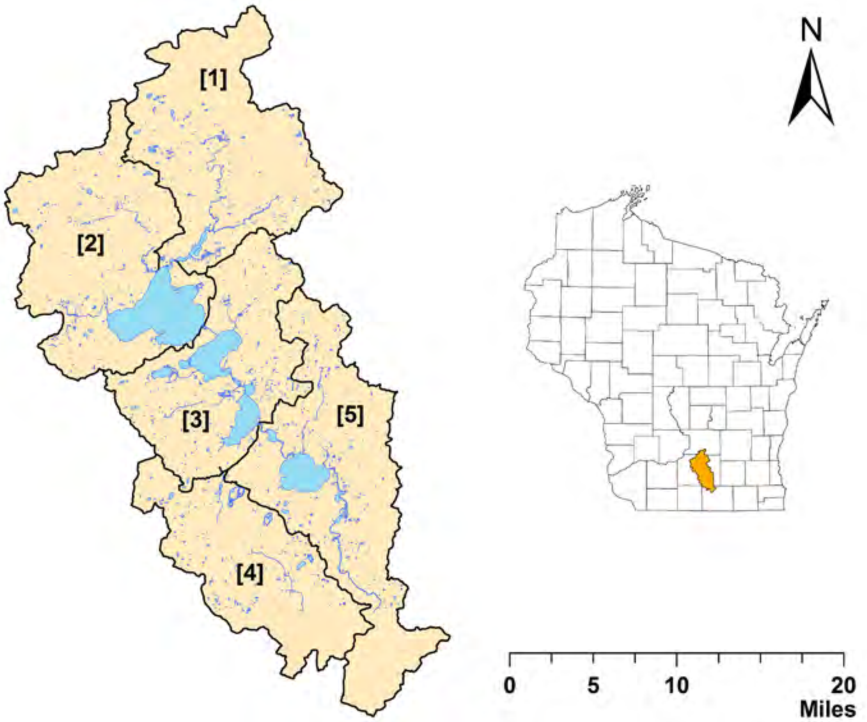
d. Develop an outreach strategy that can be utilized to encourage implementation by individual farms or groups of farms to have the most impact on water quality.

Outcome: Target producers with 100-250 animal units (as they have the least percentage with storage) to introduce manure storage systems on their farms with the potential to accept manure from other farms. There are many solid and liquid storage systems (including composting systems) that could increase storage capacity on these farms.

Introduction

Dane County is home to more than 500,000 people who share a land base of 1,238 square miles with a large number of livestock. Its agricultural economy generates $3.4 billion in economic activity (UWEX 2014). Dane County leads the state in production of corn for grain, ranks 2nd in soybean production, 4th in cattle and calves, and 5th in milk production (USDA AgCensus 2012). The Yahara Watershed, Figure 1, has goals to address nonpoint source pollution and improve water quality, particularly to reduce phosphorus concentrations associated with algae blooms and eutrophication within the lakes. In 2010, Wisconsin set a numeric limit on the amount of phosphorus that can be discharged into lakes and streams. In 2011, the USEPA approved a Total Maximum Daily Load (TMDL) for the Rock River Basin, which includes the Yahara Watershed. The TMDL requires the reduction of discharges of phosphorus by approximately 106,000 pounds per year in the Yahara Watershed, a reduction of nearly 50% from current levels of discharge. The new phosphorus rules also included an innovative regulatory compliance option, called Watershed Adaptive Management, that allows point and nonpoint sources to work together to meet phosphorus standards. It is viewed as a fiscally and environmentally sound approach for achieving compliance.

Figure 1: Yahara River Watershed Divided By Sub-Watershed [1] Yahara River Headwaters, [2] Lake Mendota, [3] Lake Monona, [4] Badfish Creek, and [5] Lake Kegonsa



Existing monitoring and modeling can provide us with useful data in developing phosphorus management plans in the county. Between 1990-2006 Lathrop measured phosphorus loads to the Yahara River Watershed and reported that phosphorus loads during January to March comprised 48% of total phosphorus measured (Lathrop 2007). Carpenter et al. (2014) published a model to better predict phosphorus loading into Lake Mendota. They analyzed phosphorus monitoring data in two sub-basins into Lake Mendota (Yahara River and Pheasant Branch Creek) and found that the highest loading days occur during snowmelt and heavy rainfall events. Further, runoff events occurring over 29 non-consecutive days of the year contributed 74% of the phosphorus loading. These data are useful in targeting solutions to reduce phosphorus movement. This will be even more important in the future as heavy rainfall events are projected to increase due to climate change, including a projected 20-40% increase in spring rainfall (Vavrus and Van Dorn 2010), and will likely lead to more phosphorus loading and be a serious obstacle to achieving water quality improvements.

Achieving phosphorus reductions of nearly 50% watershed-wide will require extensive management at the watershed level. Although the county, in collaboration with the Madison Municipal Sewerage District and other partners, has begun to align the practices in the agricultural community to meet phosphorus water quality goals, issues remain. One need is to understand the impact of livestock manure on water quality and develop clear, long-term manure management goals for the Yahara Watershed to reduce phosphorus loading from livestock manure.

Objectives

This report provides a current assessment of livestock operations, including manure phosphorus production, to guide policymakers, producers and other stakeholders in developing a long-term manure management plan that supports producers while also protecting the environment. In addition, the county has requested a specific assessment that quantifies the phosphorus loading reduction if the county government provides financial support for increasing manure storage capacity within the county. Specific objectives outlined by the county are below.

a. Assessment and quantification of the total amount of manure produced and total nutrients applied in the Yahara Watershed and how increasing storage capacity can impact water quality; include both current and future projections for total manure and facility locations;
b. Recommendations on the amount of storage needed in the county, how the location of collective or individual storage structures be can be optimized to facilitate a reduction in the importation and release of nutrients to the Yahara watershed; both current and future need;
c. Develop a strategy to identify storage locations that would have the greatest impact on water quality of the Yahara Lakes by reducing the necessity of winter spreading or other criteria;
d. Develop an outreach strategy that can be utilized to encourage implementation by individual farms or groups of farms to have the most impact on water quality.
e. Specific tasks include:
    i. Map animal densities within the county.
    ii. Develop manure production estimates based on animal numbers for high animal density areas and evaluate storage capacity within these areas.
    iii. Use manure and storage estimates and cropland availability to determine areas where there is significant need for increased land base as well as increased storage capacity.
    iv. Identify areas for detailed option evaluation and work with partners in the watershed on outreach.

Livestock Operations in Dane County and the Yahara River Watershed

As of 2012, Dane County was home to 1,340 livestock operations representing over 143,000 animal units (an animal unit represents 1,000 pounds of live animal weight regardless of type), Table 1. Over the past few decades, the number of livestock facilities in the county has decreased. However, the animal units have remained more consistent due to an increase in the size of facilities. Agriculture activities occur on a large fraction of the land base within the county, with 47% of the acreage dedicated to crop production. The

Yahara Watershed is a 536-square-mile area which spans three counties, 87% of which is in Dane County (299,665 acres) with smaller acreages also located north in Columbia County (17,694 acres) and in Rock County to the south (26,115 acres). Livestock are located throughout the county, with the exception of urban areas, but have the highest density in the Upper Yahara Watershed, Tables 2 & 3 and Figure 2. This includes the Six Mile and Pheasant Branch Creek sub-watersheds and the part of the Yahara River and Lake Mendota sub-watersheds that fall within the Dane County boundary, Figure 3. As the majority of animal units in the Yahara Watershed (80%) are located in the Upper Yahara Watershed, it is the focus area for this study.

Table 1: Animal numbers in dane county (USDA NASS 2007; USDA NASS 2012)

	Agricultural Census 2012			Agricultural Census 2007		
Animal Type	Number of Facilities	Animal Units	Fraction of Total (%)	Number of Facilities	Animal Units	Fraction of Total (%)
Cattle (including calves)	834	130,865	91.5	991	140,176	93.4
Swine	85	11,149	7.8	99	8,791	5.9
Sheep and lamb	109	311	0.2	123	363	0.2
Poultry	312	766	0.5	309	781	0.5
Total	1,340	143,090	100	1,522	150,111	100

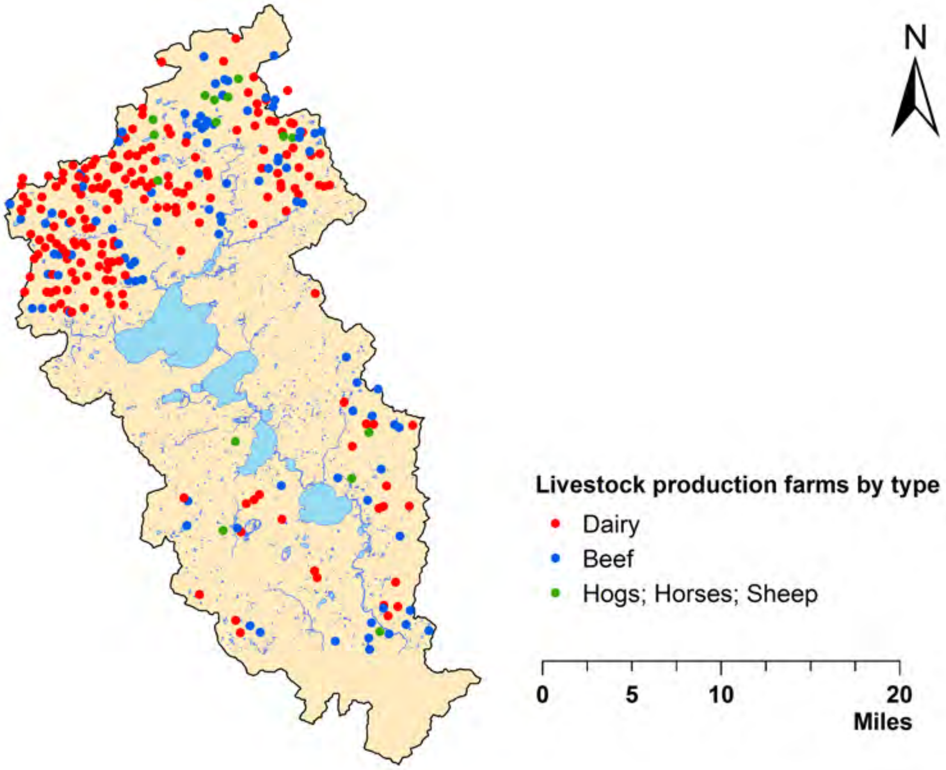


Figure 2: Distribution of Yahara Watershed livestock farms

Table 2: Animal numbers in the Yahara Watershed

Animal Type	Operations	CAFOs	Animal Units	Percent of Total
Beef	90	1	11,155	14.1
Horses	2	-	115	0.1
Sheep	4	-	147	0.2
Hogs	9	-	1,383	1.8
Dairy	186	6	66,090	83.8
Total	291	7	79,303	

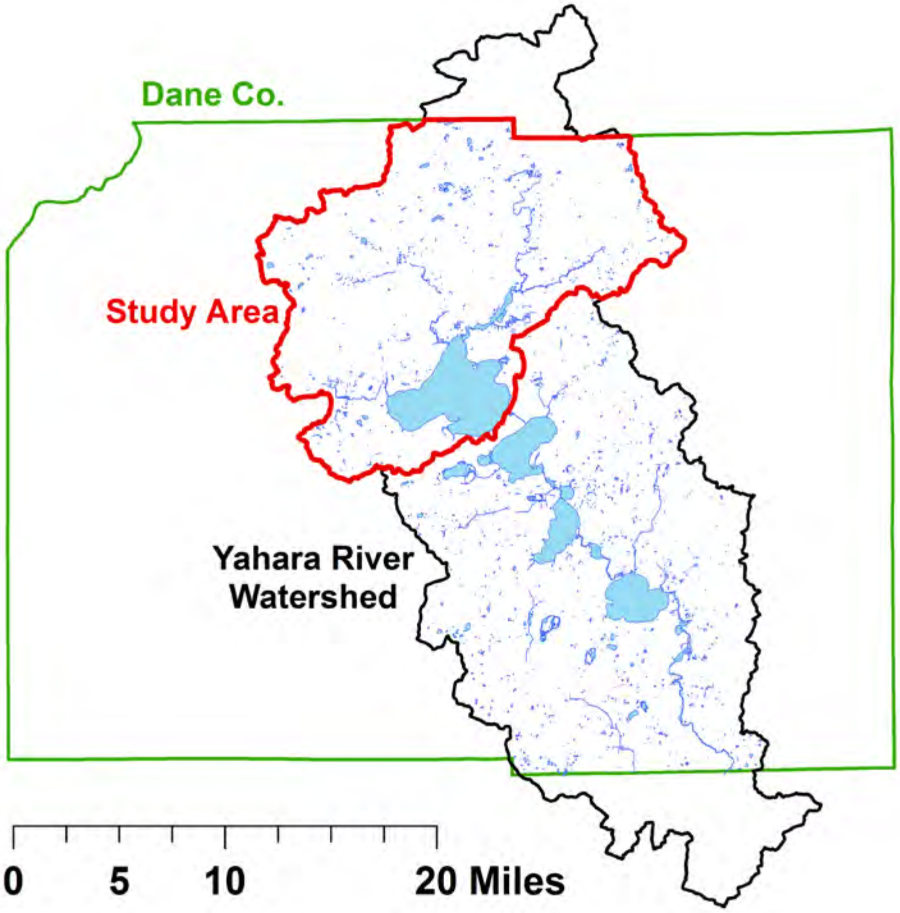


Figure 3: Upper Yahara Sub-Watershed study area

Table 3: Animal numbers in the Upper Yahara Watershed

Animal Type	Operations	CAFOs[a]	Animal Units[b]	Percent of Total
Beef	54	1	7,793	12.3
Horses	1	-	61	0.1
Hogs	5	-	580	0.9
Dairy	148	5	54,342	86.6
Total	208	6	63,110	

[a] WDNR

[b] USDA NASS 2016 special request

Aside from permitted facilities, also called concentrated animal feeding operations (CAFOs), animal numbers are only recorded through the USDA's National Agricultural Statistics Survey (NASS). This is conducted on an infrequent basis, and animal numbers are reported for the entire county making more localized assessments impossible from the NASS datasets. The animal units and their locations reported for this assessment were developed from a variety of sources.

An initial dataset (48,337 animal units) was provided from an assessment conducted using the Soil and Water Assessment Tool (SWAT), which was commissioned by the county and conducted by Montgomery Associates Resource Solutions (Montgomery 2011). This dataset was amended to ensure it contained all registered milk production facilities (provided by the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP)) and all CAFOs as reported by the Wisconsin Department of Natural Resources (WDNR). Additional validation and adjustments were made based on a special tabulation request from the USDA NASS (as requested by Booth, Yahara 2070) which was specific to the study area zip codes. The NASS data based on zip codes did not identify animal numbers for individual operations or groups of operations (USDA NASS has strict privacy rules regarding survey respondents), but gave more detail than the county level. Visual inspection using aerial photos was then used for farms within the study area to remove farms that were no longer operational.

Manure Phosphorus Production

After determining the livestock numbers, manure phosphorus production was calculated from average values (USDA NRCS 2008), Table 4, as measured values are not available. Although permitted facilities are required to obtain and report manure concentrations in nutrient management planning, they only represent 24% of the animal units within the study area. Smaller facilities, which do not require permits, are not required to report this type of information. Therefore, the theoretical calculations are the most accurate estimate that can be currently obtained.

Table 4: Phosphorus production

	Phosphorus Production (pounds/year)	
Animal Type	Yahara Watershed	Upper Yahara Watershed
Beef	400,600	279,900
Horses	600	300
Sheep	3,800	-
Hogs	17,900	7,500
Dairy	1,825,300	1,500,800
Total	2,248,200	1,788,500

Livestock in the study area produce a calculated 430 million gallons of manure per year. This represents ~80% of the manure phosphorus in the Yahara Watershed, while the land base of the study area comprises only 38% of the total cropland in the Yahara Watershed (USDA NRCS Cropscape 2008-2015). However, within the study area the production of manure phosphorus is well distributed, Figure 4.

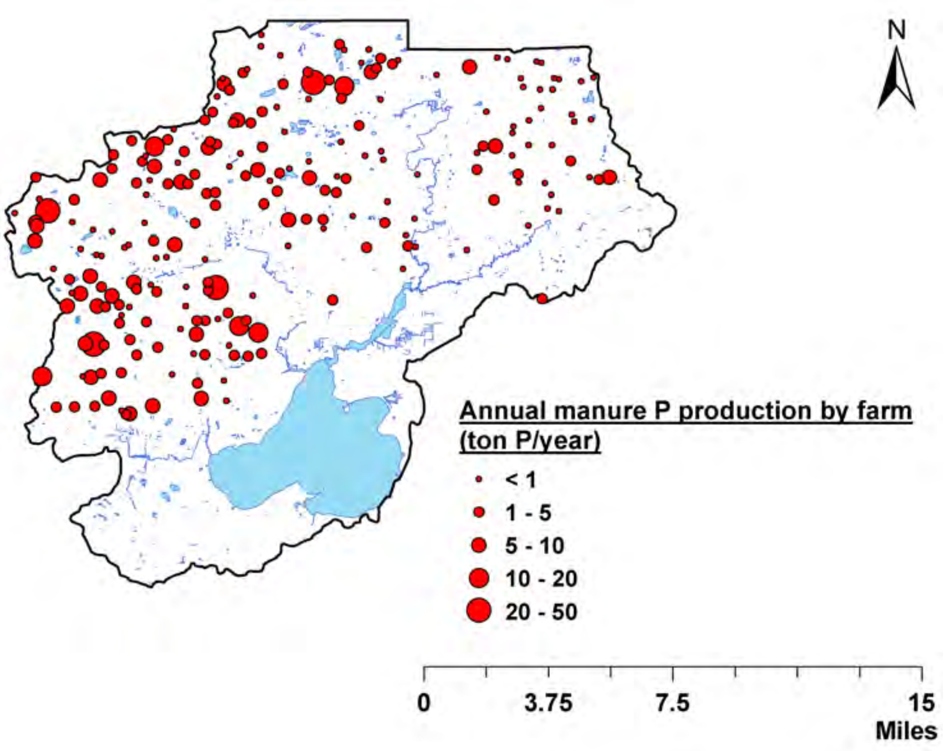


Figure 4: Manure phosphorus production in the Upper Yahara Sub-Watershed study area

Phosphorus Uptake from Cropland

Land units were analyzed for their phosphorus removal as determined by land area, crop rotation and yields. Land cover classification layers were used to outline agricultural fields, Figure 5. Cropland data layers were gathered from the USDA for 2008-2015 (Battaglia 2008-2015). This information was validated using a land use survey conducted by the county (CARPC 2010). The data provided indicate that the crops grown in Dane County are primarily corn for grain and silage, winter wheat, alfalfa, soybeans, oats, grass and hay. Land parcels were outlined using tax records (CARPC 2010) and the crop data layers were used to assign a crop rotation to each field. Crop yields were based on the average yields in the county over a 7-year period, Table 5 (Battaglia 2008-2015). Crop nutrient uptake values (Laboski and Peters 2012) and average crop yields were used to predict the annual phosphorus uptake for the county, the Yahara Watershed, and the Upper Yahara sub-watershed, Table 5 and Figure 6, with detailed data for all data sources available in Appendix A and crop data in Appendix B.

Table 5. Summary of Dane County crop yields between 2008 and 2015 (Battaglia 2008-2015)

Crop	Mean	SD	Unit
Corn, grain	175.0	20.6	bu/ac
Corn, silage	22.0	4.2	ton/ac
Soybean, grain	50.0	6.7	bu/ac
Wheat, grain	69.6	11.0	bu/ac
Alfalfa	3.4	0.5	ton/ac
Hay/Pasture	2.2	0.1	ton/ac

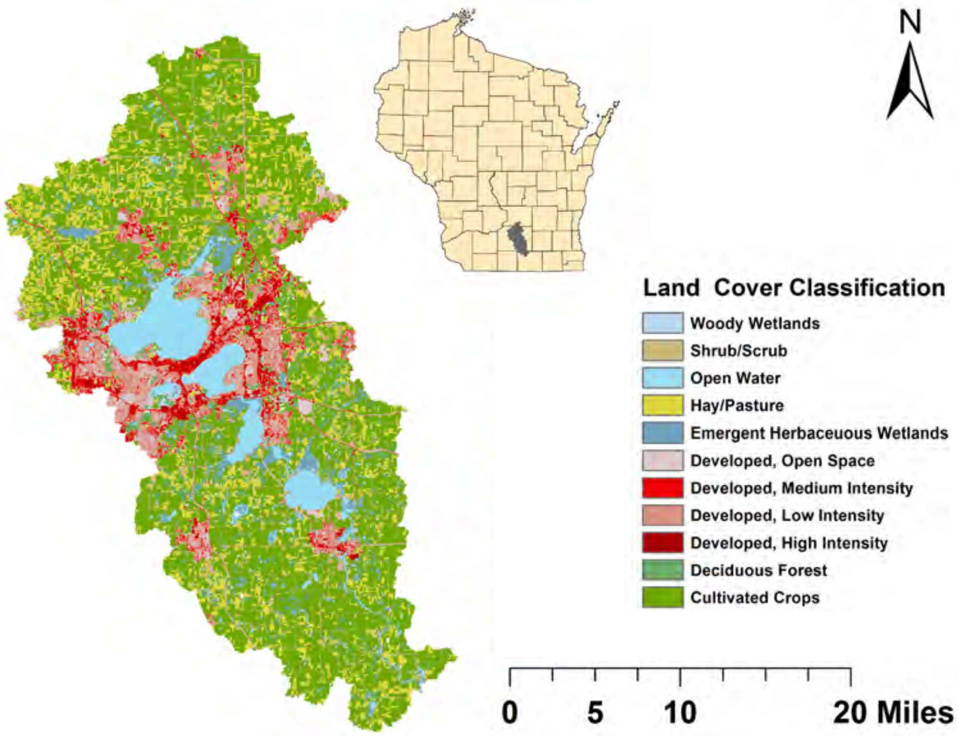


Figure 5: Land cover classification in the Yahara Watershed

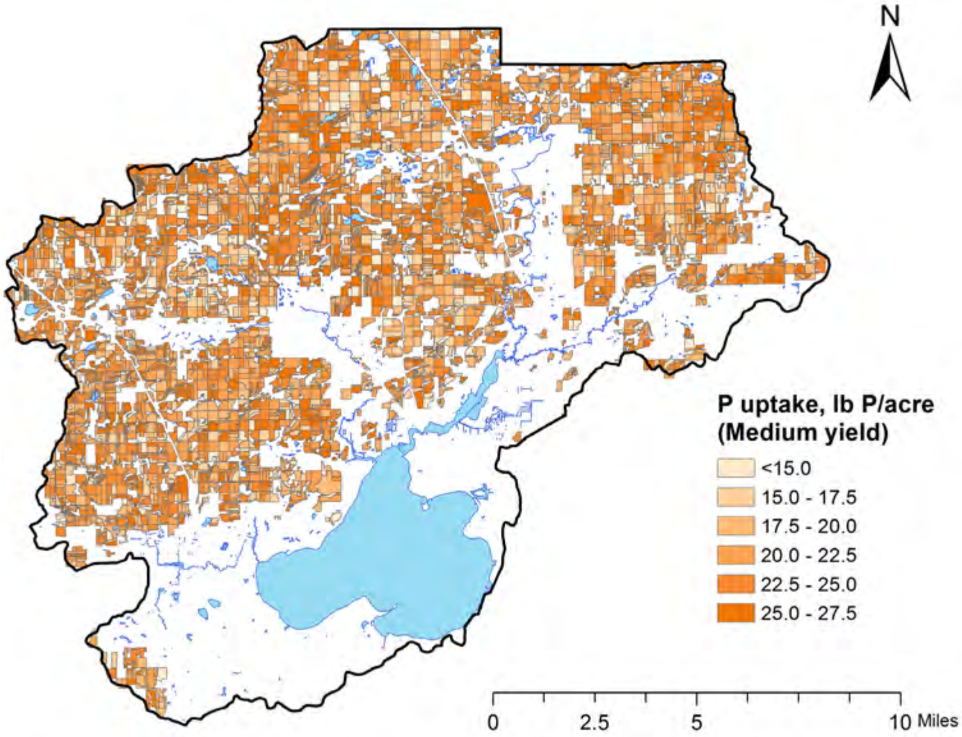


Figure 6: Phosphorus uptake by field based on crop rotations in the Upper Yahara Sub-Watershed study area

Land Application of Manure Phosphorus

The ratio of annual manure phosphorus production to crop uptake within the county is below one, Table 6, indicating that for the entire county the crops grown will remove more phosphorus than is applied in manure. Unfortunately, manure is not applied evenly over the land base as the cost of transporting manure can be prohibitive. It is in the best interest of livestock farms to reduce hauling costs by reducing the travel distance, as the farther manure is transported, the greater the cost per gallon for application. The value of the nutrients in manure only supports transport a short distance from the farmstead. This break-even distance can vary with the manure nutrient density and the method of application. For example, if only the value of nitrogen is used, dairy manure can be hauled up to two miles and swine manure up to one mile while still being as cost effective as a commercial nitrogen fertilizer (Anderson 2014).

In 2012 and 2013, the ratio of manure phosphorus production to crop uptake in the study area reached nearly double the county ratio, Table 6. Note that this ratio varies from year to year. For example, the drought in 2012 reduced yields, decreasing crop uptake. A ratio above 1 in the Upper Yahara Watershed in both 2012 and 2013 indicates an excess in manure phosphorus. In addition, this ratio does not include the application of phosphorus from other sources, such as fertilizers, biosolids from wastewater treatment plants and other agricultural byproducts, which may supply additional phosphorus to the land base.

Table 6: Manure phosphorus production and crop uptake

2012

Region	Area (mi^2)	Crop P uptake (ton P_2O_5/year)	Manure P production (ton P_2O_5/year)	P manure/ P crop
Dane County	1,237	6,491	6,124	0.94
Yahara River Watershed	536	2,984	3,091	1.04
Upper Yahara sub-watersheds (within Dane Co.)	204	1,172	2,282	1.95

2013

Region	Area (mi^2)	Crop P uptake (ton P_2O_5/year)	Manure P production (ton P_2O_5/year)	P manure/ P crop
Dane County	1,237	9,213	6,046	0.66
Yahara River Watershed	536	4,187	3,091	0.74
Upper Yahara sub-watersheds (within Dane Co.)	204	1,691	2,282	1.35

Manure Storage

Manure storage provides flexibility in the timing of manure application, allowing producers to apply manure during periods that are more favorable operationally or environmentally. Those without storage must apply manure as it is produced, even if the timing is not ideal for field application. Many farms that do not have long-term manure storage (six months and beyond), may incorporate short-term storage to decrease the hauling frequency to weekly or monthly. All permitted facilities, or CAFOs with more than 1,000 animal units, are required to maintain six months of manure storage according to NR 243. There are a number of facilities which have manure storage even though they are not required to do so. Long-term storage creates flexibility so manure does not need to be applied when soils are frozen, a situation which can lead to increased phosphorus runoff if soils had significant moisture during freezing or reach saturation during snowmelt (Srinivasan et al. 2006), and particularly if phosphorus is applied on top of snow cover (Williams et al. 2011). The manure can then be applied at times that correspond to crop needs. Additionally, flexibility in application timing also allows producers to avoid application during or around periods of precipitation, as increasing the time period between a manure application and a rainfall event reduces phosphorus runoff, particularly for intense rainfall events (Vadas et al. 2011). Despite the many advantages to storage, for many operations the cost of constructing storage is prohibitive.

Manure storage systems must meet specific technical design standards (NRCS CPS 313 2014) that require detailed engineering plans. Dane County adopted its first manure storage ordinance in 1988, which was later updated in 2005 to require permits for all new manure storage systems to assess the design, siting and sizing of manure storage systems. To get a better understanding of the number and volume of existing manure storage systems in the county, researchers reviewed these permits. This included 109 paper records, although many of these were modifications or updates and not unique storage entries. Thirty-six of these records were unique entries within the outlined study area (Upper Yahara sub-watersheds) and are on farms which are still operational. Although these records were useful in identifying storage locations, many storage systems were constructed before the county began requiring permits. Therefore, aerial images of each farm in the study area were gathered using Google Earth and evaluated to determine if a manure storage system was present on the farmstead. An additional 44 manure storage systems were identified using these methods, for a total of 80 manure storage systems within the study area, Figure 7.

For the manure storage systems in the county records, details on dimensions and volume were available. For those that were documented using Google Earth, the dimensions of the storage structure were measured in the image and a 10-foot depth was assumed to determine the volume. The current manure production in the study area was calculated to be 430 million gallons per year. There were 80 manure storages with an approximate capacity of 162 million gallons, or 38% of the 430 million gallons produced annually. However, manure storage is typically emptied twice per year, and the six-month capacity is closer to 76% of the manure production. This indicates that a minimum of 24% (or 106 million gallons per year) of manure in the study area is not stored and is therefore applied frequently throughout the year. Nearly 39% of the farms in the study area have existing manure storages, Table 7. Dairy facilities comprise the majority of these systems where 45% have manure storage. Approximately 16,700 animal units in the study area are located on a farm with no storage capacity, Table 8. As farm size increases, the percentage of facilities with existing manure storage increases. However, except for permitted facilities, even farms with storage may not have a full six months of storage, which would result in winter spreading.

Figure 7: Map of manure storages in the Upper Yahara study area

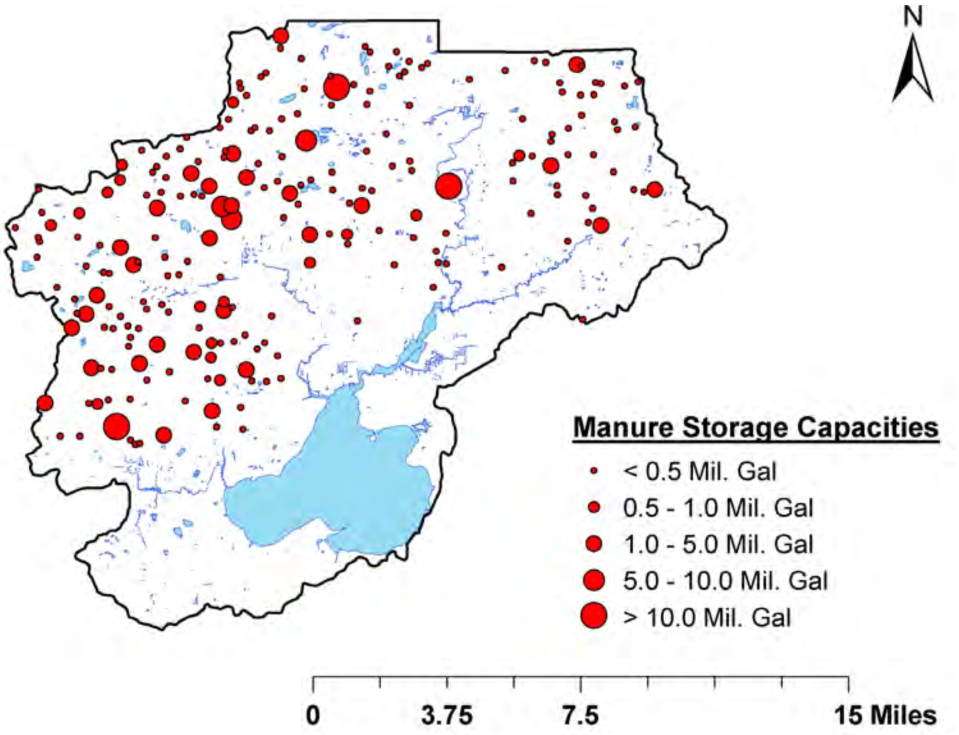


Table 7: Manure storage by animal type in the Upper Yahara study area

Animal Type	Operations	CAFOs	Operations with Manure Storage	Operations with Manure Storage (%)	Animal Units Contributing to Storage (%)
Beef	54	1	11	20	35
Horses	1	-	-	-	-
Sheep	-	-	-	-	-
Hogs	5	-	2	40	85
Dairy	148	5	67	45	79
Total	208	6	80		

Table 8: Manure storage by facility size in the Upper Yahara study area

Farm Size	Animal Units	Storage Capacity (Million gallons)	Animal Units Located on Facilities with Storage	Animal Units Located on Facilities with Storage (%)
0-100	3,494	3	334	10
101-250	15,325	15	5,376	35
251-1,000	23,692	55	20,139	85
1,000+	20,599	89	20,599	100
Total	63,110	162	46,448	

Balancing Phosphorus (Phosphorus Budget)

Managing phosphorus requires an assessment of the current phosphorus stores as well as the phosphorus inputs and outputs, also called a phosphorus mass balance or phosphorus budget. When phosphorus inputs exceed outputs on any given land base, soil phosphorus concentrations increase. This is a problem as increases in soil test phosphorus result in increased total phosphorus and dissolved reactive phosphorus concentrations in runoff (Andraski and Bundy 2003; Jokela et al. 2012), while also increasing the fraction of the total phosphorus that is in the dissolved reactive form (Jokela et al. 2012). Therefore, it is critical to balance the soil phosphorus inputs and outputs to reduce phosphorus loading to surface waters during runoff events.

A comparison of 1995 (Bennett et al. 1999) and 2007 (Kara et al. 2012) phosphorus budgets for the Lake Mendota watershed reported that total average phosphorus inputs decreased by 35% (attributed to agricultural nutrient management planning and reduction in urban phosphorus fertilizer and dairy feed supplements) and accumulations decreased by 51%. However, despite these significant reductions, phosphorus inputs (1.88 million pounds per year) still far outweighed phosphorus outputs (removal of crops, milk, meat, etc. (1.27 million pounds per year) leading to large accumulations of phosphorus in the Lake Mendota watershed each year (Kara et al. 2012).

In previous assessments, the majority of phosphorus entering the Lake Mendota watershed was from corn fertilizer (including manure) and animal feed (Bennett et al. 1999). From the data reported above, Table 6, it is clear that there is an excess of manure phosphorus being applied to fields when compared to removal during harvest. Although the rate varies, the manure phosphorus for the study area reaches application rates that nearly double the capacity of the crop uptake. Soil phosphorus concentrations on many fields already exceed the levels recommended to support crop growth. For example, for the fields covered by nutrient management plans within the Six Mile Creek watershed, including about 60% of the agricultural land within this sub-watershed of the study area, soil test phosphorus ranges from 5 to 500 ppm. The median, 50 ppm, is high enough that no phosphorus fertilizer is recommended for crops in these fields. Only 26% of the fields have soil test phosphorus levels below 36 ppm, and therefore some phosphorus amendment is recommended for the most phosphorus demanding crops in this area, including corn silage and alfalfa (Laboski and Peters 2012). Continued phosphorus applications that are greater than crop uptake will continue to build up soil phosphorus concentrations, therefore increasing runoff concentrations.

While balancing phosphorus levels in a given area to prevent soil phosphorus buildup is important, phosphorus transport to surface waters via runoff must also be managed. There are many known practices that can limit phosphorus losses to surface waters. Ideally, both a phosphorus balance and limiting phosphorus transport would be used to achieve and maintain reductions in phosphorus loading to the surface waters. One phosphorus transport mechanism requiring management is runoff from winter manure applications. By promoting manure storage installation, producers can avoid the losses of manure resulting from application when the ground is frozen. The sections below evaluate potential locations for new manure storages and estimate the likely reduction in phosphorus transport to surface waters as a result of those implementations.

Manure Storage Optimization Model: Siting Manure Storages

A two-part optimization model was developed to site manure storages in the study area that minimize hauling costs while maximizing the application of stored manure to fields, particularly those classified as sensitive. Optimization models are frequently used by decision makers to predict the best strategy or outcome. In this study, the model was designed to balance cost and environmental impact to determine the optimal placement of storages in the Upper Yahara study area.

For the purpose of this study, fields were labeled as sensitive if they have attributes which have been identified in the current nutrient management guidelines applicable in Wisconsin (NRCS CPS 590 2015) as requiring special management for winter manure applications and/or soils having a high runoff potential and/or are likely to be tile drained (Hydrologic soil group D soils), determined from the Soil Survey Geographic Database (SSURGO) data (Soil Survey Staff 2015). These attributes include:

1. Within 300 feet of a surface water feature (stream, river or lake)
2. Field slope > 6%
3. Contain intermittent streams
4. If the dominant hydrologic soil group (undrained) designation is D (high runoff potential)

If any of these features were present in a field that is not internally drained, the field was classified as sensitive, Figure 8. Sensitive fields cover 35,300 acres, or 59% of the agricultural land in the study area.

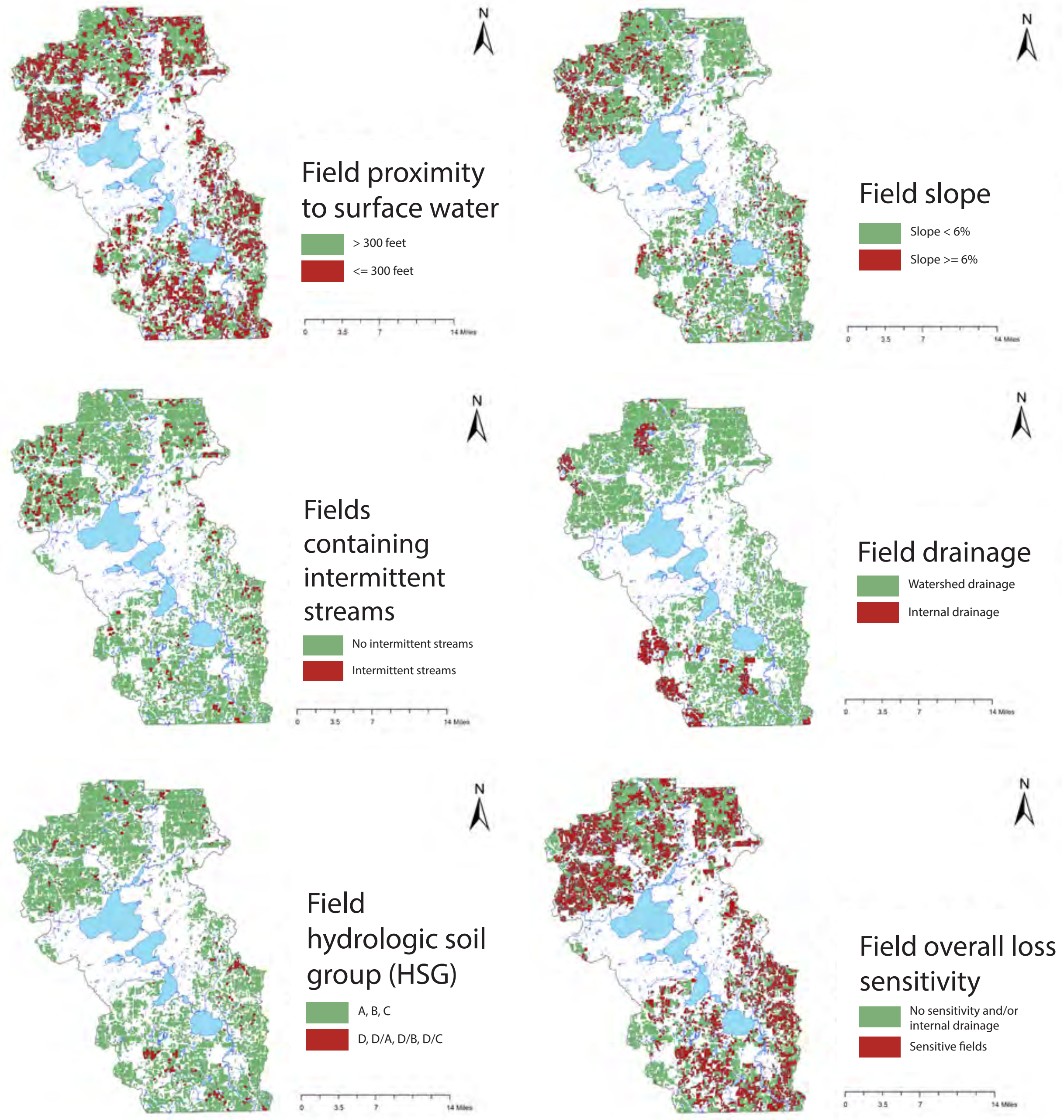


Figure 8: Sensitive fields in the Yahara Watershed

Within the model, manure is applied to each field at a rate up to 125% higher than the phosphorus uptake of the crop (meaning each field can receive up to 1.25 its predicted crop phosphorus uptake). Crop uptake was determined by multiplying the average crop yield over a 7-year period by the phosphorus uptake from Laboski and Peters (2012). Manure could be applied at 1.25 times the rate of phosphorus uptake as the average crop uptake in the study area was not enough for the manure phosphorus produced, as can be seen from the ratio of the manure phosphorus to crop phosphorus, which varied from 1.35-1.95 for the two example years provided in Table 6. Hauling routes were based on direct lines to fields, and manure transport was optimized with the goal of minimizing hauling costs, meaning manure is transported the shortest distance possible. However, in actual practice manure may travel farther based on field ownership, therefore direct distances were scaled up 1.5 times to represent over-the-road hauling distances. The optimization model scenarios were conducted to represent a variety of situations to assess the objectives as outlined by the county in respect to placement of manure storages and the impact to manure hauling. The base case scenario, which is designed to represent current conditions to compare with the five scenarios, is outlined below. Additional details on the optimization model constraints can be found in Appendix C.

Base case scenario – based on existing animal numbers, milk production of 25,100 pounds per cow per year was used to calculate manure production and is based on average USDA NASS data for the county (USDA NASS 2012).

Additional scenarios which incorporate manure storages with the following constraints:

1. Maximum capital construction cost of $5M and a maximum storage size of 4.2 million gallons (size based on 180 days of storage for 1,000 animal units)
2. Maximum capital construction cost of $5M and an unconstrained storage size
3. Maximum capital construction cost of $5M, maximum storage size of 4.2 million gallons and increased milk production based on DMI herd averages or 28,700 pounds per cow per year (increase manure production)
4. Maximum capital construction cost of $10M and a maximum storage size of 4.2 million gallons (increase capital investment)
5. Increased milk production based on USDA NASS trends for 20 years in the future or 32,500 pounds per cow per year, decrease in cropland for prediction of 20 years in the future (increase in manure production per animal, decrease in available cropland and increase in crop yields)

Manure Storage Optimization Results: Siting Manure Storages

The base case scenario, which simulates the transport of manure throughout the study area using only existing storages, had an average haul distance of 2.76 miles per gallon of manure when applying all 430 million gallons of manure produced in the study area. The total hauling cost, calculated at $0.01 per gallon per mile for the base case, is $11.2 million, Table 9. For the additional scenarios, investing $5 million to manure storage construction increased capacity by 19 million gallons, or 36% of the un-stored manure produced in the study area in a six-month period by installing an additional five manure storages. Additional storage investment of $10 million further increased the manure storage capacity in the study area to 38 million gallons, or 72% of the un-stored manure produced in the study area. In this assessment, increasing the maximum size of a manure storage, which requires additional effort to permit systems through the WDNR, increased the capacity by only 1 million gallons, but led to the construction of only one manure storage system (as there is a fixed cost for each storage system built). As expected, the addition of manure storage always increases the average haul distance and therefore hauling costs per gallon of manure. The future scenario represents a 2% increase in manure production from 430 to 439 million gallons per year with a 15% decrease in cropland from 60,000 acres to 51,000 acres in the study area, and a 2% increase in crop yield. The future scenario results in a slight increase in the amount of manure applied to sensitive fields throughout the year but only requires an additional 4.5 million gallons of storage to avoid winter spreading. Changes in herd size and crop acreage in the future were extrapolated from previous USDA census of agriculture reports (1992 to 2012). Yield increases were extrapolated using USDA reports on long-term projections (USDA OCE 2016).

Table 9: Manure storage optimization scenario outputs

Scenario	Number of New Manure Storages Constructed	Capacity of New Manure Storage Constructed (millions of gallons)	Hauling Cost (millions of USD per year)	Average Hauling Distance	Animal Units Contributing to Storage (%)
Base case	-	-	11.2	2.76	-
$5M Storage	5	19	14.9	3.19	43
$5M Unconstrained Storage Size	1	20	14.4	3.25	36
$5M Increased Milk Production	5	19	15.7	3.36	48
$10M Storage	10	38	16.0	3.19	83
Future	5	19	18.7	3.28	37

The output from the optimization models has a large number of farms contributing to each storage. This indicates that many small farms are in need of manure storage systems in the study area. In addition, all of the storages for every scenario were clustered within two regions in the study area, highlighting the need for additional storage in these areas, Figure 9. Efforts to increase manure storage systems should be directed to these regions as these represent the areas with sensitive fields and un-stored manure. For each scenario, the maximum reduction in winter spreading volume is equivalent to the new manure storage capacity installed, Table 9.

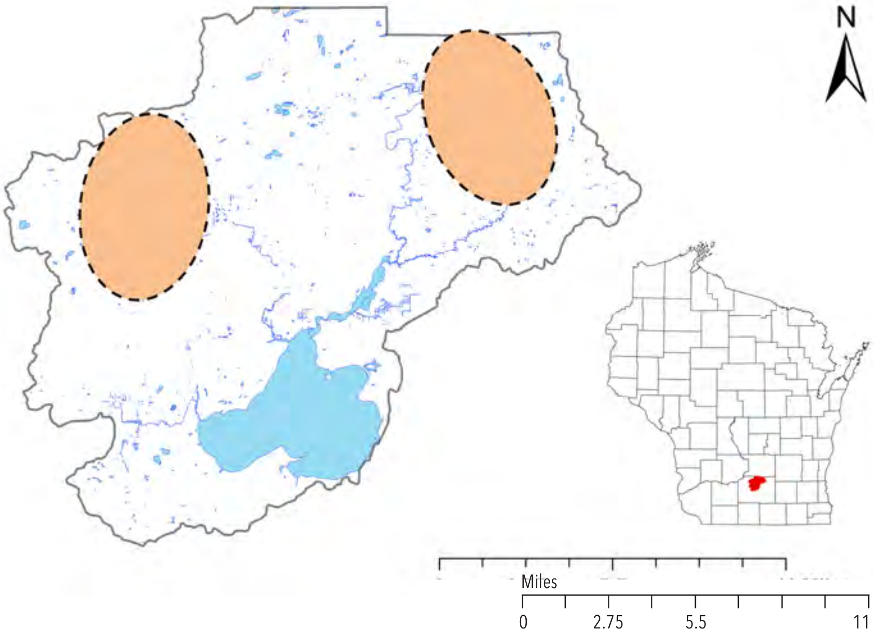


Figure 9: Manure storage optimization target manure storage locations (orange ovals represent target locations)

Phosphorus Loading to Surface Waters

In order to estimate the change in phosphorus loading to surface waters from agricultural lands with and without storage, a comparison estimated losses from 504 cropped fields (4,480 acres) in the study area with and without winter manure spreading. All 504 fields used in the analysis were classified as sensitive using the criteria described above. To represent conditions with winter spreading, a no storage scenario quantified the phosphorus losses to surface waters when solid manure was applied to all fields, with one third being applied in the winter. To represent a shift to no winter spreading, a second scenario with storage (19 million gallons) was assessed, where all manure was assumed to be stored and applied in spring and fall as a slurry. The difference in the two scenarios quantifies the impact of installing storage on phosphorus loading to surface waters.

While we have information on crops grown on these fields from the optimization analysis, we do not know how the fields are managed, the soil phosphorus concentrations, or the manure and fertilizer phosphorus application rates. To capture the impact of storage under a range of management conditions, comparisons were made for each field under two crop management scenarios designed to represent the high and low end of erosion-production in the watershed. A complete description of the crop rotations and nutrient balances for these scenarios is in Appendix D.

Our comparison used the Wisconsin P Index because it is an agricultural runoff phosphorus loss assessment used by ongoing water quality projects in the Upper Yahara Watershed and it can be used to assess relative phosphorus reductions on individual fields under a range of management conditions. The P Index is a calculation of average annual runoff phosphorus delivery from a field to the nearest surface water in pounds per acre per year. It includes an estimate of dissolved phosphorus and particulate phosphorus. To calculate how much phosphorus leaves the field, it uses estimated average erosion and runoff for a field's local weather, soil conditions and crop management along with soil phosphorus concentrations and phosphorus applied via manure and fertilizer (Good et al. 2012).

While P Index calculation units are in pounds of phosphorus per acre per year delivered to surface water, they do not represent the pounds of phosphorus entering the Yahara Lakes. The P Index is designed to help nutrient management planners identify and manage excessive runoff phosphorus loss areas, and therefore it uses the most erosion-prone soil in a field (minimum 10% of field) for the erosion and runoff calculations. Tillage descriptions are designed to err on the high-side for erosion. The P Index has a phosphorus delivery factor that accounts for deposition or infiltration of phosphorus as runoff travels from field to stream. This factor is based on straight-line distance and slope from the field to the nearest surface water and does not account for the complexity of the real flow paths due to both data-entry and model limitations. Due to the over-estimation described above, and because the delivery point is the nearest surface water rather than a lake inlet, a pound of P Index reduction will not equate directly to a pound of reduced lake delivery.

Shifting manure applications away from winter has a substantial effect on estimated phosphorus runoff losses to surface water under both high and low erosion managements, Table 10. Overall, the fields without storage had an estimated 88% lower phosphorus delivery to surface water when they were under management that minimized erosion. This shows the importance of soil-conserving practices to minimize phosphorus in runoff. Under the high-erosion management scenario, eliminating winter spreading through storage reduced the phosphorus delivery by 27%, while under the low-erosion scenario it was reduced by 49%. This suggests that as more soil conserving practices are implemented, losses from winter manure applications will make up a greater percentage of the remaining phosphorus losses, increasing the relative importance of winter spreading reductions.

The estimated reduction in P Index loading with the installation of 19 million gallons of manure storage capacity ranges from 4,100 to 18,200 pounds per year, Table 10. This results in an annual reduction of phosphorus transported to surface water of 0.22 to 0.96 pounds per thousand gallons of manure storage capacity installed. However, it should be noted that the majority of the fields under the high-erosion scenario had calculated soil loss rates that greatly exceeded the Natural Resource Conservation Services tolerable soil loss rate (T). As many of the producers in the study area are participating in conservation efforts it is unlikely that the majority of the fields are managed with little consideration for soil loss as represented in the high-erosion scenario. This conclusion is supported by the Snap Plus data as almost all of the fields assessed in the high-erosion scenario exceeded tolerable soil loss. Assuming an average life of 15 years, the storage scenario with $5 million in capital represents an annual cost of $18 (high-erosion fields) to $81 (low-erosion fields) per pound of phosphorus avoided per year. However, the capital costs are only a fraction of the total cost as there is an increase in hauling costs associated with the change in practices. In this case the change in hauling costs was $1.7 million per year, which corresponds to $93 (high-erosion) to $415 (low-erosion) per pound of phosphorus avoided per year. This indicates that even if the county supports the cost of implementation, there will still be a significant cost to producers to haul the manure each year. And as mentioned above, the fields are likely managed closer to the conditions in the low-erosion scenario corresponding to the higher end of the cost range.

Table 10: Total annual wisconsin p index loads[1] for selected sensitive fields for high and low erosion managements with and without storage by crop rotation

		High Erosion P Index Load			Low Erosion P Index Load		
Rotation	Acres[2]	No Storage	With Storage	Change with Storage	No Storage	With Storage	Change with Storage
Continuous corn	588	8,200	6,100	2,100	1,100	500	600
Row crops (2 yr corn and 1 yr soybean)	1,367	21,300	16,200	5,100	2,900	1,600	1,300
Dairy (3 yr corn and 3 yr alfalfa)	2,106	37,200	26,600	10,600	3,900	2,100	1,800
Grass hay	418	400[3]	<100[3]	400	400	<100	400
Total	4,480	67,100	48,900	18,200	8,300	4,200	4,100

[1] The Wisconsin P Index load is the rotation average P Index lb multiplied by the acres in the field and summed for all the fields in each rotation.

[2] Total acres represents acres in fields receiving manure from 19 million gallons of storage. Without storage manure is applied as solid manure with a portion applied during the winter, with storage manure is applied as a slurry manure with no winter applications.

[3] High erosion scenario with grass hay is the same as the low erosion scenario because this rotation is permanent grass cover with no tillage.

Phosphorus applications were greater than crop removal, leading to increasing soil phosphorus concentrations in all comparisons. Average annual P_2O_5-equivalent surpluses ranged from 9 pounds P_2O_5 per acre to 33 pounds P_2O_5 per acre. Soil test phosphorus (Bray P1) is expected to rise 1 ppm for every 18 pounds per acre of P_2O_5 surplus (Laboski and Peters 2012), leading to average soil test phosphorus increases of 0.5 to 1.8 ppm per year, increasing runoff losses. When the scenarios were run for 24 years, the average increase in P Index (pounds per acre per year) was 0.15 for the high-erosion management and 0.01 for the low-erosion management. With these levels of incremental increases caused by soil phosphorus buildup, it is estimated that it will take about 75 years for average phosphorus runoff losses to rise back to their pre-storage concentrations under the low-erosion scenario. Under the high-erosion scenario it would take an average of only 16 years to return to pre-storage concentrations. In contrast, if a portion of the stored manure were removed from the watershed so that manure phosphorus applications to watershed fields would be less than crop removal, runoff losses would gradually decline. With the high-erosion scenario described above, but assuming half of the stored manure is exported so only half is applied, phosphorus losses with the storage would decrease a further 10% within 24 years.

Comparison to P Removal Technologies

There are many engineering solutions available to remove phosphorus. Manure processing systems allow manure to be fractionated into a variety of streams with varying solids and nutrient levels. Typically, these systems produce a high-solids, low-volume fraction and a low-solids, high-volume fraction with the goal to allow lower application rates at more frequent intervals to improve plant uptake and facilitate precision application of nutrients or reduced transportation costs. The manure stream can also be further processed to separate the phosphorus from the nitrogen and potassium, enabling land application at ratios that better match crop requirements. Additionally, these systems may allow for water to be recycled for manure flushing or for manure fiber to be reclaimed as bedding. These processing systems may be as simple as a single dewatering screw-press or may include multiple operations from the list of screening systems, clarifiers, presses, dissolved air flotation units or centrifuges. For Dane County, with its high ratio of manure phosphorus produced to crop uptake, manure processing systems may be of interest to facilitate export of nutrients. Although outside the scope of this study, the authors suggest Ma et al. (2013) for a review.

Summary

An analysis of the livestock in the Upper Yahara Watershed study area indicates an excess of up to nearly double the manure phosphorus in comparison to crop uptake. The level of excess indicates a need to redistribute the manure outside the study area. Further investigation could provide needed economic data. An assessment of the manure storage capacity indicates there is 162 million gallons of manure storage capacity in the study area, which provides six months of manure storage for 76% of the manure produced in the study area. An additional 53 million gallons of storage capacity would be needed at a minimum to avoid all winter manure applications. The addition of $5 million in capital costs for manure storage would provide 19 million gallons of storage, or 36% of the un-stored manure in the study area over a six-month period. Scenarios indicate the northeastern and western part of the study area should be targeted for additional manure storage installation. Manure storage will initially reduce phosphorus losses to surface waters. However, if the over-application of manure phosphorus is not reduced, then the gains made initially could be lost in several decades due to an increase in soil phosphorus. In addition, as erosion is reduced from conservation practices, losses from surface applications in the winter would make up a greater percentage of the remaining losses.

Acknowledgments

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Supplemental Information

Appendix A – Summary of Data Sources for Analysis

	Data needs	Dataset used
Crop fields	Field boundary	Capital Area Regional Planning Commission (CARPC), Dane County, Wisconsin, 2010
	Crop rotations	Cropland Data Layers (CDL), 2008 – 2015 (CropScape, NRCS USDA)
	Crop yields	Wisconsin Agricultural Statistics, NASS-USDA and DATCP, 2008 – 2015
	Crop P uptake	(Laboski & Peters, 2006)
	Slope	LiDAR digital elevation model (DEM), Wisconsin Department of Natural Resources, 2015
	Soil hydrologic group	Soil Survey Geographic (SSURGO) Database, Soil Survey Staff, NRCS USDA, 2015
	Proximity to surface water	National Hydrography Dataset (NHD), U.S.Geological Survey (USGS), 2015
	Intermittent flowline	
	Internally drained regions	("Montgomery Associates," 2011)

	Data needs	Dataset used
Livestock production	Herd sizes, types, locations	(Booth et al., 2016; "Montgomery Associates," 2011)
	Livestock P production	(NRCS USDA, 2008)
	Available storages on farm	Records, Land Conservation Division, Dane County Land & Water Resources Department, Dane Co., Wisconsin
	Milk production	Wisconsin Agricultural Statistics, NASS-USDA and DATCP (2008 – 2015)

	Data needs	Dataset used
Study area boundary	Watershed boundary	Watershed Boundary Dataset (WBD), U.S. Geological Survey (USGS), 2015
	Road network	Dane County Land Information Office, 2015

Appendix B – Crop Data

Dane County Wisconsin Agricultural Surveys							
Year	2009	2010	2011	2012	2013	2014	2015
Corn:							
All corn planted (ac.)	189,000	196,500	199,000	208,000	196,000	191,500	190,500
Grain corn harvested (ac.)	160,000	167,000	171,000	160,700	167,900	177,700	144,500
Grain corn yield per acre (bu/ac)	164	178	164	112	176	181	184
Silage corn harvested (ac.)	27,700	28,000	27,000	43,600	28,100	13,800	45,600
Silage corn yield (Ton/ac)	20	23	22	12	22	22	25
Soybeans:							
All soybeans planted (ac.)	80,600	78,400	76,500	75,700	75,400	79,000	85,400
Harvested soybean (ac.)	80,500	77,900	76,200	75,500	74,400	78,800	85,000
Soybeans yield (bu/ac.)	46	58	52	44	50	50	55
Oats:							
All oats planted (ac.)	5,900	6,300	-	3,900	5,400	4,000	-
Harvested oats (ac.)	3,200	2,600	-	1,100	1,070	2,720	-
Oats yield (bu/ac.)	75	67	-	51	66	63	-
Winter Wheat:							
All wheat planted (ac.)	15,900	12,000	17,100	14,100	18,300	16,800	14,900
Harvested wheat (ac.)	14,800	11,900	16,500	14,000	16,200	14,000	14,500
Wheat yield (bu/ac.)	73	75	77	85	64	79	80
Hay Alfalfa (dry):							
All wheat planted (ac.)	15,900	12,000	17,100	14,100	18,300	16,800	14,900
Harvested wheat (ac.)	14,800	11,900	16,500	14,000	16,200	14,000	14,500
Wheat yield (bu/ac.)	73	75	77	85	64	79	80
Other Hay:							
Harvested hay (ac.)	5,800	5,900	-	-	-	-	-
Hay yield (Ton/ac.)	2	3	-	-	-	-	-
Phosphorus removal in crops:							
Tons of P_2O_5	8,553	9,684	8,945	6,491	9,213	9,421	9,875
Metric tons of P	3,387	3,835	3,543	2,571	3,649	3,731	3,911

Yahara River Watershed
Wisconsin Agricultural Surveys

Year	2012	2013
Corn:		
All corn planted (ac.)	95,641	91,741
Grain corn harvested (ac.)	75,593	78,588
Grain corn yield per acre (bu/ac)	112	176
Silage corn harvested (ac.)	20,048	13,153
Soybeans:		
All soybeans planted (ac.)	27,699	29,411
Harvested soybean (ac.)	27,699	29,411
Soybeans yield (bu/ac.)	44	50
Oats:		
All oats planted (ac.)	435	629
Harvested oats (ac.)	432	432
Oats yield (bu/ac.)	51	66
Winter Wheat:		
All wheat planted (ac.)	5,950	7,132
Harvested wheat (ac.)	5,950	7,132
Wheat yield (bu/ac.)	85	64
Hay Alfalfa (dry):		
Harvested hay/alfalfa (ac.)	17,126	17,471
Hay/alfalfa yield (Ton/ac.)	3	3
Other Hay:		
Harvested hay (ac.)	1,120	1,057
Hay yield (Ton/ac.)	2	2
Phosphorus removal in crops:		
Tons of P_2O_5	2,984	4,187
Metric tons of P	1,182	1,658

Study area (Upper Yahara River sub-watersheds)
Wisconsin Agricultural Surveys

Year	2012	2013
Corn:		
All corn planted (ac.)	38,814	36,572
Grain corn harvested (ac.)	18,766	23,419
Grain corn yield per acre (bu/ac)	112	176
Silage corn harvested (ac.)	20,048	13,153
Silage corn yield (Ton/ac)	12	22
Soybeans:		
All soybeans planted (ac.)	4,928	6,087
Harvested soybean (ac.)	4,928	6,087
Soybeans yield (bu/ac.)	44	50
Oats:		
All oats planted (ac.)	272	444
Harvested oats (ac.)	432	432
Oats yield (bu/ac.)	51	66
Winter Wheat:		
All wheat planted (ac.)	2,222	2,987
Harvested wheat (ac.)	2,222	2,987
Wheat yield (bu/ac.)	85	64
Hay Alfalfa (dry):		
Harvested hay/alfalfa (ac.)	10,893	11,576
Hay/alfalfa yield (Ton/ac.)	3	3
Other Hay:		
Harvested hay (ac.)	326	272
Hay yield (Ton/ac.)	2	2
Phosphorus removal in crops:		
Tons of P_2O_5	1,172	1,691
Metric tons of P	464	670

Appendix C – Optimization Model

Optimization models with two objective functions can be used to understand the tradeoffs between the two functions. In this case, for each increase in manure hauling costs, manure can be transported farther to avoid applying manure to sensitive fields in the winter. To examine this relationship, the optimization model was run initially using only one of the objective functions at a time. When the cost is minimized, also called the cost minimization point, the cost of hauling is low, but the application of manure to sensitive fields in the winter is high. The opposite point, titled "minimization of daily haul to sensitive fields" on the graph, allows costs to grow but minimizes the application of manure to sensitive fields in the winter. It was determined that the 0.30 point represented the lowest increase in cost but resulted in the greatest reduction in application of manure to sensitive fields in the winter. Additional increases in money spent for hauling did not significantly increase the impact to manure application, therefore we examined this point for all of the scenarios mentioned (as they all seemed to follow this trend).
In addition, a large share of P runoff to the Yahara surface waters is attributed to daily/weekly hauling of manure during the winter season; a big contribution of which comes from daily/weekly hauling to sensitive fields. It was initially our goal to configure the allocation of stored manure so that it only serves sensitive fields. However, inspecting the numbers shown above reveals that the volume of manure stored in existing storages surpasses the assimilative capacity of sensitive fields in the study area. This means that, theoretically, stored manure quantities are sufficiently large and can be allocated to only serve the sensitive fields in the study area without the need for additional storages. In reality, however, this allocation of manure is neither realistic nor optimal because:

1. Most producers who own local storages also own (or contract) fields in proximity to their livestock operations and would prefer to use locally-generated manure on their fields.
2. This allocation can lead to increased over-the-road manure traffic causing road deterioration and an excessive transportation cost.
3. Non-sensitive fields still contribute to overall P-runoff due to winter application. This means that adding new manure storages would still contribute toward reducing winter application P runoff, even if they only served non-sensitive fields.

Since we do not have a definite estimate of the relative contribution to P runoff from sensitive versus non-sensitive fields, we chose to assign a weight value of 1 to the sensitive fields, while testing different weights on the non-sensitive fields, one at a time, that range from 0 to 1. The objective of this approach is to determine the role of importance assigned to sensitive fields, relative to non-sensitive fields, on the optimization outcomes, namely, the added manure storages (location, size, number) and the overall transportation cost. This also means that for every weight assignment, say, {1} for sensitive fields and {0.5} for non-sensitive fields, multiple optimization runs were evaluated to determine the best compromise point that reduces both the daily haul to fields and the total cost of manure transportation. In the cases presented in this report, the sensitive fields were weighted to be twice as important (1/0.5 = 2) as the non-sensitive fields.

Additional constraints or guidelines for the optimization model include:

- Haul distance was determined by multiplying the straight line distance by 1.5 to represent the distance over the roads;

- Manure storage construction costs included $50,000 in fixed costs per storage and $250 per 1,000 gallons;
- Hauling costs were set at $0.01 per gallon per mile, which is conservative;
- Milk production was determined to be 25,100 pounds per cow per year for all cases except the increased milk production, which used 28,700 from DHI herds, and for the future scenario, which used 32,500 pounds per cow per year

Appendix D -Assumptions for runoff phosphorus loss reduction analysis when adding 19 million gallons of storage in Upper Yahara Sub-Watersheds

The Wisconsin P Index was run using Snap Plus software (UW Soils 2015) for 504 fields in the Upper Yahara River sub-watersheds identified as receiving liquid manure from six potential storage locations, which were identified by the optimization model described in Appendix C. Each field was assigned a rotation type according to the crops grown from 2008 to 2015. Each field was examined using 2015 aerial photos to determine if the entire field was still in cropland. Areas that were no longer cropped were eliminated from the analysis, resulting in a 3% decrease in acreage (Table C-2).

Table C-1. Acres and rotation types identified for fields used in runoff analysis

			Rotation type (Percent of Acres)			
Storage	# of sensitive fields	Acres	Dairy	Row crops	Continuous corn	Grass hay/ pasture
1	64	522.3	62	15	9	13
2	97	999	61	27	5	7
3	96	863.3	40	41	16	3
4	114	1021	17	52	19	12
5	69	534.8	54	19	12	15
6	64	539.6	66	6	17	10

Table C-2. Acres in analyzed fields in 2010 and 2015

Storage	Acres from 2010	Acres after review of 2015 aerial photos
1	532.1	522.3
2	1011.5	999
3	889.6	863.3
4	1041.8	1021
5	542.5	534.8
6	583.7	539.6

Assumptions used in Snap Plus

Initial Soil P concentrations: As soil test data are not available for these fields, the median soil test from nutrient management plans in the Six Mile Creek area was used for all fields.

Soil test: P = 57 ppm, OM% = 3.5

Representative Rotations:

Continuous corn:
High-erosion — alternating years of corn grain and corn silage with fall chisel plowing and spring disking and no-till
Low-erosion — continuous corn for grain with no-till
Manure every year

Row Crop:
High-erosion — Corn grain 1yr, corn silage 1 yr and 1 yr soybean with fall chisel plowing and spring disking
Low-erosion — Corn grain 2 yr and 1 yr soybean with no tillage
Manure every year

Dairy Rotation:
High-erosion — Corn silage 3 yr and alfalfa seeding + 2 yr established alfalfa with fall chisel and spring disking for corn and alfalfa seeding
Low-erosion — Corn grain 3 yr and alfalfa/grass mix seeding + 2 yr established alfalfa grass with no tillage
Manure before corn at rate equivalent to 2 times annual average rate and no manure in alfalfa years

Grassy hay/pasture:
Continuous grass hay with no tillage
Manure every year

Yields for crops were selected so they match as closely as possible the yields from Table 1 in the main text. Tillage was designated as up and down slope unless rows on the contour or contour strips were evident in the aerial photos.

Manure application types and rates with and without storage:

For the scenarios without storage, manure was applied as a semi-solid to the surface with one third applied in the winter. With the added storages, it was applied as stored (slurry) manure in spring and fall and incorporated with tillage in the high-erosion scenarios. For low-erosion managements (no-till) in fall and spring, the manure application was injected on fields with less than 4% slope. On higher slopes, it was surface applied because the injection increased estimated soil loss so much that it resulted in greater runoff phosphorus losses than the surface-application. On grass hay, one third of the manure was applied in the winter and two thirds in summer without storage and in fall, spring and summer with storage.

The slurry manure applied from storages to these fields averaged 8,400 gallons per acre per year at 7.8% dry matter with first year available manure analysis in pounds per 1,000 gallons of:

N surface-applied — 8.3; N incorporated — 11; N injected 13.8; P_2O_5 — 9.1
This nutrient content is equivalent to the following first year available pound per ton of semi-solid manure with 15% dry matter:
N surface-applied — 3.2; N incorporated — 3.8, P_2O_5 — 4.2