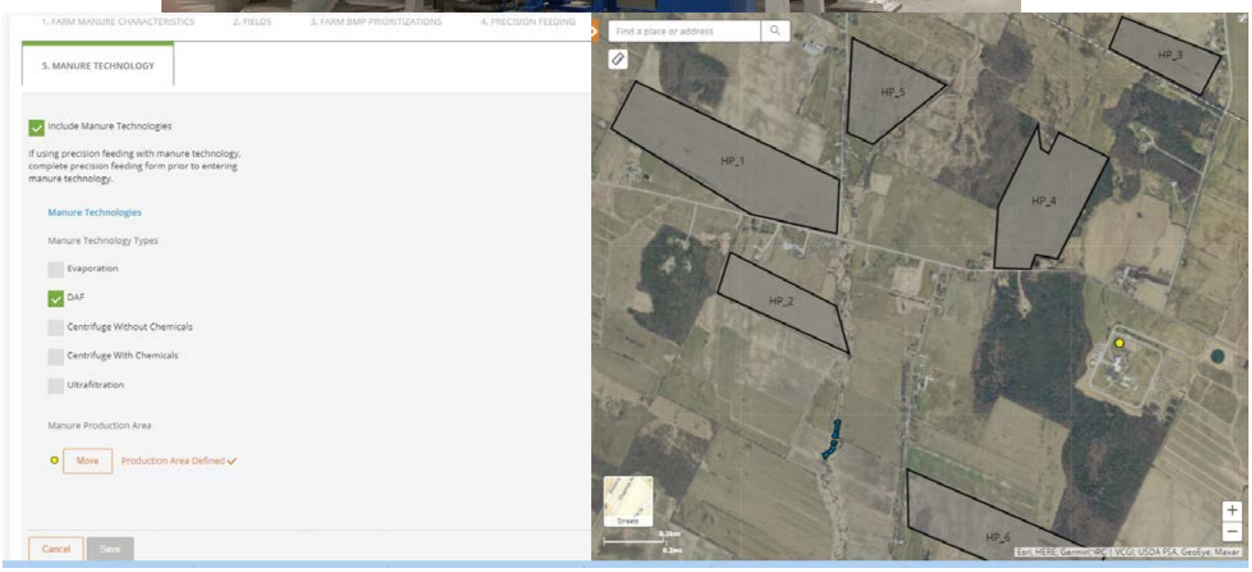
Enhancement of Farm-PREP P Management Optimization to Incorporate Innovative Manure Technologies



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Title and Approval Page

Document Title

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Executive Summary

This report documents the effort to enhance Farm_PREP phosphorus (P) management options to incorporate innovative manure technologies and precision feeding, as well as incorporating an uncertainty/variability component into the output. Farm-PREP has been developed by Stone Environmental, Inc. to objectively quantify farm-specific reductions in phosphorus losses resulting from conservation practices. Farm-PREP helps farmers and/or planners identify field by field agronomic practices that allow them to achieve a targeted reduction in phosphorus losses. Several recent projects focused on expanding and improving Farm-PREP, including efforts to expand the spatial analysis and management options to better suit the larger Lake Champlain Basin as well as to improve calibration of certain parameters based on monitoring data from both edge-of-field and tile drained sites. This work represents further development of Farm-PREP to allow users to simulate the implementation of innovative manure technologies that can provide farms with the option of storing or transporting phosphorus off-site in the form of specific manure products, thus providing the potential to reduce phosphorus losses at the farm-scale.

The new functionality allows users to select one of five technologies for implementation: evaporation, dissolved air floatation (DAF), centrifuge with chemicals, centrifuge without chemicals, and ultrafiltration. Each of these technologies generates specific manure products, generalized as a coarse fiber, a solid or semi-solid product, and a liquid product. Farm-PREP re-allocates manure products to selected farm fields based on the user specified crop rotation and soil test P, based on recommended phosphorus application rates described in the Nutrient Recommendations for Field Crops in Vermont (2018), and distance of the fields from the user specified manure source. Once manure products are reallocated, the user can select to modify application rates on each field. Additional reporting was added to Farm-PREP to summarize manure management inputs as well as better characterize the long-term soil P dynamics resulting from the simulated management options.

New functionality was also added to Farm-PREP so that a user can simulate precision feeding. Precision feeding is another farm-level practice that ultimately has the potential to reduce phosphorus in dairy manure, thereby reducing phosphorus losses from the farm.

Lastly, additional post-processing of APEX simulations was added to Farm-PREP to evaluate annual variability as a result of weather conditions. In addition to previously reporting annual average values for outputs such as phosphorus losses, Farm-PREP now also reports annual minimum, maximum, 25^{th}, and 75^{th} percentile values. This shows the user the potential range in results that might be expected due only to variability in weather.

Final Report for Enhancement of Farm-PREP P Management Optimization to Incorporate Innovative Manure Technologies

Cover Photo: Sedron Evaporation System and Farm-PREP User Interface for Selection of Manure Technology

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1. Introduction

This effort included modification of Stone's Web-based farm phosphorus management optimization tool (Farm-P Reduction Planner or Farm-PREP) and integration into the phosphorus protocol being developed by Newtrient in support of advancing environmental services markets through project efforts with the Natural Resources Conservation Service (NRCS), Lake Champlain Basin Program (LCBP), and the Vermont Clean Water Fund. This work builds upon the phosphorus management tool development efforts that Stone has led in the state of Vermont with support from the LCBP and NRCS. The adoption of innovative manure processing technologies designed to improve its form and farm utilization into the farm P management were incorporated into the optimization tool framework. Enhancements to the tool were made to account for variability in the model-simulated farm P reduction predictions. The result is a farm specific approach to quantifying P reduction potential based on strategic combinations of field-based practices, innovative manure processing technologies and precision feeding.

1.1. Farm-PREP

The Farm-P Reduction Planner (or Farm-PREP) is a web-based APEX model interface developed by Stone Environmental and Texas A&M. Farm-PREP has been specifically designed to objectively quantify farm-specific reductions in phosphorus losses resulting from conservation practices. Farm-PREP helps farmers and/or planners identify field by field agronomic practices that allow them to achieve a targeted reduction in phosphorus losses. The Agricultural Policy / Environmental Extender Model (APEX, Gassman et al., 2009; Steglich et al., 2016; BREC, 2020) serves as the water quality and agronomic modeling engine for Farm-PREP. Farm-PREP simplifies the use of APEX by pre-processing the many required inputs (such as soils, topography, and weather), through a web-interface. Farm-PREP is unique in that it offers an optimization of field-level practices to achieve a target farm-level reduction in P loss.

Other recently completed projects have supported the development and enhancement of Farm-PREP such that it is well positioned to support Newtrient efforts on advancing environmental services markets by providing a systematic and scientifically defensible approach to guiding farm practices and achieving water quality improvement goals with results that can be integrated with a phosphorus crediting protocol. Stone Environmental completed a pilot project in the St Albans Bay watershed in 2018, that tested a modeling approach for optimizing the implementation of BMPs on farms to achieve water quality goals. This resulted in the initial development of Farm-PREP, which implements APEX to quantitatively evaluate an array of possible agricultural practices across the farm. It aids in identifying management scenarios that will achieve a load-based phosphorus water quality target (based on 2016 total maximum daily loads [US EPA, 2016]), allowing the farmer to pick options that fit within their preferred farm operating methods. The Farm-PREP tool quantitatively identifies the types and locations of field-level agricultural practices that meet pre-defined P load reduction targets, all specific to a specific farm's land and operations.

A Farm-PREP Phase 2 project was also completed in 2020, with the goal of ensuring successful implementation of the tool across the state of Vermont. That project sought to increase stakeholder confidence and acceptance, create a knowledgeable user community, and make a commitment to continued technical support of the application through 2022. In Phase 2, the geographic extent of Farm-PREP databases and model inputs were expanded to encompass the entire Vermont portion of the LCB, which included updates to basin-wide agronomic practice data to cover the entire state of Vermont to provide a wider selection of agronomic input options for users. During this project, the tool was tested with stakeholders from different regions across the broader basin to evaluate Farm-PREP, including tool usability and examination of results from both the technical and practical standpoint. Feedback from the testing phase was compiled, synthesized, and ultimately lead to updates to the user interface that improved the tool's usability and functionality. An educated group of stakeholders interested in applying the tool to their farms or farms of interest to their organization was identified, including crop consultants, university extension agents, and regulators. These stakeholders were gathered in different regions of the basin for 1-day training courses on the use of the tool and interpretation of results. Widespread use of this tool across the basin provides great potential for well-informed phosphorus management at the farm scale leading to meaningful water quality improvements at the basin scale. The outcome of this project was a basin-wide tool that provides consistent and credible quantification of reductions in farm-scale P loss based on identification of field and farm level practices that meet desired water quality targets, ultimately leading to a more strategic approach to improving the water quality of Lake Champlain.

A recently completed effort was also conducted to specifically verify and improve the calibration of the APEX model executed by Farm-PREP. This effort utilized monitoring data from a selection of edge-of-field and tile drain monitoring sites in Vermont and New York to calibrate the APEX model with respect to model parameters that determine which equations are used to represent certain physical processes in the simulations and coefficient/parameter values for these equations. This effort also focused on developing model parameterizations for several innovative manure technologies and evaluating the impacts of simulated implementation of manure technologies on model-predicted phosphorus losses. The same manure technologies used in this previous effort are those that were selected to be incorporated into the Farm-PREP tool. These are further described in Section 1.2.

Most recently, in the fall of 2020, the VT Agency of Agriculture Food and Markets (VT AAFM) was awarded funding through NRCS' Regional Conservation Partnership Program Alternate Funding Arrangement (RCPP-AFA) to support a pay for performance program to incentivize Vermont farmers to adopt best management practices aimed at reducing P losses from their farms. The program is expected to provide payments based on the pounds of P reduced on the farm, and the Farm-PREP tool has been identified as the method by which P reductions will be calculated. This effort is expected to further the capabilities of Farm-PREP and significantly increase its usage throughout Vermont.

1.2. Manure Technologies

Manure is often applied at higher rates to fields close to the dairy milking facility and manure storage structure because the nutrient density is low and transporting significant distances is cost prohibitive. Manure processing technologies which can produce more storable and transportable manure products offer great potential for reducing the amount of land-applied phosphorus and in turn, lower nutrient runoff and improve water quality. The benefit tied to the adoption of manure management technologies is the generation of new manure-based fertilizer products that are both storable and transportable allowing for placement where and when the nutrients are needed, and for allowing the export of these products to agricultural land that traditionally has not benefited from dairy manure. Newtrient has identified five technologies that offer the greatest promise to be integrated into Farm-PREP: 1.) Dissolved air flotation (DAF), 2) Evaporation, 3.) Centrifuge, 4.) Centrifuge with chemical addition, and 5.) Ultrafiltration (UF/RO). Each one of these processes results in different co-product streams, each containing different physical and chemical compositions.

1.2.1. Dissolved Air Flotation

DAF systems are part of a class of technologies (fine solids flocculation systems) in which chemical inputs are introduced to aggregate small colloidal and suspended solids into larger flocs for separation, dewatering, and removal into a stackable pile. The organic N and total P fraction preferentially separates with the fine solids in the wastewater, allowing for significant partitioning of these nutrients into a denser form. In general, the partitioned solid fraction is dewatered using mechanical solid-liquid separation and can be further processed in a dryer to increase value and lower transportation costs. The products of these technology include a coarse fiber product, DAF solids, and a DAF 'tea' liquid. Approximately 75% of the organic N and total P partitions with the solids fraction with the balance in the tea water. Further details can be found in the Newtrient Technology catalog for DAF: https://www.newtrient.com//Catalog/Technology-Types/Chemical-Flocculation.

1.2.2. Evaporation

Evaporation systems represent a complete manure treatment solution, where liquid manure inputs are separated into solid and water components that are additionally heated, sterilized, and distilled. The products of this technology are a coarse fiber product, a dry solid manure product, aqua ammonia, and a 'clean' water (that can be treated to desired quality standards for reuse such as for environmental release, irrigation, reclaimed water, or wastewater treatment discharge). The coarse fiber and dry solids products contain P (most of which is in the dry solids), while the aqua ammonia contains no P but does contain nitrogen (N) that can be used to supplement commercial N products. The clean water fraction contains a small amount of ammonia-nitrogen (on the order of 125 mg/L). The substitution of commercial N with onsite manure sources is a benefit of this technology, but further work is needed, including optimization of N application and reducing use of commercial N fertilizers. Further details can be found in the Newtrient Technology catalog for evaporation: https://www.newtrient.com//Catalog/Technology-Types/Evaporative-Technologies.

Figure 1. SEDRON Evaporation System.

1.2.3. Centrifuge (with or without chemical addition)

Centrifuges are a commercially available, mature technology. Worldwide, thousands of centrifuge systems are installed for concentrating and dewatering solids in municipal, industrial, and agricultural waste streams. Manure slurry is pumped into the centrifuge where it is exposed to high centrifugal forces resulting from the inside of the machine spinning at 2,000 to 4,000 RPM. Due to the high-speed rotation and centrifugal forces, manure solids are forced to the outermost edge of the system and are moved to the discharge by a scroll or auger, the liquid portion flows through the machine and is discharged. Centrifuge systems can be configured with or without polymer. Systems using polymer have higher P and solids removal rates, but also have increased operating costs. The primary benefit of centrifugation is the removal of P and course solids from liquid manure in a single step. Centrifuge systems can remove 40-60% of P and total solids without polymer and up to 80% of the phosphorus with polymer additions. The relatively low moisture content coupled with high carbon, phosphorus, and nitrogen content makes centrifuge separated manure fiber a valuable fertilizer, soil amendment, and/or compost input. Further details can be found in the Newtrient Technology catalog for centrifuge: https://www.newtrient.com/Catalog/Technology-Types/Centrifuge.

1.2.4. Ultrafiltration

Ultrafiltration (UF) is a membrane separation technique, usually operated with a pressure driving-force such as a pump, to create a pressure difference across the face of a semipermeable membrane. The UF membrane acts as a barrier that precludes the passage of suspended solids but allows water and dissolved solids to permeate. Figure 2 presents a schematic illustrating material flow through tubular ultrafiltration membrane system (a typical UF configuration for a high-solids application). The filtered liquid is referred to as permeate or "tea water", and, in addition to water, contains dissolved constituents, most notably ammonium and potassium. The concentrate (material that does not permeate through the membrane) is rich in phosphorus and organic nitrogen and is managed as a liquid concentrated fertilizer. The extent of volume reduction achieved by an ultrafiltration system is controlled by the initial solids concentration. In general, there is a direct relationship between the total solids going in and the rate of permeate coming out with less teawater produced as the total solids concentration increases. Further details can be found in the Newtrient Technology catalog for ultrafiltration: https://www.newtrient.com/Catalog/Technology-Types/UF-Membrane.

Figure 2. Diagram of Ultrafiltration Technology.

1.3. Objectives

The purpose of this work was to modify and integrate Farm-PREP into the Phosphorus Protocol being developed by Newtrient in support of advancing environmental services markets through project efforts with the NRCS, LCBP, and the Vermont Clean Water Fund. The primary focus was to incorporate the adoption of innovative manure processing technologies designed to improve manure forms and farm utilization of manure into the farm P management optimization framework of Farm-PREP. This included enhancements to Farm-PREP that account for utilization of manure technology products (as opposed to standard unprocessed manure), the incorporation of precision feeding, as well as accounting for the uncertainty or variability in model-simulated farm P reduction predictions. The outcome is a scientifically defensible, farm-specific approach to quantifying P reduction potential based on strategic combinations of field-based practices and adoption of innovative manure processing technologies. There were three primary objectives that guided this effort.

1.3.1. Task 1. Integration of Manure Processing Technologies into Farm-P Reduction Planner (Farm-PREP)

The objectives of this task were to develop APEX model parameterizations that reflect the changes in land applied manure and processing co-products resulting from each of the five selected manure processing technologies; estimate the impact of the parameterizations on transport processes at the field scale; and identify options for targeted application of the available nutrients at the farm scale. These technology-based management opportunities were then integrated into the field practice-based farm P optimization process and tool that has already been developed for Vermont farms. Appropriate APEX parameterizations were developed to represent the transformation of manure into manure products based on user defined manure characteristics, including specification of nutrient content and form of each product. Model parameters were determined to describe application methods and associated soil/land disturbance for each product.

In addition, an approach was developed for strategically allocating processed manure and co-products to the most appropriate farm fields. The key criteria considered in this strategy was the current plant-available soil P for each field, nutrient demands of the crop rotation, physical characteristics/nutrient contents of the manure products, and distance of the field from the manure source. The goal was to apply the least desirable/storable manure products first while not exceeding plant phosphorus uptake requirements across all fields. It was assumed that if excess manure products remain available, then the balance of that material could be stored on the farm or transported off-site. These options and the logic for incorporating a manure technology and strategically applying the resulting manure products across fields on a farm were integrated into the Farm-PREP optimization tool framework. This included modifications to the user interface, as well as incorporation of additional algorithms and calculations to represent the described processes.

1.3.2. Task 2: Incorporation of Additional Farm Practices

Precision feeding is a farm-level practice that was added to the model simulation capabilities in addition to the manure processing technologies addressed in Task 1. The precision feeding practices affect the farm-level P mass balance, and ultimately, the amount of P added as manure to farm fields. Incorporating this practice into the farm-level optimization may have direct positive impacts in reducing P losses with little or no costs to the farm.

1.3.3. Task 3: Evaluation and Reporting of Model Uncertainty

The original concept for this task was to quantify and communicate to the user, the uncertainty in model-predicted farm-level P reductions resulting from implementation of a combination of field-level practices and farm-level technologies. In this case, analysis would have focused on model uncertainty associated with model inputs (e.g. soil type and characteristics), as well as with model parameter assumptions and alternative practice effectiveness. However, this objective was modified to focus on providing the user information characterizing the variability in model simulation phosphorus loss results due to inter-annual weather variability. We determined that this would be more useful to a user in understanding expected annual variability in phosphorus losses and making long-term farm management decisions. In addition, an analysis quantifying model uncertainty due to variability in a number of soil parameters obtained from SSURGO was conducted as part of an LCBP grant (Stone Environmental, 2020). The same project also included an evaluation of the effectiveness of cover cropping and cover cropping planting dates.

This task involved evaluating additional APEX model outputs for inclusion in Farm-PREP as well as the integration of additional model post-processing into the Farm-PREP framework. Also included in this task was modification of the web interface to provide the user with information characterizing the variability in flow (surface and tile), phosphorus loss (soluble, sediment, and tile), and erosion.

2. Integration of Manure Processing Technologies into Farm-PREP

The goal of this task was to determine how to simulate the implementation of manure technologies in APEX and develop appropriate model parameterizations, as well as to integrate the manure technologies into the web-based tool Farm-PREP. Implementation of manure technologies on a farm implies that all manure is converted into 3 or 4 manure products (depending on the technology) with different nutrient and physical characteristics than the original manure. Thus, two primary aspects of manure technologies were incorporated into the Farm-PREP. First, the amount and nutrient content of each manure product are calculated based on user inputs that specify and describe the nutrient contents of the original farm manure. Second, manure products are reallocated to each field in the assessment based on the storability and transportability of each product. These two sub-tasks are further described in the Section 2.1.

In order to simulate the application of manure (or manure product), the APEX model requires the following information: manure nutrient characteristics (e.g. fraction of mineral and organic nitrogen, mineral and organic phosphorus, potassium, carbon, etc.), dry matter content, as well as information on the specific applications (e.g. application date, rate, and associated equipment or application method). Incorporating the simulation of these technologies into the Farm-PREP framework required additional user inputs and implementation of new algorithms to generate appropriate model inputs. These model inputs are generated from a combination of user inputs, assumptions already incorporated in Farm-PREP, and guidance provided by Newtrient. Reporting of Farm-PREP results were also modified.

2.1. Technical Description

2.1.1. Calculation of Farm-Available Manure Products and Associated Nutrient Characteristics

The first step in simulating manure technology products through Farm-PREP is to determine nutrient and physical characteristics of manure products resulting from implementation of a user selected manure technology, as well as the amount of each manure product available at the farm (or Farm-PREP assessment) level. Farm-PREP user inputs that are critical for determining available manure product amounts and nutrient characteristics are the field specific application rates of original manure and associated manure characteristics. Users can either provide manure characteristic information specific to their farm manure, such as from a manure nutrient analysis, including the amount (lbs/1000 gal) of NH4 nitrogen, organic nitrogen, phosphorus (P2O5), potassium (K2O), and dry matter content (percent) or can choose to use the default VT manure (Table 1 shows nutrient fractions for the default manure and default commercial fertilizers). Users also provide manure application rates for each field in a farm or assessment and can select to implement one of five manure processing technologies: evaporation, DAF, centrifuge without chemicals, centrifuge with chemicals, or ultrafiltration. Figure 3 and Figure 4 show Farm-PREP user entry forms for manure characteristics and selection of manure technologies, respectively, as well as identification of the manure source area.

Table 1. Default Manure Characteristics in Farm-PREP.

Manure/Fertilizer Name	Mineral Phosphorus (fraction)	Organic Phosphorus (fraction)	Mineral Nitrogen (fraction)	Organic Nitrogen (fraction)	Potassium (fraction)	Organic Carbon (fraction)	Dry Matter (%)
VT Liquid Dairy Manure	0.005	0.0017	0.013[1]	0.025	0.031	0.614	7
Com P	0.437	0.000	0.000	0.000	0.000	0.000	100
Com N	0.000	0.000	1.000	0.000	0.000	0.000	100

[1] 99% of mineral N in manure is assumed to be in the ammonium (NH_4) form.

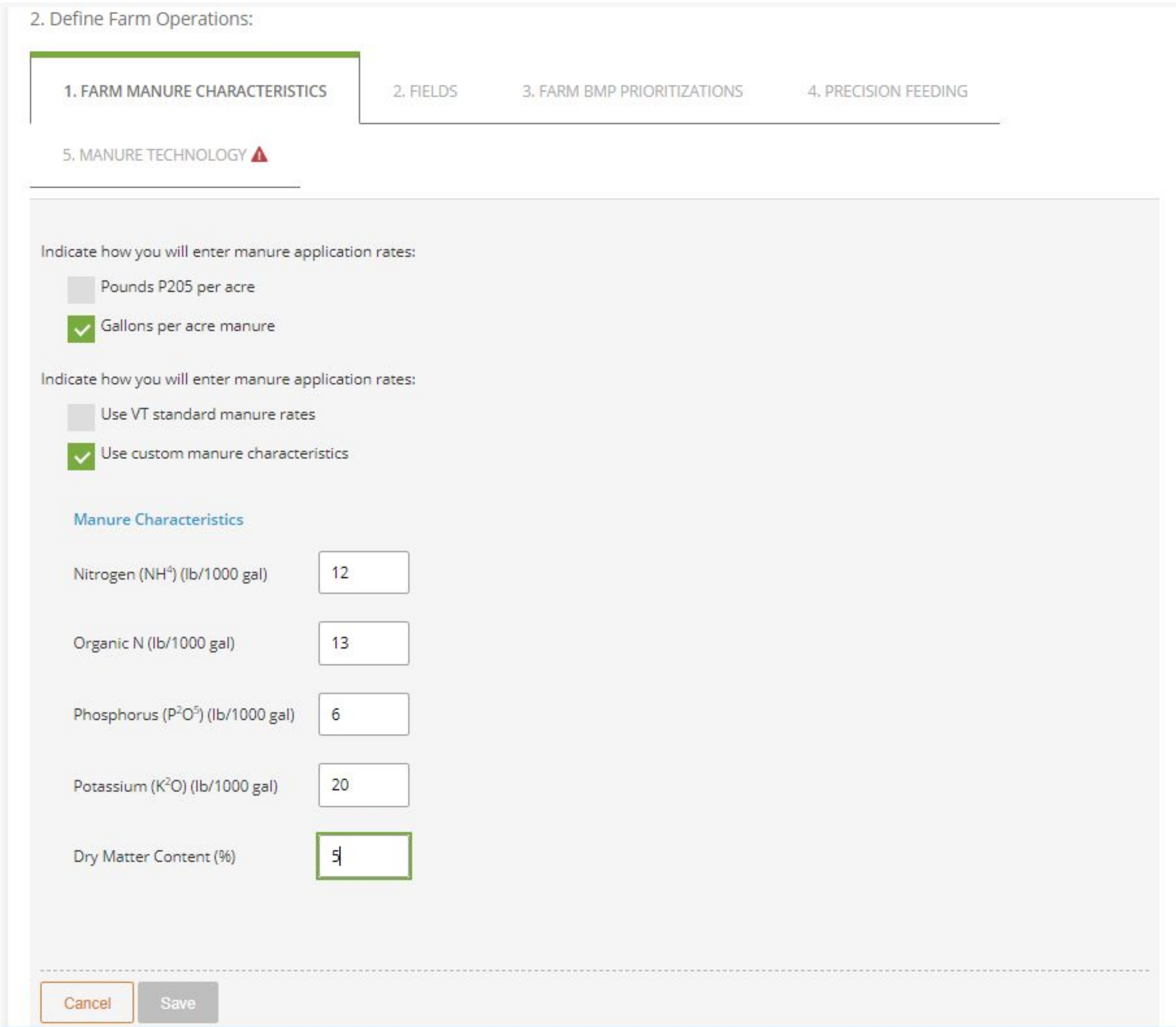


Figure 3. Farm-PREP Manure Characteristics Entry Form.

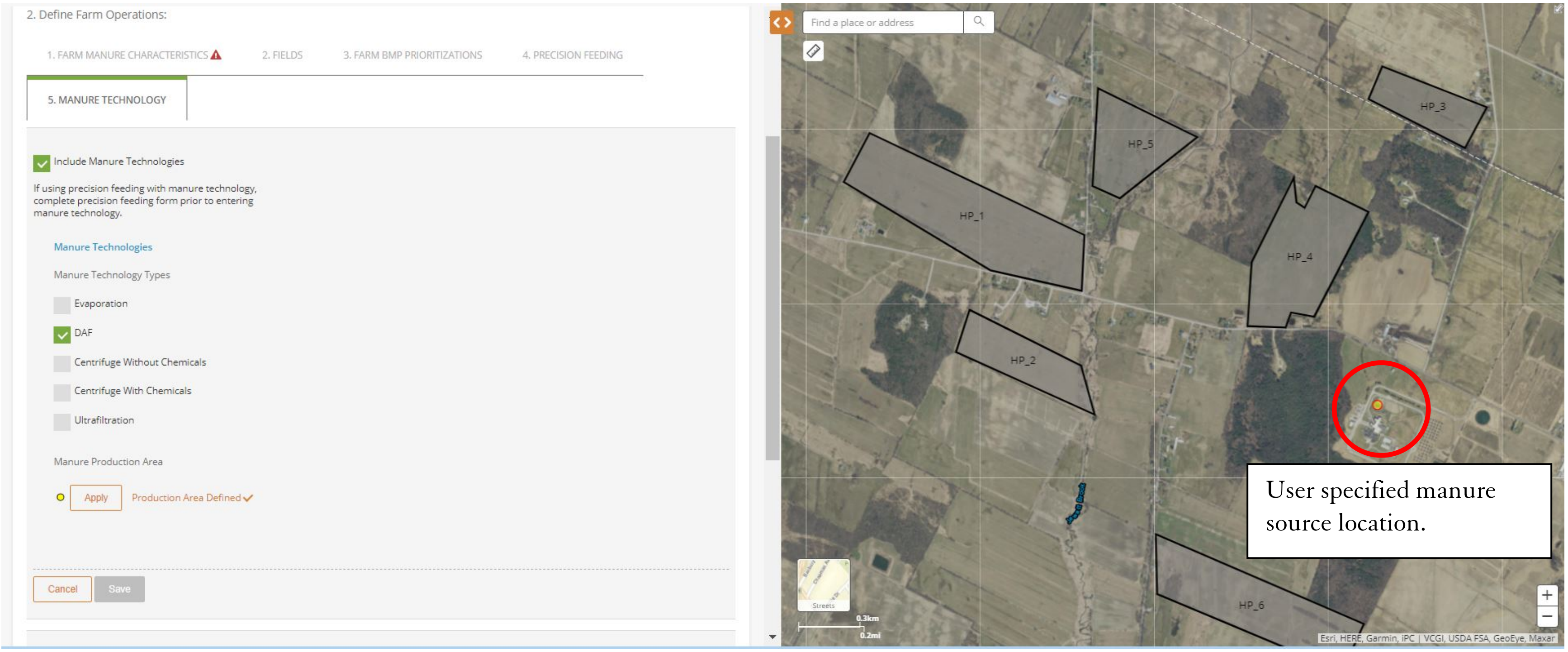


Figure 4. Farm-PREP Manure Technology and Manure Source Entry Form.

If the user selects a manure technology, the total amount of manure applied on a farm/assessment in each simulated year is calculated as the sum of manure applied on each field. This total farm-level manure is then converted into manure products specific to the technology, resulting in a total farm available amount of each product and associated manure characteristics. All technologies ultimately produce a coarse fiber product, a solid or semi-solid product, and a liquid product. While these products are specific to the technology, to simplify reporting to the user, the products will be referred to generally in Farm-PREP as 'Coarse fiber', 'Liquid', and 'Semi-Solid'. Based on guidance from Newtrient, calculations are made to convert the input manure into manure products, resulting in estimated farm-level amounts of products available and their nutrient characteristics. Table 2 shows an example of this calculation using the VT default manure characteristics, an annual average application rate of 42 lbs $P2O5$/ac, and a farm comprised of approximate 332 acres. If a user applies commercial phosphorus (P) to a field, that is not considered part of the initial amount of phosphorus available from farm manure.

Table 2. Example of Conversion of Manure into Manure Products.

	Original Farm Manure (Input)	Coarse Fiber, All Technologies	Evaporation		Dissolved Air Floatation (DAF)		Centrifuge without Chemicals		Centrifuge with Chemicals		Ultrafiltration	
			Solid	Liquid	Semi-Solid	Liquid	Semi-Solid	Liquid	Semi-Solid	Liquid	Semi-Solid	Liquid
Total Product (lbs/yr)	929566	255085	765255	18818	612204	153051	382627	382627	497416	267839	730090	35166
Annual Average Farm Available Total (lbs P2O5/yr)	13882	1388	12494	0	10995	1499	6247	6247	8121	4373	11869	625
Fraction Min P	0.004	0.002	0.005	0.000	0.005	0.003	0.005	0.005	0.005	0.005	0.005	0.005
Fraction Org P	0.022	0.001	0.002	0.000	0.003	0.001	0.002	0.002	0.002	0.002	0.002	0.003
Fraction Min N	0.021	0.005	0.000	1.000	0.005	0.119	0.003	0.053	0.003	0.074	0.017	0.261
Fraction Org N	0.029	0.012	0.023	0.000	0.021	0.034	0.023	0.024	0.025	0.011	0.024	0.013
Fraction K2O	0.029	0.006	0.036	0.000	0.006	0.152	0.004	0.067	0.004	0.095	0.021	0.333

This example is based on VT default liquid manure characteristics, an annual average application rate of 41.75 lbs P2O5/ac, and a farm comprised of 332.5 acres.

2.1.2. Field-Level Allocation of Manure Products

Once the farm-level amount of each product and associated characteristics are determined, products are reallocated to the fields included on the farm's assessment. Annual application rates of each manure product for each field are calculated based on current plant-available soil P for each field, nutrient demand of the crop rotation, the physical characteristics of manure products (represented by product application priority ranking), and distance of field from the manure source. Product application rates are calculated independently for each simulated year to account for changes in crop rotation.

Storability and transportability of each product was considered when determining application priority, and products were ultimately ranked to reflect which product should be used first and which could be stored or transported off-farm if not applied to a field (Table 3). The highest ranked products were the heavier, often less nutrient dense products that are more difficult for a farm to store or transport off-site. These highest ranked products are applied first and to the closest fields. If a user selects to implement a manure technology, the center of each delineated field is used to determine the distance from field to manure source, which the user is asked to identify as a point location on a farm map when a manure technology is selected. This would minimize the transportation cost per pound of nutrient applied, making this approach a reasonable assumption for optimization of manure allocation spatially.

Phosphorus plant demand is calculated for each field as the recommended phosphorus application rates described in the Nutrient Recommendations for Field Crops in Vermont (2018). Recommended phosphorus application rates are based on crop rotation (specified by the user) and initial soil test phosphorus. The initial soil test phosphorus value for each field is either specified by the user or assigned a default value of 5 ppm (Modified Morgan's P) is used. Again, this is done on an annual basis to account for changes in crop rotation that might alter plant demand or recommended phosphorus application rates on any field. Calculated manure application rates are not allowed to provide more phosphorus than the recommended phosphorus application rates on each field.

The inputs to the re-allocation algorithm are the total amount of each manure product available at the farm level, the distance of each field from the manure source, the plant demand or recommended phosphorus application rate for each field, and a list of ranked manure products by application priority. For each manure product, in order of lowest to highest application priority ranking (Table 3), the re-allocation algorithm iterates over each field, in order of closest to farthest from the manure source, and calculates a phosphorus application rate as the maximum amount of manure product that either meets plant phosphorus demand or equals the amount of the manure product available. As the algorithm iterates over the manure products, the total amount of phosphorus applied to each field is tracked, such that the sum of phosphorus applied across all manure products does not exceed the recommended phosphorus rate for that field.

The result of the re-allocation algorithm is field-specific annual application rates of each manure product for each year in the model simulation. Already incorporated into Farm-PREP, are built-in operations schedules and assumptions that determine appropriate timing and method of applying manure applications in association with user selected crop rotations and tillage options (Stone Environmental, 2018). The user's original selection of crop rotation and associated practices similarly dictate the application dates of each manure products, such that if the original manure was to be applied on May 3 (spring application) and October 12 (fall application), in the corresponding manure technology simulation, all three products would be applied consecutively on the same dates. Application methods were selected based on guidance from Newtrient and are shown in Table 3.

Table 3. Manure Product Information and Application Priority.

Manure Technology	Product	Equipment Used to Apply Product	Application Type/Method	Depth (cm) at Which Applied (0 for Surface)	Application Priority (Where 1 is Highest Priority)
Evaporation System[1]	Coarse Fiber	Slinger spreader	Surface	0	3
	Dry Solids	Floater spinner	Surface	0	2
	Aqua Ammonia	Injection	Injection	19-24	1
	[2]Clean Water	Irrigation	Surface	0	N/A
DAF	Coarse Fiber	Slinger spreader	Surface	0	3
	Wet DAF Solids	Slinger or Floater Spinner	Surface	0	2
	DAF Effluent ("Tea Water")	Irrigation, dragline inject	Surface or inject	0 -5	1
Centrifuge without Chemicals	Coarse Fiber	Slinger spreader	Surface	0	3
	Wet Solids	Slinger or Floater Spinner	Surface	0	2
	Centrate	Irrigation, dragline inject	Surface or inject	0 -5	1
Centrifuge with Chemicals	Coarse Fiber	Slinger spreader	Surface	0	3
	Wet Solids	Slinger or Floater Spinner1	Surface	0	2
	Centrate	Irrigation, dragline inject2	Surface or inject	0 - 5	1
Ultrafiltration[1]	Coarse Fiber	Slinger spreader	Surface	0	3
	UF Concentrate	Dragline inject or broadcast	Inject or broadcast	0-5	2
	UF Permeate	Irrigation	Surface	0	1

[1]These manure technologies in Farm-PREP are simulated without a dryer component.

[2]The 'clean water' product of the evaporation technology has no phosphorus component and therefore is currently not included in the optimization algorithm in Farm-PREP.

After field level annual application rates are calculated, any unused manure product (farm-available amount of manure product minus the sum of manure product applied on each field) is considered stored on the farm. One of the advantages of implementing manure technologies is the improved storability and transportability of manure products. The user also has the option of modifying field-level manure product annual average application rates after the automated re-allocation of manure products. This alternative is available to ensure that users can specify application rates that are realistic for their fields/farm. For example, if a user knows they will not store any manure products on the farm, they can modify field application rates to simulate the application of all farm manure to the fields each year. If not enough phosphorus was available based on conversion of farm available manure into manure products to meet phosphorus demand on every field, then commercial phosphorus (P) is applied to those fields that did not receive enough manure product to meet crop demand. Similar to manure product application rates, after results of the initial automated allocation is returned, the user can select to adjust commercial P application rates if desired.

2.2. Example

This section will walk through an example of the approach described in Section 2.1. In this example, the user has selected to enter their manure application rates in gal/ac and to use VT default manure characteristic information (Table 1). DAF was selected to be implemented on the farm. Table 4 shows a list of fields included in the assessment and user input related to soil test P and crop rotation (highlighted in gray), as well as plant demand/recommended application rates calculated based on the Nutrient Recommendations for Field Crops in Vermont (2018). Field acreage is also provided, as calculated by Farm-PREP based on field delineations. Table 5 shows the original manure application rates inputs (highlighted gray) and the results of the manure product allocation algorithm as average annual application rates.

These results demonstrate the re-allocation of phosphorus to better reflect agronomic needs. For example, fields with high soil test P (e.g. HP_3) receive no additional phosphorus, while other fields that have lower soil test P would have an increased rate of P2O5 application (e.g. HP_4). This also shows that no fields receive more P than the estimated plant demand, thereby reducing the likelihood of increasing long-term soil P. Because original manure inputs provided more than enough manure to meet crop P demands in this example, no additional commercial P was needed. This example also demonstrates that while all of the liquid and semi-solid product resulting from implementation of DAF was utilized, 431.9 lbs P2O5 was considered stored at the farm level in the form of coarse fiber, which is considered easier to move off site, sell, or store.

Table 4. Field Characteristics for Hypothetical Example Farm.

Field ID	Acreage (acres)	Soil Test P (ppm, Modified Morgans)	Crop 1	Crop 2	Plant Demand/Recommended Application Rate (lbs P2O5/ac)	Plant Demand/Recommended Application Rate (Crop 2, lbs P2O5/ac)
HP_1	97.4	2	Corn (silage)	-	60	-
HP_2	34.9	5	Corn (silage)	Grass hay	20	20
HP_3	27.5	9	Legume hay	-	0	-
HP_4	64.2	4	Grass hay	-	40	-
HP_5	38.6	4	Corn (grain)	Alfalfa mix	40	40
HP_6	70.0	3	Small grains	-	40	-

Table 5. Average Annual Application Rates of Original Manure and Manure Products on Hypothetical Example Farm.

Field ID	Original Manure (Crop1/Crop2, gal/ac)	Original Manure (Crop1/Crop2, lbs P2O5/ac)	Manure Technology Products (lbs P2O5/ac)			Commercial P (lbs/ac)
			Liquid Product	Coarse Fiber	Semi-Solid	
HP_1	7,500	60	0	9.82	50.18	0
HP_2	5,000/2,500	40/20	0	0	20	0
HP_3	2,500	20	0	0	0	0
HP_4	0	0	23.37	0	16.63	0
HP_5	7,000/0	60/0	0	0	40	0
HP_6	10,000	80	0	0	40	0
Total (lbs)	-	-	1,499	956	10,995	0.0
Farm Available (lbs)	-	-	1,499	1388	10,996	-

3. Integration of Precision Feeding Practices into Farm-PREP

The goal of this task was to incorporate precision feeding practices into the Farm-PREP workflow and APEX simulations in addition to the manure processing technologies addressed in Task 1. Precision feeding is a farm-level practice that affects the farm-level phosphorus mass balance, and ultimately, the amount of phosphorus added in manure to farm fields. It was expected that incorporating this practice into the farm-level optimization would reduce P losses, with little or no costs to the farm.

3.1. Technical Description

Precision feeding was simulated in APEX by modifying the manure nutrient characteristics. Users are asked to select whether precision feeding is implemented at the farm scale as well as specify their manure phosphorus content reduction (as a percent reduction). Users can enter a percent reduction of up to 50%. This percent reduction is then used to directly scale the amount of phosphorus contained in the farm manure (either based on the standard manure characteristics shown in Table 1 or based on user entered manure characteristics). APEX then simulates less phosphorus being applied to fields in association with specified manure applications. Figure 5 shows the user entry form for precision feeding.

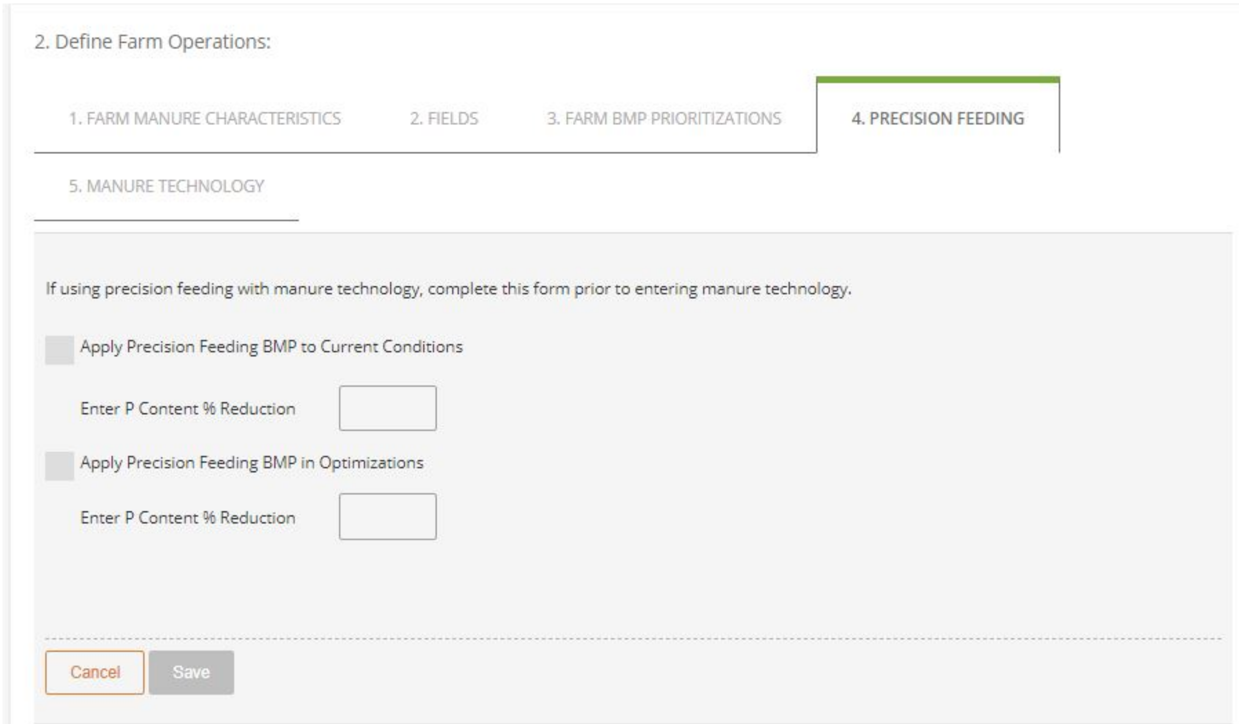


Figure 5. Farm-PREP Precision Feeding User Entry Form.

3.2. Example

Assuming a user selects precision feeding and enters a P content reduction of 10%, the lbs P2O5/1000 gal of their farm manure is reduced by 10%. For example, using the VT default manure shown in Table 1, the APEX inputs would be modified such that instead of 8 lbs P2O5/ac, the manure would contain 7.2 lbs P2O5/1000 gal.

4. Uncertainty/Variability in Model Simulation Results

The goal of this task was to provide additional information to the user that would characterize the variability in annual average APEX results that are reported. The focus is on variability due primarily to weather conditions. Other efforts have evaluated uncertainty related to soils parameters (Stone Environmental, 2020), and while there is known uncertainty in model input parameters, it was determined that presenting to a user the range in annual results would be most useful for supporting farm management decision making.

4.1. Technical Description

Currently in Farm-PREP, an assessment consists of a 15-year APEX simulation for each field and reported results (particularly with respect to phosphorus losses) are annual average values. This captures a range of conditions that occur in the weather inputs and effect model processes such as runoff generation and soil leaching, leading to variability in phosphorus loss predictions. To characterize the variability in annual results, reporting was added to the Farm-PREP that shows the range in annual model outputs both at the field and farm scale.

Current reporting largely focuses on phosphorus losses and includes total, soluble, and sediment phosphorus loss rates (lbs/ac), as well as surface flow (in), and tile flow (in). For each of these variables, the minimum, maximum, as well as 25th and 75th percentile values are now reported in addition to the average annual value. These are calculated based on the annual output for each year in an APEX simulation (totaling 15 years). For reporting at the farm scale, the area weighted field results are averaged together first for each year, then the minimum, maximum, average, and percentiles are calculated.

4.2. Example

An example of these calculations is provided in the following table for an example farm/assessment comprised of 2 fields (for simplicity). Annual results for the variables listed in Section 4.1 are shown in Table 6. The statistics presented in Farm-PREP are calculated for each field based on these annual results for each field (e.g. the minimum total P for HP_5 is the minimum of the first 15 values (associated with field HP_5) shown in the Total P column of Table 6. Statistics are shown for example fields HP_4 and HP_5 in Table 6 (where characteristics of these fields are shown in Table 4). The 'farm' variability results are then determined based on the area-weighted field average results for all fields included in an assessment. In this example, annual results for fields HP_5 and HP_4 are area-weighted to determine a farm-scale value for each year. Statistics are then calculated (Table 7).

Table 6. Annual Results for Two Example Fields.

Field ID	Year of Simulation	Precipitation (in)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	P Stress (days)	Surface Flow (in)	Tile Flow (in)
HP_4	1	30.1	0.27	0.04	0.23	0.00	0	4.6	0.0
	2	48.6	0.19	0.09	0.10	0.00	0	7.8	0.0
	3	43.6	0.17	0.07	0.10	0.00	0	4.9	0.0
	4	41.4	0.13	0.08	0.05	0.00	0	5.2	0.0
	5	42.9	0.24	0.13	0.11	0.00	0	7.1	0.0
	6	47.7	0.31	0.17	0.14	0.00	0	7.4	0.0
	7	45.1	0.28	0.16	0.12	0.00	0	6.4	0.0
	8	37.0	0.19	0.11	0.08	0.00	0	5.2	0.0
	9	38.4	0.22	0.13	0.09	0.00	0	4.8	0.0
	10	43.7	0.39	0.20	0.20	0.00	0	6.5	0.0
	11	50.3	0.81	0.24	0.57	0.00	0	7.6	0.0
	12	37.8	0.29	0.16	0.12	0.00	0	4.7	0.0
	13	41.1	0.23	0.15	0.08	0.00	0	4.1	0.0
	14	34.8	0.14	0.09	0.05	0.00	0	2.9	0.0
	15	43.4	0.30	0.19	0.12	0.00	0	5.4	0.0
HP_5	1	30.1	0.54	0.04	0.50	0.00	0	7.5	0.0
	2	48.6	0.90	0.16	0.74	0.00	0	11.0	0.0
	3	43.6	0.40	0.12	0.28	0.00	0	7.1	0.0
	4	41.4	0.45	0.18	0.27	0.00	0	9.0	0.0
	5	42.9	0.29	0.16	0.12	0.00	0	9.7	0.0
	6	47.7	0.12	0.11	0.01	0.00	0	9.1	0.0

7	45.1	0.04	0.03	0.01	0.00	0	7.0	0.0
8	37.0	0.01	0.01	0.00	0.00	0	5.5	0.0
9	38.4	0.02	0.01	0.01	0.00	0	5.4	0.0
10	43.7	0.42	0.01	0.41	0.00	0	9.3	0.0
11	50.3	1.13	0.04	1.09	0.00	0	11.1	0.0
12	37.8	0.47	0.06	0.41	0.00	0	6.9	0.0
13	41.1	0.79	0.09	0.70	0.00	0	7.0	0.0
14	34.8	0.08	0.04	0.04	0.00	0	4.6	0.0
15	43.4	0.03	0.02	0.01	0.00	0	6.6	0.0

Table 7. Field Variability Results for Two Example Fields.

Field ID	Statistic	Precipitation (in)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	P Stress (days)	Surface Flow (in)	Tile Flow (in)
HP_4	Minimum	30.1	0.13	0.04	0.05	0.00	0	2.9	0.0
	25th Percentile	38.1	0.19	0.09	0.08	0.00	0	4.7	0.0
	Average	41.7	0.28	0.13	0.14	0.00	0	5.6	0.0
	75th Percentile	44.4	0.29	0.17	0.13	0.00	0	6.8	0.0
	Maximum	50.3	0.81	0.24	0.57	0.00	0	7.8	0.0
HP_5	Minimum	30.1	0.01	0.01	0.00	0.00	0	4.6	0.0
	25th Percentile	38.1	0.06	0.02	0.01	0.00	0	6.8	0.0
	Average	41.7	0.38	0.07	0.31	0.00	0	7.8	0.0
	75th Percentile	44.4	0.51	0.12	0.46	0.00	0	9.2	0.0
	Maximum	50.3	1.13	0.18	1.09	0.00	0	11.1	0.0

Note that statistics for soluble, sediment, and total P were calculated independently and therefore the sum of soluble and sediment P may not equal total P in this table.

Table 8. Farm Variability Results, Based on the Area-Weighted Average of Two Example Fields in Farm/Assessment.

Statistic	Precipitation (in)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	P Stress (days)	Sediment/ Erosion (tons/ac)	Surface Flow (in)	Tile Flow (in)
Minimum	30.1	0.12	0.04	0.05	0.00	0	0.02	3.5	0.0
25th Percentile	38.1	0.19	0.09	0.08	0.00	0	0.04	5.4	0.0
Average	41.7	0.32	0.11	0.20	0.00	0	0.09	6.4	0.0
75th Percentile	44.4	0.39	0.13	0.29	0.00	0	0.10	7.8	0.0
Maximum	50.3	0.93	0.17	0.77	0.00	0	0.32	9.0	0.0

5. Interface Walk-through and Instructions

The following sections of this report provide an interface walk-through of a hypothetical example farm comprised of 6 fields. This demonstrates some of the options available to the user and demonstrates the suggested workflow as it relates to manure technology, precision feeding, and the variability reporting. Details on aspects of Farm-PREP that have already been developed are documented in other reports (Stone Environmental; 2018, 2020a).

5.1. Farm-PREP Data Entry for Manure Allocation and Precision Feeding

In Farm-PREP, a user creates a farm and sets up their fields by delineating or uploading field boundaries. Within a farm, multiple assessments can be created. To set up an assessment, the user first selects which fields will be included. The user then selects an assessment option, either to run a current practices assessment and/or an optimization assessment (Figure 6). Then the user defines farm operations through 5 tabs (described below).

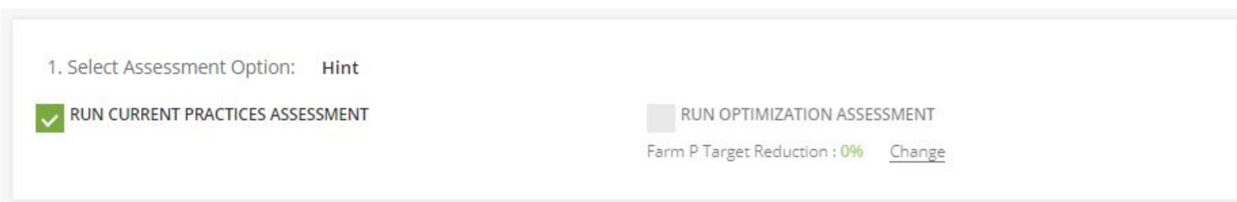


Figure 6. Selection of Assessment Options in Farm-PREP.

Tab 1: Farm Manure Characteristics

Through the Farm Manure Characteristics tab in Farm-PREP, the user provides information about farm-scale manure applications and how the user wants to provide information to the tool. This information applies to all assessments, not just those in which a manure technology is selected for implementation. The information collected includes whether a user will enter manure application rates in lbs P2O5/ac or in gal/ac, as well as either the selection to use VT default liquid manure characteristics (as shown in Figure 7 and Table 1) or to provide farm-specific manure nutrient characteristics from a manure storage structure test. In this example, manure applications at the field level will be input in gallons per acre of manure and VT default liquid dairy manure characteristics will be used.

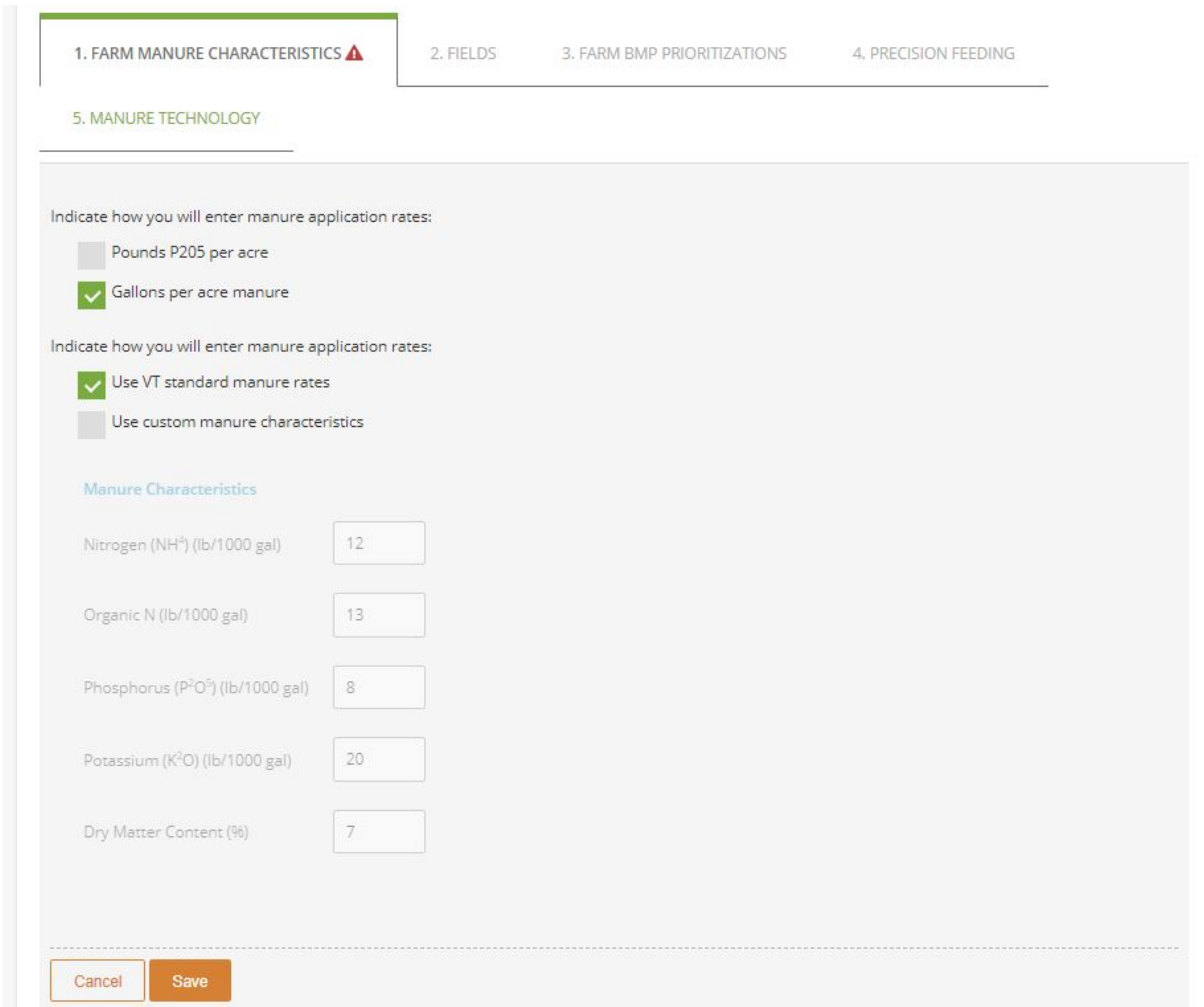


Figure 7. Farm-PREP User Interface, Define Farm Operations, Tab 1: Manure Characteristics.

Tab 2: Fields

The 'Fields' tab provides the user options to describe crop rotations, tillage practices, as well as manure and fertilizer applications (in units selected on the Manure Characteristics tab). Aside from the added ability to select the manure application units for data entry, this section was not modified for this work. Inputs in this section are independent of manure technology and precision feeding (a screen shot of this tab is shown in Figure 8). More information on these inputs can be found in Farm-PREP reports (Stone Environmental, 2018; 2020). For this example, 6 fields were included, each with different crop rotations, manure, and tillage options (Table 4).

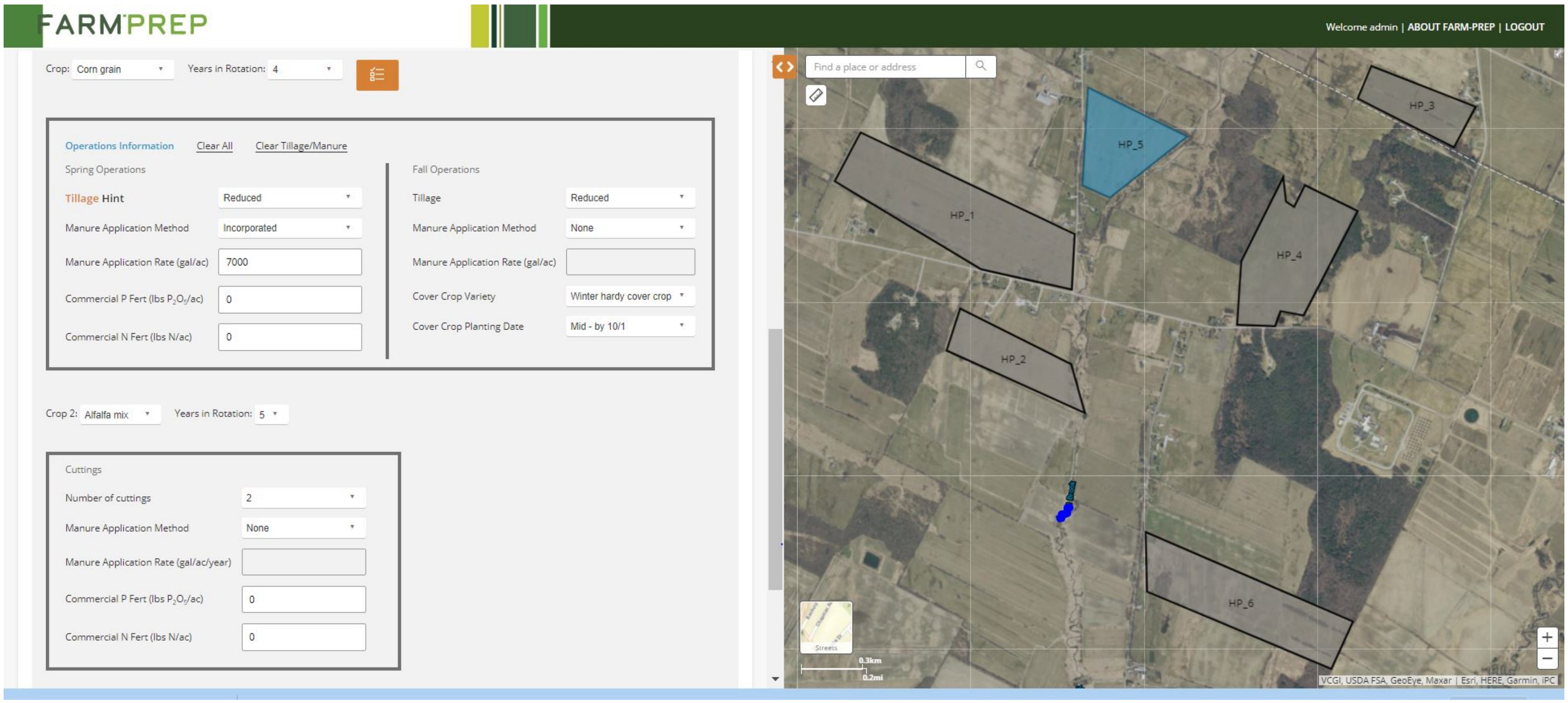


Figure 8. Farm-PREP User Interface, Define Farm Operations, Tab 2: Fields.

Step 3: Farm BMP Prioritizations

This section was also not modified in this work and more information is provided in Farm-PREP reports (Stone Environmental, 2018; 2020).

Step 4: Precision Feeding

The user must select precision feeding prior to manure technology (Tab 5) if the two options are to be used together. The 'Precision Feeding' tab allows users to apply precision feeding to the Current or Optimization scenarios and specify the reduction in P content of the manure due to precision feeding (Figure 9).

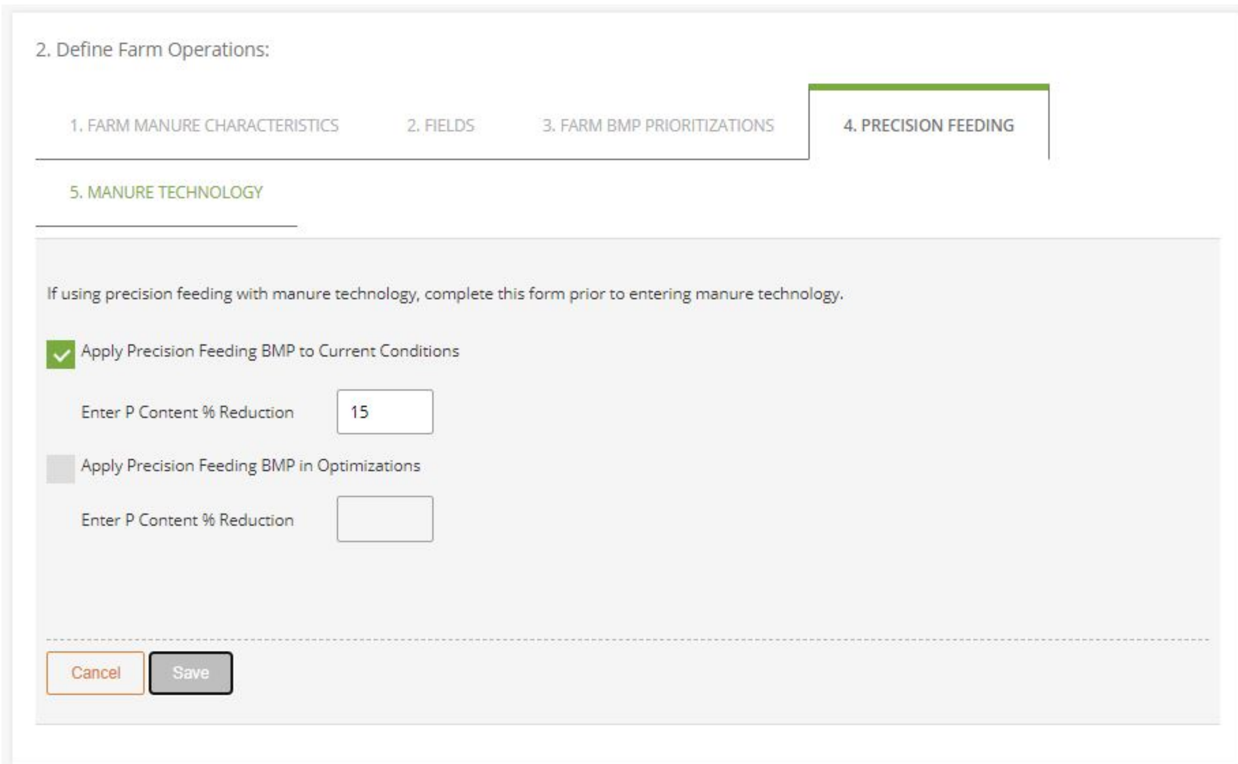


Figure 9. Farm-PREP User Interface, Define Farm Operation, Tab 4: Precision Feeding.

Step 5: Manure Technology

The Manure Technology tab is where the user can select to implement a manure technology to implement on the farm (Figure 10). One of five technologies can be selected (Evaporation, DAF, Centrifuge without Chemicals, Centrifuge with Chemicals, or Ultrafiltration). Only one technology can be implemented in a single assessment. If a manure technology is selected, the user must also identify the manure source location by navigating to and clicking on a point location on the Farm-PREP web map (yellow circle on Figure 10). The distance from the center of each field to the manure source location is used in re-allocating manure products (Section 2.1.2).

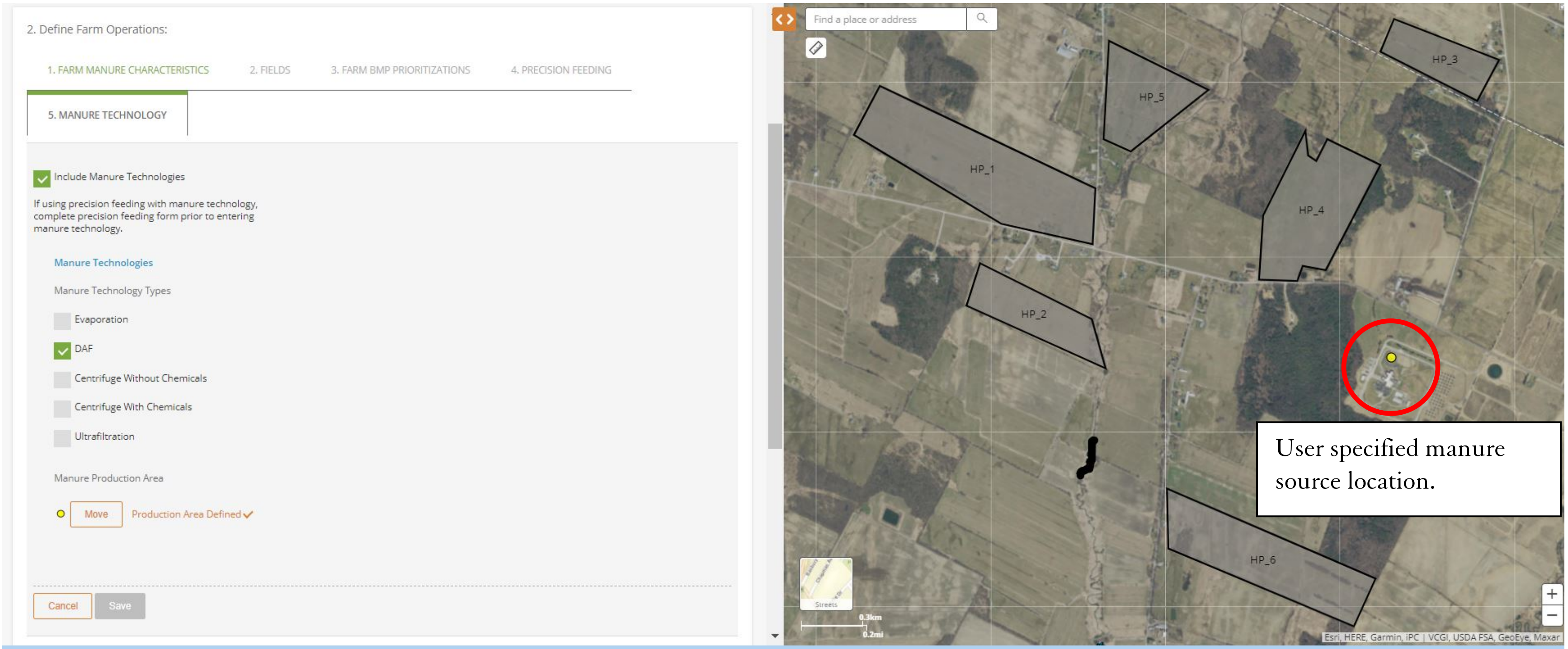
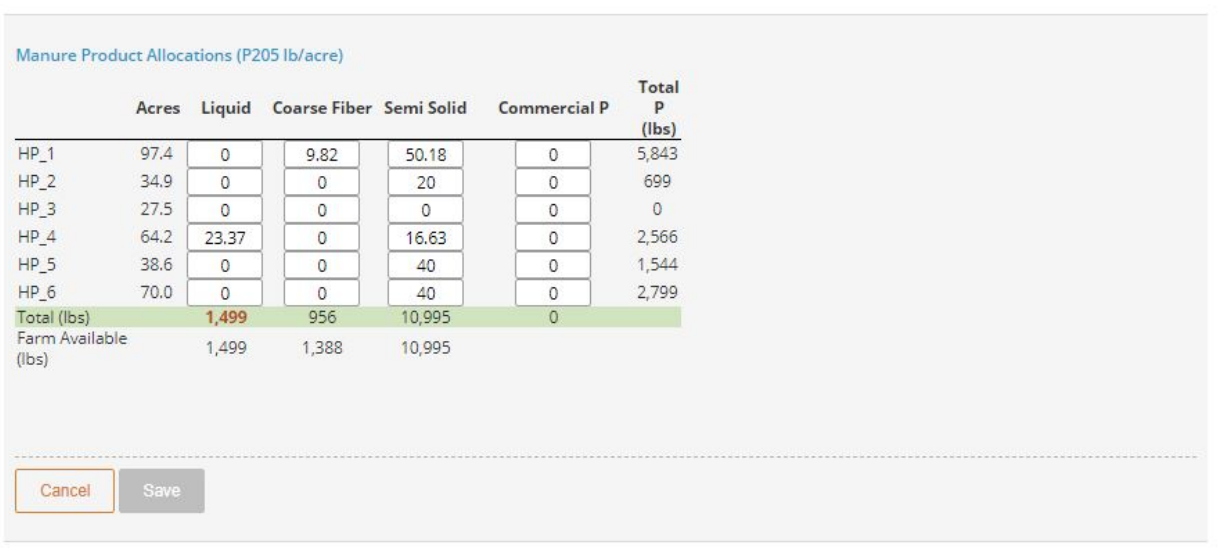


Figure 10. Farm-PREP User Interface, Define Farm Operations, Tab 5: Manure Technology.

Once the user saves the information related to manure technology, Farm-PREP calculates how much manure is applied across all fields in an assessment, converts this manure into manure products, and reallocates the manure products to fields based on crop rotation and recommended nutrient application rates, product characteristics, and distance of the field from the manure source (see Sections 2.1.1 and 2.1.2). A new table appears that provides field level information on the annual average application rate of each manure product on each field. It also provides information on the amount of each product available, the total amount of P applied across fields for each product, and the sum of products applied to each field. An example of the manure allocation output table is shown in Figure 11. The difference between the 'Farm Available (lbs)' and the 'Total (lbs)' along the bottom of the table represents the amount of each manure product that is considered stored at the farm-scale (available for sale or transport off-site).



Manure Product Allocations (P205 lb/acre)

	Acres	Liquid	Coarse Fiber	Semi Solid	Commercial P	Total P (lbs)
HP_1	97.4	0	9.82	50.18	0	5,843
HP_2	34.9	0	0	20	0	699
HP_3	27.5	0	0	0	0	0
HP_4	64.2	23.37	0	16.63	0	2,566
HP_5	38.6	0	0	40	0	1,544
HP_6	70.0	0	0	40	0	2,799
Total (lbs)		1,499	956	10,995	0	
Farm Available (lbs)		1,499	1,388	10,995		

Figure 11. Farm-PREP User Interface, Manure Allocation Results.

The user can opt at this point to modify the annual average application rates of products to fields (cells that appear white in Figure 11) and resave the nutrient allocations. This option provides flexibility to customize Farm-PREP simulation input assumptions and ensure they are consistent with acceptable agronomic practices for the farm. If for example, a farm knew they would not store any manure products, application rates could be modified to equal (not exceed) the farm available of each product.

5.2. Reporting

Once the user has entered information described above, the 'Run Assessment' button is enabled. The user runs the assessment and once complete, results can be reviewed in the reporting tabs. There are two reporting tabs: the 'Initial Results Table' and 'Variability.' The 'Initial Results Table' shows farm-scale results for each of the assessments executed (Figure 12). The user can then select to view field level results in each of the assessments (Figure 13).

Initial Results Table | Variability | Results Guide | Download CSVs | Return home

Farm Practices Scenario	Total P Reduction from Baseline (%)	Total P Reduction from Current (%)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	Total P (lbs/yr)	Manure P Applied (lbs P205/yr)	Manure P Stored (lbs P205/yr)	Commercial P Applied (lbs P205/yr)	Compare
Baseline:			1.22	0.39	0.83	0	404	13882			☑
Current:	2		1.19	0.38	0.81	0	397	13882			☐
Current_Manuretech:	14	12	1.05	0.18	0.86	0	348	13450	432	0	☐

Figure 12. Farm-PREP Reporting, Initial Results Table, Farm-Scale Assessment Results.

Initial Results Table | Variability | Results Guide | Download CSVs | Return home

Farm Practices Scenario	Total P Reduction from Baseline (%)	Total P Reduction from Current (%)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	Total P (lbs/yr)	Manure P Applied (lbs P205/yr)	Manure P Stored (lbs P205/yr)	Commercial P Applied (lbs P205/yr)	Compare
Baseline:			1.22	0.39	0.83	0	404	13882			☑
Current:	2		1.19	0.38	0.81	0	397	13882			☐
Current_Manuretech:	14	12	1.05	0.18	0.86	0	348	13450	432	0	☐

Field	Total P Reduction from Baseline (%)	Total P Reduction from Current (%)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	Total P (lbs/yr)	Manure P Applied (lbs P205/yr)	Commercial P (lbs P2O5/yr)
HP_1	2	2	2.36	0.29	2.06	0	230	5843	0
HP_2	-2	0	0.65	0.09	0.56	0	23	699	0
HP_3	26	26	0.17	0.06	0.1	0	5	0	0
HP_4	54	54	0.13	0.06	0.07	0	8	2566	0
HP_5	40	21	0.3	0.06	0.24	0	12	1544	0

Figure 13. Farm-PREP Reporting, Initial Results Table, Field-Level Assessment Results.

5.2.1. Added Reporting in Initial Results Table

To provide additional information to the user with respect to the advantages of implementing manure technologies, additional outputs were added to the Farm-PREP 'Initial Results Table' to provide information related to long-term soil phosphorus dynamics and specifics of manure applications. More information related to the amount of phosphorus applied (both field and farm-scale) and the amount stored (farm-scale) were added (Figure 13). New reporting fields include total mass of phosphorus loss (lbs P2O5/yr), manure applied (lbs P2O5/yr), manure stored (lbs P2O5/yr), and commercial P applied (lbs P2O5/yr). In the example shown in Figure 13 (which corresponds to the manure allocation results shown in Figure 11), phosphorus stored at the farm-scale is shown as Manure Stored (lbs P2O5/yr). In the example shown here, implementation of manure technologies resulted in an average reduction of 49 lbs P2O5 per year in comparison to the current practices assessment. This represents a farm reduction of 12%.

One of the advantages of implementing manure technologies is being able to manage phosphorus sources such that farmers can better maintain healthy phosphorus levels in their soils. The percent change in soil phosphorus in the plow layer (top 15 cm) is now reported, as well as the initial soil phosphorus level (based either on the Farm-PREP default value or user entered value). Additionally, crop stress due to phosphorus deficiency (in average days per year) was added to reporting. Crop stress is provided for the single primary growing season crop (if a continuous rotation) or for both major crops in a rotation, stress is not reported for cover crops. These new additions are circled in Figure 14 and shown in Figure 18, where the example shows a 45% increase in soil phosphorus (in the top 15 cm) between the first and last year simulated (where simulations currently consist of 15 years), as a result of operations on this field. It also demonstrates that neither crop in the 2-year corn and 4-year hay rotation experienced significant P stress. P stress is expected to only occur with low soil test P levels on a field and minimal or no manure/fertilizer applications.

▾ HP_2	-2	0	0.65	0.09	0.56	0	23	0	699

Soils

Soil Type	Hydrologic Soil Group	Slope (%)	Slope Length (ft)	Modified Morgans Soil P (ppm)	pH	Al (ppm)	Tile Drainage
Kingsbury	D	1.4	200	5	6.5	50	

Long-term P Dynamics

Initial Soil P (ppm)	% Change in Soil P	Crop P Stress (day of stress)	
5	45.00	Crop 1: 0	Crop 2: 0

Crops/Tillage/Manure

Crop	Tillage	Row Crop Spring Manure Application	Row Crop Spring Manure Rate (lbs P_2O_5/ac)	Row Crop Fall Manure Application	Row Crop Fall Manure Rate (lbs P_2O_5/ac)	Cover Crop	Cover Crop Planting Date	Hay Cuttings per Year	Hay Manure	Hay Manure Rate (lbs P_2O_5/ac-yr)
Corn silage: 2 years	Reduced\Reduced	Incorporated	5000	None	--	None	None	--	--	--
Grass hay: 4 years	--	--	--	--	--	--	--	3	Surface	2500

Structural BMPs

Buffer Width (ft)	Buffer Length (ft)	Grass Waterway Width (ft)	Grass Waterway Length (ft)
--	--	--	--

▸ HP_3	26	26	0.17	0.06	0.1	0	5	0	0

Figure 14. Farm-PREP Reporting, Initial Results Table, Field Details (P Dynamics).

% Change in Soil P	Crop P Stress (day of stress)	
45.00	Crop 1: 0	Crop 2: 0

Figure 15. Farm-PREP Reporting, Initial Results Table, Zoom-in on Added Results for P Dynamics.

5.2.2. Variability

A new reporting tab was added to Farm-PREP to provide the user with results from the variability analysis. Similar to the 'Initial Results Table', farm-scale results are shown for each assessment (Figure 15). For each assessment, the user can then select to view results for each field. Figure 16 shows field level results for a field with a 2-year corn and 4-year hay rotation, while Figure 17 shows field level results for a continuous hay field. Note larger variability in P losses associated with the corn-hay rotation as opposed to the continuous hay.

Initial Results Table | Variability

Results Guide | Download CSVs | Return home

Farm Practices Assessment		Annual Precipitation (in)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	P Stress (days)	Sediment/Erosion (tons/ac)	Surface Flow (in)	Tile Flow (in)
	Minimum	23.8	0.53	0.05	0.38	0.00	0	0.22	3.6	0.0
	25th percentile	30.1	0.73	0.19	0.54	0.00	0	0.31	5.5	0.0
baseline	Average	33.0	0.91	0.23	0.68	0.00	0	0.41	6.5	0.0
	75th percentile	35.0	0.96	0.27	0.71	0.00	0	0.48	7.5	0.0
	Maximum	39.7	1.38	0.34	1.19	0.00	0	0.79	9.1	0.0
	Minimum	23.8	0.51	0.04	0.36	0.00	0	0.19	3.7	0.0
	25th percentile	30.1	0.72	0.18	0.55	0.00	0	0.29	5.4	0.0
current	Average	33.0	0.89	0.22	0.67	0.00	0	0.38	6.4	0.0
	75th percentile	35.0	0.96	0.27	0.72	0.00	0	0.46	7.4	0.0
	Maximum	39.7	1.34	0.33	1.14	0.00	0	0.71	8.8	0.0
	Minimum	23.8	0.47	0.04	0.40	0.00	0	0.19	3.5	0.0
	25th percentile	30.1	0.68	0.10	0.58	0.00	0	0.32	5.4	0.0
current_manuretech	Average	33.0	0.83	0.12	0.71	0.00	0	0.40	6.2	0.0
	75th percentile	35.0	0.95	0.14	0.81	0.00	0	0.50	7.2	0.0
	Maximum	39.7	1.28	0.17	1.15	0.00	0	0.72	8.8	0.0

Figure 16. Farm-PREP Reporting, Variability, Farm-Scale Assessment Results.

Field		Annual Precipitation (in)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	P Stress (days)	Sediment/Erosion (tons/ac)	Surface Flow (in)	Tile Flow (in)
current_manuretech	Minimum	23.8	0.47	0.04	0.40	0.00	0	0.19	3.5	0.0
	25th percentile	30.1	0.68	0.10	0.58	0.00	0	0.32	5.4	0.0
	Average	33.0	0.83	0.12	0.71	0.00	0	0.40	6.2	0.0
	75th percentile	35.0	0.95	0.14	0.81	0.00	0	0.50	7.2	0.0
	Maximum	39.7	1.28	0.17	1.15	0.00	0	0.72	8.8	0.0
HP_1										
HP_2	Minimum	30.1	0.10	0.04	0.05	0.00	0	0.03	4.6	0.0
	25th percentile	38.1	0.25	0.07	0.17	0.00	0	0.12	6.4	0.0
	Average	41.7	0.65	0.09	0.56	0.00	0	0.49	7.4	0.0
	75th percentile	44.4	0.93	0.11	0.86	0.00	0	0.66	8.1	0.0
	Maximum	50.3	1.84	0.12	1.72	0.00	0	1.74	13.0	0.0
HP_3										
HP_4										
HP_5										

Figure 17. Farm-PREP Reporting, Variability, Field Scale (2-yr Corn, 4-yr Hay Field).

Field		Annual Precipitation (in)	Total P (lbs/ac)	Soluble P (lbs/ac)	Sediment P (lbs/ac)	Tile P (lbs/ac)	P Stress (days)	Sediment/Erosion (tons/ac)	Surface Flow (in)	Tile Flow (in)
current_manuretech	Minimum	23.8	0.47	0.04	0.40	0.00	0	0.19	3.5	0.0
	25th percentile	30.1	0.68	0.10	0.58	0.00	0	0.32	5.4	0.0
	Average	33.0	0.83	0.12	0.71	0.00	0	0.40	6.2	0.0
	75th percentile	35.0	0.95	0.14	0.81	0.00	0	0.50	7.2	0.0
	Maximum	39.7	1.28	0.17	1.15	0.00	0	0.72	8.8	0.0
HP_1										
HP_2										
HP_3										
HP_4	Minimum	30.1	0.04	0.03	0.02	0.00	0	0.01	2.8	0.0
	25th percentile	38.1	0.10	0.05	0.04	0.00	0	0.02	4.7	0.0
	Average	41.7	0.13	0.06	0.07	0.00	0	0.04	5.6	0.0
	75th percentile	44.4	0.15	0.08	0.07	0.00	0	0.04	6.7	0.0
	Maximum	50.3	0.27	0.10	0.23	0.00	0	0.09	8.0	0.0
HP_5										

Figure 18. Farm-PREP Reporting, Variability, Field Scale (Continuous Hay).

Conclusions

This report documents enhancements made to Farm-PREP to incorporate representation of manure technologies, precision feeding, and an analysis of variability due to weather. Farm-PREP users can now select to implement one of five manure technologies in their farm assessments. The selection of a manure technology results in a reallocation of phosphorus by aggregating user-provided field application rates, converting manure into manure products, and determining new field application rates of those products to better meet agronomic demand. Manure products can be 'stored' if the total amount of farm-scale phosphorus is determined to exceed demand. This approach can ultimately reduce phosphorus losses at the farm-scale as well as be used to determine the potential for phosphorus to be available for transporting off-site.

Precision feeding is another approach for farms to reduce their phosphorus losses. Representation of this practice in Farm-PREP allows for farms to estimate their potential Phosphorus reduction as a result of this practice. This can be implemented alone or in conjunction with manure technologies.

Additional reporting was added to Farm-PREP to provide the user with information on simulated annual variability. Farm-PREP executes 15-year simulations to account for variability in weather conditions. Annual minimum, maximum, average, as well as 25th and 75th percentile values for several parameters are now provided to the user in a new reporting tab.

These modifications provide users with more flexibility to simulate practices they may be considering or may have implemented on their farms to ultimately reduce nutrient losses. The enhanced reporting brackets model results such that the user has a better understanding on the variability that could occur due to weather alone and can help inform farm management decisions. Overall, these changes improve the capacity of Farm-PREP to evaluate farm specific approaches to quantify P reduction potential based on strategic combinations of field-based practices and innovative manure processing technologies.

References

BREC (Blackland Research and Extension Center). 2020. Agricultural hydrologic and water quality models supported and developed by BREC and USDA. Available at: https://epicapex.tamu.edu/apex/.

Gassman, P. W., J.R. Williams, X. Wang, A. Saleh, E. Osei, L. Hauck, R.C. Izaurralde, and J. Flowers. 2009. The Agricultural Policy/Environmental Extender (Apex) Model: An Emerging Tool for Landscape and Watershed Environmental Analyses. CARD Technical Reports 41.

Steglich, E.M., J. Jeong, and J.R. Williams. 2016. Agricultural Policy/Environmental eXtender Model: User's manual version 1501. Natural Resources Conservation Service, Blackland Research and Extension Center. Temple, TX. 241 pp.

Stone Environmental, Inc. 2018. Final Report: Development of an Approach and Tool to Optimize Farm-Scale Phosphorus Management and Achieve Watershed-Scale Loading Targets. Prepared for the Lake Champlain Basin Program by Stone Environmental, Inc., Montpelier, VT.

Stone Environmental, Inc. 2020a. Final Report: Implementation of a Farm Phosphorus Management Optimization Web-based Tool in the Vermont Portion of the Lake Champlain Basin. Prepared for the Lake Champlain Basin Program by Stone Environmental, Inc., Montpelier, VT.

Stone Environmental, Inc. 2020b. Final Report: Refinement of Critically Needed Assessment Tools for Tile Drainage P Loading in the Lake Champlain Basin. Prepared for the Lake Champlain Basin Program by Stone Environmental, Inc., Montpelier, VT.

University of Vermont Extension. 2018. Nutrient Recommendations for Field Crops in Vermont.

US EPA Region 1 (United States Environmental Protection Agency). 2016. Phosphorus TMDLs for Vermont Segments of Lake Champlain; June 17, 2016. Boston, MA.