

# ManureTech Decision Support Tool (DST) for Dairy

Version 1.0.2

## User and Technical Guide

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## How to Use this User and Technical Guide

This User and Technical Guide provides an introduction and detailed explanation about the ManureTech Decision Support Tool (DST) for Dairy. This document is organized into two parts. First, the User Guide presents an introduction to the DST and a Step-by-Step guide with a case study that walks the user through inputting farm-specific information and viewing results. Second, the Technical Guide provides detailed descriptions of the data, models, and analysis used in the development of the DST, as well as a list of Appendices providing additional details and supplemental information.

Throughout the User and Technical Guide, the following specific font styles are used to highlight features and content for easy identification:

- **Navigation buttons** in the DST are displayed in bold.
- *Page names* referencing the DST are written in italics.
- “Variable names” are presented in quotes.
- **User inputs** appear with a gray background.
- **[Section references](#)** within the manual are shown in blue, bold, and underlined, and they hyperlink to the relevant section for quick access.
- **Important comments** are emphasized by underlining words.

This User and Technical Guide is organized into the following sections:

### Part 1. User Guide

1. Introduction
2. Step-by-Step Quick Guide

### Part 2. Technical Guide

1. Data, Models, and Methods
2. List of Appendices

**Appendix 1** – List of Dairy MMS scenarios used in the DST.

**Appendix 2** – Descriptions and assumptions for each unit process.

**Appendix 3** – Mass balance calculations.

**Appendix 4** – Superuser features.

**Appendix 5** – List of inputs for example simulation (given in User Guide Section 2)

**Appendix 6** – Glossary of terms.

**Appendix 7** – Climate Divisions.

**Appendix 8** – References.

Use the Table of Contents on the following page to navigate directly to the sections needed by using the control key and then selecting the section of interest.

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# Part 1. User Guide

## 1 Introduction to the DST

### 1.1 Purpose

The purpose of the **ManureTech Decision Support Tool (DST) for Dairy** is to assist in optimizing manure management in freestall and compost bedded pack barns from collection to land (if any) application (if any). It is not designed to serve as a whole farm tool that considers a specific breed, herd health, milk quality, barn construction, etc. Instead, the DST is designed to demonstrate how well a user’s current or desired manure management system (called a Baseline) can meet specific economic, environmental and technical goals set for a given farm as compared to a suite of 92 total available Manure Management Systems (MMSs). The DST is designed to evaluate one Baseline at a time, not necessarily an entire farm; thus, users with more than one manure management system on a farm will run the DST separately for each system. By providing data-driven recommendations based on customizable user inputs and priorities, the DST empowers users to make better, informed decisions based on balancing economic, environmental, and technological considerations.

### 1.2 Overview of Methodology and Development

The DST evaluates a total of 92 predefined “Scenarios” (see Technical Guide [Part 2.6.1](#) (Appendix 1)) utilizing a diverse array of MMSs, encompassing processes associated with manure collection, treatment, storage, and land application. It calculates key economic, environmental, and technological metrics (Table 1a) for each scenario and integrates them into a multi-criteria decision algorithm. As one of the goals of the DST is to inform users of the capabilities of different MMSs, the DST evaluates all 92 MMSs with each run, regardless of whether a user has an interest in actually adopting some of those systems or not.

Users can assign priority levels (from 0 for low priority to 100 for high priority) to these metrics, allowing the DST to rank scenarios based on user preferences. The DST provides ranked recommendations tailored to farm-specific needs and goals.

- To learn how to specify farm priorities, see User Guide [2.3.9](#).
- For details on how priorities influence scenario rankings, see Part 2.1.

The DST was developed on an Excel-based platform following mass and energy balances for various MMS scenario alternatives representing current and emerging treatment technologies and practices. Go to User Guide [1.6](#) for information about downloading the DST.

All input variables are prepopulated with default values representing average or expected conditions. Users can replace some or all of these default inputs with farm-specific values, which are cross-checked with predefined conditions to help ensure accuracy and reliability.

Results are stored locally, ensuring privacy and enabling users to share findings at their discretion.

### 1.3 Assumptions and Limitations

This DST was developed to assist users in evaluating outcomes and tradeoffs associated with a set of 92 predefined manure management scenarios comprised of various processes and treatments. The following are some of the assumptions and limitations of this DST:

- Models manure management systems only; is not a whole farm planning DST.
- Models manure management from primarily freestall barns but includes one scenario with compost bedded pack barn.
- Evaluates relative differences in metrics across scenarios; is not meant to estimate the actual cost of any given MMS.
- Compares a user-input Baseline scenario with either the top ranked alternatives or scenarios of choice by the user.
- Uses terminology that might be different from terminology used in certain parts of the U.S. – user should review the Glossary of Terms to understand what is meant by pond, anaerobic lagoon, etc.
- Units are generally given on a per head per year basis.
- Specific animal breeds are not included in the DST, although the user can certainly adjust operative factors such as animal weight and manure characteristics to align with their on-farm breeds.
- Similarly, specific crops or crop cycles are not included in the DST, although the user can assess their average crop nutrient fertilizer needs and adjust the values in the DST to align with their on-farm circumstances.

### 1.4 Target Audience

The DST was primarily developed for use by dairy farmers, key advisors, consultants, and researchers. It models manure production in the barn(s), manure production in the milking center, and process water related to flushing the barn, rinsing the milking parlor, and contribution of sprinkler water to the manure stream, when applicable. Most scenarios in this DST use freestall barns, although one scenario uses a compost bedded pack barn. The DST evaluates manure management options under varying regional climates, costs, and farm-specific conditions, offering nationwide applicability. User-friendly, interactive, and customizable, the DST supports informed decision-making for farms of all sizes.

Table 1a. List of the eighteen priority metrics across the three impact categories evaluated in the DST.

<b>Economic</b>	<b>Environmental</b>	<b>Technology and Treatment</b>
1. Capital costs (annualized)	1. Carbon (GHG) emissions	1. Adoption rate
2. Operational costs	2. Energy requirements	2. Operational reliability
3. Cost-savings	3. Land requirements	3. Operational resilience
4. Fertilizer nutrient value of manure	4. Water requirements	4. Labor required for land application
5. Revenues	5. Nitrogen footprint	5. Land area needed for land application
6. Net economic costs or benefits	6. Phosphorus excess	6. Transportability of excess manure

## 1.5 Help and Technical Support

This DST serves as a valuable resource for evaluating diverse metrics alongside the trade-offs inherent to manure management systems. While Version 1.0 has been extensively tested, the complexity and comprehensive nature of this Excel-based program can occasionally lead to issues. Feedback is invaluable to us, as it helps us maintain and enhance this resource to better support decision-making in Dairy manure management. If there are any questions or problems with the program's functionality, contact Dr. Rick Stowell, Animal Environmental Engineer at the University of Nebraska-Lincoln.

**Contact:** Dr. Stowell via email at [richard.stowell@unl.edu](mailto:richard.stowell@unl.edu).

## 1.6 Downloading the Program

The Excel-based DST is built for Microsoft Excel 2007 or later, with optimal performance on Microsoft 365. This DST is optimized for use with the most recent versions of Excel, and older versions may not support all the features. Compatibility with other spreadsheet software, such as Google Sheets or LibreOffice, is not guaranteed, and using these platforms may lead to unexpected behavior. Please check with your system administrator if there are any default settings that must be adjusted to ensure file functionality.

The DST is free to use and can be downloaded here: <https://lpeic.org/decision-support-resources/#ProjectTool>

Save the file locally as a template to create copies for different simulations. The DST is fully self-contained and operates offline, ensuring no external data transmission. Periodically check the project website for updated versions.

The download file will include the Excel DST and this User and Technical Guide.

## 1.7 Getting Started

When opening the DST, the program begins on the *Welcome* page, which highlights the institutions involved in its development. From there, navigate to the *Example* page for sample input types and guidance on the input process.

After the *Example* page, a user can navigate to any or all of the input pages to enter farm- or site-specific inputs, including your priorities for the optimal MMS. Inputs can be modified at any time, with results updating automatically.

This DST generates results for all of the pre-defined MMSs. **Even if an input question does not apply to your existing farm, the DST still needs the input to run all of the predefined scenarios. If a user does not know how to specify an input, or otherwise prefers to use the default, those questions may be skipped, and the DST will run the simulation with the default values for those inputs.**

Once satisfied with the inputs, view each results page to see how different scenarios rank relative to each other and compare the economic, environmental, and functional and logistical outcomes of each. There may be cases where the DST recommends a scenario that you do not want to consider. For example, if you will only consider using sand bedding, the DST may still recommend organic bedding. In this case, you can adjust the Alternatives that are presented by selecting the next best ranking until the table lists only sand bedding options. See User Guide [0](#) for detailed instructions on how to do this. The User Guide [2.4](#) provides an interpretation of results.

## 1.8 Saving Your Simulation and Printing Records

Once the Excel file is downloaded it can be saved to the local drive for future reference, further analysis, or sharing with colleagues. If running multiple simulations, the file may be saved multiple times under different file names. Each Excel file serves as a complete record of the simulation, including all variables, user-defined settings, and calculated outputs.

Additionally, the DST offers a printing feature that allows users to generate a hard copy or PDF of the records. The *Inputs Summary* page and the *Results Summary* page have a print area specified in the settings to make for faster and easier printing for documentation, presentation, or decision-making purposes. You can print these pages by selecting File > Print; to make printing fast and easy, a pre-defined print area has been set.

## 1.9 Adjusting The Inputs

The DST updates all of the calculations immediately, allowing users to see the immediate effects of their input adjustments on the analysis. Upon downloading the DST, all input variables are preset to their default values. A user can navigate through the User Input pages and enter and modify values specific to the farm's circumstances. The DST provides the flexibility to revisit any of the User Input pages at any time to adjust values, refine inputs, or change priorities.

## 1.10 Advanced Customization of Input Variables

In addition to the main User Input pages, the DST includes a *User Data* page that provides access to all the variables used in the DST. While the primary input pages allow users to adjust values for key variables, the DST incorporates hundreds of variables, making it impractical to display them all on these pages. The *User Data* page serves as a comprehensive reference, listing every variable along with its name, description, minimum and maximum allowable values, and default settings. Users who want more granular control over the DST's functionality can use this page to adjust input values for any variable not covered on the main user input pages, allowing for a more customized analysis. However, making adjustments on the *User Data* page should be done with caution, as inputs that are outside the expected range may lead to errors in calculations and disrupt the functionality of the DST. See the Technical Guide [Part 2.6.4](#) for more information.

## 1.11 Troubleshooting

This Excel-based DST is a large file running many operations and may therefore be subject to glitches or crashes. It is important to save input values as they are entered into the DST. If the DST glitches or crashes, there are several steps that may be taken to resolve the issue:

- First, try closing and reopening the file to see if the problem persists.
- If this proves unsuccessful, ensure that the version of Excel is up to date (Excel 2007 to current).
- If the issue continues, redownload the DST from the original website to work with a fresh, uncorrupted version of the file. Make sure that the file is saved locally on the computer and does not run from a cloud storage location, as this can sometimes cause errors with more complex Excel functionalities.
- If errors persist, check the computer system resources (such as RAM and CPU usage) while the file is open, as running the DST alongside other resource-intensive programs can cause performance issues.

For additional support, reach out to the technical support team – go to User Guide [1.5](#) for contact information.

## 2 Step-by-Step Quick Guide

This Step-by-Step guide will walk the user through the DST, describing each input and results screen using an example case study.

### 2.1 Example Case Study

For example purposes, the case study farm used in this Step-by-Step Guide has the following characteristics:

- This is a 660 lactating, 630 heifers (replacements), and 79 dry cow dairy farm.
  - The breed of cow is not specified. Instead, inputs for cow weight and manure composition are set on other Input pages.
- The farm is located in the Finger Lake region of New York.
  - Locations are based on NOAA Climate Divisions by state and therefore the Central Lake region of New York will be selected on the appropriate input page. See Part 2.6.7 for map and list of Climate Divisions by State that is used for this DST. A hyperlink to the map is provided in the tool
- All stalls are sand bedded
- The farm uses the following “Baseline Manure Management System (MMS)” for comparison with other systems: sand bedding, skid steer, mechanical sand separator, pond, and tanker
- There are a total of 900 acres (400 ac owned, 500 ac rented) available on-farm to spread manure
- Manure is injected based on nitrogen (N) needs of the crop(s).
  - See User Guide [2.3.2](#) for instructions about specifying nutrient needs for various crops or crop rotations.
- A list of all case study farm characteristics and inputs can be found in Part 2.6.5.
- Descriptions for each of the MMS scenarios used in this DST can be found in Part 2.6.1.

## 2.2 Welcome Page

The file will open to the *Welcome* page which provides a brief overview of the purpose of the DST and lists the universities and agencies who have supported the development of this DST.

The screenshot shows the 'Welcome Page' of the ManureTech Dairy DST. The page is framed by a dark border with a navigation menu at the top and bottom. The 'Welcome Page' button is highlighted in yellow. The main content area features a blue header with the text 'Welcome to the ManureTech Dairy DST!'. Below the header are logos for 'Management of Nutrients for Reuse', 'University of Arkansas', 'Mizzou University of Missouri', and 'USDA NIFA'. The text below the logos states: 'The purpose of this DST is to assist in optimizing manure management in freestall and compost bedded pack barns from collection to land application on-farm and/or export off-farm.' It also includes 'Assumptions and Limitations' and 'Contact Information' for Dr. Richard Stowell.

The yellow buttons at the top and bottom of the page connect to the various input pages. The page currently being viewed is highlighted in a golden color. You may also click **Skip to Results Pages** to see the results. The **Next Page** button will move to the next page in the recommended sequence of pages.

For an example on how to fill out inputs, click the **Example Page** button at the bottom of the screen. Otherwise, click the **Next Page** or **Farm Info** button to move to the first input page.

## 2.3 User Input Pages

### 2.3.1 Example Input Types

The *Example Page* explains more about the DST and how to interact with it. Scroll down the page to see examples of the different types of input questions. Values entered on this page are for demonstration purposes and will not affect model results!

Note that for consistency, all DST input boxes have a light gray background color. There are variations in exactly how to interact with them which are shown in this order on the example page.

Dropdown inputs: Click the input box under “Your Choice”. A downwards pointing arrow appears on the top right of the box. The question “What is your favorite dessert?” offers five options. Click the arrow on the right side of the gray box to reveal the list of answer choices. Select the best option from the list. In this case, cake was chosen.

<i>What is your favorite dessert?</i>	
<i>Instructions</i>	<i>Your Choice</i>
Please select an entry from the dropdown:	Cake

Typed inputs: Click the answer box under “Your Value” and type in the desired value. The box under “Input Status” will show if the value is accepted (shows “Value accepted!”). If the inputted value is outside the minimum to maximum range, the box under “Input Status” will change to an orange color and state why (for example, “The value is too large!”). Adjust the answer so that the Input Status box shows “Value accepted!”. If the answer remains outside of the range provided, the default value will be used. This is to avoid accidental typos that will negatively affect the functioning of the DST.

<i>This is an example of an invalid input:</i>						
<b>Grocery Trips</b>	<b>Min</b>	<b>Max</b>	<b>Your Value</b>	<b>Default</b>	<b>Unit</b>	<b>Input Status</b>
How many?	0	100	325	50	trips/year	The value is too large!
Spending	0	300	150	100	\$/trip	Value accepted!

Click the **Next Page** or **Get Started!** Button to move to the *Farm Management Information* page.

### 2.3.2 *Farm Management Information*

The *Farm Management Information* page asks general farm questions and questions related to water use and land nutrient information.

First, a farm name may be entered to stay organized in case you run multiple simulations saved in different files.

In this case study, **Test Farm** is the name of the farm.

<b>What is the name of your farm?</b>	
<b>Instructions</b>	<b>Your Value</b>
Enter the farm name and/or a brief title for this evaluation:	Test Farm

Next, select from the predefined manure management system scenarios a baseline system for comparison with other scenario systems. This baseline scenario could reflect the current system used on farm or it could be any other system the user wishes to compare to the alternative scenarios recommended by the DST. The exact system used on farm may not be found as an option, but please choose that which most closely matches the system of choice. Once selected, a detailed description of the scenario appears in the box below. If the description does not match what is expected, try to select a similar system to see if it is a better match!

For the DST to function properly, a baseline scenario must be used. The default baseline scenario is set as a sand bedding, scrape skid, mechanical sand separator, pond, and tanker. This will be used unless you make a different selection.

<b>What manure system scenario do you want to use as the baseline for comparison?</b>	
<b>Recommendation: Select the scenario that most closely resembles your current system if you have one:</b>	
<b>Instructions</b>	<b>Your Choice</b>
Choose a scenario from the dropdown, for a longer description of the scenario see below:	Sand bedding, scrape skid, mechanical sand separation, pond, tanker
<b>Description of the scenario you have chosen:</b>	
The farm uses sand bedding in a freestall barn and a SS scrape system for barn cleaning. The scraped manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The resulting manure + wash water is pumped to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land-applied using tractor-pulled tanker method.	

Select the region of your state where your farm operates. See Part 2.3.3, [Part 2.6.2.3](#), and [Part 2.6.2.7](#) for information about how this affects the DST, for example the inputs for temperature and rain. In our case study [New York \(Central Lakes\)](#) is the location.

As mentioned above, regions are based on national climate divisions. See Part 2.6.7 to identify the climate division that corresponds to the farm location. A hyperlink within the question in the DST can take the website to identify the proper NOAA Climate Division.

<b>Where is the farm located? <a href="#">Click here to see the US Climate Divisions.</a></b>	
<b>Instructions</b>	<b>Your Choice</b>
Select an entry from the dropdown:	New York (Central Lakes)

The next set of questions is about water usage and nutrient application:

The first question asks if a sprinkler system is used to cool cattle in the barn. If “Yes” is selected, then additional information is requested about the time on per cycle, the number of cycles, and the flow rate. If “No” is selected, the DST instructs the user to skip those three questions. If some other type of water or evaporative cooling type system is used, answer “No” to using a sprinkler system.

See the Part 2.6.2.3 for more information about how sprinkler water is evaluated and used in the DST.

For this case study we’ve selected **Yes** for the use of sprinklers, the **defaults** are used for each related question.

<b>What are the sprinkler system settings and water flow rate?</b>						
<b>Sprinklers</b>	<b>Unit</b>	<b>Default</b>	<b>Your Value</b>	<b>Min</b>	<b>Max</b>	<b>Input Status</b>
Time on per cycle	min/cycle	3.00		0.00	5.00	Using default
Number of cycles	cycle/day	6.00		0.00	96.00	Using default
Flow rate	gal/head/min	0.10		0.00	3.00	Using default

The next question asks how much land is available on the farm for spreading manure each year. While land availability might vary each year, enter the average or typical amount of land available. Note that the default value is calculated based on the number of animals, as indicated on the next input page, *Animals*.

If there is no land available to apply manure nutrients, enter zero. This will create a situation where all the manure generated will be exported off-farm. See Part 2.3.3.9 and [Part 2.3.5](#) for more information about how the DST handles off-farm manure exports. If zero is entered for amount of land available, skip the next few questions about crop nutrient needs and answer the last question on this page about greenhouse gas emissions reduction credits.

In this case study, there are 900 acres available for manure application. If the farm manages some land on a phosphorus basis and some on a nitrogen basis, the tool must be run separately for each of those acres. In this case all acres are managed on the same nutrient basis so all 900 acres are entered here.

<i>How much land is available for spreading manure? Enter annual average land area.</i>						
Land Available	Unit	Default	Your Value	Min	Max	Input Status
For manure application	acre	2738	900	0	or more	Input accepted

If land is available to apply manure nutrients, answer the next two questions that ask the user to select which nutrient are applied for (i.e., is it on a nitrogen basis or a phosphorus basis?) and whether nutrients are applied using an injection or broadcast method. The DST does not account for any incorporation after application. The DST’s boundary is the first touch to the field.

In this case study nutrients are applied to meet nitrogen (N) requirements using the injection method.

<i>Which nutrient do you apply for (i.e., is it a nitrogen or phosphorus basis)?</i>	
Instructions	Your Choice
Select from dropdown:	N

<i>How will liquid and/or slurry manure streams be applied to fields?</i>	
Instructions	Your Choice
Select from dropdown:	Injection

Next, for nutrient application rates, in the “Your Value” column, enter the average annual amount of each nutrient needed to add per acre, after considering any soil test results, crop nutrient needs, and crop rotation. Enter the average annual nutrient additions you expect to need for nitrogen, phosphorus (in form of P<sub>2</sub>O<sub>5</sub>) and potassium (in form of K<sub>2</sub>O).

In this case study we will use the default values for N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O so leave the “Your Value” cells blank.

<i>After considering your soil test results and crop rotation nutrient needs for land that receives manure, what are your average annual nutrient application rates for N-P-K?</i>						
Crop Nutrient	Unit	Default	Your Value	Min	Max	Input Status
<b>Nitrogen (N)</b>	lb N/acre	195		1	500	Using default
<b>Phosphorus (P<sub>2</sub>O<sub>5</sub>)</b>	lb P <sub>2</sub> O <sub>5</sub> /acre	55		1	350	Using default
<b>Potassium (K<sub>2</sub>O)</b>	lb K <sub>2</sub> O/acre	90		1	300	Using default

The next question asks how many days are typically available in the farm’s region for applying manure, considering weather-related constraints. It’s important to note that this is not asking how many days it currently takes to complete land application, but rather the overall window of opportunity for manure application in a typical year.

This timeframe generally applies to regular manure removal, such as when manure is land applied at least once annually (e.g., storage lagoon liquids, pond slurry, separated and settled solids, and compost). Additionally, the DST accounts for scenarios with a storage lagoon that accumulates sludge over several years and manure sludge is land applied less frequently. (These timeframes can be adjusted by a Superuser. See Part 6.6.4). In such cases, manure application might take place during a particularly favorable year, increasing the number of available days. For these "sludge-year" applications, the DST assumes a 30% increase in available days due to the more flexible timing.

For further details on how the application window is factored into the DST’s calculations, refer to Part 2.3.2.3.

For this case study, 65 days are typically available to land apply manure.

<i>What is your window of opportunity, in terms of days per year, that you have available for applying manure?</i>						
Typical Year	Unit	Default	Your Value	Min	Max	Input Status
Days available	day/year	50	65	10	365	Using default

Some treatment systems like anaerobic digestion and covered lagoons might result in a reduction in carbon emissions on the farm, thus generating carbon offset credits. To see how the potential to generate carbon credits could impact the economics of possible MMSs evaluated in this DST, please list the price expected to be paid in terms of dollars per mass of CO<sub>2</sub> equivalent. See Part 2.3.5 for information about how carbon credits are generated and used within the DST.

In this case study we expect to receive \$0 per credit or \$0 per metric ton of CO<sub>2</sub>e as credits are generally not available yet throughout the US. If credits are selected, these values are in 2024 dollars.

<i>What price would you expect to be paid for eligible carbon credits? Enter a price assuming credits would be earned (1 credit = 1 metric ton CO<sub>2</sub>e)</i>						
Carbon Credits	Unit	Default	Your Value	Min	Max	Input Status
Price	\$/credit	0	0	0	50	Input accepted

Please press the **Next Page** button to continue to the *Animals on the Farm* page.

### 2.3.3 *Animals on the Farm*

The *Animals* page asks questions about the animals that contribute to the baseline manure management system selected on the *Farm Management Information* page. These animals are placed in one of three categories: 1) lactating cows; 2) dry cows; and 3) heifers.

For each type of animal, select “Yes” or “No” to whether those animals’ manure is managed with the baseline treatment system. If yes, provide the number of those animals and their average weight.

In this case study farm, there are 660 lactating cows with an average weight of 1500 pounds each.

<i>How many lactating cows do you have? What is their average body weight?</i>						
Lactating cows	Unit	Default	Your Value	Min	Max	Input Status
How many?	head	600	660	100	7500	Input accepted
Average weight	lb/head	1400	1500	800	1700	Input accepted

In this example farm, manure from 630 heifers being combined and managed with manure from the lactating herd. These animals have an average weight of 750 pounds from birth to pre-calving. Therefore, select **yes** to the first question below and enter their number and weight in the Your Value box in the second question.

<i>Is manure from heifers combined and managed with manure from the lactating herd?</i>	
Instructions	Your Choice
Select Yes or No from the dropdown:	Yes

Please answer the below questions about the number of heifers and their average body weight.

<i>How many heifers do you have? What is their average body weight?</i>						
Heifers	Unit	Default	Your Value	Min	Max	Input Status
How many?	head	0	630	0	7500	Input accepted
Average weight	lb/head	850	750	300	1100	Input accepted

There is manure from dry cows being combined and managed with the manure from the lactating and heifer herds. Therefore, answer Yes to the first question.

There are 79 dry cows in this case study, each with an average weight of 1650 pounds, the default average weight.

<i>Is manure from dry cows combined and managed with manure from the lactating herd?</i>	
Instructions	Your Choice
Select Yes or No from the dropdown:	Yes

<i>How many dry cows do you have? What is their average body weight?</i>						
Heifers	Unit	Default	Your Value	Min	Max	Input Status
How many?	head	120	79	0	7500	Input accepted
Average weight	lb/head	1500	1650	800	1700	Input accepted

Continue until all of the relevant questions have been answered for all animal types. Once to the end, click on **Next Page** to move to the *Manure Characteristics* page.

### 2.3.4 Manure Characteristics

The *Manure Characteristics* page allows for review of the values related to water used for transporting manure from the barn, as well as the characteristics of excreted manure for each type of animal evaluated in the DST.

First, the DST asks for information related to the maximum depth that you could build manure storage facilities on your farm. If you are unsure, the DST will use the default, which is **25 feet**. This example uses that default. Note that this question is asking about the maximum depth; however, the DST will use a design depth, which may be less than the maximum depth chosen here, based on the storage type (e.g., pond or storage lagoon) and number of animals. See Part 2.6.2.7 for detailed descriptions and definitions of these storage types as used in this DST.

<i>For manure storage facilities such as ponds or lagoons, what is the maximum depth that you could build them to?</i>						
Depth	Unit	Default	Your Value	Min	Max	Input Status
Maximum depth	ft	25.00		6.00	50.00	Using default

Next, enter the percentage of flush water that is recycled from manure storages when a flush water system is used for manure collection from the barn. The default value for the case study is that **100%** of flush water is recycled. If this value is changed, that percentage will be recycled water, and the remaining amount to meet requirements will be fresh water. While there are situations in which recycled water could be used, our assumption is that the water used to remove the milking barn is always fresh water.

<i>When using a flush water manure collection system, what percentage of water do you recycle from storage facilities?</i>						
Cleaning Water	Unit	Default	Your Value	Min	Max	Input Status
Percentage Recycled	%	100%		0%	100%	Using default

Next, indicate how much total water you might expect to use (sum of fresh and/or recycled water) during manure collection in the barn for each type of manure handling system. If you are unsure about the amount of water that would be used for any of the systems listed, please leave it blank and the DST will use the default value. Also, note that water used to rinse manure from the milking parlor is always assumed to be fresh water.

The case study uses the **default** amount of water for both the Flush and Scrape systems.

<b>How much water would you use to clean the following manure handling systems? Default value estimate changes with number of animals on farm.</b>						
<b>Cleaning Water</b>	<b>Unit</b>	<b>Default</b>	<b>Your Value</b>	<b>Min</b>	<b>Max</b>	<b>Input Status</b>
Flush System	gal/head/day	55.48		39.63	237.75	Using default
Scrape System	gal/head/day	0.00		0.00	2.64	Using default

The remaining questions focus on the animal manure characteristics associated with each of the possible animal types.

The user may adjust the properties of the manure for any of the animal types whose manure is treated with the MMS. The case study uses the default values for all the manure properties for all herds. The estimates for manure production and characteristics are based on published sources and are discussed in detail in the Technical Guide [Part 2.6.2.1](#).

<b>What properties of the lactating herd's manure would you like to adjust?</b>						
<b>Category</b>	<b>Unit</b>	<b>Default</b>	<b>Your value</b>	<b>Min</b>	<b>Max</b>	<b>Input Status</b>
<b>Manure produced</b>	lb/head/day	166.01		114.64	216.05	Using default
<b>Total Solids (TS)</b>	lb/head/day	21.54		15.06	28.02	Using default
<b>Volatile Solids (VS)</b>	lb/head/day	18.36		12.85	23.88	Using default
<b>Nitrogen</b>	lb/head/day	0.99		0.68	1.30	Using default
<b>Phosphorus as P2O5</b>	lb/head/day	0.66		0.46	0.86	Using default
<b>Potassium as K2O</b>	lb/head/day	0.64		0.44	0.84	Using default

<b>What properties of the heifer herd's manure would you like to adjust?</b>						
Category	Unit	Default	Your value	Min	Max	Input Status
Manure produced	lb/head/day	44.97		30.86	59.53	Using default
Total Solids (TS)	lb/head/day	6.72		4.70	8.75	Using default
Volatile Solids (VS)	lb/head/day	5.62		3.92	7.32	Using default
Nitrogen	lb/head/day	0.18		0.11	0.24	Using default
Phosphorus as P2O5	lb/head/day	0.09		0.04	0.13	Using default
Potassium as K2O	lb/head/day	0.15		0.09	0.22	Using default

<b>What properties of the dry cow herd's manure would you like to adjust?</b>						
Category	Unit	Default	Your value	Min	Max	Input Status
Manure produced	lb/head/day	84.24		57.32	110.23	Using default
Total Solids (TS)	lb/head/day	10.63		7.43	13.82	Using default
Volatile Solids (VS)	lb/head/day	9.17		6.42	11.93	Using default
Nitrogen	lb/head/day	0.35		0.24	0.46	Using default
Phosphorus as P2O5	lb/head/day	0.20		0.13	0.27	Using default
Potassium as K2O	lb/head/day	0.37		0.24	0.51	Using default

Once the relevant manure characteristics have been reviewed, click **Next Page** to continue to the *Bedding Costs and Excess Manure Streams* page.

### 2.3.5 *Bedding Costs and Excess Manure Stream Fates*

On this page, specify how much organic or sand bedding is expected to be used, the price expected to pay for bedding, and how excess manure might be managed when the available land cannot accommodate all the manure nutrients produced. Input how much manure is expected to be paid to haul off-farm, given away, or sold, as well as any costs or potential income from these actions.

First, enter how much organic or sand bedding you would expect to use for each type of system. Note that these values are based on dry weight. Even if you use only sand bedding as in this example, the DST needs an organic bedding amount to evaluate MMS scenarios which include organic bedding. If you are unsure, use the default value.

In this case study the default is used for each bedding type.

<i>Default values have been entered for both sand and organic bedding. Adjust as appropriate for your region.</i>						
Bedding Type	Unit	Default	Your Value	Min	Max	Input Status
Organic bedding	lb/head/day	4.34	10	2.20	11.02	Input accepted
Sand bedding	lb/head/day	44.09	65	33.07	110.23	Input accepted

#### Bedding Usage – Default & User Inputs:

Default bedding values (dry weight basis) are pre-entered based on regional averages. Users can adjust using the

The default bedding usage values (both organic and sand, on a dry weight basis) were derived from regional averages reported in the NRCS Agricultural Waste Management Field Handbook (AWMFH), Chapter 4 (Tables 4-11 and 4-12) (USDA NRCS, 2019), and adapted using data from university extension publications. These values were selected to represent typical bedding usage rates observed in commercial dairy operations.

Second, similar to organic and sand bedding amounts, the DST will evaluate economics associated with scenarios using the cost for each type of bedding. If the cost of a certain type of bedding is unknown, leave it blank and the DST will use the default value.

The default prices are used for the case study.

<i>What are your prices for organic or sand bedding?</i>						
Costs	Unit	Default	Your Price	Min	Max	Input Status
Organic bedding	\$/ton (2000 lb)	170.00		60.00	350.00	Using default
Sand bedding	\$/ton (2000 lb)	14.00		9.00	23.00	Using default

The next table refers to any excess manure that may be generated on-farm. Note that when organic bedding is used in a MMS scenario, any separated or composted solids will first be recycled for bedding. After that, when manure nutrients generated on farm exceed the amount that can be applied on-farm (based on the land availability, crop nutrient application rates, and manure nutrient characteristics as specified on the *Farm Management Information* page) they

must be exported off-farm in one or more of the following ways: 1) paying to have it hauled off, 2) giving it away or 3) selling it.

Given the variety of predefined manure management scenarios evaluated by the DST, several types of treated-manure effluent streams may be generated and managed differently. The following lists all of the possible manure effluent streams in the order in which they are used on farm and then potentially exported (again, after solids and compost are recycled as bedding, when applicable):

1. liquids from lagoon storage;
2. slurry from pond storage;
3. sludge from lagoon storage;
4. separated solids from solid-liquid separation;
5. settled solids from settling basin or weeping wall; and
6. compost.

Some of these streams may apply to the chosen current system, while others may represent an alternative system. Please see Part 2.6.6 for definitions of these systems.

In the first table, enter the percentage of each manure stream that, if in excess of land nutrient needs, a farmer would:

1. Pay to haul off – farm pays an individual to haul manure off farm. Farm incurs a cost, based on a unit cost in \$/volume or weight.
2. Give away – farm allows an individual to come take the manure. Farm incurs NO costs and receives no benefits. If the farm is expected to use any resources, such as agitating prior to giving it away, they should include that cost in “Pay to haul off” by estimating the cost in \$/volume or weight.
3. Sell – farm sells manure to an individual. Farm earns revenue, based on a unit cost in \$/volume or weight.

The percentages for each stream should add up to 100%. If the total for a given manure stream does not equal 100%, the DST will use the default values.

Even if the farm doesn't currently handle one or more of these manure streams, the DST requires input on how excess amounts would be managed. For example, if the farm does not generate compost, the user can either input values based on potential circumstances or leave the field blank to use the default values.

The default values for each stream are shown in the “Default” column, with percentages listed in the following order: 1) % pay to haul off; 2) % to give away; and 3) % to sell. For example, for liquid manure, the default shows “0% - 100% - 0%”, meaning that the farmer does not have to pay for any amount to be hauled off; that 100% of the excess liquid manure is given away at no cost and no revenue for the farmer; and that the farmer does not sell any of the manure liquids

This case study uses the default values for each manure type. For liquid, slurry, and sludge, 100% of any excess manure of these types is given away at no cost to the farmer. For separated solids, settled solids, and compost, 100% of any excess manure of these types is sold.

<i>If you have excess manure that cannot be applied to your land, what would you do with it?</i>						
Excess Manure	Default	Pay to haul off	Give away	Sell	Your Sum	Input Status
Liquid	0% - 100% - 0%				0%	Sum is not 100%, using defaults
Slurry	0% - 100% - 0%				0%	Sum is not 100%, using defaults
Sludge	0% - 100% - 0%				0%	Sum is not 100%, using defaults
Separated Solids	0% - 0% - 100%				0%	Sum is not 100%, using defaults
Settled Solids	0% - 0% - 100%				0%	Sum is not 100%, using defaults
Compost	0% - 0% - 100%				0%	Sum is not 100%, using defaults

If "pay to haul off" for one or more manure streams was indicated in the table above, enter the expected cost in the next table in the "Price Paid" column.

<i>If you PAY to have any excess manure streams hauled off-farm, what is the cost?</i>						
Manure Costs	Unit	Default	Price Paid	Min	Max	Input Status
Liquid	\$/1000 gal	\$16.50		\$0.01	\$60.00	Using default
Slurry	\$/1000 gal	\$16.50		\$0.01	\$60.00	Using default
Sludge	\$/1000 gal	\$16.50		\$0.01	\$60.00	Using default
Separated Solids	\$/ton (2000 lb)	\$41.00		\$0.01	\$117.00	Using default
Settled Solids	\$/ton (2000 lb)	\$41.00		\$0.01	\$117.00	Using default
Compost	\$/ton (2000 lb)	\$41.00		\$0.01	\$117.00	Using default

Likewise, if “Sell” was indicated for any excess manure, indicate the expected selling price in the final table. In the case study the **default** prices are assumed for any separated solids, settled solids and/or compost that is sold.

<i>If you receive revenues from any excess manure streams SOLD off-farm, what is the price?</i>						
Manure Sales	Unit	Default	Sale Price	Min	Max	Input Status
Liquid	\$/1000 gal	\$3.50		\$0.01	\$16.00	Using default
Slurry	\$/1000 gal	\$6.00		\$0.01	\$30.00	Using default
Sludge	\$/1000 gal	\$40.00		\$0.01	\$534.00	Using default
Separated Solids	\$/ton (2000 lb)	\$26.50		\$0.01	\$188.50	Using default
Settled Solids	\$/ton (2000 lb)	\$2.50		\$0.01	\$14.50	Using default
Compost	\$/ton (2000 lb)	\$45.00		\$0.01	\$80.00	Using default

Once these tables are completed, click on **Next Page** to be taken to the *Tractor Properties* page.

### 2.3.6 Tractor, Drag Hose, and Tanker

The DST evaluates a variety of manure management processes, including land application activities.

For the first two entries, use the drop-down arrow to indicate the maximum and average distances expected to apply manure to fields on your farm, as these can impact results.

Then, use the drop down to select the tanker size that is expected to be used (regardless of if a tanker is already used or not, as some scenarios will evaluate the use of a tanker for application). If you use multiple tanker sizes on your farm, you can choose the most representative one from the list or run the DST multiple times to capture impacts of different tanker sizes.

The last three entries relate to the number of hours a tractor is expected to be used over the course of a typical day or year.

If any items do not apply to the user, or if there is zero (0) land available for manure application (as input on the *Farm Info* page), please leave the cell blank and allow the default value to be used. This ensures that the DST can evaluate the variety of systems simulated in the DST.

See the Technical Guide [Part 2.3.2.3](#) and [Part 2.6.2.8](#) for more information about these inputs and how they are used in the DST.

In the case study, an average of 3 miles and a maximum of 5 miles is assumed for the one way distance for land application of manure by drag hose or tanker. The tanker size is 4500 gallons. All other tractor values are left to their default.

<i>Specify the information below about land application distances and equipment usage.</i>						
Property	Unit	Default	Your Value	Min	Max	Input Status
Average distance for land application of manure on-farm (drag hose or tanker)	miles	2	3	0.1	50	Input accepted
Maximum distance for land application of manure on-farm (drag hose or tanker)	miles	4	5	3	100	Input accepted
Tanker Size (select from dropdown)	gal	9000	4500	3000	9000	Input accepted
Number of hours an individual tractor is used for all on-farm activities (MMS and otherwise) over a year	hr/year	1000		600	2000	Using default
Maximum number of hours that a tractor can be used in a single day	hr/day	12		1	24	Using default
Maximum number of hours that a tractor can be used over a year	hr/year	2000		1500	8760	Using default

Once you have provided any applicable information, please click **Next Page** to move to the *Capital Costs* page.

### 2.3.7 Capital Costs

See the Technical Guide [Part 2.3.2](#) for details about how capital costs are calculated.

The *Capital Costs* page allows you to adjust the overall costs for construction activities and equipment items. You can do so by adjusting all costs in the construction and/or equipment categories.

Construction items include sand lane, reception pit, concrete settling basin, weeping wall, pond, lagoon, concrete slab, transfer channel, installation of equipment, and engineering design. Equipment items include things like agitators, pumps, separators, and tractors. National data were used to estimate all of these capital costs. Therefore, costs may vary according to user-specified location and landscape conditions. For example, a farm located in an area with shallow bedrock could make it more difficult to excavate, causing construction costs to be generally higher than the default used in the DST.

The reference table toward the top of the page shows national average prices for some of the common equipment items used in the DST. If a user thinks that their costs are generally higher or lower compared to the national average, they can adjust costs by using a multiplier for construction activities and/or equipment items. Each multiplier will be applied to the default

costs. The default multiplier is set at 1.0, meaning that construction and/or equipment costs reflect no adjustment from the national average costs.

Entering a value less than 1.0 means that the user believes the farm’s costs are that percentage of the national costs. For example, entering a 0.5 means the farm’s costs are 50% (or half) of the national average while entering a 0.2 means the farm’s costs are 20% of the national average.

Entering a value greater than 1.0 means that the user believes that the farm’s costs are higher than the national average. For example, entering a 2.0 means that the farm’s costs are two times (or twice) the national average while entering a 2.7 means the farm’s costs are 2.7 times the national average. When the user changes the multiplier for construction, the DST will run the cost equations and adjust accordingly, in the background.

See Technical Guide [Part 2.3.2](#) for more information about how these costs were calculated for minimum, maximum, and default values.

No adjustments are made to the construction and equipment costs in the case study, the values are left as the **default**.

<i>What overall adjustments do you want to make to your construction and equipment costs?</i>						
Costs	Unit	Default	Your Value	Min	Max	Input Status
Construction	multiplier	1.00		0.10	10.00	Using default
Equipment	multiplier	1.00		0.10	10.00	Using default

Click the **Next Page** button to continue to the *Operational Costs* page.

### 2.3.8 Operational Costs

The *Operational Costs* page shows the costs for many of the day-to-day costs associated with a manure management system, including labor, utilities, and fertilizer. Note that labor cost includes only the wage rate and does not include taxes or benefits. Also note that for water pumped on the farm, whether surface or groundwater, the rate can be calculated and entered for Fresh water cost. Please enter the unit price paid for each of the eight potential inputs used on-farm. If any of these do not apply to the farm, or if costs are unknown, you can leave it blank and the DST will use the default value when evaluating each of the predefined scenarios. Note that the default wage rate represents that hourly rate component only and does not include taxes, fringe rates or any other costs that are the responsibility of the employer. Acknowledging that different types of employees may have different wage rates, use the average across all employees in the DST. See the Technical Guide [Part 2.3.3](#) for more information about how these costs are estimated and used in the DST.

The case study assumes the **default** prices for these operational costs.

### What are the costs of labor, water, electricity, fuel, and fertilizer for your farm?

Costs	Unit	Default	New Cost	Min	Max	Input Status
Labor cost, hourly average	\$/hr	\$17.45		\$9.55	\$30.76	Using default
Electricity	\$/kWh	\$0.08		\$0.01	\$2.01	Using default
Diesel	\$/gal	\$4.54		\$0.25	\$15.00	Using default
Gasoline	\$/gal	\$3.66		\$0.25	\$15.00	Using default
N fertilizer	\$/lb	\$0.53		\$0.10	\$1.00	Using default
P2O5 fertilizer	\$/lb	\$0.53		\$0.10	\$1.00	Using default
K2O fertilizer	\$/lb	\$0.45		\$0.10	\$1.00	Using default
Fresh water	\$/1000 gal	\$0.669132		\$0.008762	\$29.410151	Using default

Click the **Next Page** button to continue to the *Priorities* page.

#### 2.3.9 Priorities

The priorities page is a unique feature of this DST. The decisions made here can have large impacts on the rankings of the scenarios in the results. Therefore, it is strongly recommended that the Technical Guide [Part 2.1](#) is read for a more detailed description of this feature before making selections on this page.

On this page, select three classes of input parameters that will be used to help rank the MMSs (scenarios) for your farm: 1) importance of sludge vs non- sludge year, 2) level of environmental impacts, and 3) priority metrics.

The first question is related to the relative importance of sludge year, non-sludge years, or both in the choice of MMS. All scenarios in the DST have a land application component that occurs every year (termed “non-sludge year”), while some of the scenarios also have a land application component that happens every 10 years (by default; termed “sludge year”). Some of the predefined scenarios evaluated in the DST include treatment or storage that results in sludge accumulation (i.e., lagoon and possibly covered lagoon if superuser variables are adjusted). This sludge is land applied every 10 years (by default). The average of all years adds the non-sludge year with the average of the sludge year (sludge year divided by the interval, which is 10 years by default in the DST). The choice made here will impact some of the metrics in the Functionality and Logistics section of the priorities.

The case study selects **non-sludge year** from the drop down as being more important than non-sludge year.

<i>Which is most important to you regarding manure management: non-sludge year, sludge year (when applicable), or both (average)?</i>	
<i>Instructions</i>	<i>Your Value</i>
Choose Non-Sludge Year, Sludge Year, or Both from the dropdown:	Non-Sludge Year

The second question concerns the six environmental metrics included in the priority metrics. As explained in the Technical Guide [Part 2.2](#), these metrics are based on life cycle analysis (LCA) and reflect the environmental impacts across the life cycle (i.e., including upstream production of resources consumed on-farm) of each MMS component, not only the on-farm resource use. The calculated on-farm resource use, such as water, electricity, and diesel, is displayed on the *Resources Results* page. Note that while this DST accounts for some of the upstream environmental impacts of the production of resources used on-farm, it is beyond the scope of this DST to account for all of these impacts.

This section asks to choose the level of environmental impact the DST should consider when ranking scenarios. "Farm" impacts refer to environmental impacts that result directly from farm operations, while "Net" impacts include both on-farm activities and off-farm processes that generate environmental impacts, such as the production of fuel, electricity, and commercial fertilizer. This example focuses on **Farm** Impacts. See Technical Guide [Part 2.2.2](#) for a discussion of the pros and cons of selecting Net Impacts.

<i>What environmental impact type do you want to use for scenario rankings?</i>	
<i>Instructions</i>	<i>Your Value</i>
Choose Farm or Net from the dropdown:	Farm

The third section of the page asks to rate how important each of 18 economic, environmental (those discussed above), and technological metrics is for the farm. The selections here can have a large impact on the ranking of each MMS scenario.

The 18 metrics are separated into 3 categories, as follows:

1. Economic – Capital costs (Capital), Operational costs (Operating), Net benefits (Net), Fertilizer values (Fertilizer), Cost savings (Savings), and Revenues (Revenue)
2. Environmental – Carbon footprint (Carbon), Energy footprint (Energy), Land footprint (Land), Water consumption (Water), Nitrogen footprint (Nitrogen), and Phosphorus footprint (Phosphorus)
3. Technological – Adoption rate (Adoption), Operational reliability (Reliability), Operational resilience (Resilience), Labor hours (Labor), Land required for manure application (Application), and Manure export (Export)

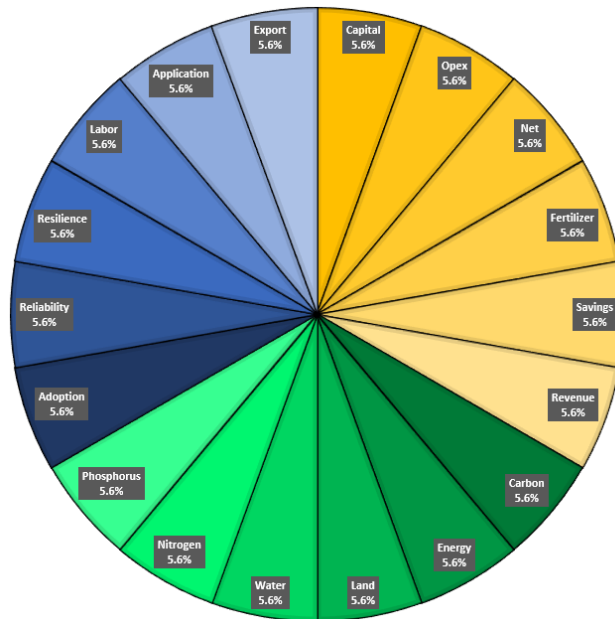
Table 2a, below, briefly describes each metric. Detailed descriptions of each metric as well as information on how each is calculated can be found in the Technical Guide [Part 2.2](#), [Part 2.3](#), and [Part 2.4](#).

Note that some metrics may be considered better when the result is high, while lower values for results may be considered better for other metrics.

- Metrics considered better when results are high: net benefits, fertilizer value, cost savings, revenues, adoption rate, operational resilience.
- Metrics considered better when results are low: capital costs, operational costs, carbon footprint, energy footprint, land footprint, water consumption, nitrogen footprint, phosphorus footprint, operational reliability (presented as percent downtime), labor hours for land application, land required for manure application, manure export.

Rate each metric by how important this metric is for the farm, not if high or low *results* are better or worse. Each metric on a scale of 0 to 100, where 0 is considered unimportant and 100 is considered very important when making manure management decisions. The DST defaults to a rating of 50 for all of the metrics, giving equal importance to each. Further, if every metric is given the same rating, they will all have equal weight for importance. For example, if all metrics are set to 10, the results will be the same as rating all metrics at 50, and also the same as if all metrics were set to 100.

When all priorities are given a rating of 50 the pie chart looks like this:



Because each individual priority is weighted equally, the weight associated with each priority is 100% divided by 18, which equals 5.55% (or 5.6% as rounded in the graph).

The user can adjust how to prioritize the importance of each metric by entering a number in the Rating column, using a scale of 0 (unimportant) to 100 (very important). As the rating for various metrics is changed, the DST shows how those changes affect the relative weight (i.e., the relative importance of each of the metrics) by looking in that column and by looking at the pie chart.

For this case study, capital costs, operating costs and net benefits within the economic metrics have been set at 80. All remaining economic metrics as well as environmental and functional and logistical priorities have been set as 10. Note that values can be copied and pasted down the column (just as can be done in any excel spreadsheet).

The choice of priorities will greatly impact the results, particularly among the economic metrics as well as the relative importance of economic metrics vs others. See Section 3 below for examples. The user is encouraged to use this tool iteratively – that is run the tool multiple times with varying priorities to ensure the tool is selecting the system best for the farm.

With these new ratings the pie chart changes to that below. The weights associated with each of the environmental priorities are the least while the weights for the economic priorities are the greatest.

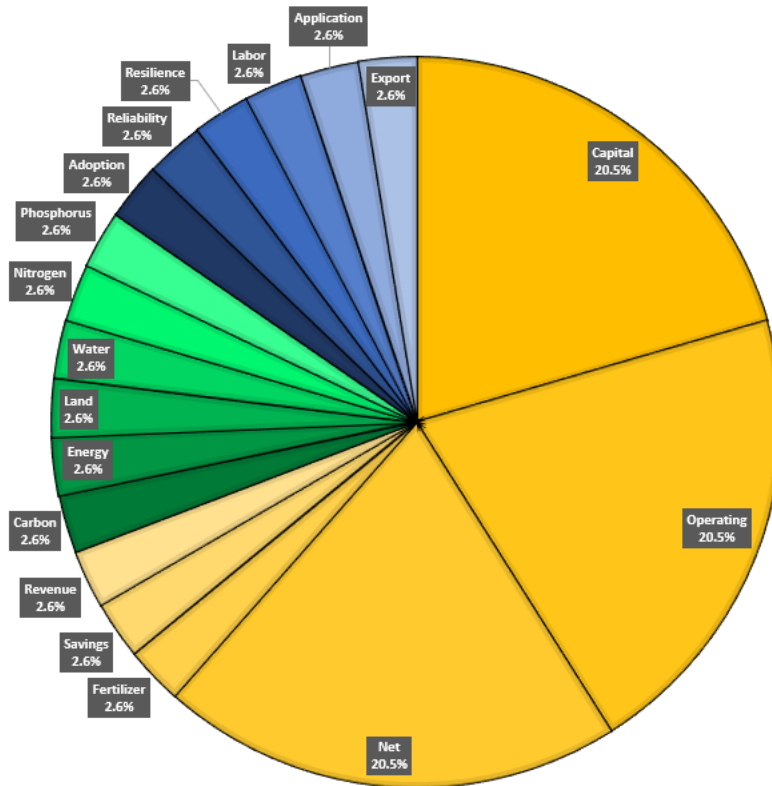


Table 2a. Lists each metric evaluated in the DST with a brief explanation.

Category	Metric	Definition
Economic	Capital costs (annualized)	They include costs of construction and equipment needed for all unit processes in the given MMS scenario. These costs are calculated from the initial purchase price, expected lifetime, salvage value, and interest (opportunity cost). For tractors, the percent usage for MMS activities is calculated, such that the capital costs associated with the MMS is allocated to this cost, while use for other farm activities is excluded.
	Operational costs	These costs include insurance, repair and maintenance, electricity, fuel, lubrication, and labor for the MMS in the given scenario.
	Fertilizer value	This is the value of manure nutrients that can be land applied, given the manure nutrient content, fertilizer nutrient needs, nutrient to apply for (N or P), and the acres available for land application.
	Cost savings	These include cost savings from avoided resource use, such as recycled water and bedding.
	Revenues	These include revenues from resources generated on-farm which can be sold, such as manure end products, bedding, and energy from anaerobic digestion.
	Net costs or net benefits	This is the net direct economic costs or benefits, given by the following: Revenues – Capital Costs – Operational Costs. Negative values indicate that costs exceed benefits by the given amount; positive values indicate that benefits exceed costs by the given amount.
Environmental	Carbon footprint	Includes CO <sub>2</sub> equivalent emissions derived from methane (CH <sub>4</sub> ) and nitrous oxide (N <sub>2</sub> O) produced during the storage, and treatment. Additionally, it accounts for off-farm emissions from the production of resources like water, electricity, diesel, urea, and other fertilizers, which are used in the on-farm manure management process.
	Land footprint	Includes the land required for manure storage, drying, processing, and land application of manure on the farm.
	Energy footprint	Off-farm includes energy consumed in producing materials such as electricity, diesel, and fertilizer that are used on the farm, but produced off-site. There is not an on-farm energy footprint, given the LCA methodology.
	Water footprint	Measures the total volume of water used in the management of dairy manure, including water for flushing, cleaning, and dilution during manure processing. Additionally, it accounts for the water used in the production of materials such as electricity, and fuel used in the on-farm manure management process.
	Nitrogen footprint	Includes on-farm reactive nitrogen emissions, primarily from ammonia (NH <sub>3</sub> ) and nitrates (NO <sub>3</sub> ), released into the air and water during the storage and treatment of manure.
	Phosphorus footprint	Measures any excess phosphorous that remains after the manure has been applied, based on crop or land nutrient requirements.
Functional and logistical (Technological)	Adoption rate	An indicator of how many farms are using the technology relative to the total number of farms on which it could be appropriately used.
	Operational reliability	An indicator of the functioning of a system as designed over its expected useful life on a farm with minimal intervention. The scores are based upon the frequency of malfunctions.
	Operational resilience	An indicator of the ability of the manure management system and broader farm operation to continue to function acceptably with minimal delay or other negative impact when the technology breaks, goes offline, malfunctions, or fails for any reason.
	Labor during land application	The estimated hours of labor required to land apply manure nutrients on-farm.
	Additional land needed	Calculated as the difference between the estimated land needed to apply all manure nutrients and the amount of land available, as indicated on the <i>Farm Management</i> page.
	Manure exported	A measure of how much manure must be exported off farm, which happens when there is not enough land available.

At the bottom of this page is a table that shows the top ten ranked scenarios based on the example inputs and priorities used. Changes to any inputs, priorities or both can change the top ten ranked scenarios. More information about the top ranked scenarios (should you choose to view them) can be found in the output tabs.

Once you have selected your priorities hit the **Next Page** button to continue to the *Scenario Choices* page.

#### 2.3.10 Scenario Choices

On this page, the user can choose which scenarios will be displayed in the results.

The baseline scenario (as indicated on the *Farm Management* page, in this case sand bedding, scrape with skid steer, mechanical sand separation, pond, tanker) is always displayed in the results. The other four alternatives, by default, are the top 4 ranked scenarios. The user can change which scenarios are displayed in the results by using the drop downs in the left column to select the specific scenario(s) of interest. This case study uses the Baseline Scenario as well as the top four ranked scenarios. It is possible that the baseline scenario could be one of the top four scenarios, in which case the user can choose the fifth ranked scenario to display. The scenarios chosen are up to the user.

As stated in the User Guide [1.1](#), the DST is designed to demonstrate how well a user's current or desired manure management system (called a Baseline) can meet specific economic, environmental and technical goals set for a given farm as compared to a suite of 92 other available MMSs. While top ranked scenarios are expected to be the most commonly chosen scenarios, these may not be reasonable alternatives depending on the farm's current situation. For example, a farm might currently operate a freestall barn and would be unlikely to convert to a compost bedded pack barn, even if that scenario is a top ranked alternative in this DST. In such cases a user can select other scenarios that are more likely to be feasible for adoption. The information below is meant to aid in interpretation of the results. The user will have to decide if these priorities align with the realities of manure management selection on the farm.

The choices below determines which scenarios you will see on the graphs and plots in other results pages. By default, the DST will compare your chosen baseline farm to the top 4 ranked scenarios. You may click a dropdown box to change any of the top 4 scenarios to another of your choosing. The description column gives a full description of how each scenario is setup. The rank column tells you how the scenario compares to others based on the priorities you provided in the UI.Priorities tab.

Choose Scenarios for Results (Dropdown)	Description
<b>Your baseline scenario:</b>	The farm uses sand bedding in a freestall barn and a SS scrape system for barn cleaning. The scraped manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The resulting manure + wash water is pumped to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land-applied using tractor-pulled tanker method.
<b>Top ranked scenario</b>	The farm uses sand bedding in a freestall barn and a flush water system for barn cleaning. The flushed manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The effluent flows through a passive sand lane to capture the extra sand and the remaining manure + wash water flows to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land applied using tractor-pulled drag hose method.
<b>Second ranked scenario</b>	The farm uses sand bedding in a freestall barn and a vacuum scrape system for barn cleaning. The scraped manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The effluent flows through a passive sand lane to capture the extra sand. The resulting manure + wash water is pumped to a solid-Liquid separator (Rotary drum screen + Roller press) to remove coarse solid fibers. The screened effluent from S/L separation flows to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land-applied using tractor-pulled drag hose method.
<b>Third ranked scenario</b>	The farm uses sand bedding in a freestall barn and a SS scrape system for barn cleaning. The scraped manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The effluent flows through a passive sand lane to capture the extra sand. The resulting manure + wash water is pumped to a solid-Liquid separator (Rotary drum screen + Roller press) to remove coarse solid fibers. The screened effluent from S/L separation flows to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land-applied using tractor-pulled drag hose method.
<b>Fourth ranked scenario</b>	The farm uses sand bedding in a freestall barn and a vacuum scrape system for barn cleaning. The scraped manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The effluent flows through a passive sand lane to capture the extra sand. The resulting manure + wash water is pumped to a solid-Liquid separator (Rotary drum screen + Roller press) to remove coarse solid fibers. The screened effluent from S/L separation flows to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land-applied using tractor-pulled tanker method.

Click on the **Next Page** button to go to the *Inputs Summary* page.

### 2.3.11 Input Summary

The *Inputs Summary* page shows the values for all inputs that have been selected, or left to the default, on each input screen of the decision support DST. Each table shows the value, the unit used and whether or not this value was the default (Yes) or Your Value (no). An example of the first table is presented below. A full list of the inputs used in this Test Farm example are available in the Technical Guide [Part 2.6.5](#). Please review this page to ensure that the inputs represent the farm (or the user’s expectations) accurately. Each table represents one of the previous input screens in the DST. For example, the screenshot below shows everything that was selected on the Farm Management Information page. The user can print this page by selecting File > Print; to make printing fast and easy, a pre-defined print area has been set.

At this point, if the user would like to adjust any of the inputs, select the buttons at the top of the page to go to any of the inputs pages to make those changes. Otherwise, click **Go to Results!** to view the *Results Summary* page.

Farm Info Variable Description	Value	Unit	Default Used?
The name of your farm	New York Case Study 1	name	No
The baseline manure handling system for your farm	Sand bedding, scrape skid, mechanical sand separation, pond, tanker		
The region of your state that your farm resides in	New York (Central Lakes)	state index	No
Are sprinklers used on your farm?	Yes	Yes or No	No
The length of time that sprinklers spray water per cycle	3	min/cycle	Yes
The number of cycles that the sprinkler system goes through in a day	6	cycle/day	Yes
The flow rate of the sprinkler system	0.1	gal/head/min	Yes
The amount of land available for manure application each year	900	acre	No
The primary nutrient for which to apply manure	N	nutrient	No
The method by which manure is applied	Injection	type	No
The quantity of N applied on the land area	195	lb N/acre	Yes
The quantity of P2O5 applied on the land area	55	lb P2O5/acre	Yes
The quantity of K2O applied on the land area	90	lb K2O/acre	Yes
Timeframe to land apply on a typical year (constraint on liquids, slurry)	65	day/year	No
Value of carbon offset credits	0	\$/credit	No

### 2.3.12 Lagoon Super User Interface

Before reviewing results, some users might consider visiting a few extra input pages, termed “Super User” pages. **To access these pages, the user needs to unhide tabs.**

First, the *Lagoon* page was designed for superusers who wish to further customize the DST's important (but sometimes complicated or obscure) variables for lagoon systems. For most users all of these lagoon properties should be set to their default. For this case study, all values have been left in their default settings.

The first row allows the user to **change all lagoon systems to pond systems**, meaning that the storage will shift from lagoon liquid irrigation multiple times per year plus the sludge accumulation to be removed every several years to full agitation and removal twice a year (as for normal pond scenarios). To make this change, enter 1 in Your Value. Doing so will automatically change default values for some of the other variables on this page.

Another common change a user might want to make is the **sludge accumulation time**. The default is set at 10 years, but many farmers may choose to remove and land apply sludge more frequently. For example, if you know you clean out the lagoon sludge every 3 years, you can enter 3 in Your Value. In this case study, the sludge accumulation time has been kept at the default of 10.

There are several other input specifications on this page that you can choose to adjust.

### 2.3.13 Solid Separation User Interface

There are many types of solid liquid separators evaluated in this DST. Actual separation efficiencies may depend on many factors. The user can adjust specifications for each type of

separator using this page. For this case study, all of these values have been kept at their defaults.

#### *2.3.14 Anaerobic Digester User Interface*

Anaerobic digesters are becoming more widespread and may be implemented on farm via a wide array of financial strategies. This input page allows the user to specify financial details as well as technical details about a potential digester.

The first three rows are related to the proportion of costs and revenues the farmer pays or receives. The capital cost may be paid for through a cost share grant with a government agency or similar entity. For example, if a farmer expects to receive a grant that will cover 25% of the capital cost of the digester, they would enter 0.75 in Your Value (since the farmer will cover the other 75%). Another example is if a farmer contracts with a third party who owns and operates the digester. In that case, the third party pays the full cost and the farmer would enter 0 in Your Value for both capital costs and operational costs. If the contractor pays the farmer for influent manure, they would enter 1 in Your Value for Revenue paid to farmer.

There are several other input specifications on this page that you can choose to adjust. For this case study, all of these values have been kept at their defaults.

## 2.4 Results Pages

### *2.4.1 Results Summary*

This page provides a summary table of the five scenarios chosen on the Scenario Choices tab, their ranking, and their resulting economic, environmental, technological, resource use and long term average nutrient concentrations as land applied values. These five categories of results are also shown on individual results tabs in the DST, along with associated graphs for visual representation. Note that the first three categories of results are used in the ranking process, while the fourth and fifth categories are for additional information only.

All economic results are in units of \$/head/year; environmental results are in amount/head/year; the first three metrics under functionality and logistics are unitless; the last three results under functionality and logistics are in amount/year; the results under resources are in amount/year, except for the last result is in acres; and the nutrients in slurry liquids and sludge are in lbs/1000 gal while the nutrients in separated solids and partially composted material are in lbs/ton. More details are provided in the following subsections.

# ManureTech Dairy DST

Applying manure for N. Export concern is for Non-Sludge Year.

Results Summary					
Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Overall Ranking	9	1	2	3	4
<b>Economics</b>	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Annualized capital costs (\$/head/year)	\$151	\$169	\$166	\$150	\$178
Operational costs (\$/head/year)	\$183	\$121	\$107	\$143	\$121
Fertilizer value for on-farm use (\$/head/year)	\$114	\$114	\$114	\$114	\$114
Cost savings (\$/head/year)	\$176	\$176	\$222	\$188	\$176
Revenues from sale of manure product or energy (\$/head/year)	\$0	\$0	\$0	\$0	\$0
<b>(NET COSTS) or NET BENEFITS (\$/head/year)</b>	(\$220)	(\$176)	(\$159)	(\$180)	(\$185)
<b>Environmental</b>	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Carbon footprint (ton (2000 lb) CO <sub>2</sub> E/head/year)	2.63	2.55	2.53	2.55	2.56
Land footprint (acre/head/year)	0.66	0.66	0.66	0.66	0.66
Energy footprint (kWh/head/year)	0.00	0.00	0.00	0.00	0.00
Water consumption (gall/head/year)	2,041	2,041	2,041	4,214	2,041
Nitrogen footprint (lb/head/year)	54.5	54.5	54.5	54.5	54.5
Phosphorous excess (lb/head/year)	81.5	81.5	81.5	81.5	81.5
<b>Functionality and Logistics</b>	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Adoption rate	3.7	3.6	2.4	3.4	3.1
Operational reliability	3.4%	2.0%	2.2%	2.0%	2.4%
Operational resilience	1.7	1.7	1.7	1.7	1.7
Labor hours for application (hours/year) during Non-Sludge Year	1,550	190	190	201	190
Additional Land Required for Application (acre/year) during Non-Sludge Year	84	84	84	84	84
Manure Exported (ton (2000 lb)/year) during Non-Sludge Year	3,944	3,944	3,831	5,496	3,944
<b>Resources</b>	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Electricity Required for Operations (kWh/year)	24,907	24,907	97,262	11,434	24,907
Fresh Water Used on Farm (gall/year)	2,790,691	2,790,691	2,790,691	5,761,563	2,790,691
Diesel Used on Farm (gall/year)	19,757	10,359	7,677	10,317	11,349
N in treated manure (liquids + slurry) (ton (2000 lb)/year)	101	101	101	101	101
N in treated manure (sludge + solids) (ton (2000 lb)/year)	0	0	0	0	0
P2O5 in treated manure (liquids + slurry) (ton (2000 lb)/year)	93	93	93	93	93
P2O5 in treated manure (sludge + solids) (ton (2000 lb)/year)	0	0	0	0	0
Land Required for Treatment Facilities (acre)	2.9	2.9	2.9	3.6	2.9

These results will be presented below in larger format. Click on the **Next Page** button to go to the *Scenarios Rankings and Description* page.

### 2.4.2 Scenario Rankings and Descriptions

The *Scenario Rankings and Descriptions* page lists all 92 scenarios and their descriptions in order from highest (1) to lowest (92) rank. The figure below shows the top results only as an example. This is an informative page designed to be printable for your records. You can print this page by selecting File > Print; to make printing fast and easy, a pre-defined print area has been set.

Click the **Next Page** button to display the *Economic Results* page.

## Scenario Rankings

Return to Priorities

For your convenience, all of the scenarios, their rankings, and their descriptions are below. At any time, you can press the return to the priorities page to adjust how scenarios are ranked. If you wish to change which scenarios show up in the remaining results pages, you can press the results choice button to quickly move back to that page.

Scenario Choices

Scenario	Rank	Description
<b>Sand bedding, scrape skid, mechanical sand separation, pond, drag hose</b>	1	The farm uses sand bedding in a freestall barn and a SS scrape system for barn cleaning. The scraped manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The resulting manure + wash water is pumped to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land-applied using tractor-pulled drag hose method.
<b>Sand bedding, flush, mechanical sand separation, pond, drag hose</b>	2	The farm uses sand bedding in a freestall barn and a flush water system for barn cleaning. The flushed manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The effluent flows through a passive sand lane to capture the extra sand and the remaining manure + wash water flows to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land applied using tractor-pulled drag hose method.
<b>Sand bedding, flush, sand lane, pond, drag hose</b>	3	The farm uses sand bedding in freestalls and a flush water system for barn cleaning. The flushed manure + sand bedding flows through a sand lane where sand settles out and is recovered for reuse. The remaining manure + flush water flows into a storage pond where it remains for 180 days before being emptied. The accumulated pond slurry is agitated and land applied using tractor-pulled drag hose method.
<b>Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose</b>	4	The farm uses sand bedding in a freestall barn and a vacuum scrape system for barn cleaning. The scraped manure + sand bedding flows to a reception pit and is pumped to a mechanical sand separation system to recover sand. The resulting manure + wash water is pumped to the pond for 180 days of storage before it is emptied. The accumulated pond slurry is agitated and land-applied using tractor-pulled drag hose method.

### 2.4.3 Economic Results

The *Economic Results* page provides economic information related to the baseline scenario and the four alternative scenarios (Alt 1 to Alt 4) suggested by the DST or selected by you on the *Results Choice* page. A table of results is shown at the top of the page, while a figure of results can be seen underneath.

In the first column of the table, each of the economic metrics are listed with a note that gives a description of the metric. Mouse over the cell name to view the note. For a detailed description about the calculations behind these economic results, see the Technical Guide [Part 2.3](#).

All scenarios have capital and operating costs, which are represented as negative values (red parentheses in table and negative numbers on the graph). Some scenarios may have values for fertilizer, cost savings, and or revenues (black text in table and positive numbers on the graph). The net economic value could be a net cost (shown as a negative value) or a net benefit (shown as a positive value). Note that Net costs or net benefits include the actual direct economic costs and benefits, given by the following equation: (Revenues + Fertilizer value) – (Capital Costs + Operational Costs).

## Economic Results

Applying manure for N. Export concern is for Non-Sludge Year.

Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Overall Ranking	9	1	2	3	4
Economic results (\$/head/year)	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Annualized capital costs	(\$151)	(\$169)	(\$166)	(\$150)	(\$178)
Operational costs	(\$183)	(\$121)	(\$107)	(\$143)	(\$121)
Fertilizer value (on-farm use)	\$114	\$114	\$114	\$114	\$114
Cost savings	\$176	\$176	\$222	\$188	\$176
Revenues (sale of manure product or energy)	\$0	\$0	\$0	\$0	\$0
<b>(Net costs) or Net benefits</b>	<b>(\$220)</b>	<b>(\$176)</b>	<b>(\$159)</b>	<b>(\$180)</b>	<b>(\$185)</b>

NOTE: Negative values (red parentheses) represent costs or net costs and positive values (black text) represent benefits or net benefits.

NOTE: Bar color represents economic metric.

Negative values represent costs or net costs; positive values represent benefits or net benefits.

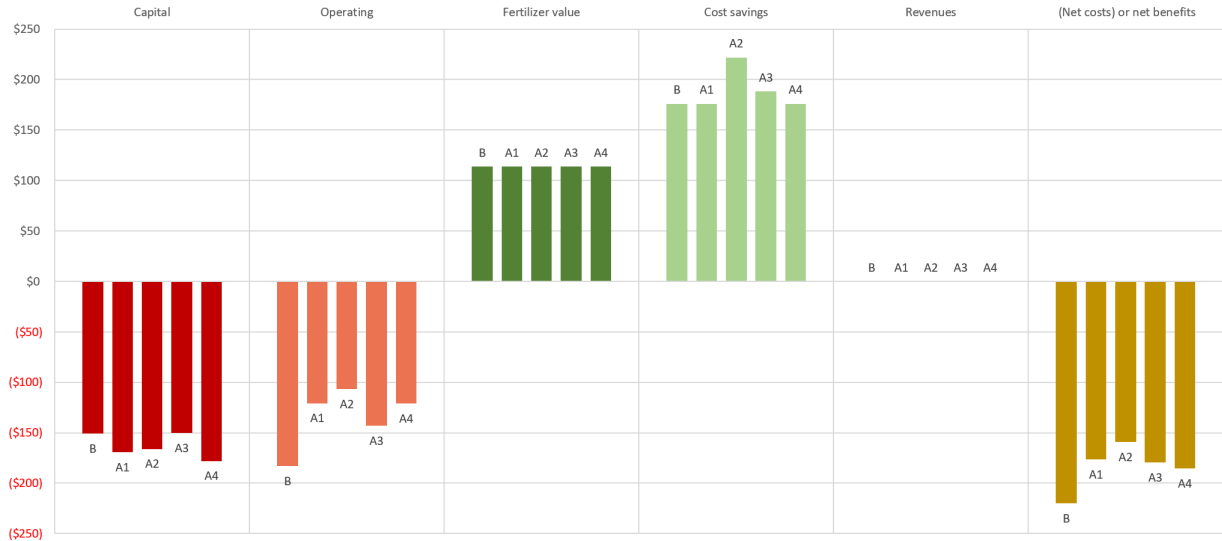
\* Mouse over cell to view description about how to interpret results

In this case study, our Baseline Scenario ranked 9<sup>th</sup> out of 92 possible options. This scenario has capital costs of \$151 per head per year. Although Alternative 1 has higher capital costs of \$169 per head per year, the operational costs are much lower at \$121 per head per year. This is also reflected in lower net costs compared to the baseline. The baseline scenario generated net costs of \$220, which is \$44 more than Alternative 1 (Sand bedding, scrap skid, mechanical sand separation, pond, drag hose). Because capital costs, operating costs and net cost metrics were given the highest weight in the priorities selection, it is not surprising that a lower cost option is preferred to higher cost ones. Interestingly, while Alternative 2 has lower capital, operating, and net costs compared to other scenarios, it is still ranked #2. This is because there was some weighting for the other priority metrics, such that these costs are not the only driving factor for the rankings.

The annualized results for each of the economic categories are also shown graphically. For each type of economic value, B represents the Baseline Scenario value where A1 through A4 represents the values associated with Alternatives 1 through 4, respectively. The graph allows for easy visual comparison of the performance of each of the scenarios selected in each of the economic categories. For example, this graph easily highlights that A4 has the highest capital costs and the baseline has the highest operating costs and net costs (most negative).

Click on **Next Page** to see the *Environmental Results* page.

**Economic Results (Annualized)**



**2.4.4 Environmental Results**

The *Environmental Results* page provides environmental information related to the baseline scenario and the four alternatives.

As described in the Technical Guide [Part 2.2.2](#), there are two levels of environmental results reported in this DST – on-farm only and net (includes both on-farm and off-farm) impacts. Based on the LCA methodology used, all energy footprint values are categorized as off-farm so they only show up in the Net Impact values. Results are shown for both levels in the tables at the top of the page and also represented in graphs underneath. In all cases, lower values are considered better than higher values.

Note that while this DST accounts for some of the off-farm environmental impacts related to the production of resources used on-farm, it is beyond the scope of this DST to account for all of these impacts as well as impacts associated with off-farm application of manure when it is exported off-farm. As a result, Farm Emissions and Net Impact are the same for the Land, Nitrogen and Phosphorus footprint.

Tables are presented for both the farm and the net impacts, however in this example, because farm impacts were chosen on the *Priorities* page, only farm impacts influence rankings of MMSs.

## Environmental Results

Applying manure for N. Export concern is for Non-Sludge Year.

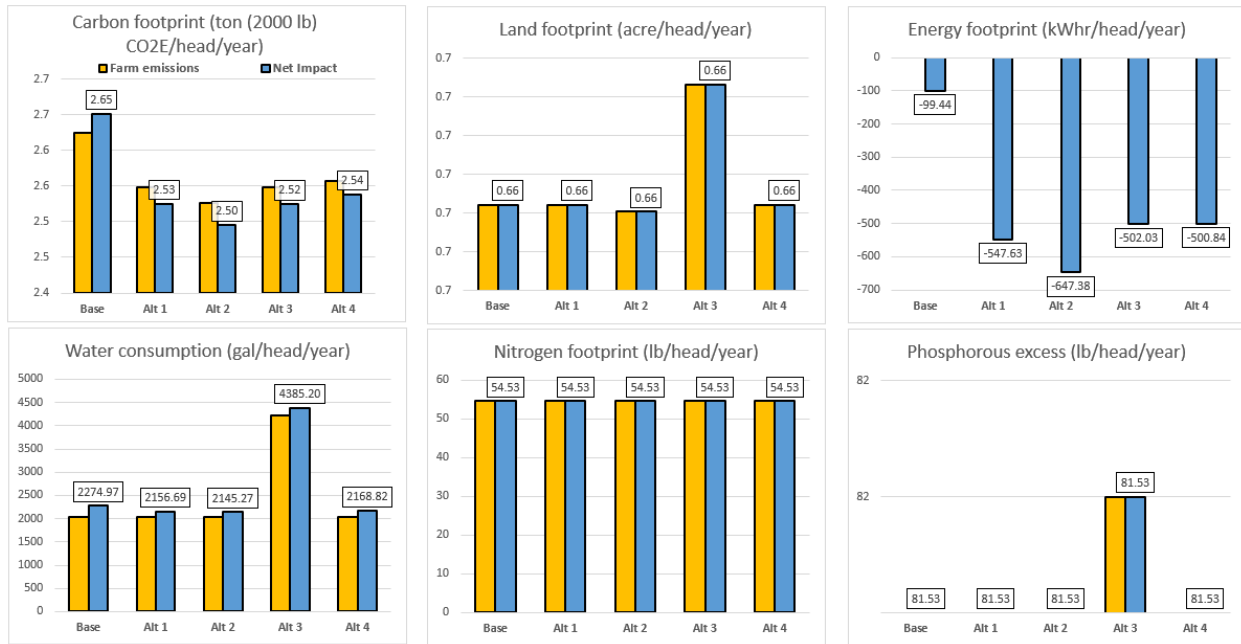
Farm emissions					
Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Overall Ranking	9	1	2	3	4
<b>Environmental Results</b>	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Carbon footprint (ton (2000 lb) CO <sub>2</sub> E/head/year)	2.6	2.5	2.5	2.5	2.6
Land footprint (acre/head/year)	0.7	0.7	0.7	0.7	0.7
Energy footprint (kWhr/head/year)	0.0	0.0	0.0	0.0	0.0
Water consumption (gal/head/year)	2041.0	2041.0	2041.0	4213.8	2041.0
Nitrogen footprint (lb/head/year)	54.5	54.5	54.5	54.5	54.5
Phosphorous excess (lb/head/year)	81.5	81.5	81.5	81.5	81.5

Net Impact					
Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
<b>Environmental Results</b>	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Carbon footprint (ton (2000 lb) CO <sub>2</sub> E/head/year)	2.7	2.5	2.5	2.5	2.5
Land footprint (acre/head/year)	0.7	0.7	0.7	0.7	0.7
Energy footprint (kWhr/head/year)	-99.4	-547.6	-647.4	-502.0	-500.8
Water consumption (gal/head/year)	2275.0	2156.7	2145.3	4385.2	2168.8
Nitrogen footprint (lb/head/year)	54.5	54.5	54.5	54.5	54.5
Phosphorous excess (lb/head/year)	81.5	81.5	81.5	81.5	81.5

In this example, the Baseline scenario performed worse than all the top ranked scenarios for the on-farm carbon footprint. Because the processes in this example perform similarly as they relate to carbon and nutrient mass balances, many of the environmental metrics outcomes are similar or equal across alternatives. Although the environmental metrics priorities were set equally at 10, much lower than some of the economic metrics, these environmental values contributed to the overall rankings of each scenario.

The graphs that present the environmental results are structured differently from those for the economic results. On each of these environmental graphs, the yellow bars represent the on-farm impacts while the blue bars represent the net impacts. In most cases the addition of off-farm impacts to the on-farm impacts leads to a higher overall net impact. The one exception is the energy footprint.

In the LCA methodology, energy footprint only applies to off-farm impacts through the production of electricity, fuel, and fertilizers. However, when manure nutrients are used in place of commercial fertilizer, there is a credit, or subtraction on the energy footprint since the use of manure reduces the energy that would be required to apply that amount of nutrients using commercial fertilizer. When the credit for fertilizer is greater than the debit for the production of electricity and diesel used on-farm, the net farm footprint for energy will be negative as is seen below. The energy footprint for diesel is very high compared to the energy footprint for electricity, therefore the net energy footprint is influenced by the relative use of electricity and diesel by each alternative.



Click on **Next Page** to see the *Functionality and Logistics Results* page.

#### 2.4.5 Functionality and Logistics (or Technological) Results

The *Functionality and Logistics Results* page provides information related to the functionality of technologies and some of the logistical impacts associated with land application of manure. For short, we refer to these as the Technological Results. See the Technical Guide [Part 2.4](#) for more information about how each of the Technological results are calculated.

Results are shown in the table at the top of the page and presented in graphs underneath. In the first column of the table, each of the metrics are listed with a description of the metric. Mouse over the cell name to view the note.

## Functionality and Logistics Results

Applying manure for N. Export concern is for Non-Sludge Year.

Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
<b>Overall Ranking</b>	<b>9</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Functionality and Logistics</b>	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Adoption rate	3.69	3.56	2.38	3.44	3.06
Operational reliability	3.4%	2.0%	2.2%	2.0%	2.4%
Operational resilience	1.67	1.67	1.67	1.67	1.67
Labor hours for application (hours/year) during Non-Sludge Year	1550	190	190	201	190
Additional Land Required for Application (acre/year) during Non-Sludge Year	84	84	84	84	84
Manure Exported (ton (2000 lb)/year) during Non-Sludge Year	3944	3944	3831	5496	3944

\* Mouse over cell to view description about how to interpret results

Results for Adoption Rate are on a five-point scale, where a higher value represents a set of technologies that are more commonly used on-farm. See the Technical Guide [Part 2.4.2](#) for details about what each score means across the five-point scale. In our example, the Baseline has the highest adoption rate (3.69) where Alternative 2 has by far the lowest (2.38).

As mentioned above in the Priorities section, Operational Reliability is presented in terms of percent downtime, such that lower values represent technologies that are expected to break down less frequently. See the Technical Guide [Part 2.4.3](#) for details about what the values for percent downtime mean in terms of the technologies used. Scores for each unit process in the technology can range from 1.14% (very reliable, with breakdowns less than once every two or more years) to 14.25% (very unreliable, with breakdowns likely weekly). The overall score is calculated as the product of all of the scores for each unit process in a given scenario. The Baseline has the second highest downtime (3.4%) while Alternatives 1 and 3 have the lowest (2.2%).

Results for Resilience are on a five-point scale, where a higher value represents technologies that operated relatively independently such that a malfunction would not greatly impact the overall functioning of the entire MMS. Resilience scores range from 1 (technology performs a critical task without backup measures normally being easily implemented; where consequences of malfunction are potentially very significant and extend beyond manure management) to 5 (technology performs an independent task where consequences of malfunction have minimal or no negative consequence for the rest of the manure management system or farm operation), where larger values are considered better. The score provided in the results for each scenario is taken as the minimum score across all technologies/unit processes comprising a given scenario, since the resilience of the whole system is based on the weakest link of the system. All systems have at least one component that is ranked at 1.67. More information about this metric can be found in the Technical Guide [Part 2.4.4](#).

The three remaining metrics are highly influenced by two choices made on the user input pages: 1) whether the user wants to prioritize non-sludge year, the sludge year, or both (as an annual average), and 2) whether manure nutrients are applied to the land for nitrogen or phosphorus. In this case study applying for N was selected on the *Farm Management Information* page. Red text at the top of the results table on the Functionality and Logistics page shows which nutrient was selected for application and which type of year (sludge or non-sludge) is prioritized.

Also in this example, **Non-Sludge Year** was chosen on the Priorities page, therefore, the MMS scenario rankings are based on the Non-Sludge Year results for labor hours, land, and manure exported, which are also represented in this results table.

If Sludge Year was selected, the scenario rankings and results for Functionality and Logistics metrics for labor, land and manure exported would change to reflect those for a sludge year and the description of the metric would also change on the results (image on left below). Finally, if Both (representing sludge and non-sludge years) was chosen, the scenario rankings and results table would change again to report values for labor, land and manure exported for both non-sludge and sludge years (graph on right below).

Applying manure for N. Export concern is for Sludge Year.

Scenario
Overall Ranking
<b>Resources</b>
Electricity Required for Operations (kWh/year)
Fresh Water Used on Farm (gal/year)
Diesel Used on Farm (gal/year)
N in treated manure (liquids + slurry) (ton (2000 lb)/year)
N in treated manure (sludge + solids) (ton (2000 lb)/year)
P2O5 in treated manure (liquids + slurry) (ton (2000 lb)/year)
P2O5 in treated manure (sludge + solids) (ton (2000 lb)/year)
Land Required for Treatment Facilities (acre)

Applying manure for N. Export concern is for Both (non-sludge AND sl)

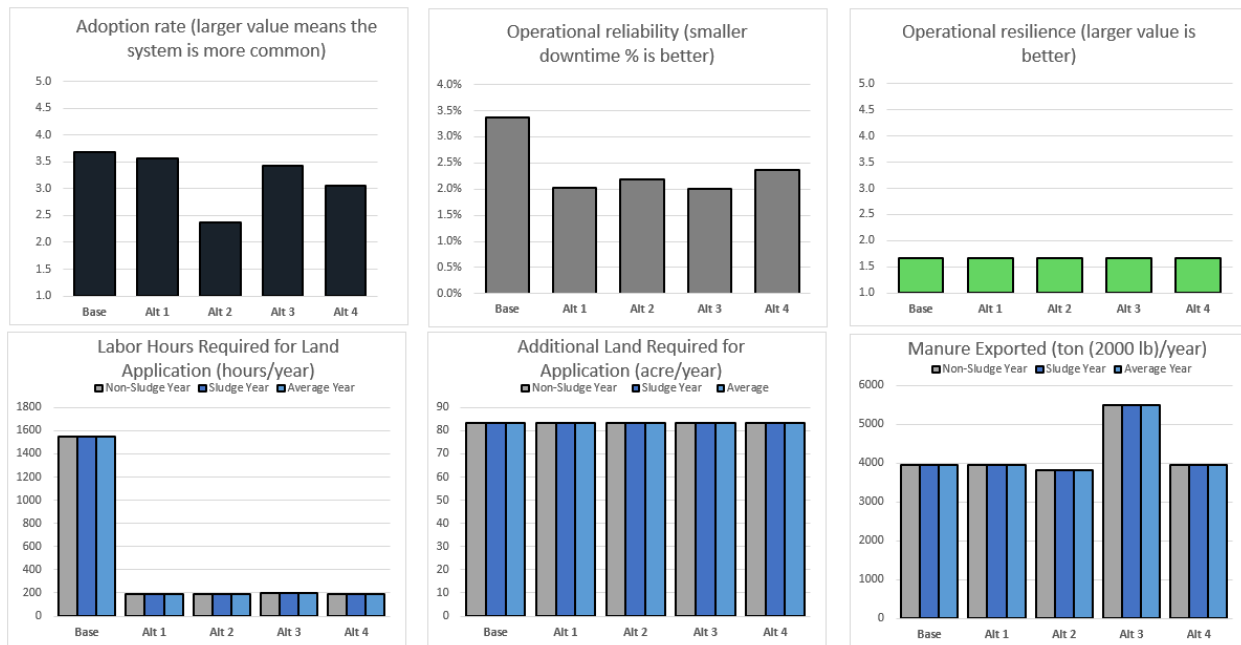
Scenario
Overall Ranking
<b>Resources</b>
Electricity Required for Operations (kWh/year)
Fresh Water Used on Farm (gal/year)
Diesel Used on Farm (gal/year)
N in treated manure (liquids + slurry) (ton (2000 lb)/year)
N in treated manure (sludge + solids) (ton (2000 lb)/year)
P2O5 in treated manure (liquids + slurry) (ton (2000 lb)/year)
P2O5 in treated manure (sludge + solids) (ton (2000 lb)/year)
Land Required for Treatment Facilities (acre)

Note, as priorities are changed among non-sludge, sludge and both, the top alternatives are likely to change as well. Changes in top alternative scenarios can also happen when manure is applied to meet P needs instead of N. Thus, as a reminder, it is important to review the scenario descriptions for Alternatives 1 through 4 as any changes are made to the user inputs before a comparison of results across cases is made.

For this case study, the number of labor hours, the amount of land, and the amount of manure exported is shown in the table for the non-sludge year and applying for N. Because labor hours are given equal weight to most metrics, the baseline technology is hurt in the rankings by needing about 7.5 times more labor hours for application as other scenarios.

Below the table, results are presented in graphical form. Values on the graph match those in the table for the Adoption Rate, Operational Reliability and Operational Resilience metrics. However, labor, land, and manure exported are shown across the baseline and four alternatives for non-sludge year, as well as sludge year and the average of both.

While only the non-sludge year values are used in the scenario rankings (because non sludge year was chosen on the *Priorities* page), results for the sludge year and average annual are also shown as this can provide additional information for decision making. In this case study, the top ranked scenarios all contain ponds, and thus are emptied every year. As such, the values for the non-sludge, sludge, and average year are all the same. These numbers will vary for alternate systems that include lagoons.



### 2.4.6 On-Farm Resources Results

The *Resources Results* page presents the amount of eight resources used or generated directly on-farm (whereas the *Environmental Results* page presents the environmental impact based on the LCA associated with MMS construction and use). It is important to note that these calculations are not directly part of the priorities that are used to determine the best scenarios for a farm's unique circumstances but do influence the operational costs and some of the environmental footprints.

The DST calculates total electricity, fresh water, and diesel used on-farm across all the manure management activities for each scenario, and those results are reported here.

## Resource Use on Farm

These results are NOT included in the ranking of scenarios

Applying manure for N. Export concern is for Non-Sludge Year.

Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Overall Ranking	9	1	2	3	4
Resources	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Electricity Required for Operations (kWh/year)	24,907	24,907	97,262	11,434	24,907
Fresh Water Used on Farm (gal/year)	2,790,691	2,790,691	2,790,691	5,761,563	2,790,691
Diesel Used on Farm (gal/year)	19,757	10,359	7,677	10,317	11,349
N in treated manure (liquids + slurry) (ton (2000 lb)/year)	101	101	101	101	101
N in treated manure (sludge + solids) (ton (2000 lb)/year)	-	-	-	-	-
P2O5 in treated manure (liquids + slurry) (ton (2000 lb)/year)	93	93	93	93	93
P2O5 in treated manure (sludge + solids) (ton (2000 lb)/year)	-	-	-	-	-
Land Required for Treatment Facilities (acre)	2.9	2.9	2.9	3.6	2.9

Additionally, through the environmental mass balance of nutrients, the DST calculates the nitrogen and phosphorus in each manure stream, such as liquids, slurry, sludge, solids, and compost (see the Technical Guide [Part 2.6.3](#) for more information about these calculations).

This page reports the total amount of each nutrient in terms of non-sludge (i.e. liquid and slurry) and sludge plus solids. As a reminder, non-sludge manure streams include liquid, slurry, solids, and compost, which are assumed to be land applied every year. Sludge manure streams account for the sludge accumulated in long-term storages like lagoons and digesters. As all listed systems include ponds, there are no sludge+solids in these results.

See User Guide [2.3.9](#) for more information about non-sludge and sludge year calculations.

The graphs allow for an easy comparison of these nutrients for each manure stream aggregation.

Finally the DST calculates the number of acres needed solely for the treatment facilities.



### 2.4.7 Nutrients Results

The *Nutrients Results* page shows the long-term average nutrient content (as land applied) of different types of manure treated by the Baseline system and the four alternative systems presented on the screen. Results include nitrogen, phosphorus (P2O5) and potassium (K2O) in liquids, sludge, separated solids and composted materials. Not all systems have all types of manure, therefore, the value in the table and graphs for some types of manure may be zero. For example, the none of the scenarios in this example produce sludge, separated solids or composted material, therefore the values for all nutrients for these manure types is listed as zero. The table allows for a quick comparison across all manure types and the five scenarios.

# Long-Term Average Nutrient Concentrations as Land Applied

These results are NOT included in the ranking of scenarios

Applying manure for N. Export concern is for Non-Sludge Year.

Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
<b>Overall Ranking</b>	<b>9</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Resources</b>	<b>Sand bedding, scrape skid, mechanical sand separation, pond, tanker</b>	<b>Sand bedding, scrape skid, mechanical sand separation, pond, drag hose</b>	<b>Sand bedding, flush, mechanical sand separation, pond, drag hose</b>	<b>Sand bedding, flush, sand lane, pond, drag hose</b>	<b>Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose</b>
Nitrogen in slurry and/or liquids (lb/1000 gal)	18.91	18.91	19.47	13.57	18.91
P2O5 in slurry and/or liquids (lb/1000 gal)	17.36	17.36	17.87	12.46	17.36
K2O in slurry and/or liquids (lb/1000 gal)	18.76	18.76	19.31	13.46	18.76
Nitrogen in sludge (lb/1000 gal)	0.00	0.00	0.00	0.00	0.00
P2O5 in sludge (lb/1000 gal)	0.00	0.00	0.00	0.00	0.00
K2O in sludge (lb/1000 gal)	0.00	0.00	0.00	0.00	0.00
Nitrogen in separated solids (lb/ton (2000 lb))	0.00	0.00	0.00	0.00	0.00
P2O5 in separated solids (lb/ton (2000 lb))	0.00	0.00	0.00	0.00	0.00
K2O in separated solids (lb/ton (2000 lb))	0.00	0.00	0.00	0.00	0.00
Nitrogen in partially composted material (lb/ton (2000 lb))	0.00	0.00	0.00	0.00	0.00
P2O5 in partially composted material (lb/ton (2000 lb))	0.00	0.00	0.00	0.00	0.00
K2O in partially composted material (lb/ton (2000 lb))	0.00	0.00	0.00	0.00	0.00

A zero in any cell in the table indicates that stream does not exist in the scenario.



### 3 Consequences of Changing Ratings on the *Priorities* Page

The default ratings for each of the 18 metrics on the *Priorities* page were selected for two reasons. First, most farms base decisions primarily on economic factors such as capital costs and operational costs. Second, the range of possible values across each metric differs. For example, the differences in net benefits can total hundreds of dollars where the range in cost savings or fertilizer value can be just a fraction of that. If both net benefits and cost savings receive the same priority rating, results may rank MMSs with the highest cost savings (\$10) over systems whose net benefits may be \$100 cheaper. The tool is functioning properly; it prioritized metrics as it was programmed to do. Therefore, the user is encouraged to run the tool iteratively (changing

different ratings of metrics in different runs) to help identify the MMSs best for the farm. Below are some examples of what can happen when the ratings are changed.

In the case study above, Capital Costs, Operating Costs and Net Benefits received a rating of 80, while all other metrics were given a rating of 10. The tool selected sand bedding systems as the top ranked scenarios as shown in the table below. As explained above, although three economics metrics received higher rankings than the remaining 15 metrics, the values associated with those metrics played a role in the results because the ratings were not 0. Setting those ratings even higher can change results substantially. Three examples of the consequences of changing the ratings are shown below.

## ManureTech Dairy DST

Applying manure for N. Export concern is for Non-Sludge Year.

Results Summary					
Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
<b>Overall Ranking</b>	9	1	2	3	4
<b>Economics</b>	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Annualized capital costs (\$/head/year)	\$149	\$167	\$164	\$149	\$176
Operational costs (\$/head/year)	\$183	\$119	\$105	\$142	\$119
Fertilizer value for on-farm use (\$/head/year)	\$114	\$114	\$114	\$114	\$114
Cost savings (\$/head/year)	\$165	\$165	\$202	\$179	\$165
Revenues from sale of manure product or energy	\$0	\$0	\$0	\$0	\$0
<b>(NET COSTS) or NET BENEFITS (\$/head/year)</b>	<b>(\$218)</b>	<b>(\$173)</b>	<b>(\$156)</b>	<b>(\$177)</b>	<b>(\$182)</b>
<b>Environmental</b>	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Carbon footprint (ton (2000 lb) CO <sub>2</sub> E/head/year)	2.63	2.55	2.53	2.55	2.56
Land footprint (acre/head/year)	0.66	0.66	0.66	0.66	0.66
Energy footprint (kWhr/head/year)	0.00	0.00	0.00	0.00	0.00
Water consumption (gall/head/year)	2,041	2,041	2,041	4,214	2,041
Nitrogen footprint (lb/head/year)	54.5	54.5	54.5	54.5	54.5
Phosphorous excess (lb/head/year)	81.5	81.5	81.5	81.5	81.5
<b>Functionality and Logistics</b>	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Adoption rate	3.7	3.6	2.4	3.4	3.1
Operational reliability	3.4%	2.0%	2.2%	2.0%	2.4%
Operational resilience	1.7	1.7	1.7	1.7	1.7
Labor hours for application (hours/year) during Non-	1,550	190	190	201	190
Additional Land Required for Application (acre/year)	84	84	84	84	84
Manure Exported (ton (2000 lb)/year) during Non-Sludge	3,944	3,944	3,831	5,496	3,944
<b>Resources</b>	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
Electricity Required for Operations (kWh/year)	24,907	24,907	97,262	11,434	24,907
Fresh Water Used on Farm (gall/year)	2,790,691	2,790,691	2,790,691	5,761,563	2,790,691
Diesel Used on Farm (gall/year)	19,757	10,359	7,677	10,317	11,349
N in treated manure (liquids + slurry) (ton (2000 lb)/year)	101	101	101	101	101
N in treated manure (sludge + solids) (ton (2000 lb)/year)	0	0	0	0	0
P <sub>2</sub> O <sub>5</sub> in treated manure (liquids + slurry) (ton (2000	93	93	93	93	93
P <sub>2</sub> O <sub>5</sub> in treated manure (sludge + solids) (ton (2000	0	0	0	0	0
Land Required for Treatment Facilities (acre)	2.9	2.9	2.9	3.6	2.9

### 3.1 Changing the Priority to Cost Savings

When the rating for Cost Savings is changed from 10 to 80 and all other priorities are set to 10, the top four results change. For example, the table below shows how the baseline rank changes and how the previously top ranked alternatives become less favorably ranked. The baseline scenario rank fell from 9 to 55. The previous top four ranked alternatives fell to ranking between 40 and 49. The next table shows the baseline with the new top ranked Alternatives, all different from the original best ranked scenarios. The new top ranked alternatives have cost savings of \$291/head/year, while the original alternatives ranged from \$165 to \$202/head/year. However, their net benefits, carbon emissions, and labor hours for application are substantially higher. These drastic changes in results suggest it will be very important to use the tool iteratively, checking the impact of different priorities when evaluating the outcomes associated with different MMSs.

### ManureTech Dairy DST

Applying manure for N. Export concern is for Non-Sludge Year.

Results Summary					
Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
<b>Overall Ranking</b>	55	46	40	47	49
<b>Economics</b>	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose	Sand bedding, flush, mechanical sand separation, pond, drag hose	Sand bedding, flush, sand lane, pond, drag hose	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
Annualized capital costs (\$/head/year)	\$149	\$167	\$164	\$149	\$176
Operational costs (\$/head/year)	\$183	\$119	\$105	\$142	\$119
Fertilizer value for on-farm use (\$/head/year)	\$114	\$114	\$114	\$114	\$114
Cost savings (\$/head/year)	\$165	\$165	\$202	\$179	\$165
Revenues from sale of manure product or energy (\$/head/year)	\$0	\$0	\$0	\$0	\$0
<b>(NET COSTS) or NET BENEFITS (\$/head/year)</b>	<b>(\$218)</b>	<b>(\$173)</b>	<b>(\$156)</b>	<b>(\$177)</b>	<b>(\$182)</b>
<b>Environmental</b>	<b>Baseline</b>	<b>Alt 1</b>	<b>Alt 2</b>	<b>Alt 3</b>	<b>Alt 4</b>
Carbon footprint (ton (2000 lb) CO <sub>2</sub> E/head/year)	2.63	2.55	2.53	2.55	2.56
Land footprint (acre/head/year)	0.66	0.66	0.66	0.66	0.66
Energy footprint (kWh/head/year)	0.00	0.00	0.00	0.00	0.00
Water consumption (gal/head/year)	2,041	2,041	2,041	4,214	2,041
Nitrogen footprint (lb/head/year)	54.5	54.5	54.5	54.5	54.5
Phosphorous excess (lb/head/year)	81.5	81.5	81.5	81.5	81.5
<b>Functionality and Logistics</b>	<b>Baseline</b>	<b>Alt 1</b>	<b>Alt 2</b>	<b>Alt 3</b>	<b>Alt 4</b>
Adoption rate	3.7	3.6	2.4	3.4	3.1
Operational reliability	3.4%	2.0%	2.2%	2.0%	2.4%
Operational resilience	1.7	1.7	1.7	1.7	1.7
Labor hours for application (hours/year) during Non-Sludge Year	1,550	190	190	201	190
Additional Land Required for Application (acre/year) during Non-Sludge	84	84	84	84	84
Manure Exported (ton (2000 lb)/year) during Non-Sludge Year	3,944	3,944	3,831	5,496	3,944
<b>Resources</b>	<b>Baseline</b>	<b>Alt 1</b>	<b>Alt 2</b>	<b>Alt 3</b>	<b>Alt 4</b>
Electricity Required for Operations (kWh/year)	24,907	24,907	97,262	11,434	24,907
Fresh Water Used on Farm (gallyear)	2,790,691	2,790,691	2,790,691	5,761,563	2,790,691
Diesel Used on Farm (gallyear)	19,757	10,359	7,677	10,317	11,349
N in treated manure (liquids + slurry) (ton (2000 lb)/year)	101	101	101	101	101
N in treated manure (sludge + solids) (ton (2000 lb)/year)	0	0	0	0	0
P2O5 in treated manure (liquids + slurry) (ton (2000 lb)/year)	93	93	93	93	93
P2O5 in treated manure (sludge + solids) (ton (2000 lb)/year)	0	0	0	0	0
Land Required for Treatment Facilities (acre)	2.9	2.9	2.9	3.6	2.9

# ManureTech Dairy DST

Applying manure for N. Export concern is for Non-Sludge Year.

Results Summary					
Scenario	Baseline	Alt 1	Alt 2	Alt 3	Alt 4
<b>Overall Ranking</b>	55	1	2	3	4
<b>Economics</b>	Sand bedding, scrape skid, mechanical sand separation, pond, tanker	Organic bedding, scrape skid, screw press, centrifuge, lagoon, irrigation + drag hose	Organic bedding, scrape vacuum, centrifuge, lagoon, irrigation + drag hose	Organic bedding, scrape skid, centrifuge, lagoon, irrigation + drag hose	Organic bedding, scrape vacuum, screw press, centrifuge, lagoon, irrigation + drag hose
Annualized capital costs (\$/head/year)	\$149	\$325	\$333	\$332	\$333
Operational costs (\$/head/year)	\$183	\$172	\$175	\$167	\$175
Fertilizer value for on-farm use (\$/head/year)	\$114	\$46	\$46	\$45	\$46
Cost savings (\$/head/year)	\$165	\$291	\$291	\$291	\$291
Revenues from sale of manure product or energy (\$/head/year)	\$0	\$2	\$2	\$1	\$2
<b>(NET COSTS) or NET BENEFITS (\$/head/year)</b>	<b>(\$218)</b>	<b>(\$449)</b>	<b>(\$461)</b>	<b>(\$453)</b>	<b>(\$461)</b>
<b>Environmental</b>	<b>Baseline</b>	<b>Alt 1</b>	<b>Alt 2</b>	<b>Alt 3</b>	<b>Alt 4</b>
Carbon footprint (ton (2000 lb) CO <sub>2</sub> E/head/year)	2.63	5.16	6.10	6.09	5.17
Land footprint (acre/head/year)	0.66	0.32	0.30	0.30	0.32
Energy footprint (kWhr/head/year)	0.00	0.00	0.00	0.00	0.00
Water consumption (gall/head/year)	2,041	1,676	1,676	1,676	1,676
Nitrogen footprint (lb/head/year)	54.5	59.3	60.6	60.6	59.3
Phosphorous excess (lb/head/year)	81.5	39.6	33.0	33.0	39.6
<b>Functionality and Logistics</b>	<b>Baseline</b>	<b>Alt 1</b>	<b>Alt 2</b>	<b>Alt 3</b>	<b>Alt 4</b>
Adoption rate	3.7	2.5	2.0	2.5	2.1
Operational reliability	3.4%	2.7%	2.5%	2.2%	3.0%
Operational resilience	1.7	1.3	1.3	1.3	1.3
Labor hours for application (hours/year) during Non-Sludge Year	1,550	301	229	229	301
Additional Land Required for Application (acre/year) during Non-Sludge	84	0	0	0	0
Manure Exported (ton (2000 lb)/year) during Non-Sludge Year	3,944	0	0	0	0
<b>Resources</b>	<b>Baseline</b>	<b>Alt 1</b>	<b>Alt 2</b>	<b>Alt 3</b>	<b>Alt 4</b>
Electricity Required for Operations (kWh/year)	24,907	203,767	175,635	175,635	203,767
Fresh Water Used on Farm (gal/year)	2,790,691	2,291,006	2,291,006	2,291,006	2,291,006
Diesel Used on Farm (gallyear)	19,757	8,142	9,120	7,704	9,558
N in treated manure (liquids + slurry) (ton (2000 lb)/year)	101	23	32	32	23
N in treated manure (sludge + solids) (ton (2000 lb)/year)	0	43	43	43	43
P2O5 in treated manure (liquids + slurry) (ton (2000 lb)/year)	93	19	24	24	19
P2O5 in treated manure (sludge + solids) (ton (2000 lb)/year)	0	43	41	41	43
Land Required for Treatment Facilities (acre)	2.9	9.9	11.0	11.0	9.9

## Part 2. Technical Guide

This Part represents the technical guide for the DST, providing information on data, methods, assumptions, and analysis. For detailed information about descriptions and assumptions for each unit process in an MMS, see Appendix [6.2](#). For mass balance calculations see Appendix [6.3](#).

### 1 User Priorities and Scenario Rankings

A unique feature of this DST is that each of the priority metrics can be weighted by the user, affecting how the scenarios are ranked against each other. The top alternatives recommended by the DST represent scenarios that perform better in terms of the metrics that are given more weight or importance to the user.

The 18 metrics are separated into 3 categories, as follows:

1. Economic – Capital costs (Capital), Operational costs (Opex), Net costs (Net), Fertilizer values (Fertilizer), Cost savings (Savings), and Revenues (Revenue)
2. Environmental – Carbon footprint (Carbon), Energy footprint (Energy), Land footprint (Land), Water consumption (Water), Nitrogen footprint (Nitrogen), and Phosphorus excess (Phosphorus)
3. Technological – Adoption rate (Adoption), Operational reliability (Reliability), Operational resilience (Resilience), Labor hours (Labor), Land required for manure application (Application), and Manure export (Export)

Table 2a in the User Guide briefly describes each metric, while more detailed descriptions of each metric as well as information on how each is calculated can be found in this Technical Guide [2](#) (Environmental), [3](#) (Economics), and [4](#) (Technological).

Each metric can be rated on a scale of 0 to 100, where 0 is considered unimportant and 100 is considered very important when making manure management decisions. The DST defaults to a rating of 80 for capital and operating costs and net costs, and 10 for all other metrics.

Rating the importance of each metric can be done by entering a number in the Rating column, using a scale of 0 (unimportant) to 100 (very important). As the ratings are adjusted for various metrics, those changes will affect the relative weight (i.e., how much importance each metric has compared to the other metrics) by looking in that column and by looking at the pie chart.

Some metrics may be considered better when the result is high, while lower values for results may be considered better for other metrics.

- Metrics considered better when results are high: net cost (i.e., less negative), fertilizer value, cost savings, revenues, adoption rate, operational reliability, operational resilience.

- Metrics considered better when results are low: capital costs, operational costs, carbon footprint, energy footprint, land footprint, water consumption, nitrogen footprint, phosphorus footprint, labor hours, land required for manure application, manure export.

There are different categories of results that can be chosen for some metrics for use in the ranking. Either the non-sludge year, the sludge year, or both can be selected, which apply to some of the Technological metrics (labor hours for land application, additional land required for application, and manure exported). Either on-farm or net impacts can also be selected, which apply to the Environmental metrics. Review the User Guide [Part 1.2.3.9](#) for more information about these differences.

The DST calculates all metrics for each scenario. Then, within each metric, a relative score is calculated for each scenario by dividing its value by the minimum or maximum value (depending on which is considered better when the result is high versus when the result is low). This gives a value between 0 and 1 for each metric and scenario. Next, the percentage that is calculated from the priority value indicated on the *Priorities* page is multiplied by the relative score for each metric and scenario, applying the level of importance placed on that metric to each scenario score. A final score for each scenario is calculated by adding together the priority-weighted scores. These final scores are then ranked by value to give the overall rankings across scenarios.

**Note:** The influence of each metric on the overall ranking depends on the magnitude of its result and the scale of its variation across scenarios. For instance, revenues may range from \$0 to \$20 per head, while capital costs may range from \$100 to \$500 per head. If both metrics are weighted equally, alternatives with higher revenues could also carry disproportionately higher capital costs. Careful consideration is needed when assigning weights to each metric.

## 2 Environmental Methods: Data, Models, and Analysis

This section outlines the methodologies used to assess the environmental impacts of each manure management system (MMS) or process. The environmental analysis takes a life cycle inventory approach. The environmental impact categories in this DST include the Carbon Footprint, Land Footprint, Energy Footprint, Water Footprint, Nitrogen Footprint, and Phosphorus Excess. Environmental impacts are calculated and reported in per head per year (/head/y).

To estimate methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and ammonia (NH<sub>3</sub>) emissions during manure management, emission factors from the Intergovernmental Panel on Climate Change (IPCC) were used (Gavrilova et al., 2019; Hergoualc’h et al., 2019). The California GREET 4.0 model (CARB, 2023; U.S. Department of Energy, 2017) was applied to obtain emission factors for carbon dioxide (CO<sub>2</sub>), water, and energy consumption associated with the resources and activities modeled in the DST. Developed by Argonne National Laboratory, the GREET model evaluates life cycle emissions for various fuels, energy systems, and technologies, enabling a comprehensive accounting of on-farm and off-farm environmental impacts. Both IPCC and GREET models supporting off-farm emissions estimates.

The analysis for phosphorus excess is based on the P<sub>2</sub>O<sub>5</sub> content of each manure stream applied on-farm, the crop fertilizer nutrient needs, whether applying for N or P, and whether applying via broadcast or injection. When manure is set to be applied on an N basis, there is often more P<sub>2</sub>O<sub>5</sub> than is needed by the crop, resulting in overapplication of P<sub>2</sub>O<sub>5</sub> – this is the Phosphorus excess. When manure is set to be applied on a phosphorus basis, there will be no P excess. Note that when applying for phosphorus, nitrogen will often be underapplied. The DST does not account for the need to apply commercial N fertilizer to supplement manure N under P-based application.

## 2.1 Life Cycle Assessment (LCA) Method

A Life Cycle Assessment (LCA) method is utilized to evaluate the potential environmental impacts of the simulated MMS. The LCA process consists of four main stages:

### 2.1.1 Goal and Scope Definition:

This stage involves setting the objective of the evaluation and defining a suitable functional unit, kg of manure treated per cow per year. Unit conversions from metric to imperial are applied as needed.

### 2.1.2 Life Cycle Inventory Evaluation:

Detailed quantification of inputs and outputs of material and energy flows in the process is conducted. This includes quantifying the amount of manure to be collected, treated, stored, and land applied, as well as emissions at different stages of manure handling. Based on the defined functional unit, a reference flow of materials that are consumed within the assumed system boundary are quantified. The system boundary for each MMS alternative is displayed as a flow chart that involves multiple individual practices including- manure and wash water generation, collection, handling, processing, storage and application.

At the output level, LCA also defines and quantifies the main product, co-products, and all emissions. A system boundary has been prepared to illustrate the reference flow of materials and emissions occurring in the background and foreground systems. The background system represents all the related upstream production sectors that supply required raw materials (e.g. fuels, machinery and implements, water) and are integral elements of the foreground system (i.e. the main MMS under study).

### 2.1.3 Life Cycle Impact Assessment:

This stage (LCIA) involves integrating the results of the inventory analysis with characterization factors of emissions to estimate the environmental impacts. It includes quantifying environmental impact scores for emissions such as methane, nitrous oxide, and other emissions during the operation of the MMS.

### 2.1.4 Interpretation:

The final stage involves interpreting the results of the assessment to draw conclusions and make recommendations. In the DST the LCIA results are used as weighted metrics in the scenario ranking previously described and not used as stand-alone metrics for recommendations.

Data associated with the inputs and outputs of material flows are sourced from GREET 4.0 model (CARB, 2023; U.S. Department of Energy, 2017).

#### *2.1.5 Data Acquisition:*

Emission factors for the materials produced off-farm were extracted from the GREET model, which provides standardized values based on extensive research and data collection across multiple sectors, including agriculture, transportation, and energy production.

#### *2.1.6 References*

Values for emissions factors referenced in this analysis are sourced directly from the IPCC and the CA Greet 4.0 model, ensuring that the calculations are grounded in credible and widely accepted scientific data. For more detailed information on the model, including specific emission factors and methodologies, please refer to the official documentation of the CA Greet 4.0 model available from Argonne National Laboratory:

<https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation>.

## **2.2 Three Categories of Environmental Emissions Results**

The environmental analysis is conducted using three categories: On-Farm, Off-Farm, and Net Emissions. These categories provide a comprehensive evaluation of environmental impacts for each scenario analyzed. A summary of the components included in each on-farm and off-farm footprint is presented below in Table 3a.

#### *2.2.1 On-Farm Impacts*

On-farm emissions are those impacts related to manure management activities on the farm, from collection, treatment, storage, and land application activities. For CO<sub>2</sub> and energy footprints, these are also known as Scope 1 emissions.

#### *2.2.2 Off-Farm Impacts*

Off-farm emissions are related to the mining, manufacturing, production, and transport of materials and equipment sourced outside the farm but utilized in manure management activities within the farm. For carbon and energy footprints, these are known as Scope 2 and Scope 3 emissions. Electricity used in manure management activities on the farm is considered a Scope 2 emission, which is classified as an Off-Farm emission in this DST. When manure is used as fertilizer, Off-Farm emissions associated with avoided commercial fertilizer are accounted for as a negative impact, representing an environmental benefit.

**Note: In cases where there is not enough land to apply all manure nutrients on-farm, the DST does not calculate off-farm impacts related to land use, reactive nitrogen, or excess phosphorus because there is no information about how manure will be managed once it leaves the farm. As a result, these values may be underestimated.**

To estimate potential off-farm impacts, users can increase the on-farm land area available to spread manure in the DST so that all manure is applied on-farm. Then, manually calculate the difference between this simulation and the original simulation where some manure had to be exported to approximate off-farm impacts.

### 2.2.3 Net Impacts

The net emissions are the sum of On-Farm and Off-Farm impacts.

## 2.3 Variables Used to Calculate Environmental Impacts

### 2.3.1 Methane, Nitrous Oxide, and Ammonia Emissions (ton)

Greenhouse gas (GHG) emissions, including methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) (both direct and indirect), and ammonia (NH<sub>3</sub>) from manure management systems, are estimated using a combination of published data and Intergovernmental Panel on Climate Change (IPCC) methodologies, specifically the Tier 2 approach (Gavrilova et al., 2019).

Methane emissions are calculated based on the CH<sub>4</sub> production potential (Bo), the volatile solids (VS) content in each manure stream, and methane conversion factors (MCFs) specific to each treatment and storage method, as outlined in Table 10.17 of Gavrilova et al. (2019). In this DST, MCF values are dynamically adjusted based on the type of manure treatment and storage system in use (e.g., storage pond, anaerobic lagoon, solid storage, composting) and the prevailing regional climate. To facilitate this, IPCC climate zone classifications were overlaid with NOAA climate divisions used in

Table 3a. List of each environmental metric and its associated On-Farm and Off-Farm components considered in this Tool.

Carbon Footprint		Land Footprint		Energy Footprint		Water Footprint		Reactive Nitrogen Footprint		Phosphorus Excess	
On-farm	Off-farm	On-farm	Off-farm	On-farm	Off-farm	On-farm	Off-farm	On-farm	Off-farm	On-farm	Off-farm
Methane	Fresh water	Manure storage	N/A	N/A	Fresh water	Fresh water	N/A	N/A	N/A	Excess P2O5	N/A
Nitrous Oxide	Electricity	Solids drying					Electricity	NH3-N			
Diesel use	Diesel production	Land application		Diesel production			Diesel production	NOx-N			
	Sand			Fertilizers substitution							
	Fertilizer substitution										

the DST, enabling assignment of MCFs by climate division.

N<sub>2</sub>O emissions encompass both direct emissions originating from the manure management and storage system on-farm and indirect emissions resulting from the release of volatilized ammonia and nitrates. Direct N<sub>2</sub>O emissions are calculated based on the mass balance of N in each manure stream and the N<sub>2</sub>O emission factor, which varies by treatment and storage type as shown in Table 10.21 (Gavrilova et al., 2019). Indirect N<sub>2</sub>O emissions are calculated using N volatilization factors, which vary by treatment and storage system type as shown in Table 10.22 (Gavrilova et al., 2019), and using the emission factor for N<sub>2</sub>O from the deposition of volatilized NH<sub>3</sub> and NO<sub>x</sub>, which varies by climate type as shown in Table 11.3 (Hergoualc'h et al., 2019).

### 2.3.2 Electricity Usage (kWh)

Electricity usage, measured in kilowatt-hours (kWh), refers to the energy consumed by various equipment involved in manure management. This includes the operation of motors used for automatic alley scrapers, manure transfer channels, solid-liquid separators, mechanical sand separators, and flush recycling systems.

### 2.3.3 Diesel Usage (gal)

Diesel usage, measured in gallons, pertains to the fuel consumed by machinery involved in manure management activities. This includes tractors used for transporting manure and performing field operations, as well as skid steers and other equipment employed for handling manure. Diesel is also consumed by land application machinery that spreads manure on fields.

### 2.3.4 Water Usage (gal)

Water usage, measured in gallons, includes the total volume of fresh water utilized for various manure management activities. This encompasses the water required for cleaning barns and other water usage during manure processing and treatment, as well as any fresh water used to supplement or dilute treatments in ponds and lagoons, while excluding recycled water for flushing.

### 2.3.5 Land Requirement (acres)

Land requirement, measured in acres, encompasses all areas associated with manure management activities on the farm, and does not consider land requirements associated with any off-farm processes. This analysis accounts for the on-farm land needed for sand lanes, reception pits, and solid-liquid separator construction areas. Additionally, it covers solid drying areas and various manure storage facilities, such as storage pond, lagoon, covered lagoon, and anaerobic digester etc. The land requirement also accounts for areas designated for the application of manure streams on-farm following treatment processes.

## 2.4 Carbon Footprint (ton CO<sub>2</sub> equivalent)

**On-Farm:** Includes CO<sub>2</sub> emissions from methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) generated during the on-farm processes of manure storage, and treatment. It also includes emissions from diesel or other fuel use on the farm.

$$\text{On-Farm Emissions} = \sum (\text{Emissions}_i \times \text{Emission Factor}_i)$$

Where:

- Emissions<sub>i</sub> = emissions from different sources (e.g., methane, nitrous oxide, etc.).
- Emission Factor<sub>i</sub> = CO<sub>2</sub> conversion factor for each emission type (e.g., for CH<sub>4</sub> and N<sub>2</sub>O, these factors will vary).

**Off-Farm:** Includes emissions from the production of electricity off site that is consumed within farm. It also includes emissions from the production of materials such as water, sand and diesel, which are produced off the farm but used in the on-farm manure management process. Emissions generated in the production of fertilizer are also included.

$$\text{Off-Farm Emissions} = \sum (\text{Resource Use}_j \times \text{Emission Factor}_j)$$

Where:

- Resource Use<sub>j</sub> = represents the use of different resources like electricity, water, diesel, sand as well as nitrogen, phosphorus and potassium fertilizer.
- Emission Factor<sub>j</sub> = CO<sub>2</sub> conversion factor for each resource (e.g., CO<sub>2</sub> per kWh of electricity, per gallon of diesel, etc.).

**Net Emissions:** The total carbon footprint, which is the sum of on-farm emissions from manure management and off-farm emissions from material production.

$$\text{Net CO}_2 \text{ emissions footprint} = \text{On-Farm Emissions} + \text{Off-Farm Emissions}$$

## 2.5 Land Footprint (ac)

**On-Farm:** Represents the land directly required for manure storage, drying, processing, and land application on the farm.

$$\text{On-Farm Land Footprint} = \sum (\text{Land Area for Activity}_i)$$

Where:

- Land Area for Activity<sub>i</sub> = land area used for each specific activity (e.g., manure storage, drying, processing, etc.).

**Off-Farm:** The land footprint associated with off-farm activities is beyond the scope of this analysis. It should be noted that when there is not enough land to apply all manure nutrients on-farm, the excess manure is exported off-farm and will require land to manage that manure – this

DST does not account for land needed off-farm, thus underrepresenting the reported land footprint.

$$\text{Off-Farm Land Footprint} = 0$$

**Net Footprint:** The total land footprint, is the sum of the on-farm land use requirements plus the off-farm land requirements for material production.

$$\text{Net Land Footprint} = \text{On-Farm Land Footprint} + \text{Off-Farm Land Footprint}$$

## 2.6 Energy Footprint (MJ)

**On-Farm:** There is no direct on-farm energy footprint (as diesel is produced off-farm). Note that emissions from diesel burned on the farm for tractors, machinery, and manure management are allocated to the farm's carbon footprint (see section above).

$$\text{On-Farm Emissions} = 0$$

**Off-Farm:** Accounts for the energy consumed in producing materials like electricity, diesel, and fertilizers that are used on the farm but produced off-site.

$$\text{Off-Farm Emissions} = \sum (\text{Resource Use}_j \times \text{Emission Factor}_j)$$

Where:

- Resource Use<sub>j</sub> = represents the use of different resources like electricity, water, diesel, etc.
- Emission Factor<sub>j</sub> = CO<sub>2</sub> conversion factor for each resource (e.g., CO<sub>2</sub> per kWh of electricity, per gallon of diesel, etc.).

**Net Footprint:** The sum of on-farm energy use and off-farm energy consumed in the production of materials used in manure management.

$$\text{Net Energy Emissions Footprint} = \text{On-Farm Emissions} + \text{Off-Farm Emissions}$$

## 2.7 Water Footprint (gallons)

**On-Farm:** Measures the water directly used on the farm for manure management activities, such as flushing, cleaning, and dilution during manure treatment and application.

$$\text{On-Farm Water Footprint} = \sum (\text{Water Used for Activity}_i)$$

Where:

- Water Used for Activity<sub>i</sub> = the amount of fresh water used for each specific activity related to manure management.

**Off-Farm:** Represents the water used in the production of materials such as electricity, urea, and fertilizers, which are consumed on the farm but produced off-site.

$$\text{Off-Farm Water Footprint} = \sum (\text{Water for Material Production}_j)$$

Where:

- Water for Material Production<sub>j</sub> = the amount of fresh water used in the production of materials like electricity, fertilizers, and other resources used on the farm.

**Net Footprint:** The total water footprint, combining on-farm water use with the off-farm water required for material production.

$$\text{Net Water Footprint} = \text{On-Farm Water Footprint} + \text{Off-Farm Water Footprint}$$

## 2.8 Reactive Nitrogen Footprint (lb N)

**On-Farm:** Includes reactive nitrogen emissions, primarily from ammonia (NH<sub>3</sub>) and nitrates (NO<sub>3</sub>), and NO<sub>x</sub> released into the air and water during the on-farm processes of manure storage, and treatment.

$$\text{On-Farm Nitrogen Emissions} = \sum (\text{Emissions}_i \times \text{Emission Factor}_i)$$

Where,

Emissions<sub>i</sub> = emissions from different sources (e.g., ammonia (NH<sub>3</sub>), nitrates (NO<sub>3</sub>), NO<sub>x</sub>, etc.).

Emission Factor<sub>i</sub> = emission factor for each source.

**Off-Farm:** Off farm nitrogen footprint is not currently calculated in the DST. Net impacts are currently the same as on-farm footprint.

$$\text{Off-Farm Nitrogen Emissions} = 0$$

Where:

- Resource Use<sub>j</sub> = the amount of manure N that is exported off farm.

- Emission Factor<sub>j</sub> = N emission factor for each resource.

**Net Emissions:** The total nitrogen footprint, which is the total of on-farm and off-farm nitrogen emissions.

$$\text{Net Nitrogen Emissions Footprint} = \text{On-Farm Emissions} + \text{Off-Farm Emissions}$$

## 2.9 Phosphorus Excess (lb P<sub>2</sub>O<sub>5</sub>)

**On-Farm:** This metric quantifies any excess phosphorus that remains after the manure has been land applied, based on crop or land nutrient requirements. The phosphorus excess includes contributions from both liquid and sludge forms of manure.

$$\begin{aligned} \text{On-Farm Phosphorus Excess} \\ = \sum (\text{Manure Phosphorous Applied}_i - \text{Phosphorous Uptake by Crop}_i) \end{aligned}$$

Where,

Manure Phosphorus Applied<sub>i</sub> = This is the total amount of **phosphorus** that is applied to the land through manure (liquid and/or sludge).

Phosphorus Uptake by Crop<sub>i</sub> = This represents the amount of **phosphorus** that is absorbed and used by the crops.

**Off-Farm:** Off-farm phosphorus footprint is not currently calculated in the DST. Net impacts are currently the same as on-farm footprint.

$$\text{Off-Farm Phosphorus Emissions} = 0$$

**Net Footprint:** The total phosphorus excess, which is the total of on-farm phosphorus footprint.

$$\text{Net Phosphorus Emissions Footprint} = \text{On-Farm Emissions} + \text{Off-Farm Emissions}$$

## 3 Economic Methods: Data, Models, and Analysis

The DST is designed to estimate costs and benefits associated with process components related to each MMS scenario. The economic analysis takes a partial budget approach, where defined MMS activities are accounted for (see Appendix [6.1](#) for a list of processes included in each scenario). The economics of each scenario are determined on an average annual basis, and include capital costs, operational costs, cost-savings, fertilizer value of manure nutrients used on-farm, revenue generation from manure products which are exported off-farm, and net benefits. Results are reported in \$/head/year by dividing by the total number of head contributing to the MMS.

As needed, values were adjusted to 2024 U.S. dollars using the following producer price indices (PPIs):

PPI by Commodity: Machinery and Equipment: Agricultural Machinery and Equipment (WPU111) - <https://fred.stlouisfed.org/series/WPU111>

PPI for New Industrial Building Construction Sector (NAICS 236211) - <https://data.bls.gov/timeseries/PCU236211236211>

PPI by Commodity: Machinery and Equipment: Domestic Water Systems (WPU11411311) - <https://fred.stlouisfed.org/series/WPU11411311>

All values are modeled in 2024 U.S. dollars.

Different methods may be used to evaluate costs and benefits, based on available data. These methods include unit cost estimating and parametric (i.e., linear and power) cost estimating. Tables have been created to identify unit costs for some items (e.g., utilities and some equipment and implements). Factors such as the manure volume being processed and the equipment capacity dynamically determine the size and quantity needed for a set of model inputs.

Parametric models have been developed, where inputs across a range of values (e.g., manure volume) were related to the associated costs at that input value, so that user- or DST-defined inputs can be used to estimate the cost for a given item or system. This method allows estimation that accounts for economies of scale.

However, a limitation is that the effect of geographic and farm-specific conditions are not included in the estimation. Therefore, the user may adjust large categories of costs (i.e., construction and equipment) by using a multiplier. Each multiplier will be applied to the default costs. The default multiplier is set at 1.0, meaning that construction and or equipment costs reflect no adjustment from the national average costs.

Entering a value less than 1.0 means that you believe your costs are that percentage of the national costs. For example, entering a 0.5 means you believe your costs are 50% (or half) of the national average while entering a 0.2 means you believe your costs are 20% of the national average.

Methods for each process component are described in detail below.

### 3.1 Overview of Economic Metrics

Economic considerations play a crucial role in decision support DSTs for Dairy manure management. Understanding the economic outcomes of manure management decisions enable users to assess the economic costs and benefits across a range of choices. The economic metrics are reported as \$/head/year and include:

1. Capital costs – costs of construction and equipment needed for all unit processes in the given MMS scenario. These costs are calculated from the initial purchase price, expected lifetime, annual usage, salvage value, and interest. A priority rating of 100 corresponds to

a preference for capital costs to be low. A priority rating of 0 indicates that capital costs are not important for decision making.

2. Operational costs – costs for insurance, repair and maintenance, water, electricity, fuel, lubrication, and labor for the MMS in the given scenario. Similar to capital costs, a priority rating of 100 corresponds to a preference for operational costs to be low where a rating of 0 suggests that costs are of no concern.
3. Fertilizer value of manure nutrients – the value of manure nutrients that can be land applied on-farm, given the manure nutrient content, fertilizer nutrient needs, nutrient to apply for (N or P), and the acres available for land application. For MMS scenarios where a storage is emptied less than every year, the annual average value over the storage time period is used. When available land is not adequate for complete application of manure nutrients, the excess manure nutrient value is NOT counted towards fertilizer value; rather, it may be included in revenues if it can be sold, costs if it must be paid to haul away, or excluded from costs or benefits if it is given away. A priority rating of 100 corresponds to a preference for fertilizer value of N and P in the manure to be high. A rating of 0 means that fertilizer value is not important.
4. Cost savings – cost savings from avoided resource use, such as recycled water and bedding. A priority rating of 100 corresponds to a preference for cost savings to be high, while a rating of 0 means cost savings are not important to decision making.
5. Revenues – revenues from resources generated on-farm which can be sold, such as manure end products, bedding, and carbon credits from anaerobic digestion. For MMS scenarios where a storage is emptied less than every year, the annual average value over the storage time period is used. A priority rating of 100 corresponds to a preference for revenues to be high, while a rating of 0 means that generating revenues from manure management is not important.
6. Net costs (or net benefits) – considers direct (revenues, capital costs, operating costs) and indirect (fertilizer value) economic impacts, given by the following equation:  $\text{Fertilizer Value} + \text{Revenues} - \text{Capital Costs} - \text{Operational Costs}$ . Negative values (i.e., net costs) indicate that costs exceed benefits by the given amount; positive values (i.e., net benefits) indicate that benefits exceed costs by the given amount. A priority rating of 100 means that it is important for net costs to be low or that benefits outweigh costs and net benefits are high. A rating of 0 means that net costs or net benefits are not important for decision making.

### 3.2 Capital Costs (\$/head/y)

Capital costs are evaluated as an annual average capital recovery value (CRV). The CRV is estimated from the initial investment cost for each machinery and construction item, as well as the expected lifetime, salvage value, and annual usage (when applicable) for each item. For each pre-defined scenario within the DST, the engineering model helps determine the resource needs of the simulated system (e.g., number or size of machinery items).

Capital costs for certain machinery and equipment may include the cost of the primary equipment, ancillary equipment required, installation, and engineering design, according to information collected from vendor surveys, literature, and extension reports, adjusted to 2023 dollars using an appropriate PPI.

### *3.2.1 Expected lifetime (y or h)*

The expected lifetime of equipment is typically set to 10 years (Rotz et al., 2018), unless otherwise indicated by the vendor for given equipment or from literature and extension reports (Painter, 2011; Stenglein et al., 2011). Structures and construction items with no salvage value have an expected lifetime set at 20 years (Rotz et al., 2018; Sefeedpari et al., 2019). Tractors have an expected lifetime of 16,000 hours (ASABE, 2011); the expected hours of use for each tractor are estimated in the DST, and the expected years of life are calculated.

### *3.2.2 Salvage value (% of purchase price)*

The salvage value of equipment (e.g., its value at the end of its expected useful life) is typically set at 20% of the initial purchase price, unless other indicated by the vendor or from literature and extension reports. Buildings, construction, and engineering design have a salvage value of 0%.

### *3.2.3 Annual usage of tractors (h/y)*

The annual usage for equipment items evaluated in the DST may vary widely according to farm-specific usage and manure amount and characteristics. Because tractors are ubiquitous on farm and likely are used across manure management processes and other non-manure management activities, we evaluate the annual usage of tractors as hours for a given unit process and calculate the percentage of total use for all on-farm activities. This allows us to estimate the annualized costs of tractors specific to manure management.

We assume that a tractor is used on-farm (for all activities, manure-related and otherwise) for at least 1000 hours. We also assume that a tractor is used for all on-farm activities no more (i.e., a maximum) than 2000 hours (personal communication, Popp 2024). The minimum number of hours will be used to calculate the percentage of the time the tractor is used for manure management, whereby the capital cost of the tractor is allocated proportionally to the manure management scenario. The maximum number of hours will be used to calculate how many tractors will need to be purchased for the given scenario. For example, a single tractor can be used to remove sand from a sand lane for up to 2000 h/y; when more time is needed on this unit process, then a second tractor is expensed).

The amount of time available for land application (i.e., spreading window) and the maximum amount of time a given tractor may be used on any given day may also influence tractor usage, quantities needed, and costs. The default for the land application spreading window for regular manure removal (when manure is removed at least once a year) is 65 days. The DST also accounts for scenarios where lagoon sludge accumulates over several years and is removed less frequently. In such cases, manure application might take place during a particularly favorable year, increasing

the number of available days. For these "sludge-year" applications, the DST assumes a 30% increase in available days due to the more flexible timing.

The default for the number of hours any given tractor may run in a single day is 12 h/d. From these assumptions and information about resource requirements, we evaluate the quantity of tractors needed for each unit process, the total cost of purchasing the tractors, and the proportional annualized cost of the tractors used specifically for manure management activities.

#### 3.2.4 Interest rate (%/y)

An interest rate of 5.5% is assumed (USDA FSA, 2024).

#### 3.2.5 Capital recovery method (\$/head/y)

The capital recovery method is used to calculate the annualized cost of capital purchases accounting for interest, depreciation, and expected lifetime of the asset (Takele, 2013; USDA Economic Research Service, 2023). A capital recovery factor (CRF), representing a ratio used to calculate the capital recovery value (CRV), is determined for each asset as follows:

$$CRF = i / (1 - (1 + i)^{-n})$$

where  $i$  = the interest rate, as a percentage

$n$  = expected lifetime, in years

From the CRF, the CRV is calculated as follows:

$$CRV = ((PP - SV) * CRF) + (SV * i)$$

where  $PP$  = initial investment cost

$SV$  = salvage value = % of initial cost \* initial cost

### 3.3 Operational Costs (\$/head/y)

Energy data were obtained from the U.S. Energy Information Administration (US EIA, 2024). More details about these and other operational costs are described below.

#### 3.3.1 Electricity (\$/kWh)

State-level data by month were obtained for "End-Use Sector, by State" data series. Minimum, average, and maximum values were calculated for 2024 for each state, and converted from c/kWh to \$/kWh.

#### 3.3.2 Natural Gas (\$/1000 ft<sup>3</sup>)

State-level data by month were obtained for "Industrial Price" data series. Minimum, average, and maximum values were calculated for 2024 for each state. Data were not available for the District of Columbia, so Virginia's pricing was used. Sometimes, a monthly value for a given state may be missing; in such cases the 12-month average was calculated without an observation for that month.

### 3.3.3 Gasoline (\$/gal)

State- or region-level data by week were obtained for “Gasoline-All Grades” and includes the cost of taxes. The following states have state-specific values reported: CA, CO, FL, MA, MN, NY, OH, TX, and WA. All other states are included in defined regions, or “PADDs” (Petroleum Administration for Defense Districts), such that values are the same across all states in a given PADD. Minimum, average, and maximum values were calculated for 2024 for each state.

### 3.3.4 Diesel (\$/gal)

Region-level data (i.e., by “PADDs”) by week were obtained for “Diesel-All Types” and includes the cost of taxes. California is the exception, where state-level data were available. Minimum, average, and maximum values were calculated for 2024 for each state.

### 3.3.5 Water (\$/ 1000 gal)

State-level data for year 2023 were obtained from the USDA NASS Irrigation and Water Management Survey for “Expenses for Irrigation Water from Off-Farm Suppliers” (Table 15) (USDA NASS, 2024). Costs were obtained in average cost per acre-foot of water and converted to average cost per 1,000 gallons, and then adjusted for inflation using the PPI by Commodity: Machinery and Equipment: Domestic Water Supply (WPU11411311). Given the age of the data, uncertainty due to variable survey response inputs, and fluctuations in costs over time, users are encouraged to replace the default value with their expected costs for the farm being considered. Note that for water pumped on the farm, whether surface or groundwater, the rate can be calculated and entered into the User Input page for Freshwater cost.

### 3.3.6 Labor (\$/h)

Two types of labor are used in this DST: non-specialized and specialized. State- or region-level data were obtained from the Bureau of Labor Statistics (BLS) for non-specialized (i.e. “Agricultural Equipment Operators” code 45-2091) and specialized (i.e. “Farmers, Ranchers, and Other Agricultural Managers” code 11-9013) for the period of May 2024 (US BLS, 2024). When data were not available for a state or the District of Columbia, an average was taken from other states in the region, as specified in the USDA NASS Farm Labor Regions (USDA NASS, 2025). Data for managers in California was not available, and California is in its own region, so values for states in the neighboring Pacific Region were used. The District of Columbia was not included in any region, so an average was taken across states in Northeast I and Northeast II, as DC borders a state in each of these regions. Data for specialized labor in Alaska was not available, so an average of states in the neighboring Pacific Region was used.

Labor for tractor operation is set at 10% more time than the number of hours the tractor is in operation (Lattz and Schnitkey, 2017; Rotz et al., 2018). Note that labor cost includes only the wage rate, and does not include taxes or benefits.

### 3.3.7 Maintenance (% of purchase price/y or \$/y)

Information about maintenance costs was gathered from published literature, extension reports, and vendor surveys (Horner et al., 2020; Painter, 2011; Rotz et al., 2018). In most cases, these are

evaluated as a percentage of the purchase price of equipment; in other cases, maintenance cost is evaluated as a dollar cost (\$) per year and adjusted to 2023 dollars using the PPI by Commodity: Machinery and Equipment: Agricultural Machinery and Equipment (WPU111).

### *3.3.8 Insurance (% of purchase price)*

Insurance is assumed to be 0.5% of the purchase price for machinery and equipment (Rotz et al., 2018).

### *3.3.9 Pay to Export Excess Manure*

When there is not enough land to apply manure nutrients on-farm, the excess manure must be exported. When the farm has to pay to haul manure off-farm, this is accounted for as an operational cost. The user can input information related to how much of each potential excess stream will need to be paid to haul off, and the cost per volume or mass that they expect to pay.

### *3.3.10 Other*

Operational costs for the anaerobic digester (digester alone) are estimated as a single combined annual cost modeled as a percentage of the capital cost (Astill, Shumway, and Frear, 2018). This is reflected in the “Annual Maintenance” value for operation of the digester alone, and includes energy, labor, and supplies for daily operations, maintenance, and repair.

## **3.4 Manure Nutrient Fertilizer Value (\$/head/y)**

Manure contains essential nutrients for crop growth and can supplement or replace the need for mineral fertilizers. The type of MMS can impact the characteristics of each manure stream (e.g., liquid, slurry, sludge, solid, compost) and thus affect the nutrient value. The nutrient content of the manure is evaluated as it passes through each treatment process in a given scenario to provide manure nutrient characteristics of each stream that may be land applied. The mode of application will impact the nitrogen availability, where it is assumed that surface application results in 75% nitrogen availability (i.e., 25% is lost) while subsurface application results in 95% nitrogen availability (i.e., 5% is lost).

Crop nutrient needs, acres available for manure application, and fertilizer prices can affect the value of manure nutrients as well. DTN Progressive Farmer was used to evaluate 2024 fertilizer prices (DTN Progressive Farmer, 2024). When a nutrient is applied in excess of crop needs, the value of that excess is zero. The DST uses default values for these variables unless the user changes them. The model used to estimate manure nutrient value was adapted from Massey and Lory (2020).

## **3.5 Revenues (\$/head/y)**

As the Dairy industry evolves, there may be increased opportunity to create new revenue streams from the sale of treated manure (e.g., separated solids, composted manure) and energy and carbon credits from the capture of methane produced during anaerobic digestion.

When more manure is generated than can be land applied on-farm, that excess manure is assumed to be exported off-farm – either at a cost (pay to haul off), for free (given away at no cost to the user), or revenue-generating (sold off-farm). The DST uses default values for the percentage of each stream (i.e., liquids, slurry, sludge, solids, compost) in excess that must be exported in these different ways, as well as the costs or revenues received for each. These values can be changed by the user. The revenue value of each manure stream is based on the expected average nutrient content aggregated for N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O. According to Ackerman and Cicek (2013), livestock farmers typically receive less than 50% of the actual nutrient value in manure. The total nutrient value for each manure stream was multiplied by 10%, 25%, and 100% to calculate the low, default, and high prices received. Sale prices of compost were similar when compared to values found in the literature (Kaffka et al., 2016; Li, Miito, and Lim, 2022).

For the purposes of this DST, carbon offset credits are associated with covered lagoons and anaerobic digesters. CO<sub>2</sub>e emissions are estimated for each scenario using LCIA (in terms of kg CO<sub>2</sub>e/y). The emissions reductions are calculated by subtracting emissions of the baseline scenario from the emissions from each scenario. For scenarios that include a covered lagoon or anaerobic digester, any emissions reductions will be multiplied by the unit price of carbon offset credits, resulting in positive revenue for the scenario. The value of carbon offset credits can vary over time and by location. The default value used in the DST may be on the lower end for a more conservative estimate, although prices may be higher (Sapkota and White, 2020). The user may adjust the price.

### 3.6 Cost Savings (\$/head/y)

Cost savings can be realized for water and bedding reuse. Water can be pumped from manure storages and used for barn flushing. Solids can be separated and reused for bedding. These processes can result in avoided costs which are accounted as cost savings in the DST. When water or bedding are recycled, the cost savings are equal to the retail price per unit multiplied by the number of units generated.

### 3.7 Net Costs or Net Benefits (\$/head/y)

Net costs or net benefits are calculated by subtracting the total economic benefits from the total economic costs, given by the following equation: Fertilizer Value + Revenues – Capital Costs – Operational Costs. When costs outweigh benefits, net costs are given and represented as a negative value; when benefits outweigh costs, net benefits are given and represented as a positive value.

## 4 Technological Methods: Data, Models, and Analysis

### 4.1 Overview of Functionality and Logistics Metrics

While economic and environmental factors are important to decision making, so too is understanding how technologies may function and what different treatment systems might mean for land application logistics.

Manure management professionals were surveyed to evaluate the three functionality metrics – Adoption Rate, Operational Reliability, and Operational Resilience – for each technology or unit process considered in the DST. The survey was presented as a series of tables (one for each metric) which listed all the technologies and unit processes considered in the DST. Participants were asked to provide a score on a 5-point scale for each technology and metric. Scores from each survey respondent for a given technology were averaged, resulting in a single score for each technology or unit process. These data were further processed to give an overall score for each functionality metric associated with each scenario evaluated in the DST. More information about these methods is provided in the subsections below.

**Note: The number of responses was relatively low, which may limit the generalizability of the findings. While the survey data provides valuable insights, it may not fully capture the diversity of perspectives or experiences within the larger population, or the geographical differences among systems. Therefore, the results and recommendations should be interpreted with caution.**

The DST also evaluates logistical metrics related to the on-farm land application of manure. These six metrics are described below.

### 4.2 Adoption Rate (1 to 5 scale)

Adoption Rate is a measure of how many farms are using the technology relative to the total number of farms on which it could be appropriately used. Scores range from 1 (very rare) to 5 (very common), where larger values are considered better. The score provided in the results for each scenario is calculated as the average across all technologies/unit processes comprising a given scenario.

A priority rating of 100 corresponds to a preference for adoption rate to be high where a rating of 0 suggests that adoption rate is not important in your decision making.

### 4.3 Operational Reliability (percent downtime)

Operational Reliability is a measure of the functioning of a system as desired over its expected useful life on a farm with minimal intervention. For purposes of this DST, we report this as it's inverse, showing results for percent downtime, where smaller numbers are more favorable. In the survey, reliability scores ranged from 1 to 5, given the following descriptions for frequency of malfunction:

1. Weekly (very unreliable)

2. Monthly
3. Twice a year
4. Once a year
5. Once every two or more years (very reliable).

For use in the DST, scores for each technology/unit process were converted from the 1 to 5 scale to Percent Downtime. To do this, we calculated percent uptime by calculating 1 minus the probability of failure. The probability of failure was evaluated as the frequency of malfunction over a year. For example, for a survey score of 1, the probability of failure is 0.1425, given that weekly malfunctions are represented by 52 malfunctions/365 days. A survey score of 5 results in a probability of failure of 0.0014, given that malfunctions every two years are represented by  $1/(2*365)$ . Then we calculated percent downtime by taking 1 minus the percent uptime.

The score provided in the results for each scenario is calculated as the product across all technologies/unit processes comprising a given scenario.

Routine maintenance where the system is purposefully and/or only very briefly nonfunctional should not be considered here.

A priority rating of 100 corresponds to a preference for the percent downtime to be low (operational reliability is high) where a rating of 0 suggests that reliability is not important in your decision making.

#### 4.4 Operational Resilience (1 to 5 scale)

Operational Resilience is a measure of the ability of the manure management system and broader farm operation to continue to function acceptably with minimal delay or other negative impacts when the technology breaks, goes offline or otherwise malfunctions. Resilience scores range from 1 (technology performs a critical task without backup measures normally being easily implemented; where consequences of malfunction are potentially very significant and extend beyond manure management) to 5 (technology performs an independent task where consequences of malfunction have minimal or no negative consequence for the rest of the manure management system or farm operation), where larger values are considered better. The score provided in the results for each scenario is taken as the minimum score across all technologies/unit processes comprising a given scenario, since the resilience of the whole system is based on the weakest link of the system.

A priority rating of 100 corresponds to a preference for operational resilience to be high where a rating of 0 suggests that resilience is not important in your decision making.

#### 4.5 Labor Hours during Land Application Activities (h/y)

Labor hours is a measure of the labor requirements associated with land application for a given scenario. Scenarios that have higher labor requirements will require more time to manage and might run into challenges when labor availability is scarce. Lower values are considered better. A

priority rating of 100 indicates that low labor requirements are very important, while a value of 0 indicates that labor requirements are not important in decision making.

#### 4.6 Additional Land Required for Application (ac/y)

Additional land required is a measure of the amount of land that is required for manure application in situations where there is not enough land available on-farm. This is calculated as the number of acres needed to apply all manure nutrients minus the land available for application on-farm. The number of acres needed to apply all manure nutrients from each type of manure stream in a given scenario is determined by the crop fertilizer nutrient needs, manure nutrient characteristics, which nutrient to apply for, and whether manure will be injected or surface applied. While the DST uses a mass balance approach to evaluate manure nutrient characteristics, the other variables can be set on the *Farm Management Information* page. A priority rating of 100 indicates that you prefer not to need additional land to apply all manure nutrients, while a value of 0 indicates that the need for additional land is not important in your decision making.

#### 4.7 Manure Exported (ton/y)

Manure Exported is a measure of the amount of manure that must be exported off-farm, where a lower value is considered better. A priority rating of 100 indicates that having low manure export requirements is very important to you, while a value of 0 indicates that manure export needs are not important in your decision making.

## 5 Resource Use On-Farm: Data, Models, and Analysis

### 5.1 Overview of Resource Metrics

The decision-making process for manure management often revolves around three key categories of metrics: environmental, economic, and functional/logistical. To complement these, this DST evaluates eight additional “Resource Use on Farm” metrics. While these metrics are not part of the decision algorithm that ranks MMSs, these results provide detailed insights into the resource demands and implications of various MMSs. These metrics include electricity, fresh water, and diesel use; nitrogen and phosphorus in treated manure (distinguished between non-sludge and sludge years, where applicable); and the land required for manure treatment facilities. The specifications for evaluating these metrics are detailed below.

### 5.2 Electricity Used (kWh/y)

This metric captures the electricity consumed by equipment integral to the MMS, including electrical motors used for automatic alley scrapers, manure transfer channels, solid-liquid separators, mechanical sand separators, and flush recycling systems.

### 5.3 Fresh Water Used (gal/y)

This metric accounts for freshwater use associated with the MMS. Examples include water for cleaning milking parlors, water required for mechanical sand or solid separation processes, and water needed for manure dilution for purposes of pumping.

### 5.4 Diesel Used (gal/y)

Diesel consumption reflects the fuel required to operate heavy equipment such as skid steers, tractors, and pump and agitation trailers. For scenarios involving a sludge-year manure application, the reported value represents an annual average.

### 5.5 Nitrogen (N) in Treated Manure on Non-Sludge Year (ton/y)

Using a nutrient mass balance approach, the DST evaluates the nitrogen content in manure streams throughout treatment processes. On non-sludge years, nitrogen contributions come from liquid, slurry, separated solids, settled solids, and compost, all of which are land-applied at least once annually.

### 5.6 Nitrogen (N) in Treated Manure on Sludge Year (ton/y)

For sludge years, the DST applies the same nutrient mass balance approach. Nitrogen contributions originate from accumulated sludge in lagoons or digesters, which is removed and land-applied less frequently (e.g., once every 10 years by default).

### 5.7 Phosphorus ( $P_2O_5$ ) in Treated Manure on Non-Sludge Year (ton/y)

Phosphorus (measured as  $P_2O_5$ ) is also evaluated using a nutrient mass balance approach. During non-sludge years, phosphorus contributions come from liquid, slurry, separated solids, settled solids, and compost, all of which are land-applied at least once per year.

### 5.8 Phosphorus ( $P_2O_5$ ) in Treated Manure on Sludge Year (ton/y)

In sludge years, phosphorus contributions are derived from accumulated sludge in lagoons or digesters. This sludge is removed and land-applied on a less frequent schedule (e.g., once every 10 years by default).

### 5.9 Land Required for Treatment Facilities (ac)

This metric reports the land area needed exclusively for manure treatment facilities. While the Land Footprint metric in the Environmental Analysis encompasses all land used for manure management (including facilities and land application), this metric focuses solely on treatment facility requirements. The land needed can vary significantly depending on the types of treatment and storage employed, making it an important consideration in MMS feasibility.

# 6 List of Appendices

## 6.1 Appendix 1. List of Dairy MMS scenarios used in the DST.

Number	Description
1	Sand bedding, flush, sand lane, pond, tanker
2	Sand bedding, flush, sand lane, pond, drag hose
3	Sand bedding, flush, sand lane, lagoon, tanker
4	Sand bedding, flush, sand lane, lagoon, drag hose
5	Organic bedding, flush, lagoon, tanker
6	Organic bedding, flush, lagoon, drag hose
7	Organic bedding, flush, rotary drum, lagoon, tanker
8	Organic bedding, flush, rotary drum, lagoon, drag hose
9	Organic bedding, flush, rotary drum, covered lagoon, pond, tanker
10	Organic bedding, flush, rotary drum, covered lagoon, pond, drag hose
11	Organic bedding, flush, slope screen, lagoon, tanker
12	Organic bedding, flush, slope screen, lagoon, drag hose
13	Organic bedding, scrape auto, screw press, lagoon, tanker
14	Organic bedding, scrape skid, screw press, lagoon, tanker
15	Organic bedding, scrape vacuum, screw press, lagoon, tanker
16	Organic bedding, scrape auto, screw press, lagoon, drag hose
17	Organic bedding, scrape skid, screw press, lagoon, drag hose
18	Organic bedding, scrape vacuum, screw press, lagoon, drag hose
19	Organic bedding, scrape auto, rotary drum + roller press, lagoon, tanker
20	Organic bedding, scrape skid, rotary drum + roller press, lagoon, tanker
21	Organic bedding, scrape vacuum, rotary drum + roller press, lagoon, tanker
22	Organic bedding, scrape auto, rotary drum + roller press, lagoon, drag hose
23	Organic bedding, scrape skid, rotary drum + roller press, lagoon, drag hose
24	Organic bedding, scrape vacuum, rotary drum + roller press, lagoon, drag hose
25	Sand bedding, flush, mechanical sand separation, pond, tanker
26	Sand bedding, flush, mechanical sand separation, pond, drag hose
27	Sand bedding, flush, mechanical sand separation, rotary drum + roller press, pond, tanker
28	Sand bedding, flush, mechanical sand separation, rotary drum + roller press, pond, drag hose
29	Compost bedding, flush, slope screen, composting, pond, tanker
30	Compost bedding, flush, slope screen, composting, pond, drag hose
31	Sand bedding, flush, sand lane, weeping wall, pond, tanker
32	Sand bedding, flush, sand lane, weeping wall, pond, drag hose
33	Organic bedding, scrape auto, AD, rotary drum + roller press, pond, tanker
34	Organic bedding, scrape skid, AD, rotary drum + roller press, pond, tanker
35	Organic bedding, scrape vacuum, AD, rotary drum + roller press, pond, tanker
36	Organic bedding, scrape auto, AD, rotary drum + roller press, pond, drag hose
37	Organic bedding, scrape skid, AD, rotary drum + roller press, pond, drag hose
38	Organic bedding, scrape vacuum, AD, rotary drum + roller press, pond, drag hose
39	Organic bedding, scrape auto, AD, screw press, pond, tanker
40	Organic bedding, scrape skid, AD, screw press, pond, tanker
41	Organic bedding, scrape vacuum, AD, screw press, pond, tanker
42	Organic bedding, scrape auto, AD, screw press, pond, drag hose
43	Organic bedding, scrape skid, AD, screw press, pond, drag hose

44	Organic bedding, scrape vacuum, AD, screw press, pond, drag hose
45	Organic bedding, scrape auto, AD, centrifuge, pond, tanker
46	Organic bedding, scrape skid, AD, centrifuge, pond, tanker
47	Organic bedding, scrape vacuum, AD, centrifuge, pond, tanker
48	Organic bedding, scrape auto, AD, centrifuge, pond, drag hose
49	Organic bedding, scrape skid, AD, centrifuge, pond, drag hose
50	Organic bedding, scrape vacuum, AD, centrifuge, pond, drag hose
51	Organic bedding, scrape auto, covered lagoon, pond, tanker
52	Organic bedding, scrape skid, covered lagoon, pond, tanker
53	Organic bedding, scrape vacuum, covered lagoon, pond, tanker
54	Organic bedding, scrape auto, covered lagoon, pond, drag hose
55	Organic bedding, scrape skid, covered lagoon, pond, drag hose
56	Organic bedding, scrape vacuum, covered lagoon, pond, drag hose
57	Organic bedding, compost bedded pack barn, scrape skid, pond, tanker
58	Organic bedding, compost bedded pack barn, scrape skid, pond, drag hose
59	Organic bedding, compost bedded pack barn, scrape vacuum, pond, tanker
60	Organic bedding, compost bedded pack barn, scrape vacuum, pond, drag hose
61	Sand bedding, scrape auto, mechanical sand separation, rotary drum + roller press, pond, tanker
62	Sand bedding, scrape skid, mechanical sand separation, rotary drum + roller press, pond, tanker
63	Sand bedding, scrape vacuum, mechanical sand separation, rotary drum + roller press, pond, tanker
64	Sand bedding, scrape auto, mechanical sand separation, rotary drum + roller press, pond, drag hose
65	Sand bedding, scrape skid, mechanical sand separation, rotary drum + roller press, pond, drag hose
66	Sand bedding, scrape vacuum, mechanical sand separation, rotary drum + roller press, pond, drag hose
67	Sand bedding, flush, sand lane, weeping wall, lagoon, tanker
68	Sand bedding, flush, sand lane, weeping wall, lagoon, drag hose
69	Sand bedding, scrape auto, mechanical sand separation, pond, tanker
70	Sand bedding, scrape skid, mechanical sand separation, pond, tanker
71	Sand bedding, scrape vacuum, mechanical sand separation, pond, tanker
72	Sand bedding, scrape auto, mechanical sand separation, pond, drag hose
73	Sand bedding, scrape skid, mechanical sand separation, pond, drag hose
74	Sand bedding, scrape vacuum, mechanical sand separation, pond, drag hose
75	Organic bedding, scrape auto, centrifuge, AD, pond, tanker
76	Organic bedding, scrape skid, centrifuge, AD, pond, tanker
77	Organic bedding, scrape vacuum, centrifuge, AD, pond, tanker
78	Organic bedding, scrape auto, centrifuge, AD, pond, drag hose
79	Organic bedding, scrape skid, centrifuge, AD, pond, drag hose
80	Organic bedding, scrape vacuum, centrifuge, AD, pond, drag hose
81	Organic bedding, scrape auto, centrifuge, lagoon, irrigation + tanker
82	Organic bedding, scrape skid, centrifuge, lagoon, irrigation + tanker
83	Organic bedding, scrape vacuum, centrifuge, lagoon, irrigation + tanker
84	Organic bedding, scrape auto, centrifuge, lagoon, irrigation + drag hose
85	Organic bedding, scrape skid, centrifuge, lagoon, irrigation + drag hose
86	Organic bedding, scrape vacuum, centrifuge, lagoon, irrigation + drag hose
87	Organic bedding, scrape auto, screw press, centrifuge, lagoon, irrigation + tanker
88	Organic bedding, scrape skid, screw press, centrifuge, lagoon, irrigation + tanker

89	Organic bedding, scrape vacuum, screw press, centrifuge, lagoon, irrigation + tanker
90	Organic bedding, scrape auto, screw press, centrifuge, lagoon, irrigation + drag hose
91	Organic bedding, scrape skid, screw press, centrifuge, lagoon, irrigation + drag hose
92	Organic bedding, scrape vacuum, screw press, centrifuge, lagoon, irrigation + drag hose

## 6.2 Appendix 2: Description and Assumptions for Each Unit Process

### 6.2.1 Animal Types, Manure Production and Characteristics

This DST focuses on three dairy animal types, categorized by weight ranges, including Lactating (800-1700 lbs), Heifers (300-1100 lbs), and Dry cows (800-1700 lbs). The manure production and characteristics are from "Manure Characteristics MWPS-18 Manure Management Systems Series, December 2000" and "ASABE D384.2 MAR2005 (R2024) Manure Production and Characteristics". The manure production estimates are based on values presented in the following reference tables: Table 6 – Daily manure production and characteristics, as-excreted (per head per day) from MWPS-18, Section 1, Second Edition and Table 1.b – Section 3 – All other livestock and poultry from ASAE D384.2 MAR2005 (R2024) (ASAE, 2025; Lorimor, Powers, and Sutton, 2004).

To enhance user-friendliness and flexibility, the DST employs regression equations tailored to each animal type to calculate the total amount of manure produced. You can enter the number of animals and adjust the average body weight for each type of cow on the *Animals on the Farm* page. You can also adjust the manure properties (e.g., manure produced per head, solids, and nutrient content) for each animal type on the *Manure Characteristics* page. The DST dynamically calculates corresponding manure characteristics. This approach allows users to simulate manure production and characteristics based on their unique animal populations with ease and precision.

### 6.2.2 Pumps, Motors, and Equipment Operation

The operation time for each piece of equipment is determined by the capacity volume of the equipment. When treatment volume exceeds the equipment's capacity, either larger or additional units are needed. The assumption is that equipment runs no more than 12 h/d. When operation time exceeds this, additional units are added.

The horsepower (hp) calculation for motors running pumps and other equipment is determined by the formula below. Total head in feet = 92, Pump and motor efficiency = 70%, the flow rate is set based on the volume of liquids to be pumped, gallons per minute (gpm).

$$hp = \frac{gpm \times \text{total head in feet}}{3960 \times \eta_{\text{pump \& motor}}}$$

The motor is equipped with a fixed hp rating, and power calculations are based on the standard conversion of 1 hp = 745.7 watt. By considering the annual motor operation (as hp\*hr), the kWh/year energy consumption is determined.

### 6.2.3 Animal Cooling – Sprinkler Water Usage

Automatic sprinklers are commonly used to cool animals during warmer months. While the automatic sprinkler system and the fresh water flowing through the system are not considered within the scope of this DST, the water that ends up in the MMS is calculated and accounted for in this DST since it contributes to manure volume and affects characteristics.

The cooling system relies on parameters such as sprinkler on/off times per cycle, water flow rates, and the number of cycles per day. The thermostat should be set to turn the sprinkler on when

the air temperature exceeds 70° Fahrenheit (Harner et al., 1999). This allows the DST to calculate the final freshwater volume from sprinklers that ends up in the MMS.

The sprinkler system parameters in the DST include the following:

Sprinklers ON Time per Cycle: This parameter determines the duration for which the sprinklers remain active during each cycle, ensuring adequate cooling while minimizing water wastage.

Number of Timer Cycles: Users can adjust the frequency of the sprinkler system operation within a day based on animal comfort requirements and environmental conditions.

Water Flow Rate: This parameter specifies the volume of water delivered by the sprinkler system per minute, influencing the effectiveness of cooling and water consumption.

Utilizing Climatic Data for Optimization: The DST incorporates climatic data specific to all 50 states in the USA, including the average number of hot days per year. This data helps tailor the sprinkler system settings to provide optimal cooling while conserving water resources.

Minimum, Maximum, and Default Values: The DST provides minimum and maximum allowable values for each parameter, ensuring realistic input. Default values serve as starting points, especially for users unfamiliar with optimal settings.

Adjusted Water Usage for Evaporative Cooling: The DST calculates adjusted water usage for evaporative cooling based on user-defined efficiency (1% to 30%). This parameter directly impacts the amount of water consumed per head per day for cooling purposes.

#### Sprinkler System Setup & User Inputs:

The tool is configured with a sprinkler system cycle comprising of:

- ON Time: User-defined (e.g., 1 minute, 3 minutes, etc.)
- OFF Time: Automatically adjusted to complete the 5-minute cycle
- Cycle Frequency: Sprinklers can operate up to 288 cycles per day, allowing flexible watering schedules.

Suppose for example water was applied during 6 cycles a day, each lasting 3 minutes and the flow rate of the sprinkler nozzle used is 0.1 gallons per head per minute. Based on location (state), calculations are made to estimate the number of days the temperature is above 70 F and use those days for annual water usage calculations. In our example the annual water usage value is 50.4 gallons a year, with effective usage of 37.8 gallons a year when adjusted for evaporation loss. Calculations would progress as follows:

1. Sprinkler Cycles per Day: 6 cycles/day
2. Water Applied per Cycle: 3 minutes×0.1 gallons/minute=0.3 gallons
3. Daily Water Usage: 6 cycles/day×0.3 gallons/cycle=1.8 gallons/day
4. Annual Water Usage: 1.8 gallons/day×28 days/year=50.4 gallons/year

5. Adjusted for Evaporation Loss (~25%):  $50.4 \text{ gallons/year} \times 0.75 = 37.8 \text{ gallons/year}$

#### 6.2.4 Barn and Parlor

While the economic and environmental impacts of the barn and milking parlor are outside the scope of this DST, the bedding, freshwater, and recycled water are evaluated because they directly contribute to the manure management system. The environmental and economic impacts of bedding are accounted for here.

Additionally, the cost of any freshwater used in the MMS, whether in the barn or elsewhere, is accounted for here. For example, freshwater is used in the mechanical sand separation unit. The cost of the freshwater is assigned to the barn and parlor module rather than the mechanical sand separation unit. This allocation does not influence the results shown on the results pages, but will influence supplementary results shown on the *EconResultsDetail* page.

#### 6.2.5 Collection

The DST considers four methods for manure collection: flush system, scrape system with skid steer, scrape system with automatic alley scraper, and scrape system with vacuum truck.

The DST allows users to input the daily water usage for each cleaning method, measured in gallons per head per day (gal/head/day). To guide users in setting appropriate water usage values, the DST provides defined minimum, maximum, and default values for each cleaning method. These values are based on industry standards, regulatory requirements, and best practices for water conservation and management.

By default, there is no water needed for scrape systems. However, the user can input a value in the *Manure Characteristics* page if any cleaning water is needed for scraping the barn, and this water is expected to be fresh water.

##### 6.2.5.1 Scrape with Skid Steer for Manure Collection

When using a skid steer to scrape manure for collection, the DST assumes that three passes with the scraper happen each day. The skid steer is assumed to move at 1 m/s, where the total alley length is calculated based on 2.4 m/head needed for every 2 head in the barn. To account for maneuvering time, a 1.5 multiplier is applied to the alley scrape time to calculate total operation time. The fuel usage rate is assumed to be 3.5 gal/h. From this, skid steer operation time, fuel, and the number of units needed are calculated.

##### 6.2.5.2 Scrape with Automatic Alley Scraper for Manure Collection

The automatic alley scraper is operated by drive units with electric motors, where one unit is needed for every 100 head. When using an automatic alley scraper for manure collection, the DST assumes that ten passes happen each day. The automatic scraper moves at 2.8 m/min and the total alley length is calculated based on 2.4 m/head for every 2 head. From this, the operation time and electricity use are calculated.

### 6.2.5.3 Scrape with Vacuum Truck for Manure Collection

When using a vacuum truck for manure collection, the DST assumes that three passes with the truck happen each day. The truck is assumed to move at a rate of 0.045 min/head. To account for maneuvering time, a 1.5 multiplier is applied to the vacuum scrape time to calculate total operation time. The fuel usage rate is assumed to be 9.7 gal/h. From this, the operation time and fuel use are calculated (MMV – Vendor Survey, 2022).

### 6.2.5.4 Flush Water Recycling

A flush water recycling system is used in scenarios with a flush water system for manure collection from the barn. By default, 100% of the flush water is recycled from the storage pond or lagoon, although this can be adjusted on the *Manure Characteristics* input page (see Section [Part 1.2.3.4](#)).

### 6.2.5.5 Manure Transfer Channel

In scenarios with a flush system, the manure transfer channel is assumed to be gravity based and carries manure to a sand lane, reception pit, or directly to the storage or pond, lagoon, or digester. In scenarios with skid or automatic alley scraper, a mechanical transfer channel is assumed. The length of the transfer channel is based on number of head, where 0.107 m/head is needed. For scrape with vacuum truck, no transfer channel is needed.

### 6.2.5.6 Reception Pit

Most scenarios evaluated in this DST include a reception pit that receives manure after collection and then pumps manure to treatment (e.g., sand separation, solid-liquid separation) or storage. The reception pit is sized with constant dimensions for width (20 m) and depth (3.657 m), while the length is determined by the manure volume entering the pit each day. A 15 hp electric motor runs a reception pit agitation pump. The operation time is determined by the manure volume being processed and the pump capacity. The assumption is that a pump runs at a maximum of 12 h/d, and when operation time exceeds this, additional pumps are needed. Electricity requirements are determined by the operation time.

## 6.2.6 Treatment

Several treatment options are evaluated in this DST and described below.

**NOTE FOR ALL SOLID-LIQUID SEPARATORS:** These separate solids into a solids fraction that is recycled as bedding with the rest being land applied, and a liquid stream which goes to further processing or the storage system. The equipment efficiency values used in the system are derived from various vendors, literature sources, and expert opinion. The required size and number of units is based on the manure inflow volume, the processing rate of the equipment, and constrained by a maximum of 12 h/d of use for each separation unit. Additionally, the DST offers flexibility for the user to adjust these efficiency numbers as needed. The model accommodates customizable settings, with minimum, maximum, and default ranges provided to ensure that the equipment's performance can be tailored to meet specific needs. Solids that leave the separator are assumed to fall into a pile and then get moved to a storage slab each day with a tractor and

front-end loader. Solids are stored here for 14 days before being recycled as bedding. Any solids not needed for bedding are moved to a secondary storage where they remain until they are land applied every 90 days.

For the economic analysis, separated solids that are recycled for bedding is accounted for as a cost-savings. Any additional or new bedding that is needed to fulfill bedding needs is accounted for as an operational cost.

#### 6.2.6.1 Passive Sand Lane and Storage

A sand lane is used in scenarios with sand bedding and a flush water system for manure collection from the barn. The sand lane captures sand based on an 80% removal efficiency. The dimensions of the sand lane are assumed to be 300 feet long by 20 feet wide with a 0.5 foot side wall. The number of sand lanes required is determined by the number of head, where one lane is needed for every 500 head, rounded to the nearest 500. For example, for 749 head, 1 lane is needed; for 750 head, 2 lanes are needed.

Sand is removed from the lane with a 94 pto hp tractor with front end loader and transferred to a concrete slab where it is piled and stored for further drying for 30 days before reuse as bedding. Storage area is a factor of total sand volume accumulated over the 30 days, pile dimensions, and then multiplied by 1.1 to account for maneuvering space between piles.

For the economic analysis, all sand bedding that is captured and recycled for bedding is accounted for as a cost-savings. Additional sand needed to fulfill bedding requirements, beyond what is recycled, is accounted for as an operational cost.

#### 6.2.6.2 Mechanical Sand Separation

The mechanical sand separator (MSS) is designed to extract bedding sand from manure prior to further processing. The MSS captures sand based on a 92.5% removal efficiency. The components of the system include a 20" x 22' MSS, a complimentary unit that removes an additional amount of fine sand, and a dewatering screen. An 11" x 22' inclined auger is used to transfer sand-laden dairy manure (SLDM) from a reception pit to the MSS. Each unit operates for a maximum of 12 hours per day. Equipment operation, including pumps and motors, as well as economic considerations, are referenced from Gooch et al. (2003).

Sand falls into a pile at the end of the MSS and is then transferred to a concrete storage slab each day using a 94 pto hp tractor with front end loader for further drying over 21 days before it is reused as bedding. The sand storage slab is factor of total sand volume accumulated over the 21 days, pile dimensions, and then multiplied by 1.1 to account for maneuvering space between piles.

For the economic analysis, all sand bedding that is captured and recycled for bedding is accounted for as a cost-savings. Additional sand needed to fulfill bedding requirements, beyond what is recycled, is accounted for as an operational cost.

### 6.2.6.3 Windrow Composting

In the scenario that treats manure through composting in windrows, it is assumed that a 300-foot-long composting row is utilized, where the manure solids are mixed with carbonaceous materials. Regular turning of the composting rows ensures proper aerobic conditions are maintained. The composting process is set at 60 days, with consistent turning using a 94 pto hp tractor-pulled compost turner to facilitate aeration and decomposition. The number of composting rows, turning frequency, equipment specifications, and fuel consumption are dynamically calculated based on the farm size and daily manure production. These calculations consider composting area design, operation time of compost turning equipment, and all associated economic costs.

### 6.2.6.4 Compost Bedded Pack Barn

In the compost bedded pack barn scenario, it is assumed that the barn is split between the cow resting space and the feeding alley. Manure from the resting space is compost bedded pack, while the manure dropped in the feeding alley is scraped for further processing or storage.

The bedded pack is turned with a tiller twice per day with a 94 pto hp tractor. The resting space is cleaned out every 180 days. For conservative estimates of land application constraints, it is assumed that half of the manure cleaned out each year must be stored outside of the barn while awaiting land application, while the other half can be land applied immediately from the barn.

### 6.2.6.5 Rotary Drum Screen Separation

There are three possible sizes of rotary drum screen – 94, 138, and 188 ft<sup>2</sup> surface area (RDS – Vendor Survey, 2022).

### 6.2.6.6 Rotary Drum Screen plus Roller Press Separation

This system separates 28% of the wet solids, 35% of the total solids, 40% of the N, 53% of the P<sub>2</sub>O<sub>5</sub>, and 49% of the K<sub>2</sub>O into the solids stream, with the remaining staying in the liquid stream. The equipment efficiency values used in the system are derived from various vendors, literature sources, and expert opinion. Additionally, the DST offers flexibility for the user to adjust these efficiency numbers as needed. The model accommodates customizable settings, with minimum, maximum, and default ranges provided to ensure that the equipment's performance can be tailored to meet specific needs.

There are three possible sizes of rotary drum screen – 94, 138, and 188 ft<sup>2</sup> surface area (RDS -RP - Vendor Survey, 2022). The number of rotary drum screens is set equal to the number of roller presses.

### 6.2.6.7 Inclined Slope Screen Separation

This system separates 20% of the wet solids, 25% of the total solids, 30% of the N, 32% of the P<sub>2</sub>O<sub>5</sub>, and 30% of the K<sub>2</sub>O into the solids stream, with the remaining staying in the liquid stream.

There are three possible sizes of slope screen – 32, 64, or 96 ft<sup>2</sup> surface area (ISS – Vendor Survey, 2022). The required size and number of units is based on the manure inflow volume, the processing rate of the equipment, and constrained by a maximum of 12 h/d of use for each separation unit.

#### 6.2.6.8 Screw Press Separation

This system separates 28% of the wet solids, 25% of the total solids, 25% of the N, 28% of the P<sub>2</sub>O<sub>5</sub>, and 35% of the K<sub>2</sub>O into the solids stream, with the remaining staying in the liquid stream.

There are three possible sizes of screw press – 10, 20, or 25 ft<sup>2</sup> surface area (SP – Vendor Survey, 2022). The required size and number of units is based on the manure inflow volume, the processing rate of the equipment, and constrained by a maximum of 12 h/d of use for each separation unit.

#### 6.2.6.9 Decanting Centrifuge Separation

This system separates 30% of the wet solids, 65% of the total solids, 25% of the N, 36% of the P<sub>2</sub>O<sub>5</sub>, and 38% of the K<sub>2</sub>O into the solids stream, with the remaining staying in the liquid stream.

There are three possible sizes of decanting centrifuge – 158, 209, and 452 ft<sup>3</sup> (DC – Vendor Survey, 2022). The required size and number of units is based on the manure inflow volume, the processing rate of the equipment, and constrained by a maximum of 12 h/d of use for each separation unit.

#### 6.2.6.10 Screw Press followed by Decanting Centrifuge Separation

### 6.2.7 Storage

#### 6.2.7.1 Pond

A storage pond is an earthen facility designed to temporarily store manure and wastewater, typically without providing biological treatment. By default, contents are agitated and removed twice a year, or every 182.5 d. Pond design volume is determined by manure volume, rainfall and 25-year rain event, and freeboard. Data for rainfall is based on state and region-level data; the location you enter on the *Farm Management Information* page will influence rainfall amounts. The DST follows a mass balance for N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, total solids, and volatile solids through pond storage. By default, the DST assumes no losses for P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, and total solids; losses for N, and VS are 40, and 85%, respectively. Losses determine the manure nutrient characteristics that, which will impact land application calculations.

#### 6.2.7.2 Anaerobic Treatment Lagoon

An anaerobic treatment lagoon is an earthen, long-term manure storage facility specifically designed with additional water volume to enable biological treatment by anaerobic microorganisms. These lagoons accumulate sludge over time and maintain a permanent pool of liquid to support continuous microbial activity. Some scenarios include long-term manure

treatment and storage in an anaerobic lagoon. By default, a “liquid” manure stream is removed from lagoons twice a year, or every 182.5 d, while the “sludge” manure stream accumulates over 10 years and is then removed. Lagoon design volume is determined by manure volume, rainfall and 25-year rain event, and freeboard (USDA NRCS, 2009). Data for rainfall is based on state and region-level data; the location you enter on the *Farm Management Information* page will influence rainfall amounts. The DST follows a mass balance for N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, total solids, and volatile solids through lagoon treatment and storage, where a fraction may remain in liquids, remain in sludge, or be lost to the atmosphere. The sludge accumulation rate (SAR) is assumed to be 0.0046 m<sup>3</sup>/kg TS (Chastain, 2006). The DST follows a mass balance approach for nutrients and solids (N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, total solids, and volatile solids) through lagoon treatment and storage. A fraction of these components may remain in the liquid portion, accumulate in the sludge, or be lost to the atmosphere, based on IPCC and other emission loss models. The system ensures that nutrient and solids distribution is accurately balanced between the liquid and sludge portions as per these mass balance principles.

### 6.2.7.3 Covered Treatment Lagoon

A covered treatment lagoon is a treatment lagoon equipped with an impermeable cover added to capture emitted biogas during manure treatment. Like uncovered lagoons, it accumulates sludge over time. The produced biogas is flared, thus reducing methane and total GHG emissions. The hydraulic retention time is set at 45 days, after which manure liquids/slurry goes to a short-term storage pond (see Appendix [6.2.7.1](#) for assumptions about the storage pond), while sludge accumulates in the covered lagoon and is removed after 10 years. Covered lagoon design volume is determined by manure treatment volume, sludge volume accumulation, and top cover biogas volume. The sludge accumulation rate (SAR) is assumed to be 0.00217 m<sup>3</sup>/kg TS (Chastain, 2006). This is the same value used for anaerobic lagoon SAR. Although actual rates may vary between the two systems, certainty in existing data is lacking. The biogas generation rate is set at 0.35 m<sup>3</sup>/kg VS, where 60% is assumed to be in the form of methane.

The DST follows a mass balance for N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, total solids, and volatile solids through the covered treatment lagoon, where a fraction may remain in liquids, remain in sludge, or be lost to the atmosphere. The DST follows a mass balance approach for nutrients and solids (N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, total solids, and volatile solids) through lagoon treatment and storage. A fraction of these components may remain in the liquid portion, accumulate in the sludge, or be lost to the atmosphere, based on IPCC and other emission loss models. The system ensures that nutrient and solids distribution is accurately balanced between the liquid and sludge portions as per these mass balance principles.

The components of a covered treatment lagoon include the constructed volume, a geomembrane liner, and flexible membrane cover. The assumption is that all biogas is flared. Flaring biogas can reduce overall emissions, and may generate carbon reduction credits, depending on the baseline scenario being evaluated. While flaring can generate a small revenue stream, other uses for produced biogas may be more economically valuable, such as electricity generation or

compressed natural gas. These uses also cost significantly more to install. This DST does not consider costs or benefits of electricity generation or compressed natural gas production.

#### 6.2.7.4 Earthen Digester (Anaerobic Digester)

An earthen digester, also referred to as a simple anaerobic digester, is designed with earthen construction, a specified hydraulic retention capacity, and a cover to capture biogas. The system tends to accumulate grit over time, and the resulting digestate is directed to a separate long-term storage, typically a traditional storage pond. Some scenarios include an anaerobic digester (i.e., specifications for a steady-state continuously stirred tank reactor) where produced biogas is flared, thus reducing methane and total GHG emissions.

The hydraulic retention time is set at 25 days, after which manure liquids/slurry goes to a short-term storage pond, while sludge accumulates in the anaerobic digester and is removed after 10 years. Anaerobic digester design volume is determined by manure treatment volume, sludge volume accumulation, and top cover biogas volume (USDA NRCS, 2009). The sludge accumulation rate (SAR) is assumed to be 3% of the VS loaded. The biogas generation rate is set at 0.38 m<sup>3</sup>/kg VS, where 60% is assumed to be in the form of methane.

The assumption is that all biogas is flared. Flaring biogas can reduce overall emissions, and may generate carbon reduction credits, depending on the baseline scenario being evaluated. While flaring can generate a small revenue stream, other uses for produced biogas may be more economically valuable, such as electricity generation or compressed natural gas. These uses also cost significantly more to install. This DST does not consider costs or benefits of electricity generation or compressed natural gas production.

The capital cost of an anaerobic digester include the cost of materials, construction, installation, and engineering. This cost is modeled from the Washington State AD Calculator (Astill et al., 2018). Operational costs are assumed to be 5% of the capital cost.

#### 6.2.8 Land Application

For impacts associated with the on-farm land application of manure nutrients, the analytical boundary is the first touch to the field, such that emissions in the time after application are not considered.

##### 6.2.8.1 Irrigation Land Application

In scenarios where there is liquid (i.e., in storage lagoon scenarios), these liquids are land applied using irrigation equipment. The maximum volume that can be irrigated on a given day is 10,000 gallons per acre, although liquids can be applied up to once every 28 days.

##### 6.2.8.2 Tanker Land Application

In scenarios where there is slurry or sludge to be removed from storage and land applied, the DST evaluates this process using tanker land application. Slurry is land applied two times per year, while sludge is land applied once every 10 years (default application “events”). The maximum volume of manure that can be applied during a given application event is 10,000 gallons per acre.

This process includes three types of tractors – a 160 pto hp for agitating, a 180 pto hp for pumping, and a 160 pto hp for pulling the tanker. By default, the tanker size is 4500 gal, although this size can be changed on the *Tractor, Drag Hose, and Tanker* page with options ranging from 3000 to 9000 gal (Harrigan, 1997).

It is assumed that manure agitation starts three hours before the first load is pumped into the tanker. The tractor pulling the tanker is used for a maximum of 12 h/d, although this can also be changed on the *Tractor, Drag Hose, and Tanker* page. The tractor for agitating can run a maximum of 15 h/d. Pumping only occurs while filling the tanker, thus running less than 12 h/d naturally.

The operation time for the tractor pulling the tanker is determined by manure volume being removed and land applied on-farm and the effective unloading rate. The effective unloading rate is determined by the tanker size, maneuvering time near the storage and in the field, the travel speed while the tanker is loaded and unloaded, and the average distance to the field. The distance to the field is set at 4 miles, although this can be changed on the *Tractor, Drag Hose, and Tanker* page.

The total operation time is used to determine how many tractors are needed, constrained by the maximum h/d the tractor can run and the number of days available for land application. By default, liquids and slurry can be applied over the course of 50 d/y, while sludge years get an additional 15 d for application (when applicable).

Operation time for pumping is determined by manure volume and pump rate. Operation time for agitation is determined by the number of days needed to land apply manure (for pre-loading agitation time) and the time the tractor with tanker is running. Operation time also determines fuel usage, where fuel consumption of each tractor size is calculated based on the tractor pto power and operational time multiplied by the value of 0.044, as per (0.044 gallons per horsepower per hour) (Grisso et al., 2010).

While nurse trucks may be used by larger operations to increase efficiency, evaluating their use is beyond the scope of this DST. Custom hauling may also be done by some farms, but its use is beyond the scope of this DST. However, you can apply a work-around by setting land available to zero and then entering the custom hauling cost in “Pay to Haul Off”, even though manure will be applied to your land.

### 6.2.8.3 Drag Hose Land Application

In scenarios where there is slurry or sludge to be removed from storage and land applied, the DST evaluates this process using drag hose land application. Slurry is land applied two times per year, while sludge is land applied once every 10 years (default application “events”). The maximum volume of manure that can be applied during a given application event is 10,000 gallons per acre.

This process includes two types of tractors – a 580 pto hp for pulling the applicator and hose reel, and a 340 pto hp for the support tractor with a hose pulley. This process also includes a support

pickup truck, a diesel-powered agitation trailer, a diesel-powered lead pump, and a diesel-powered booster pump (when applicable) (DHL – Vendor Survey, 2022).

The operation time for the tractor pulling the drag hose is determined by the manure volume and the application rate. The application rate is determined by the average speed of the drag hose during application, set at 2 mi/h, and the bar width, assumed to be 20 ft, where the maximum application rate is 3000 gal/min.

The number of tractors needed to pull a drag hose is determined by the total operation time, constrained by a maximum of 12 h/d that a single tractor can run and the number of days available for land application. By default, liquids and slurry can be applied over the course of 50 d/y, while sludge years get an additional 15 d for application (when applicable). The number of tractors with hose reel, the number of agitation trailers, and the number of lead pumps is equal to the number of tractors pulling a drag hose. A booster pump is needed for every two miles distance from storage to the field, determined by the maximum distance to the field. By default, this distance is 4 miles, although this can be changed on the *Tractor, Drag Hose, and Tanker* page.

The operation time for each piece of equipment is determined as a percentage of the operation time for land application. It is assumed that agitating and pumping occurs for 100% of the time the drag hose is running, while the booster pump runs at 75% time and the pickup truck runs at 15% time. The operation time for each tractor and piece of equipment determines the fuel usage. The fuel usage rate is 6 gal/h for agitating, 18 gal/h for the lead pump, 10 gal/h for the booster pump, and 6 gal/h for the pickup truck (DHL – Vendor Survey, 2022; Expert, personal communication, January 13, 2023).

#### 6.2.8.4 Box Spreader Land Application

In scenarios where there are separated solids, settled solids, or compost to be land applied on-farm, the DST evaluates this process using a tractor-pulled box spreader. This process includes a 94 pto hp tractor with front end loader and an 85 pto hp tractor to pull the box spreader.

The operation time for the tractor with box spreader is determined by the volume of manure, the capacity of the box spreader, and the time per trip required. The operation time for the tractor with front end loader is determined by the bucket capacity and time needed to move manure into the box spreader. The operation time for each tractor determines the fuel usage.

## 6.3 Appendix 3: Mass Balance Calculations

### 6.3.1 Solid- Liquid Separation and Bedding Recovery

In this DST, some scenarios may include solid-liquid separation for manure solids (fibrous solids). Different types of separators are associated with their own efficiency for separating total solids, nitrogen (N), phosphorus ( $P_2O_5$ ), potassium ( $K_2O$ ), and other components. Separated solids are assumed to be used as recycled bedding, with any excess generated beyond bedding needs going to land application. The removal efficiency data was collected from various vendors across the USA and literature reports, with minimum, maximum, and default values provided within the DST that can be customized by the user.

**“Separated solids” or “solid fraction”**: The predominantly fibrous material that is recovered/separated from the slurry and discharged by the separator mechanism. Note that manure separated solids typically contain a relatively high water content (70-90% water by weight). This document refers to the mass and volume of the manure solids both on a dry matter (DM) basis (e.g., the weight or proportion of the material exclusive of water) as well as on a wet basis (the dry material plus any water present).

**“Manure effluent” or “liquid fraction”**: The liquid remaining after manure has passed through the separator and manure solids have been extracted. Note that not all solids present in the manure are removed by the separator, so the manure liquid fraction still contains some solids.

**Treatment efficiency**: The rate at which a specific separator can remove manure solids or other nutrients from slurry, expressed as a fraction (kg of nutrient per kg of slurry passed through separator). This can also be expressed for the liquid fraction as (1 - treatment efficiency), because any solids/nutrients not separated into the solid fraction naturally remain with the liquid fraction; the treatment efficiency values for the liquid fraction are the complement of the solid treatment efficiency for each corresponding property of the manure.

The DST evaluates a variety of solid-liquid separators, including an inclined slope screen, screw press, rotary drum screen, decanting centrifuge, and roller press. The separators for fibrous solids effectively separate solid materials from liquids or classify substances based on their size and density (Mukhtar, Sweeten, and Auvermann, 1999; USDA NRCS, 2019). Treatment efficiency, the efficiency of recovery of dry matter/solids from the slurry, is the primary differentiator among mechanical fibrous solids separators.

Separate calculations are implemented for the solids portion and liquid portion. The default separation/removal efficiencies are assumed to refer to the solid fraction of the manure slurry treated.

Let’s look at an example for a manure separator – Inclined Slope Screen (ISS): Equation [M.1.A.1] represents the Nitrogen separation efficiency along with the manure solids that have been separated from the manure slurry. Equation [M.1.A.2] addresses the separation efficiency of the remaining nitrogen solids in the liquid fraction separated from the manure slurry. The separation

efficiency values for the solid fraction are the complement of the liquid separation efficiency for each corresponding property of the manure. The time “t” represents the daily amount of manure that is separated via the solid-liquid separation process.

**Solid fraction:**

Let  $(N_{\text{Solid}}^{\text{Manure Separator}})_t$  be the total daily Nitrogen (N) in manure solids recovered in the solid separated from the manure slurry at time t, in kg, such that:

$$(N_{\text{Solid}}^{\text{Manure Separator}})_t = N_t^{\text{Manure}} \times \text{Rate}_{\text{N loss}}^{\text{Manure ISS}} \quad \text{[M.1.A.1]}$$

where,

$N_t^{\text{Manure}}$  is the total daily nitrogen (N) in the manure slurry at time t, in kg.

$\text{Rate}_{\text{N loss}}^{\text{Manure ISS}}$  is the rate of nitrogen lost (separation efficiency) from the manure slurry, (kg N\_solid/kg  $N_t^{\text{Manure}}$ ).

**Liquid fraction:**

Let  $(N_{\text{Liquid}}^{\text{Manure Separator}})_t$  be the total daily Nitrogen (N) in the liquid stream recovered from the manure slurry, in kg, such that:

$$(N_{\text{Liquid}}^{\text{Manure Separator}})_t = N_t^{\text{Manure}} \times (1 - \text{Rate}_{\text{N removal}}^{\text{Manure ISS}}) \quad \text{[M.1.A.2]}$$

where,

$N_t^{\text{Manure}}$  is the total daily nitrogen (N) in the manure slurry at time t, in kg.

$\text{Rate}_{\text{N removal}}^{\text{Manure ISS}}$  is the rate of nitrogen loss (separation efficiency) from the manure slurry, (kg N\_solid/kg  $N_t^{\text{Manure}}$ ).

**6.3.2 Anaerobic Lagoon**

Anaerobic lagoons are large earthen containment structures used to store and treat manure generated from Dairy farms. These lagoons are much larger than storage basins that provide long term storage and offer biological treatment as compared to the basins. Some of the advantages of the lagoons include handling of manure through flush systems, pumps, and irrigated

equipment. Due to higher stabilization of waste, it reduces the odors during land application. Also, the land requirement for effluent application is minimized due to nitrogen transformation and reduction during the storage/treatment. The decomposition of organic matter in the manure, along with anaerobic conditions in the lagoon, can lead to the production of various gases, including methane (CH<sub>4</sub>) and ammonia (NH<sub>3</sub>), nitrous oxide etc. The lagoon storage is typically designed to accommodate 365 days of manure storage, sludge volume, rainwater storage, freeboard volume etc., as per NRCS lagoon design criteria. The manure liquid (effluent) is removed and land applied two times in a year and sludge is land applied every 10 years. The sludge accumulation for Dairy manure is based on published data (ASAE, 2025; Chastain, 2006).

**Solids and Nutrient mass calculations:**

The solids and nutrient mass are updated in two portions of Anerobic Lagoon i.e., the liquid portion and sludge portion.

**Liquid portion**

Liquid Manure  $DM_t^{\text{Anaerobic Lagoon}}$  is the total dry matter (DM) in the manure liquid/slurry period t, in kg.

$$DM_t^{\text{Manure Liquid, Anaerobic Lagoon}} = (DM_t^{\text{Manure Liquid}}) - DM_t^{\text{Loss}} \quad \text{[M.1.B.1]}$$

where,

$DM_t^{\text{Manure liquid}}$  is the total dry matter (DM) in the manure liquid/slurry period t, in kg.

$DM_t^{\text{loss}}$  is the mass of dry matter (DM) loss (treatment efficiency) in the manure liquid/slurry period t, in kg.

Liquid Manure  $N_t^{\text{Anaerobic Lagoon}}$  is the total daily nitrogen (N) in the manure liquid/slurry period t, in kg.

$$N_t^{\text{Manure Liquid, Anaerobic Lagoon}} = (N_t^{\text{Manure Liquid}}) - N_t^{\text{Loss}} \quad \text{[M.1.B.2]}$$

where,

$N_t^{\text{Manure liquid}}$  is the total daily nitrogen (N) in the manure liquid/slurry period t, in kg.

$N_t^{\text{loss}}$  is the mass of nitrogen loss (treatment efficiency) in the manure liquid/slurry period t, in kg.

$(\text{Liquid Manure } P_{2O_5})_t^{\text{Anaerobic Lagoon}}$  is the total daily total phosphorous (P2O5) in the manure liquid/slurry period t, in kg.

$$(\text{Liquid Manure } P_{2O_5})_t^{\text{Anaerobic Lagoon}} = (P_{2O_5})_t^{\text{Manure Liquid}} - (P_{2O_5})_t^{\text{Loss}} \quad \text{[M.1.B.3]}$$

where,

$P_{2O_5}^{\text{Manure liquid}}$  is the total daily phosphorous (P2O5) in the manure liquid/slurry period t, in kg.

$P_{2O_5}^{\text{loss}}$  is the mass of phosphorous loss (treatment efficiency) in the manure liquid/slurry period t, in kg.

$\text{Liquid Manure } K_{2O}_t^{\text{Anaerobic Lagoon}}$  is the total daily total potassium (K2O) in the manure liquid/slurry period t, in kg.

$$\text{Liquid Manure } K_{2O}_t^{\text{Anaerobic Lagoon}} = (K_{2O}_t^{\text{Manure liquid}} - K_{2O}_t^{\text{loss}}) \quad \text{[M.1.B.4]}$$

where,

$K_{2O}_t^{\text{Manure liquid}}$  is the total daily potassium (K2O) in the manure liquid/slurry period t, in kg.

$K_{2O}_t^{\text{loss}}$  is the mass of potassium loss (treatment efficiency) in the manure liquid/slurry period t, in kg.

### **Sludge portion**

$\text{Sludge Manure } DM_t^{\text{Anaerobic Lagoon}}$  is the total daily dry matter (DM, total solids) in sludge manure period t, in kg.

$$\text{Sludge Manure } DM_t^{\text{Manure Ssludge}} = \text{Sludge Accumulation } V_t^{\text{Anaerobic Lagoon}} * \text{DM fraction} * 1000 \quad \text{[M.1.B.5]}$$

where,

Sludge Accumulation  $V_t^{\text{Anaerobic Lagoon}}$  is the total sludge accumulation volume (SAV) period t, in m<sup>3</sup>.

DM fraction is the dry matter fraction in the manure sludge, in kg.

**The N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O losses are calculated as the difference from that lost from the liquid portion and the total input to the system:**

Sludge Manure  $N_t^{\text{Anaerobic Digestion}}$  is the total daily nitrogen (N) in the manure sludge period t, in kg.

$$\text{Sludge Manure } N_t^{\text{Anaerobic Lagoon}} = N_t^{\text{Manure Sludge}} * \{(1 - N)_t^{\text{loss}}\} \quad \text{[M.1.B.6]}$$

where,

$N_t^{\text{Manure Sludge}}$  is the cumulative nitrogen (N) in the manure sludge period t, in kg.

$N_t^{\text{loss}}$  is the mass of nitrogen loss (treatment efficiency) in the manure sludge period t, in kg.

Sludge Manure  $P_t^{\text{Anaerobic Lagoon}}$  is the total daily phosphorus (P) in the manure sludge period t, in kg.

$$\text{Sludge Manure } P_{2O5}_t^{\text{Anaerobic Lagoon}} = P_{2O5}_t^{\text{Manure Sludge}} * \{(1 - P_{2O5})_t^{\text{loss}}\}$$

**[M.1.B.7]**

where,

$P_{2O5}_t^{\text{Manure Sludge}}$  is the cumulative phosphorus (P<sub>2</sub>O<sub>5</sub>) in the manure sludge period t, in kg.

$P_{2O5}_t^{\text{loss}}$  is the mass of phosphorus loss (treatment efficiency) in the manure sludge period t, in kg.

Sludge Manure  $K_{2O}_t^{\text{Anaerobic Lagoon}}$  is the cumulative potassium (K<sub>2</sub>O) in the manure sludge period t, in kg.

$$\text{Sludge Manure } K2O_t^{\text{Manure Sludge}} = K2O_t^{\text{Manure Sludge}} * \{(1 - K2O)_t^{\text{loss}}\}$$

**[M.1.B.8]**

where,

$K2O_t^{\text{Manure Sludge}}$  is the cumulative potassium (K2O) in the manure sludge period t, in kg.

$K2O_t^{\text{loss}}$  is the mass of potassium loss (treatment efficiency) in the manure sludge period t, in kg.

**Sludge Accumulation Volume:**

Sludge Accumulation  $V_t^{\text{Anaerobic Lagoon}}$  is the total sludge accumulation volume (SAV) period t, in m<sup>3</sup>.

$$\begin{aligned} \text{Sludge Accumulation } V_t^{\text{Anaerobic Lagoon}} \\ = \{ (VS)_t^{\text{Manure}} * \text{Sludge } \tau_t^{\text{Constant}} * \text{Sludge Accumulation period} * 365 \} \\ / 1000 \end{aligned}$$

**[M.1.B.9]**

where,

Sludge Accumulation  $V_t^{\text{Anaerobic Lagoon}}$  is the total sludge accumulation volume (SAV) period t, in m<sup>3</sup>.

$VS_t^{\text{Manure}}$  is the Daily Manure Total Volatile Solids (kg)

$\text{Sludge } \tau_t^{\text{Constant}}$  is the sludge accumulation volume (SAV) constant default set at 0.03 (min and max; 0.02 and 0.04; % of VS).

Sludge Accumulation period is the time allowed for the sludge accumulation, default set at 1 year (min and max; 1 and 10).

## 6.4 Appendix 4. Superuser Features

The DST supports over 750 user adjustable variables. While only some variables are linked to the user interface, all variables can be modified within the “UD” tab. This tab is formatted similarly to a database table and can be sorted and filtered to easily find specific information and variables. Each of the variables has a unique key which is used as the basis for a named range that makes it accessible to the rest of the worksheets.

**All superuser tabs are hidden. On the tab bar, right click, select unhide and choose the tab(s) you would like to add to the bar.**

Column A holds the “Module\_Calc\_ID”, short for “Module calculation ID”, which is the first component of the unique variable key. Modules are named after systems and group specific variables that influence that system together. The module name “anaer\_lagoon” is used to group variables for anaerobic lagoon systems. Column B holds the “Variable\_Name”. Variables represent specific aspects of a system, such as an anaerobic lagoon’s design depth (“depth”). The module calculation ID and the variable name are combined together to form the unique key in the format “UDV.module\_calc\_ID.variable\_name” found in column C that is called “Lookup\_Name”. The value for any variable from any module can be referenced using its unique key. For instance, the anaerobic lagoon’s depth can be referenced in other tabs as “UDV.anaer\_lagoon.depth”.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Module_Calc_ID	Variable_Name	Lookup_Name	Final_Value	Final_Units	Gated_Val	User_Input	Default_Val	User_Units	Input_Type	UI_Page	Input_Min	Input_Max	Meets_Restrict	Module_Description
44	anaer_lagoon	effluent_time	182.5	days	182.5		182.5	days	Constant		90	365		1 Anaerobic lagoon effluent and sludge ren
45	anaer_lagoon	freeboard	0.6096	m	2		2	ft	Override		1	5		0 Anaerobic lagoon
46	anaer_lagoon	depth	5.334	m	17.5		17.5	ft	Override		6	25		0 Anaerobic lagoon
47	anaer_lagoon	evap_modifier	0.80	multiplier	0.80		0.80	multiplier	Override		0	1		1 Anaerobic lagoon
48	anaer_lagoon	evap_modifier_sl	0.99	multiplier	0.99		0.99	multiplier	Override		0	1		1 Anaerobic lagoon
49	anaer_lagoon	evap_modifier_flush	0.95	multiplier	0.95		0.95	multiplier	Override		0	1		1 Anaerobic lagoon
50	anaer_lagoon	evap_modifier_scrape	0.75	multiplier	0.75		0.75	multiplier	Override		0	1		1 Anaerobic lagoon
51	anaer_lagoon	evap_modifier_ob	0.20	multiplier	0.20		0.20	multiplier	Override		0	1		1 Anaerobic lagoon
52	anaer_lagoon	HRT	365	days	365		365	days	Override		182.5	365		0 Anaerobic lagoon
53	anaer_lagoon	clarifier_time	10	years	10		10	years	Override		6	20		0 Anaerobic lagoon

A superuser can make changes to any variable in the UD tab and therefore greatly influence the results of the model. The UD tab serves as a line-by-line based UI, with each uniquely keyed variable taking up one line. Because multiple unit systems are accessible to users and the model itself uses specific units for inputs, there is a unit conversion system built into the UD tab. Column D holds the “Final\_Value”, which is the value used directly by the model to perform calculations. Column E holds the “Final\_Units” which are the units expected by the model’s calculations. Column F holds the “Gated\_Value”, which is either the user input value or the default value when the user input value is invalid for some reason. **It is recommended that a superuser does not modify any of columns D through F because doing so can easily break the model or hurt its ability to function in the future.**

Instead of modifying those columns, superusers should bring their focus to column G, “User\_Input”. For variables that link back to the user interface, a value will already be populated in the appropriate row in this UD tab. When the variable’s value is listed in the UD tab, it is recommended that user changes the value directly within the relevant UI tab which is identified in column K, “UI Input Page”. If the cell is blank in the UD tab, a user may enter an appropriate value in this column. If the inputted value meets the criteria defined by columns L and M, which are the “Input\_Min” and “Input\_Max” columns, it will be accepted. If no value is placed in column

G or if the value entered in column G does not meet the min-max criteria, the model will revert to using the default value for that variable that is listed in column H, “Default Value”. User inputs and default values follow the units in column I’s “User\_Unit”, which may differ depending on whether you are using the US or metric version of the DST. Changing the unit will not change the unit conversions that are applied to adjust the user value to the final value that is used by the model.

Some variables and their default, minimum, and maximum values will automatically adjust based on the value of other variables. Column J, “Input\_Type” gives you a hint for where this happens because any input type that includes the word “Calc” as part of its description will update in certain circumstances. Some values are also based on reference tables, for example rainfall and evaporation data. The DST will lookup those values for your selected region and pull the appropriate information on your behalf.

Module and variable descriptions are in columns O, “Module\_Description”, and P, “Variable\_Description”. The variable description column tells more about what the variable stands for and sometimes has suggestions about how to change it if desired. Columns beyond this point are for developers only, modifying them in any way is not recommended.

**If you wish to change any variables in the UD tab, be sure that you have a reasonable value to input. While the allowable input ranges are purposefully broad, default values are set up to work for most users and deviating away from them can impact results in unexpected ways.**

In some cases, you should change multiple variables together because changing just one will make results unrealistic. As an example, if you expect your sludge accumulation rate for anaerobic lagoons to be higher for your simulated farm, you would want to change two different variables: UDV.anaer\_lagoon.sludge\_accumulation\_ratio\_base, UDV.anaer\_lagoon.sludge\_accumulation\_ratio\_sol\_sep.

One of these variables sets the SAR for systems without solid separation while the other sets it for systems with solid separation. Both types of farm setups are simulated within the DST and changing both can avoid favoring one setup unnecessarily. Similarly, if you increase SAR, it is likely that your lagoon will accumulate a higher fraction of total nutrients (N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O) in the sludge as well.

#### *6.4.1 Lagoon and Pond Specifications and Superuser Adjustments*

Superusers can adjust lagoon specifications on the SU.Lagoon input page. The first row of this table allows the user to toggle from modelling lagoon systems to pond systems, for applicable scenarios. Specifically, for scenarios that include a lagoon, here the user can set the “Pond toggle” value to 1, turning all lagoons in the DST into ponds. This will have large effects on storage volume and land application components. This functionality significantly expands the scope of the DST, nearly doubling the manure management systems (MMSs) that can be modeled. It also improves geographic applicability, since some regions use ponds exclusively rather than lagoons.

The next rows in the table allows the user to adjust many of the specifications relevant to modelling these systems. Note that when you change the first row's entry to 1 (i.e., "Pond"), some of the default values for subsequent specifications change automatically. For any adjustments desired, the user can type their value into the "Your Value" column.

One of the more common specifications that a user might want to adjust is the sludge time for lagoon systems. By default, sludge time is set to 10 years for lagoons. Another one may be the effluent time (i.e., time between manure removal and land application) for ponds, which is set at 182.5 days (approximately 6 months).

## 6.5 Appendix 5. List of Inputs for Example Simulation – Test Farm

<b>Farm Info Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
The name of your farm	Test Farm	name	No
The baseline manure handling system for your farm	Sand bedding, scrape skid, mechanical sand separation, pond, tanker		
The region of your state that your farm resides in	New York (Central Lakes)	state index	No
Are sprinklers used on your farm?	Yes	Yes or No	No
The length of time that sprinklers spray water per cycle	3	min/cycle	Yes
The number of cycles that the sprinkler system goes through in a day	6	cycle/day	Yes
The flow rate of the sprinkler system	0.1	gal/head/min	Yes
The amount of land available for manure application each year	900	acre	No
The primary nutrient for which to apply manure	N	nutrient	No
The method by which manure is applied	Injection	type	No
The quantity of N applied on the land area	195	lb N/acre	Yes
The quantity of P2O5 applied on the land area	55	lb P2O5/acre	Yes
The quantity of K2O applied on the land area	90	lb K2O/acre	Yes
Timeframe to land apply on a typical year (constraint on liquids, slurry)	65	day/year	No
Value of carbon offset credits	0	\$/credit	No
<b>Animal Characteristics Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
The number of lactating cows on your farm	660	head	No
The average weight of lactating cows on your farm	1500	lb/head	No
Is manure from heifers treated?	Yes	Yes or No	No
The number of heifers on your farm	630	head	No
The average weight of heifers on your farm	750	lb/head	No
Is manure from dry cows treated?	Yes	Yes or No	No
The number of dry cows on your farm	79	head	No

<b>Farm Info Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
The average weight of dry cows on your farm	1650	lb/head	No
<b>Manure Characteristics Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
Maximum Depth for manure storage facilities	25	Ft	Yes
Fraction of flush water that is recycled (RFW)	1	fraction	Yes
Flush system water usage	55.48	gal/head/day	Yes
Scraping system water usage	0.0	gal/head/day	Yes
Holding and parlor system water usage	9.51	gal/head/day	Yes
Lactating cow manure production	166.01	lb/head/day	Yes
Total solids (TS) in lactating cow's manure	21.54	lb/head/day	Yes
Volatile solids (VS) in lactating cow's manure	18.36	lb/head/day	Yes
Nitrogen (N) in lactating cow's manure	0.99	lb/head/day	Yes
Phosphorus (P) in lactating cow's manure	0.66	lb/head/day	Yes
Potassium (K) in lactating cow's manure	0.64	lb/head/day	Yes
Heifer cow manure production	44.97	lb/head/day	Yes
Total solids (TS) in heifer cow's manure	6.72	lb/head/day	Yes
Volatile solids (VS) in heifer cow's manure	5.62	lb/head/day	Yes
Nitrogen (N) in heifer cow's manure	0.18	lb/head/day	Yes
Phosphorus (P) in heifer cow's manure	0.09	lb/head/day	Yes
Potassium (K) in heifer cow's manure	0.15	lb/head/day	Yes
Dry cow manure production	84.24	lb/head/day	Yes
Total solids (TS) in dry cow's manure	10.63	lb/head/day	Yes
Volatile solids (VS) in dry cow's manure	9.17	lb/head/day	Yes
Nitrogen (N) in dry cow's manure	0.35	lb/head/day	Yes
Phosphorus (P) in dry cow's manure	0.20	lb/head/day	Yes
Potassium (K) in dry cow's manure	0.37	lb/head/day	Yes
<b>Bedding and Manure Expenses Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
Organic bedding usage rate	10	lb/head/day	No
Sand bedding usage rate	65	lb/head/day	No
Bedding, organic, non-manure	168	\$/ton (2000 lb)	Yes

<b>Farm Info Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
Cost for sand bedding	15	\$/ton (2000 lb)	Yes
Liquid manure, percentage to export at cost	0	% of excess	Yes
Slurry manure, percentage to export at cost	0	% of excess	Yes
Sludge manure, percentage to export at cost	0	% of excess	Yes
Separated solids manure, percentage to export at cost	0	% of excess	Yes
Settled solids manure, percentage to export at cost	0	% of excess	Yes
Compost manure, percentage to export at cost	0	% of excess	Yes
Liquid manure, percentage to give away	100	% of excess	Yes
Slurry manure, percentage to give away	100	% of excess	Yes
Sludge manure, percentage to give away	100	% of excess	Yes
Separated solids manure, percentage to give away	0	% of excess	Yes
Settled solids manure, percentage to give away	0	% of excess	Yes
Compost manure, percentage to give away	0	% of excess	Yes
Liquid manure, percentage to sell	0	% of excess	Yes
Slurry manure, percentage to sell	0	% of excess	Yes
Sludge manure, percentage to sell	0	% of excess	Yes
Separated solids manure, percentage to sell	100	% of excess	Yes
Settled solids manure, percentage to sell	100	% of excess	Yes
Compost manure, percentage to sell	100	% of excess	Yes
Liquid manure, cost to export	16.7	\$/1000 gal	Yes
Slurry manure, cost to export	16.7	\$/1000 gal	Yes
Sludge manure, cost to export	16.7	\$/1000 gal	Yes
Separated solids manure, cost to export	41.5	\$/ton (2000 lb)	Yes
Settled solids manure, cost to export	41.5	\$/ton (2000 lb)	Yes
Compost manure, cost to export	41.5	\$/ton (2000 lb)	Yes
Liquid manure, price to sell	3.5	\$/1000 gal	Yes
Slurry manure, price to sell	6	\$/1000 gal	Yes

<b>Farm Info Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
Sludge manure, price to sell	40	\$/1000 gal	Yes
Separated solids manure, price to sell	26.5	\$/ton (2000 lb)	Yes
Settled solids manure, price to sell	2.5	\$/ton (2000 lb)	Yes
Compost manure, price to sell	45	\$/ton (2000 lb)	Yes
<b>Tractor, Drag Hose and Tanker</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
Average distance for land application of manure on farm.	3	miles (land app)	No
Maximum distance for land application of manure via drag hose or tanker	5	miles (land app)	No
Manure tanker size	4500	gal	No
Annual tractor usage for all farm activities	1000	hr/year	Yes
Maximum tractor usage, day	12	hr/day	Yes
Maximum tractor usage, year	2000	hr/year	Yes
<b>Capital Expenses Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
The routine equipment (tractors) cost adjustment factor	1	multiplier	Yes
The construction cost adjustment factor	1	multiplier	Yes
<b>Operational Expenses Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
The non-specialized labor cost for the chosen state or an override by user	26.77	\$/hr	Yes
The utility electricity cost for on-farm usage	0.0997	\$/kWh	Yes
The average price you pay for diesel fuel	3.90	\$/gal	Yes
The average price you pay for gasoline	3.18	\$/gal	Yes
Cost of N (nitrogen) based fertilizer	0.53	\$/lb	Yes
Cost of P2O5 (phosphorus) based fertilizer	0.53	\$/lb	Yes
Cost of K2O (potassium) based fertilizer	0.45	\$/lb	Yes
Average cost of obtaining water for farm usage	2.266515	\$/1000 gal	Yes

<b>Farm Info Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
<b>Priorities Page Variable Description</b>	<b>Value</b>	<b>Unit</b>	<b>Default Used?</b>
Type of year considered (non sludge year, sludge year, or both)	Non-Sludge Year	Year type	Yes
Environmental impact type used for scenario rankings	Farm	impact type	No
<b>Priorities Weightings</b>	<b>Value</b>	<b>Weight of 100%</b>	<b>Default Used?</b>
Weighting for capital costs	80	0.205	No
Weighting for operating costs	80	0.205	No
Weighting for net benefits	80	0.205	No
Weighting for fertilizer costs	10	0.026	No
Weighting for cost savings	10	0.026	No
Weighting for revenues	10	0.026	No
Weighting for carbon footprint	10	0.026	No
Weighting for energy footprint	10	0.026	No
Weighting for land footprint	10	0.026	No
Weighting for water consumption	10	0.026	No
Weighting for nitrogen footprint	10	0.026	No
Weighting for phosphorus footprint	10	0.026	No
Weighting for adoption rate	10	0.026	No
Weighting for operational reliability	10	0.026	No
Weighting for operational integrity	10	0.026	No
Weighting for labor hours requirement	10	0.026	No
Weighting for land required for manure application	10	0.026	No
Weighting for transportability of manure	10	0.026	No
<b>Scenarios that are compared against your baseline scenario</b>		<b>Name on charts</b>	<b>Default Used?</b>
Top ranked scenario		Alt 1	Yes
Second ranked scenario		Alt 2	No
Third ranked scenario		Alt 3	No
Fourth ranked scenario		Alt 4	No

## 6.6 Appendix 6. Glossary of Terms

1. Gas emissions: IPCC Tier 2
2. Methane - amount of volatile solids (VS) produced in the manure and the maximum amount of methane able to be produced from that manure ( $B_0$ ), with respect to temperature.
3. Nitrous oxide – emission factor \* annual average N excretion.
4. Electricity - Pumps/motors flushing.
5. Fuel - Land application (Tractor drawn).
6. Liquid manure N,  $P_2O_5$  &  $K_2O$  – Open Lagoon 365 days storage and 182.5 days removal.
7. Liquid manure N,  $P_2O_5$  &  $K_2O$  – Storage pond 182.5 days storage and removal.
8. Sludge N,  $P_2O_5$  &  $K_2O$  – Open lagoon 10 years removal.
9. Sludge N,  $P_2O_5$  &  $K_2O$  – Anaerobic digestion and Covered lagoon 10 years removal.
10. On-farm emissions (kg  $CO_2e/year$ )– Includes all emissions related to the manure management activities from manure generation to land application and the raw materials consumed on the farm. Farm emissions include those associated with the direct on-farm use of water, electricity, fuel, and land as they relate to manure management. For example, if 100 kg per year of water is used on the farm, then the  $CO_2$  equivalent emissions associated with that water is estimated. All parameters are summed to estimate this value. These emissions do not include those related to the manufacturing of manure management equipment and machinery.
11. Off-farm emissions (kg  $CO_2e/year$ ) – Emissions related to manure management activities, encompassing everything from manure generation to land application.
12. Environmental Impact category - We have presented Carbon footprint (kg  $CO_2$  eq), Land footprint (acres), Energy footprint (MJ), Water footprint ( $m^3$ ), Nitrogen footprint (kg reactive N), and Phosphorus footprint (kg P).
13. Carbon footprint (kg  $CO_2e/year$ ) – all gas emissions, water usage, electricity, and fuel associated with on-farm manure management is converted to kg  $CO_2e/year$ .
14. Energy footprint (MJ/year) – all energy used for on-farm manure management, including diesel and electricity to operate equipment and machinery.
15. Land footprint/use (acres/year) – all the land related to manure management, including land area receiving manure nutrient application and the footprints for storage ponds and lagoons, reception pit, and concrete area for sand lane and solid separation and storage.
16. Nitrogen footprint (lb N/year) – the amount of nitrogen that transforms into reactive nitrogen when manure is land-applied. Reactive nitrogen includes nitrous oxide ( $N_2O$ ), nitrate ( $NO_3$ ), nitrite ( $NO_2$ ), ammonia ( $NH_3$ ), and ammonium ( $NH_4^+$ ).
17. Phosphorous footprint (lb P/year) – the leach-potential of each kg of P land applied, according to the IPCC leach emission factor (i.e., 0.05 kg P leached for each kg of manure P land applied).
18. Capital costs – Capital costs are annualized as \$/head/year. They include costs of construction and equipment needed for all unit processes in the given MMS scenario.

These costs are calculated from the initial purchase price, expected lifetime, annual usage, salvage value, and interest.

19. Operational costs – Operational costs are reported in annual \$/head/year. These costs include insurance, repair and maintenance, electricity, fuel, lubrication, and labor for the MMS in the given scenario.
20. Cost savings – Cost savings are reported in \$/head/year. These include cost savings from avoided resource use, such as recycled water and recycled bedding.
21. Fertilizer value – Fertilizer value is reported in \$/head/year. This is the value of manure nutrients that can be land applied, given the manure nutrient content, crop nutrient needs, nutrient to apply for (N or P<sub>2</sub>O<sub>5</sub>), and the acres available for land application. For MMS scenarios where a storage is emptied less than every year, the annual average value over the storage time period is used. When available land is not adequate for complete application of manure nutrients, the excess manure nutrient value is NOT counted towards fertilizer value; rather, it may be included in revenues if it can be sold, costs if it must be paid to haul away, or excluded from costs or benefits if it is given away.
22. Revenues – Revenues are reported in \$/head/year. These include revenues from resources generated on-farm which can be sold, such as manure nutrients, bedding, and energy from anaerobic digestion. For MMS scenarios where a storage is emptied less than every year, the annual average value over the storage time period is used.
23. Net costs or net benefits – This is the net direct economic costs or benefits, given by the following: Fertilizer Value + Revenues – Capital Costs – Operational Costs. Negative values indicate that costs exceed benefits by the given amount; positive values indicate that benefits exceed costs by the given amount.
24. Acres needed, slurry manure – This is the acres needed to land apply manure nutrients from pond slurry, where manure nutrients are applied at least one time each year. This is based on manure nutrient content, crop nutrient needs, and which nutrient (N or P<sub>2</sub>O<sub>5</sub>) to apply for.
25. Acres needed, liquid manure (non-sludge year) – This is the acres needed to land apply manure nutrients from lagoon liquids, where manure liquids are applied at least one time each year. This is based on manure nutrient content, crop nutrient needs, and which nutrient (N or P<sub>2</sub>O<sub>5</sub>) to apply for.
26. Acres needed, liquid + sludge manure (sludge year) - This is the acres needed to land apply manure nutrients from lagoon liquids and sludge, where manure sludge is applied less than one time each year. This is the total land needed in that year in which sludge is removed. This is based on manure nutrient content, crop nutrient needs, and which nutrient (N or P<sub>2</sub>O<sub>5</sub>) to apply for.
27. Excess N applied (lb/y) - This is the estimated amount of excess N applied each year (on average in cases where lagoon sludge is removed less than one time per year). This is based on manure nutrient content, crop nutrient needs, and which nutrient (N or P<sub>2</sub>O<sub>5</sub>) to apply for.

28. Excess P applied (lb/y) - This is the estimated amount of excess P applied each year (on average in cases where lagoon sludge is removed less than one time per year). This is based on manure nutrient content, crop nutrient needs, and which nutrient (N or P<sub>2</sub>O<sub>5</sub>) to apply for.
29. Lagoon or pond constructed volume (ft<sup>3</sup>) - This is the estimated size needed for a lagoon or pond storage, based on manure volume and characteristics.
30. Labor requirements (h/y) - This is the estimated labor time required to operate the MMS for the given scenario. This includes labor time for operation of skid steer and tractor for handling sand and manure (when applicable) and land applying manure. It also includes labor needed to operate other major MMS equipment (e.g. manure separation, anaerobic digestion, etc, when applicable).
31. Labor requirements (\$/y) - This is the estimated labor costs required to operate the MMS for the given scenario. This includes labor costs for operation of skid steer and tractor for handling sand and manure (when applicable) and land applying manure. It also includes labor needed to operate other major MMS equipment (e.g. manure separation, anaerobic digestion, etc, when applicable).
32. Fuel requirements (gal/y) - This is the estimated fuel needed to operate the MMS for the given scenario. This includes fuel for operation of skid steer and tractor for handling sand and manure (when applicable) and land applying manure. It also includes labor needed to operate other major MMS equipment (e.g. manure separation, digestion, etc, when applicable).
33. Fuel requirements (\$/y) - This is the estimated fuel costs associated with the operation of the MMS for the given scenario. This includes fuel for operation of skid steer and tractor for handling sand and manure (when applicable) and land applying manure. It also includes fuel needed to operate other major MMS equipment (e.g. manure separation, digestion, etc, when applicable).
34. Lagoon constructed volume – the size of the lagoon which is required to handle the manure loading (and other required volumes like rainfall runoff and freeboard) between pump outs, which is a function of manure processing pre-lagoon inflow
35. AHP ranking -We have used the Analytic hierarchy process (AHP) that allows the user to prioritize their farm preference to rank the MMS alternative. We allow the user to select a preference in Criteria and sub-criteria that influences the ranking order.

## 6.7 Appendix 7. Climate Divisions

This DST uses the U.S. Climate Division delineations from the National Oceanic and Atmospheric Administration (2025) found at this link: <https://psl.noaa.gov/data/usclimdivs/data/map.html>. See below for the U.S. Climate Divisions map and tables.



### List of states and their climate divisions.

Alabama (1): 1 North Valley, 2 Appalachian Mountain, 3 Upper Plains, 4 Eastern Valley, 5 Piedmont Plateau, 6 Prairie, 7 Coastal Plain, 8 Gulf.

Arizona (2): 1 Northwest, 2 Northeast, 3 North Central, 4 East Central, 5 Southwest, 6 South Central, 7 Southeast.

Arkansas (3): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

California (4): 1 North Coast Drainage, 2 Sacramento Drainage, 3 Northeast Interior Basins, 4 Central Coast Drainage, 5 San Joaquin Drainage, 6 South Coast Drainage, 7 Southeast Desert Basin.

Colorado (5): 1 Arkansas Drainage, 2 Colorado Drainage, 3 Kansas Drainage, 4 Platte Drainage, 5 Rio Grande Drainage.

Connecticut (6): 1 Northwest, 2 Central, 3 Coastal.

Delaware (7): 1 Northern, 2 Southern.

Florida (8): 1 Northwest, 2 North, 3 North Central, 4 South Central, 5 Everglades and Southwest Co, 6 Lower East Coast, 7 Keys.

Georgia (9): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Idaho (10): 1 Panhandle, 2 North Central Prairies, 3 North Central Canyons, 4 Central Mountains, 5 Southwestern Valleys, 6 Southwestern Highlands, 7 Central Plains, 8 Northeastern Valleys, 9 Upper Snake River Plains, 10 Eastern Highlands.

Illinois (11): 1 Northwest, 2 Northeast, 3 West, 4 Central, 5 East, 6 West Southwest, 7 East Southeast, 8 Southwest, 9 Southeast.

Indiana (12): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Iowa (13): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Kansas (14): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Kentucky (15): 1 Western, 2 Central, 3 Blue Grass, 4 Eastern.

Louisiana (16): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Maine (17): 1 North, 2 South Interior, 3 Coastal.

Maryland (18): 1 Southeastern Shore, 2 Central Eastern Shore, 3 Lower Southern, 4 Upper Southern, 5 Northeastern Shore, 6 North Central, 7 Appalachian Mountains, 8 Allegheny Plateau.

Massachusetts (19): 1 West, 2 Central, 3 Coastal.

Michigan (20): 1 West Upper, 2 East Upper, 3 Northwest Lower, 4 Northeast Lower, 5 West Central Lower, 6 Central Lower, 7 East Central Lower, 8 Southwest Lower, 9 South Central Lower, 10 Southeast Lower.

Minnesota (21): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Mississippi (22): 1 Upper Delta, 2 North Central, 3 Northeast, 4 Lower Delta, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast, 10 Coastal.

Missouri (23): 1 Northwest Prairie, 2 Northeast Prairie, 3 West Central Plains, 4 West Ozarks, 5 East Ozarks, 6 Bootheel.

Montana (24): 1 Western, 2 Southwestern, 3 North Central, 4 Central, 5 South Central, 6 Northeastern, 7 Southeastern.

Nebraska (25) Note- there is no division 4 in Nebraska.: 1 Panhandle, 2 North Central, 3 Northeast, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Nevada (26): 1 Northwestern, 2 Northeastern, 3 South Central, 4 Extreme Southern.

New Hampshire (27): 1 North, 2 South.

New Jersey (28): 1 Northern, 2 Southern, 3 Coastal.

New Mexico (29): 1 Northwestern Plateau, 2 Northern Mountains, 3 Northeastern Plains, 4 Southwestern Mountains, 5 Central Valley, 6 Central Highlands, 7 Southeastern Plains, 8 Southern Desert.

New York (30): 1 Western Plateau, 2 Eastern Plateau, 3 Northern Plateau, 4 Coastal, 5 Hudson Valley, 6 Mohawk Valley, 7 Champlain Valley, 8 St. Lawrence Valley, 9 Great Lakes, 10 Central Lakes.

North Carolina (31): 1 Southern Mountains, 2 Northern Mountains, 3 Northern Piedmont, 4 Central Piedmont, 5 Southern Piedmont, 6 Southern Coastal Plain, 7 Central Coastal Plain, 8 Northern Coastal Plain.

North Dakota (32): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Ohio (33): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 Central Hills, 7 Northeast Hills, 8 Southwest, 9 South Central, 10 Southeast.

Oklahoma (34): 1 Panhandle, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Oregon (35): 1 Coastal Area, 2 Willamette Valley, 3 Southwestern Valleys, 4 Northern Cascades, 5 High Plateau, 6 North Central, 7 South Central, 8 Northeast, 9 Southeast.

Pennsylvania (36): 1 Pocono Mountains, 2 East Central Mountains, 3 Southeastern Piedmont, 4 Lower Susquehanna, 5 Middle Susquehanna, 6 Upper Susquehanna, 7 Central Mountains, 8 South Central Mountains, 9 Southwest Plateau, 10 Northwest Plateau.

Rhode Island (37): 1 Rhode Island.

South Carolina (38): 1 Mountain, 2 Northwest, 3 North Central, 4 Northeast, 5 West Central, 6 Central, 7 Southern.

South Dakota (39): 1 Northwest, 2 North Central, 3 Northeast, 4 Black Hills, 5 Southwest, 6 Central, 7 East Central, 8 South Central, 9 Southeast.

Tennessee (40): 1 Eastern, 2 Cumberland Plateau, 3 Middle, 4 Western.

Texas (41): 1 High Plains, 2 Low Rolling Plains, 3 North Central, 4 East Texas, 5 Trans Pecos, 6 Edwards Plateau, 7 South Central, 8 Upper Coast, 9 South, 10 Lower Valley.

Utah (42): 1 Western, 2 Dixie, 3 North Central, 4 South Central, 5 Northern Mountains, 6 Uinta Basin, 7 Southeast.

Vermont (43): 1 Northeastern, 2 Western, 3 Southeastern.

Virginia (44): 1 Tidewater, 2 Eastern Piedmont, 3 Western Piedmont, 4 Northern, 5 Central Mountain, 6 Southwestern Mountain.

Washington (45): 1 West Olympic Coast, 2 North East Olympic San Juan, 3 Puget Sound Lowlands, 4 East Olympic Cascade Foothills, 5 Cascade Mountains West, 6 East Slope Cascades, 7 Okanogan Big Bend, 8 Central Basin, 9 Northeastern, 10 Plouse Blue Mountains.

West Virginia (46): 1 Northwestern, 2 North Central, 3 Southwestern, 4 Central, 5 Southern, 6 Northeastern.

Wisconsin (47): 1 Northwest, 2 North Central, 3 Northeast, 4 West Central, 5 Central, 6 East Central, 7 Southwest, 8 South Central, 9 Southeast.

Wyoming (48): 1 Yellowstone Drainage, 2 Snake Drainage, 3 Green and Bear Drainage, 4 Big Horn, 5 Powder, Little Mo & Tongue Drainages, 6 Belle Fourche Drainage, 7 Cheyenne Niobrara Drainage, 8 Lower Platte, 9 Wind River, 10 Upper Platte.

## 6.8 Appendix 8. References

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