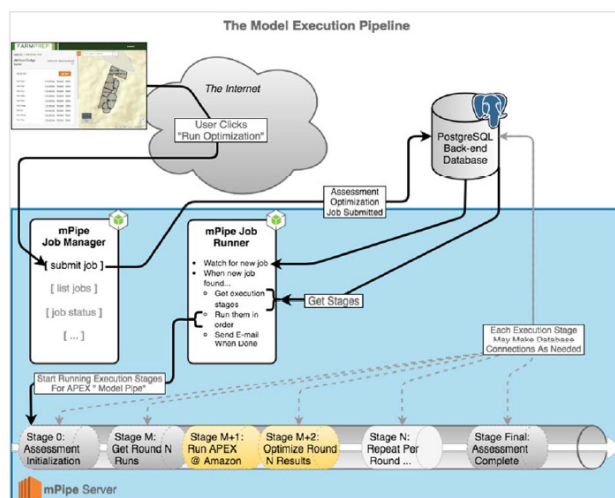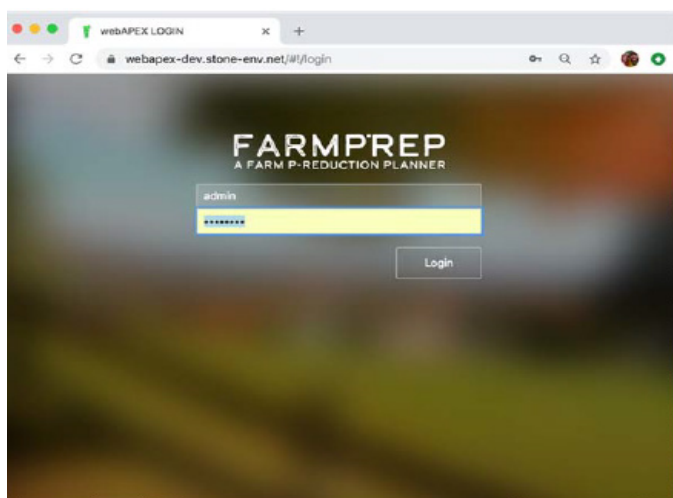# Development of an Approach and Tool to Optimize Farm-Scale Phosphorus Management and Achieve Watershed-Scale Loading Targets

October 2018

Final Report

Prepared by:
Michael Winchell
Stone Environmental

For:
The Lake Champlain Basin Program and
New England Interstate Water Pollution Control Commission

Development of an Approach and Tool to Optimize Farm-Scale Phosphorus Management and Achieve Watershed-Scale Loading Targets: Final Report

STONE ENVIRONMENTAL

NEIWPCC
New England Interstate Water Pollution Control Commission

Lake Champlain Basin Program

Acknowledgements

Title and Approval Page

Document Title

Development of an Approach and Tool to Optimize Farm-Scale Phosphorus Management and Achieve Watershed-Scale Loading Targets: Final Report, 9/26/18

Document Prepared by

Stone Environmental, Inc., 535 Stone Cutters Way, Montpelier, VT 05602

Document Preparer Approvals

Michael Winchell, Vice President & Senior Environmental Modeler, Stone Environmental, Inc.

_____

Signature   Date

Barbara Patterson, Senior Database Applications Developer, Stone Environmental, Inc.

By my signature, I hereby certify that I have reviewed this document.

_____

Signature   Date

Jody Stryker, Environmental Modeler, Stone Environmental, Inc.

By my signature, I hereby certify that I have reviewed this document.

_____

Signature

                                                                                                 Date

Executive Summary

A new web-based tool, the Farm-P Reduction Planner (Farm-PREP), was developed to enable farmers to more effectively and efficiently identify modifications to their field operations in order to meet a target reduction in phosphorus (P) leaving the farm and help to achieve water quality improvement goals at the watershed scale. Development of this tool was motivated by the need to quantify reductions in P loads leaving farms due to the adoption of best management practices (BMPs) and to determine how those reductions compare to targets established based on the Lake Champlain Basin P Total Maximum Daily Load (TMDL). The Farm-PREP tool is based on the US Department of Agriculture, Natural Resource Conservation Service's Agricultural Policy/Environmental eXtender Model (APEX). The APEX model is a physically-based agronomic and water quality model designed for simulations at the field to farm/small watershed scale. The unique aspects of this project include the implementation of APEX through a streamlined, web-based user interface and the incorporation of optimization functionality that automatically identifies field-specific management options that meet water quality targets. The project represents a Phase 1 pilot of the Farm-PREP tool, with initial demonstration in the St. Albans Bay watershed in St. Albans, Vermont.

The project began with an evaluation of potential approaches for establishing farm-level P loss targets that are consistent with the Lake Champlain Basin P TMDL at the watershed (lake segment) level. Considerations were given to three different approaches to establishing P load targets at the farm level: (1) a uniform absolute per acre loading rate to all agricultural land, (2) a uniform percent reduction per acre loading rate to all agricultural land, and (3) a tiered approach to P load reductions based on landscape conditions and crop rotation. This evaluation concluded that option 2, the uniform percent reduction, would be an appropriate approach to use in this pilot demonstration. This approach would expect all farms to make some contributions to improving water quality, result in greater overall load reductions from farms prone to higher baseline P losses, allow for some fields to achieve higher or lower reductions that the farm-level average, and acknowledge the P load reductions already achieved on a farm through current adoption of alternative practices.

The development of the Farm-PREP tool required compilation of datasets required to run APEX model simulations on Vermont farms, including digital topography, soils, and weather time series. Development of APEX field operation schedules was a key component of the model development effort and focused on defining and parameterizing agronomic practices typical of Vermont dairy operations in the St. Albans Bay watershed and across the State of Vermont. The selected field operation schedules and best management practice options were tested in the APEX model to ensure successful execution and that appropriate simulation results were realized. A methodology to efficiently simulate large numbers (thousands) of APEX simulations on the web was created to provide the functionality needed to optimize the field-level operations and achieve farm-level P load targets.

The web-based implementation of the Farm-PREP tool required a thoughtful approach to designing the front-end user interface and subsequent linkages to the back-end databases and APEX model execution processes. The tool design focused on intuitiveness and simplicity for the user in providing the farm information needed to conduct the APEX model simulations and optimization. The approach developed for

execution of APEX simulation on the web was designed to be both efficient and scalable by taking advantage of Amazon Cloud resources on demand. The completed tool was tested on a pilot farm within the St. Albans Bay watershed and valuable feedback was provided by the farm's crop consultant and University of Vermont (UVM) Extension faculty. This feedback will be used to guide the continued development and enhancement of the Farm-PREP tool in upcoming projects with the Lake Champlain Basin Program.

The completion of this pilot project and Version 1.0 of the Farm-PREP tool marks an important milestone in the effort to apply state-of-the-art agronomic models to quantify farm-specific P loads and reductions achieved by adopting alternative management practices. The optimization capability efficiently provides farmers and their consultants with field and farm management tactics that strategically reach a desired improvement in P losses. The Farm-PREP approach and tool will continue to evolve and ultimately lead to better informed farm planning and improved water quality of Lake Champlain.

Development of an Approach and Tool to Optimize Farm-Scale Phosphorus Management and Achieve Watershed-Scale Loading Targets: Final Report

Contents

List of Figures

Table of Tables

1. Project Introduction

In formulating the phosphorus (P) Total Maximum Daily Load (TMDL) for Lake Champlain, the EPA-developed Best Management Practice (BMP) scenario tool was used to simulate the impacts of a set of BMPs implemented on suitable lands (e.g., cover cropping on annual cropland acres; stormwater ponds to treat developed land acres) and determine whether or not these BMPs had the potential to reduce P loads to a degree that would realize in-lake water quality concentration goals (Tetra Tech, Inc., 2015b; USEPA, 2016). This approach, however, does not quantitatively consider the impact that increasing levels of soil test P will have on the ability of BMPs to adequately reduce P loading rates from farms to meet in-lake phosphorus targets. In addition, the approach fails to consider the variability in climate, landscape, and agronomic practices across farms and fields when estimating the benefits associated with BMPs in reducing P losses. For example, the benefits of cover cropping a corn silage field will vary based on soil texture, field slope, rainfall characteristics, and past agronomic practices. As a result, the use of generalized BMP efficiencies to estimate farm- and watershed-scale reductions in P losses may lead to over and/or under representations of the water quality improvement achieved, particularly at the farm-to-sub-watershed-scale. At the farm-level, this could lead to farmers either over-implementing or under-implementing BMPs designed to achieve a target P load reduction. A solution to address these challenges is the implementation of a farm-specific analysis that accounts for the influence of local landscape conditions and practices on water quality outcomes.

A physically-based agricultural hydrologic and water quality model provides the greatest opportunity to evaluate the impacts of agronomic practices on water quality at the farm-scale. The US Department of Agriculture (USDA), in collaboration with the Texas A&M Blackland AgriLife Research and Extension Center (BREC), have led the development of this class of models in the US. These models include the Environmental Policy Integrated Climate (EPIC), Soil and Water Assessment Tool (SWAT), and Agricultural Policy Environmental eXtender (APEX) (BREC, 2018). The APEX model, which is explicitly designed for addressing nutrient fate and transport at the farm-to-small-watershed-scale, has seen extensive application and development over the past 20 years (Williams et al., 1988; Gassman et al., 2009; Ford et al., 2015). The APEX model simulates field-specific land/soil conditions, as well as agronomic management practices, and predicts off-field surface and sub-surface (tile drain) transport of soluble and particulate (sediment bound) P. APEX accounts for the P balance in the soil and the response of crop growth to P deficiency, which allows for a careful examination of necessary P inputs to cropland. When looking at an entire farm, different combinations of agronomic practices can be applied to different fields and P sources to meet an overall P loading reduction target. Accounting for P levels currently in the soil enables more realistic representations of the role of BMPs in reducing the losses of P over time. The APEX model provides the necessary capabilities to better quantify farm-scale P losses and potential benefits from implementation of BMPs.

The APEX model has been available with several different desktop user interfaces for nearly 15 years, including: WinAPEX (Magre et al., 2006; Steglich and Williams, 2008), ArcAPEX (Tuppad et al., 2009), and i_APEX (CARD, 2018; Siemers et al., 2014). More recently, there have been efforts to bring the APEX model to a broader number of interested scientists and stakeholders through web-based user interfaces that further streamline the modeling process. These have included the Nutrient Tracking Tool (NTT), developed by

Tarleton State University (Saleh et al., 2011), and the Systematic Tool for Analyzing Resources (STAR), developed by Stone Environmental and Texas A&M University (Stone Environmental, 2015). However, one of the challenges associated with applying user interfaces to complex agronomic and water quality models like APEX, is providing the capability to appropriately parametrize the model while keeping the level of effort and complexity of the inputs at a manageable level for the intended audience.

This project has focused on the development of an APEX-based tool and user interface for conducting farm-specific analysis to optimize and quantify the benefits of implementing alternative agronomic practices across the farm. The Farm-P Reduction Planner (Farm-PREP) tool has been designed to efficiently capture field-level agronomic practice information that impacts P losses over an entire farm. The tool is unique among existing APEX model interfaces in that it can efficiently execute large numbers of APEX simulations to evaluate different combinations of agronomic practices across a farm and optimize a target reduction in P losses at the farm-scale. This functionality was designed to directly support the needs of farms throughout St. Albans Bay, Vermont and more broadly, the Lake Champlain Basin, by providing the crop consultant and farmer with a suite of management alternatives that both fit their farm operation and achieve P loss reductions consistent with a specified target. The Farm-PREP tool that has resulted from this project effort is a full functioning prototype application that will continue to benefit from further testing and enhancement by a range of stakeholders with shared interest in achieving water quality improvements in the Lake Champlain Basin through optimal use of resources, informed by quantifiable and credible scientific analysis.

This report begins with a discussion of possible approaches, and an example application, for determining a farm-level P reduction target that satisfies the P load allocations determined by the Lake Champlain P TMDL at the lake-segment-level. The example is based on the St. Albans Bay lake segment and uses data directly from the associated TMDL. This evaluation sets the stage for discussion of the development of the Farm-PREP APEX modeling framework, including a description of the compilation of source datasets for the modeling, determination of model inputs and parameters, and strategies employed for using APEX simulations to identify field-level management practices across an entire farm that achieve target reduction in P loss. The development of the Farm-PREP web application is then discussed, providing an overview of the system architecture, the design process, and computational strategies employed. A simple Farm-PREP user guide accompanies the report section on the web application development. The results from a pilot application of the tool to a farm in the St. Albans Bay watershed, including direct feedback from potential users of the tool, complete this report, along with conclusions and recommendations for future use of the Farm-PREP tool. While this report provides the necessary background information and documentation of the data and process for development of the Farm-PREP tool, the tool itself serves as the primary deliverable from this project effort.

2. Tasks Completed

The tasks completed in this project closely followed the approved project workplan. These tasks are described in this section.

2.1. Task 1: Development of Quality Assurance Project Plan

The first task of this project was to develop a secondary data Quality Assurance Project Plan (QAPP). This task was completed, and the plan followed throughout the course of the project. The plan focused on review of existing datasets compiled for use in the Farm-PREP tool, checking of APEX model inputs compiled as part of the Farm-PREP database, and review of APEX simulation results.

2.2. Task 2: Establishment of Loading-Based P Targets

The second task of this project was to establish an approach for identifying water quality-based per-acre P loading rate targets to be applied at the farm-scale. This involved a review of the Lake Champlain TMDL results for St. Albans Bay watershed to understand how projected agricultural P loads from across the watershed varied spatially, and the impacts this might have on establishment of P load reduction targets. Several different approaches for setting a farm-level, per-acre P loss target consistent with the TMDL requirements were investigated, along with example applications of those approaches to the St. Albans Bay watershed, both at the watershed- and farm-scale. The outcome from the completed task included a recommended approach for setting a per-acre P reduction target to be applied at the farm-scale that is consistent with the TMDL requirements and considers BMPs already in place on a farm.

2.3. Task 3: Development of a Farm P Management Optimization Modeling Approach

The third task of this project was to develop a methodology to optimize farm management operations to achieve the per-acre P loading target at the farm-scale. One component of Task 3 was to identify the appropriate farm field practices and BMP alternatives required to simulate typical Vermont dairy operations. The task then focused on how to appropriately parameterize these practices in APEX model simulations. This included compilation of APEX model inputs and testing of the model. The next key component to this task was developing an approach for evaluating APEX model simulations at the farm-scale to optimize operations such that the target P loading rates set for the farm are achieved. This required a design that would allow efficient simulation of large numbers of APEX model simulations to identify farm field management scenarios that would meet water quality objectives. This completed task resulted in the modeling foundation that is implemented in the Farm-PREP web user interface.

2.4. Task 4: Integration of the Farm Optimization Model into a Web-Based Tool

The fourth task of this project was to develop of a web-based tool for conducting the farm-level P-load reduction optimization. This task involved a user interface design component that brought in feedback from

stakeholders and potential users of the tool. This included the establishment of logical workflow and user input options that users would be familiar with. The task also involved the establishment of a back-end database to store information necessary for running APEX simulations and interfacing with the web-based front-end. In addition, the logic and methods for managing and executing APEX simulations and the optimization of farm field operations was applied within a web application environment in this task. The final focus of Task 4 was the design and implementation of providing farm simulation results aimed at guiding the selection of field management practices to meet farm-level water quality goals. The completion of this task resulted in the web-based Farm-PREP tool, which has been evaluated for a pilot farm within the St. Albans Bay watershed and will be further developed in upcoming project efforts.

2.5. Task 5: Compilation of Final Report

The fifth and final task of this project was the compilation of a final report. This report documents the methodology followed in executing the primary tasks of this project. The report also includes a User Guide for the Farm-PREP application.

3. Methodology

3.1. Establishment of P Loading-Based Water Quality Target

The first objective of this project was to evaluate approaches for determining per-acre P loading targets for agricultural lands in the St. Albans Bay watershed that are required to meet water quality standards for Lake Champlain. An absolute P loading rate target for all agricultural land in the St. Albans Bay watershed can be calculated based on the TMDL total P allocation and the acreage of agricultural land within the watershed. The question then arises, as to whether loading rate targets should be uniform across all agricultural land, or whether targets should vary by crop rotation, soil type, land slope, or even existing soil P levels. Alternatively, should the target loading rate be calculated relative to "current" estimated loading rates and be applied as a constant percentage reduction to all agricultural land, and should land owners/farmers be given "credit" for practices already implemented on their farms?

As has been shown in previous work in the Lake Champlain Basin (Stone Environmental, 2011), targeting the implementation of BMPs to portions of a watershed with the highest loading rates (critical source areas) is significantly more efficient than random or uniform implementation of practices. While this advocates against a strategy requiring load reductions on all agricultural land, there will be some situations where watershed-scale load reductions targets are so high that mitigation on all agricultural lands may be necessary. In addition, a uniform "percent reduction" approach applied to all agricultural land would not provide credit to farmers who have already adopted more desirable nutrient management and cropping practices (from a P reduction perspective) on portions of their land. Setting crop-specific target loading rates may also have unintended consequences. For example, allowing higher loading rates for certain cropping systems (e.g., continuous corn) may encourage more farmers to reduce hay production, which would throw off the balance that prescribed P reductions are intended to achieve.

Completion of this task required review of existing data related to TMDL determination, identification of potential approaches to setting a per acre P loading target, and spatial analysis aimed at assessing a small set of feasible approaches. A primary focus of the first Project Advisory Committee (PAC) meeting was to obtain feedback from PAC members on the small set of approaches. This work lead to determination of a method for calculating a per acre P loading target for non-point agricultural areas in the St Albans Bay watershed that was then built into the Farm-PREP tool.

3.1.1. Review of Existing Data

In 2016, the EPA reassessed and redefined P TMDLs for each lake segment in the Vermont portion of Lake Champlain (U.S. EPA Region 1, 2016) in order to meet criteria specified in Section 3-04 of the Vermont Water Quality Standards (Vermont Agency of Natural Resources, 2014). TMDLs are calculated as the sum of waste load allocations for individual point sources and load allocations for non-point sources, as well as a margin of safety. Using long-term monitoring data and SWAT modeling analyses, source-specific load allocations were determined for each lake segment (Tetra Tech Inc., 2015a; Tetra Tech Inc, 2015b). The undeveloped land, non-point source P allocations were separated into forest, stream, and agricultural sources. In addition, annual average P base loads for the 2001-2010 period were estimated for each segment and similarly separated into wastewater, developed, forest, stream, and agriculture. This analysis provided the

baseline for assigning a required percent reduction from the current estimated loads. For the St. Albans Bay lake segment, the non-point source allocation for agriculture was set at 5.52 metric tons annually, which would require a 34.5% reduction from 2001-2010 base loads.

In addition to the TMDL documents, SWAT model data (inputs and outputs) were also reviewed. The original SWAT models developed for determining the TDMLs included relatively large watersheds within the Lake Champlain Basin, such as the Missisquoi and Winooski watersheds (Tetra Tech Inc., 2015a). The area

comprising the St. Albans Bay watershed was split between three SWAT models: the Missisquoi SWAT model, the Lamoille SWAT model, and the Direct Drainage model that included areas along the lake edge (specifically along St. Albans Bay) that drain directly to Lake Champlain (Figure 3-1). As part of the initial data review, the subbasins within each of these SWAT models that are part of the St. Albans Bay watershed were extracted and recombined to represent just the St. Albans Bay watershed. Original spatial datasets representing land use, soil, and slope were used to recreate the hydrologic soil units (HRUs) using the same distinctions as in the original models (Tetra Tech Inc., 2015a). All HRUs present in the original SWAT models (in the St. Albans Bay watershed area) were accounted for in the recombined model. Based on this recombined St. Albans Bay watershed data, the area of non-point source agricultural land (including land classified as corn-hay, corn, hay, and pasture) was 12,905 acres, where the Tetra Tech Inc. (2015a) reported 12,891 acres based on the original SWAT models. This was considered a close enough match to assume the recombined model was sufficiently accurate to use those areas for further assessment of potential approaches to setting a per-acre P loading target.
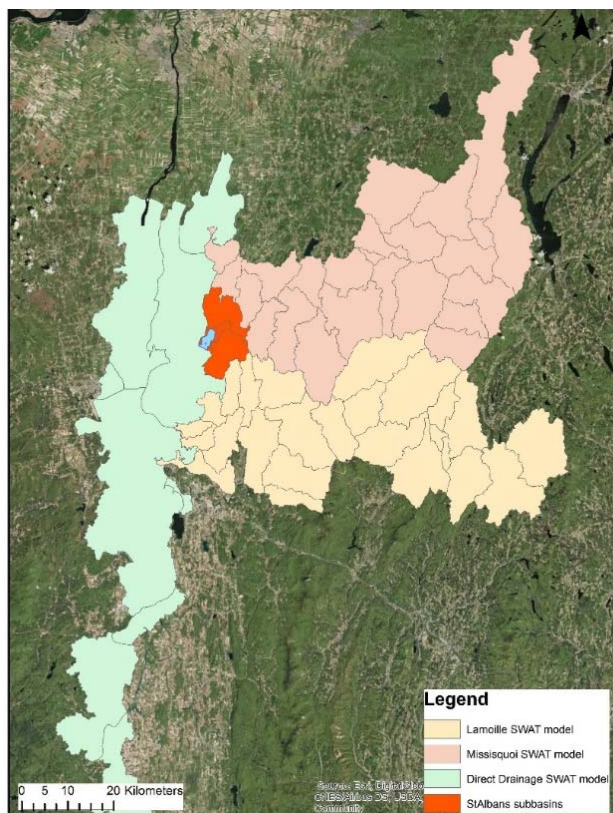
Figure 3-1. Original and recombined SWAT model extents, including subbasin delineations.

One of the reported results of the original SWAT modeling conducted for the TMDL determination, were P base load estimates associated with the model HRUs. These base load estimates were reassigned to the recombined HRUs and used to calculate proposed P loading targets in conjunction with the area on non-point agricultural land in the St. Albans Bay watershed. Table 3-1 shows the range of total P loads assigned to HRUs assigned as non-point agricultural land use category in the St. Albans Bay watershed. The category with the highest average and maximum annual load was corn with clay soils, where the maximum for any HRU in this category was 27.08 lbs/acre and the average was 8.31 lbs/acre.

Table 3-1. Baseline load ranges for non-point agricultural lands in the St. Albans Bay watershed.

Crop/Land use category	Total area (acres)	Minimum load (lbs/acre)	Average load (lbs/acre)	Maximum load (lbs/acre)
Corn-Hay (clay soils)	1976	0.49	2.49	6.47

Corn-Hay (non-clay soils)	4158	0.25	0.86	1.91
Corn (clay soils)	1536	1.61	8.31	27.08
Corn (non-clay soils)	838	0.21	1.34	5.30
Hay	2989	0.18	0.42	0.96
Pasture	1408	0.16	1.69	4.73

Figure 3-2 shows baseline loads assigned to recombined HRU's in the St. Albans Bay watershed. Although the HRUs do not cover the full spatial extent of agricultural land in the St. Albans Bay watershed when mapped (due to model design), the areas attributed to the HRUs represent the full extent of existing agricultural land areas, and all areas are represented in the model calculations. Because SWAT estimates of loading rates did not explicitly account for existing BMPs, those BMPs would not be considered as contributing to the P reduction required by the TMDL.
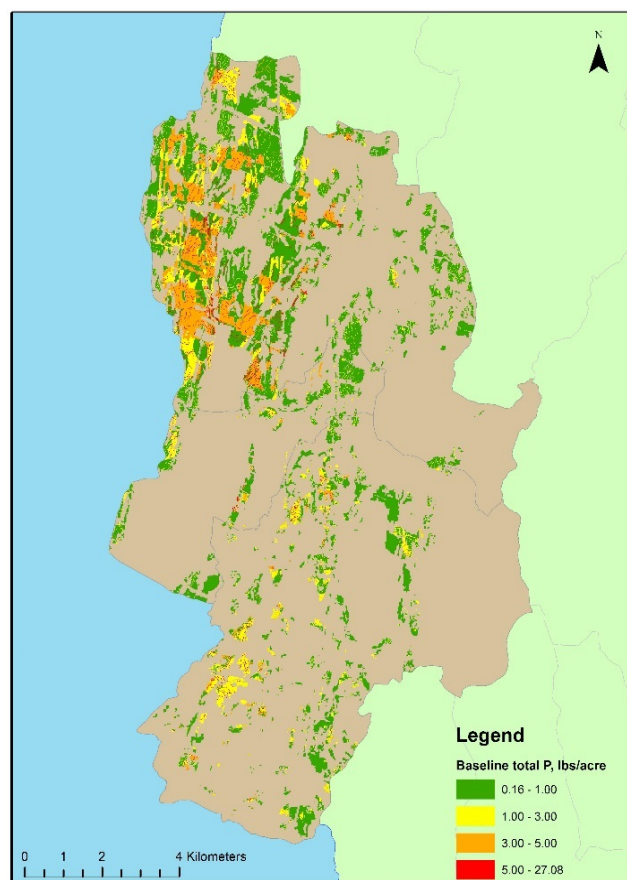
Figure 3-2. Baseline loads assigned to non-point agricultural lands in the St. Albans Bay watershed.

3.1.2. Target P Reduction Approaches Considered

The approach adopted for determining per acre P loading targets in this pilot study will be used in the context of testing the application of this APEX-based farm P optimization tool (FARM-PREP). The approach should be reasonable and feasible, and is not necessarily the final approach to be adopted at a larger scale or for regulatory/compliance purposes. Several general approaches were considered, including an evenly distributed total P load rate target that is the same for all non-point agricultural land, a uniform percent reduction across all agricultural land, as well as focused or tiered reductions based on land vulnerability or other landscape metrics. In the case of all approaches, the per-acre loading target is to be applied to the entire farm's acreage for evaluation (so that a farm could potentially allow some acreage to exceed its per-acre target but other acreage could be significantly under its per-acre target, such that a farm as a whole is meeting its overall target P load reduction).

3.1.2.1. *Uniformly Applied Absolute Load Target*

The simplest approach would be to apply a uniform, absolute P loading target to all non-point agricultural land in the St. Albans Bay watershed. Based on the TMDL load allocation of 5.52 metric tons and the total area of agricultural land in the watershed (12,905 acres), this would imply a 0.94 lbs/acre P loading target for all types of agricultural land. Although this approach treats all types of agricultural land the same, this would likely be a larger effort for some land owners/farmers than others. Farms with higher baseline P loads would need to reduce more where farms with lower baseline loads would be required to reduce less or potentially would not be required to reduce P loads at all. Figure 3-3 shows the required reductions in the St. Albans Bay watershed, both in terms of the reduction in lbs/acre (panel a) and as a percent of the original model-simulated baseline loads (panel b).
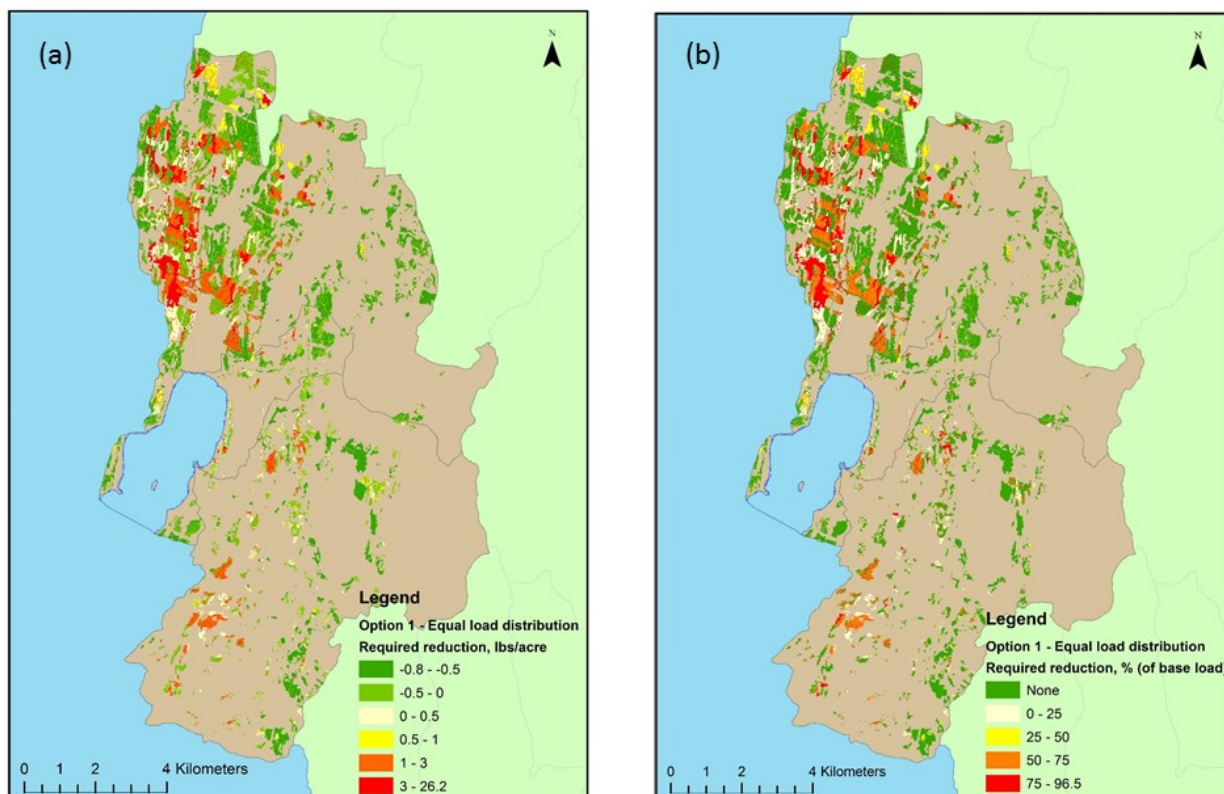
Figure 3-3. Required P reductions from agricultural land in the St. Albans Bay watershed assuming a uniform P loading target of 0.94 lbs/acre annually.

Negative numbers in panel a show that based on SWAT model results, those areas already produce less that the absolute target load of 0.94 lbs/acre annually and therefore either do not need to reduce further or could potentially be assigned a credit for those areas. Note that in and following figures, the colored areas in these maps are the SWAT model HRUS representing agricultural land only (including areas classified as corn/hay, corn, hay, and pasture).

3.1.2.2. Uniformly Applied Percent Load Reduction

The second approach considered was to apply the TMDL percent reduction (34.5%) to all non-point agricultural land in the St. Albans Bay watershed. This approach could more evenly distribute the effort required to meet the larger watershed/lake segment goal of 5.52 MT per year. This would require all land owners/farmers to lower P losses to some degree. However, this approach would also likely require additional reductions for land owners/farmers who have already made efforts to mitigate P losses. Acknowledging (and perhaps giving credit to) practices already implemented on a farm would require establishment of an APEX baseline condition representative of conventional farming practices without adoption of BMPs. In the context of the Farm-PREP tool, this would require consideration of both a "baseline" and "current" scenario. This baseline scenario would provide the initial P load estimates on which percent reductions would then be assessed. Figure 3-4 shows the required reductions from agricultural lands in the St. Albans Bay watershed assuming a 34.5% reduction from simulated baseline loads.
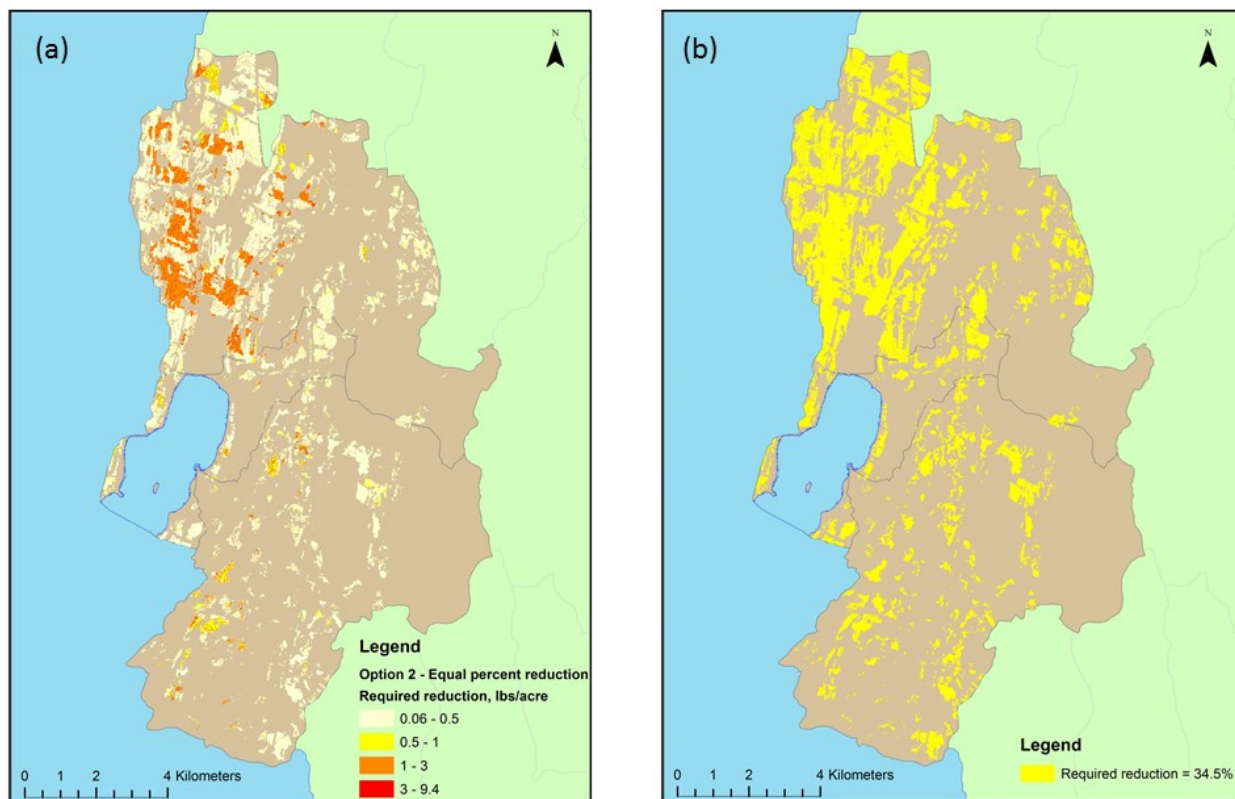
Figure 3-4. Required P reductions from agricultural land in the St. Albans Bay watershed, assuming a 34.5% reduction from all agricultural land.

3.1.2.3. *Tiered or Focused Reductions*

In addition to the above approach of applying either an absolute or percent reduction to all agricultural lands uniformly, more targeted determination approaches were also considered. For example, a tiered percent reduction approach could be devised where higher percent reductions are required for higher vulnerability land. This could potentially be more effective, targeting higher reduction from areas producing higher losses (similar to a critical source analysis); however, it could also put more pressure on land owners/farmers who may be at a disadvantage because of slope, soil, or other conditions. Similarly, targets could be based on crop rotation or land use (either as an absolute load or as a percent reduction). This could also be more effective, such as by focusing P reductions on crops that typically generate greater P loss. This would likely target land planted with corn for higher reductions than hay or pasture areas and, as a result, could potentially have an impact on yields and/or have the unintended consequences of altering farming practices. Another challenge would be in assigning specific farms to tiers developed on basin-scale SWAT loads, as there is no farm-scale data represented in the SWAT models used to develop the TMDLs. An approach that would also take into consideration the feasibility of implementing BMPs on certain land types was considered. However, this would also prove complicated from a policy standpoint, as well as a modeling approach. Because of the increased complexity of the approach and because of the increased variability in the per-acre loading target, this type approach tiered approach was not recommended.

3.1.3. **Farm-Scale Application of Per-Acre Loading Targets**

A farm-scale analysis was conducted to understand the potential impacts of these per-acre loading target approaches and investigate variability at the farm-scale. An important consideration was that the baseline loads simulated by the original SWAT model and used to come up with the TMDL required percent reduction for each lake segment did not simulate any nutrient management practices or BMPs. The implications of this are that P loading targets determined using this data would not take into consideration any BMPs that are currently implemented. To assess the implications of incorporating a farm's current condition, where a farmer may have already implemented some BMPs and achieved some level of P reduction, the following farm-scale analysis also included comparison of resulting reductions on a hypothetical farm using baseline loads (no BMPs), as well as 'current condition' loads. To simulate current conditions, a hypothetical BMP was implemented on land within that 'farm' classified as corn with clay soils and a 0-5% slope. Those areas where BMPs were applied were assumed to reduce total P yield by 50%. This was considered a reasonable, although high, reduction based on the SWAT-based BMP efficiencies used in the EPA BMP Scenario Tool (Tetra Tech Inc, 2015b). For example, either through implementing conservation tillage (50% efficiency) or a combination of cover cropping and crop rotation (63% efficiency).

A hypothetical 'farm' was delineated and extracted from the recombined St. Albans Bay SWAT model, including baseline load values assigned to HRUs within that 'farm.' Required P reductions at the farm-scale (both total pounds P and lbs/acre reduction) were calculated using the uniform absolute P load (Section 3.1.2.1) and the uniform percent reduction approaches (Section 3.1.2.2), based both on the per-acre baseline loads and per-acre 'current condition' loads. These results are shown in Figure 3-5, where panel 'a' shows the total reduction needed to meet the 0.94 lbs/acre target at the farm-scale based on original baseline loads, panel 'b' shows the total reduction needed to meet the 0.94 lbs/acre target based on the 'current condition' loads described above, panel 'c' shows the total reduction needed to meet a 34.5% reduction at the farm-scale based on baseline loads, and panel 'd' shows the total farm reduction needed to meet a 34.5% reduction based on 'current condition' loads. These reductions are also provided in Table 3-2. For this specific example farm, where a relatively large portion of property had high base loads, a farmer would benefit from Option 2, particularly if 'current conditions' at the farm included some already implemented BMPs. However, it should be noted that this could be different for farms with different characteristics such as a higher percentage of the property having low base loads.
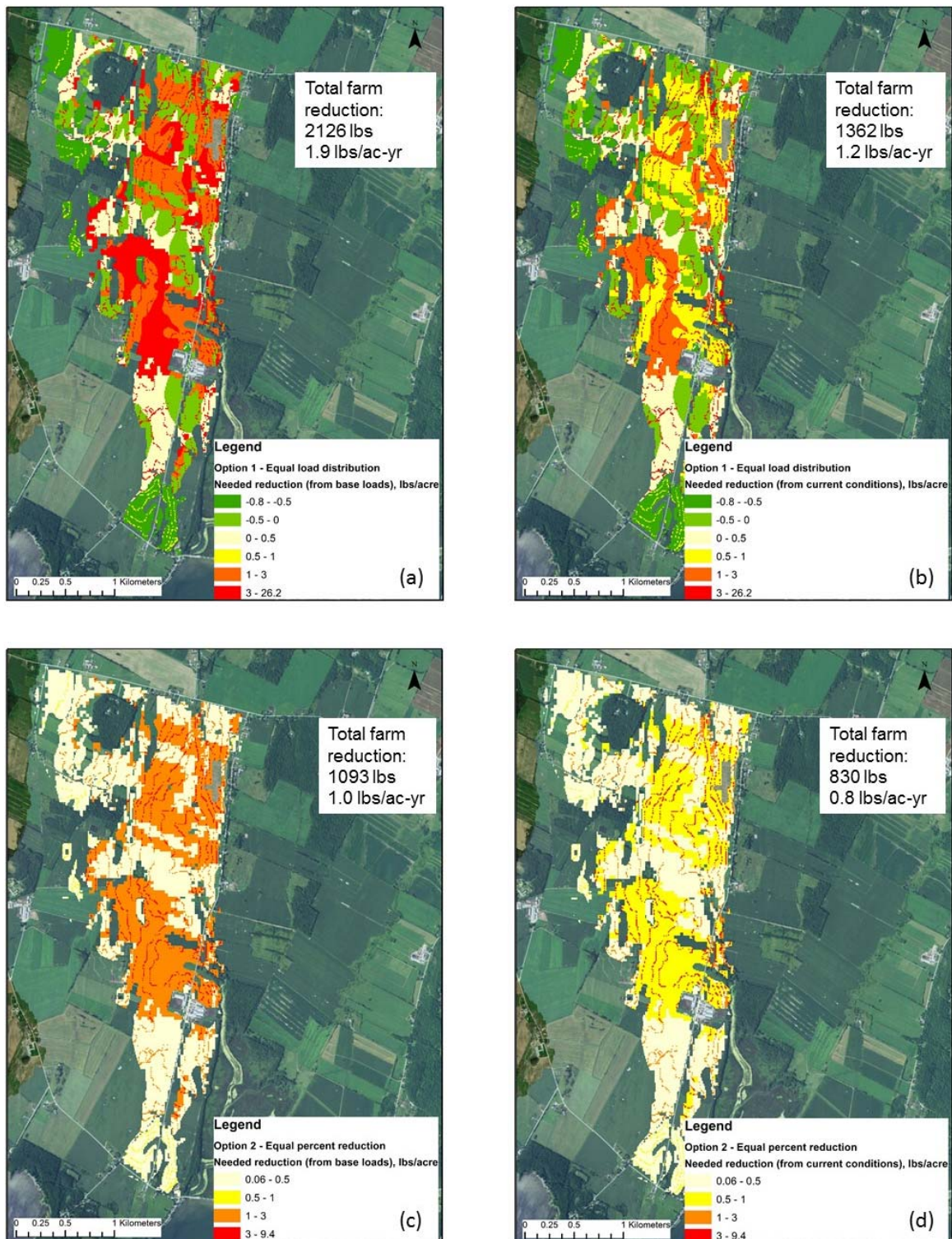
Figure 3-5. Example of farm-scale implementation of uniform absolute load target and uniform percent reduction targets, applied to baseline loads and current condition loads.

Although a tiered or targeted approach was not considered ideal for this project, an example of this approach was also applied to the hypothetical farm example. Here, a tiered approach was developed where if an HRU's baseline load or 'current condition' load was less than 0.94 lbs/acre no reduction was simulated, if baseline/current load was 0.94-2 lbs/acres a 10% reduction was implemented, if baseline/current load was 2-5 lbs/acre a 50% reduction was implemented, and if baseline/current loads were greater than 5 lbs/acre, a 75% reduction was implemented. The necessary farm-scale reductions resulting from this approach fall between the uniform absolute and uniform percent reduction approach for this farm. Mapped results are shown in Figure 3-6 and farm reduction results are included in Table 3-2.
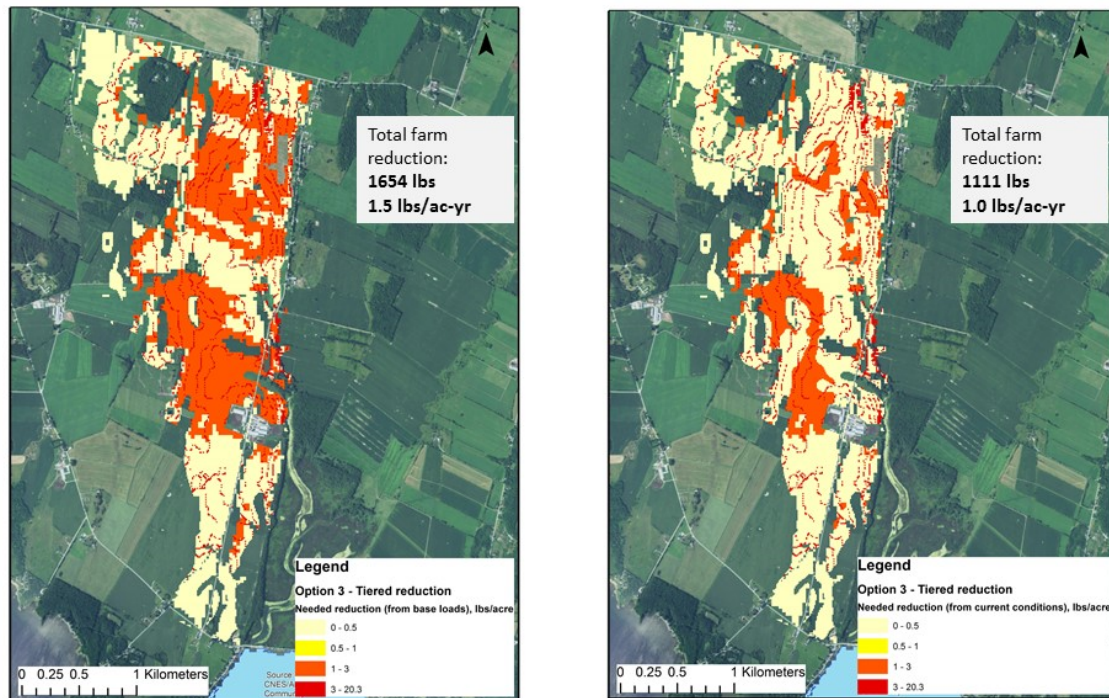
Figure 3-6. Required farm-scale reductions based on a tiered approach an applied to both baseline loads and 'current condition' loads.

Table 3-2. Required farm reductions based on applying three target load approaches to both baseline loads and 'current condition' loads.

Crop/Land Use Category	Target = 0.94 lbs/acre (baseline loads)	Target = 0.94 lbs/acre (current conditions)	Target = 34.5% (baseline loads)	Target = 34.5% (current conditions)	Target = tiered (baseline loads)	Target = tiered (current conditions)
Total Farm Reduction (lbs/yr)	2126	1363	1093	830	1654	1111
Total Farm Reduction (lbs/acre/yr)	2	1	1	1	2	1

3.1.4. Project Advisory Committee Feedback

The options described above for determining a per-acre P loading target were presented at the first PAC meeting. It was Stone's recommendation that a uniform percent reduction of 34.5% be applied to current conditions on a farm in order to come up with per acre target loading rates. Attendees of the meeting included stakeholders from several government agencies and UVM Extension who work with farmers, as well as at a larger scale, on nutrient management and BMP adoption. Feedback from this meeting was incorporated into the decision on which approach to adopt.

Discussion centered on coming up with an approach that was fair and feasible, but that would still achieve reductions necessary to meet lake quality goals. Concern was raised that a 0.94 lb/acre target may not be possible for many farms. It was also evident from the meeting that it would likely not be worth the investment necessary to reduce P losses from lands where P losses are already low (e.g. some hay land). There was general support for including a farm's current conditions in the determination of their loading target, so that credit could be given for the good efforts already made.

Another issue discussed was the potential discrepancies between SWAT model predictions of absolute loads and those predicted in APEX through the Farm-PREP tool. Because this pilot project uses a different model (APEX) for simulating P losses and the impacts of BMPs on those losses, there is no guarantee that even given the same inputs, APEX would predict the exact same P losses as SWAT did for the TMDL modeling due to the differences in how biophysical processes are simulated. The recommended approach will not redo any modeling done for determining the TMDL, nor will it calibrate APEX to the SWAT model output (for reasons including scale differences and project scope). This supports using a percent reduction approach as it would not be as dependent on an absolute P load number or be as affected by differences in the two models.

3.1.5. Selected Approach for Determining P Loading Targets

Based on the analysis presented in above sections and the feedback received from the PAC, it was decided that determination of a per-acre P loading target, for the purposes of development of the farm P optimization tool (Farm-PREP) would be a uniform percent reduction. For the St. Albans Bay watershed, this equates to a 34.5% reduction for all agricultural land. A baseline simulation in APEX would assess P loading without any BMPs implemented on the farm: this would provide the initial baseline loads estimates from which a 34.5% reduction would be required. Current conditions on the farm would then be simulated, including currently implemented nutrient management strategies and BMPs. An individual farm's target load would include reductions resulting from these current conditions, such that their final required reduction might be less than 34.5% of current practices. The concept of both a "baseline" and "current" P loss for a farm is an important component to the Farm-PREP tool and will be used in discussion throughout the remainder on this report.

The approach selected for determining P load reductions at the farm-scale was used in this pilot project as the starting point for developing and testing a framework for optimizing P loss reduction strategies using the Farm-PREP tool. It is fully expected that further considerations and possible modifications will be required prior to implementation of this tool in practice. For example, there will likely be requirements for flexibility in situations where a farm operator has limited or no opportunities for further P loss reductions. Similarly, there will likely be situations where the cost of implementing BMPs for a limited reduction in P losses is impractical, both from an economic and environmental perspective. Following completion of this Phase 1 pilot project, opportunities will exist for further discussion and refinement in how farm-specific P-loss reduction targets are set and how the results from the farm simulations can be used to improve P-loss management and water quality.

3.2. Development of a Farm P Management Optimization Modeling Approach

3.2.1. Objectives and Methods

The development of the modeling and optimization approach for the Farm-PREP tool was designed to make use of existing datasets as much as possible. The primary data sources largely came from government agencies and research institutions. The compilation of these datasets was conducted so that many of the APEX model inputs and parameters would be derived automatically by the tool, thereby reducing the additional inputs provided by the user. The development of farm agronomic practices focused specifically on representing the most common agricultural practices in Vermont. The strategy of pre-determining these practices resulted in both a reduction of inputs required when applying the tool, and the opportunity to review and evaluate these important model inputs prior to running any APEX simulations. The approach for optimizing the P-loss reduction on a farm was designed to efficiently evaluate many different combinations of field practices, incrementally increasing the number of additional BMPs, to achieve a farm-level reduction as close to a specified target as possible. Section 3.2 of this report will provide discussion on these key modeling components of the Farm-PREP application development.

3.2.2. Database Development

3.2.2.1. Climate Data

The APEX model requires daily time series of precipitation and temperature. The model should be run for a minimum of 10 years in order to obtain sufficient variability in annual P losses that accounts for a range of wet, dry, and average years. The Texas A&M BREC, developers of the APEX model, works with partners in the NRCS to conduct APEX modeling as part of the national assessments, such as the Conservation Effects Assessment Project (CEAP). BREC provided a database of daily precipitation and temperature stations that included 165 station locations in Vermont spanning from 1900 through 2015. The stations represent Cooperative Observer (COOP), as well as primary airport stations with data collected and compiled by the National Climatic Data Center (NCDC). The time series in the database from BREC provided continuous datasets for each station by interpolation and extrapolation from nearby stations during periods of missing data.

The selection of a climate station for an APEX simulation conducted with the Farm-PREP tool is determined for each field independently. The centroid of a field is compared to the coordinates of each daily climate station and the climate station closest to the field is then assigned to the APEX simulation for that field. There is the potential, for larger farms spread over broader areas, for different climate stations to be assigned to different fields in the same farm assessment. This situation is expected to be rare, and in cases where it does occur, it may accurately reflect variability in precipitation and temperature, such as when elevation change across the farm is significant. The APEX simulations for use in the Farm-PREP tool are currently set at 15-year simulations, representing the historical climate period from January 2001 through December of 2015.

3.2.2.2. Topographic Data

Topographic data is used by the APEX model in field-level simulations to determine the average field slope. After the field slope is determined, slope lengths can be estimated as a function of slope steepness. Both factors, slope length and slope steepness, are important in APEX algorithms for calculating soil erosion and sorbed P losses. A calculation of field slope from digital elevation models (DEMs) provides a reasonable estimate for purpose of APEX erosion calculation, although when available, field observations of slope can serve as a refinement.

The USGS Vermont 10-meter resolution statewide DEM was previously obtained from Vermont Center for Geographic Information (VCGI) when the APEX-based VT-STAR tool was developed in 2012 (Stone Environmental, 2015). This dataset was extracted from the USGS National Elevation Dataset (NED) 1/3 arc second data. A 1-meter resolution slope grid was calculated using ArcGIS from the elevation grid dataset. The average field slope was calculated by averaging slopes from the 10-meter grid cells covering the entire field.

3.2.2.3.   Soil Data

Farm field soil conditions are important inputs to the APEX model as soil conditions affect the transport processes of pollutants from the fields. For example, the hydrologic soil group can greatly influence surface runoff from a field. The application allows for user input of soil phosphorus test results, pH, and aluminum values but determination of other soil parameters values and default values for these parameters are determined from SSURGO database soils data.

The USDA NRCS SSURGO 2017 10-meter data for Vermont was downloaded from DATA.GOV for use in the application. The 10-meter raster was imported to the backend database. For each soil 'mapunit' a representative set of soil attributes were extracted from the SSURGO component and horizon tables. The first choice of soil component to represent the mapunit was the dominant component (highest percentage of the mapunits). In cases where the dominant component was missing key soil parameters (e.g., bulk density, organic matter, sand %), then a component that was most complete for critical soil parameters used by the APEX model were imported to the database.

As farm fields are created in the Farm-PREP application, a spatial query is executed intersecting the farm field polygons with the SSURGO raster spatial dataset to determine the dominant soil in the field. The SSURGO soil attributes of the selected soil are then used in parameterizing the APEX model. A list of soil parameters used by APEX is provided in Table 3-13 on page 30

3.2.2.4.   Farm Agronomic Practices

Farm agronomic data, including crop rotations, tillage practices, and BMPs, represents some of the most important data requirements for the APEX model. In compiling agronomic data, the objective was to identify the combinations of crop rotations and management practices that best represent typical dairy operations in Vermont. The expertise provided by University of Vermont Extension staff and Tom Eaton, a crop consultant with the Agricultural Consulting Service (ACS), was integral in identifying these crop rotations and management practices. The agronomic practice information compiled was used to establish APEX model management operation schedules used in the simulation modeling. A summary of the common crop rotations compiled for APEX simulations is provide in Table 3-3.

Table 3-3. Crop Rotations for APEX Simulations Representing Vermont Dairy Operations.

Crop 1	Number of Years	Crop 2	Number of Years
Corn grain	Continuous	N/A	N/A
Corn silage	Continuous	N/A	N/A
Small grains	Continuous	N/A	N/A
Grass hay	Continuous	N/A	N/A
Legume hay	Continuous	N/A	N/A
Corn grain	1	Soybean	1

Crop 1	Number of Years	Crop 2	Number of Years
Corn grain	4	Grass hay	4
Corn grain	4	Legume hay	4
Corn silage	1	Soybean	1
Corn silage	2	Grass hay	4
Corn silage	3	Grass hay	4
Corn silage	4	Grass hay	4
Corn silage	2	Legume hay	4
Corn silage	3	Legume hay	4
Corn silage	4	Legume hay	4
Corn silage	2	Alfalfa mix	4
Corn silage	3	Alfalfa mix	4
Corn silage	4	Alfalfa mix	4

The typical agronomic operations and practices associated with each of the crops in the rotations shown in Table 3-3 were identified through further consultation with UVM Extension, ACS, and consultation with the PAC. These practices included planting, harvest, tillage, fertilizer and manure applications, and cover cropping. The characteristics and timing of each operation/practice were selected to reflect common agronomic management in Vermont. The APEX model includes a tillage operation database with hundreds of different tillage tools. To streamline determination of APEX model inputs through the Farm-PREP tool, a simplified set of tillage operations were created to represent the generalized categories of "No-till", "Reduced", and "Conventional", and "Reduced and Conventional". "No-till" at planting assumes that only a no-till planter is used for the planting operation. A tandem disk was selected to represent the "Reduced" till operation in the spring or fall. A more aggressive moldboard plow was selected to represent the "Conventional" tillage option in the fall. Finally, a moldboard plow followed by a tandem disk was selected to represent the "Conventional and Reduced" tillage option.

The operations selected for nutrient applications to a field included both commercial and organic (manure) fertilizer. Commercial fertilizer applications are set to occur once per year at the start of the growing season and can include both P and N applications. The manure applications can occur at multiple times throughout the year and depend upon the crop. Manure applications can be surface-applied, incorporated, or injected. While manure injection is currently uncommon in Vermont, the option was included to evaluate its potential role as a BMP to reduce P losses. Manure incorporation is surface applied manure followed by a tillage operation one day later. Injected manure can also be followed by a tillage operation, resulting in further incorporation in the soil.

Cover cropping is a management practice for corn and soybean crops. Several different cover cropping practices were identified for simulation with APEX as part of the crop rotations shown in Table 3-3. A cover crop planted post-harvest can be planted early (September 15th) or late (October 15th). The cover crop planted at this time can be either a winter kill species or a winter hardy species. In addition, an inter-seeded cover crop

(winter hardy) can be planted during the growing season, with continued growth and cover post-harvest through the following spring.

The agronomic operation options for each crop are summarized in Table 3-4 through Table 3-7 for corn, soybean, small grains, and hay. For corn (Table 3-4), harvest can be either early (September) or late (October). Cover cropping options also correspond to these dates. There are seven different tillage options which implement different combinations of no-till, reduced, and conventional till. Manure application in the spring occur 10 days before planting, and if incorporation occurs via tillage, it occurs one day following the application. Manure application in the fall occurs two days after harvest, and if incorporation occurs via tillage, it occurs one day following application. The agronomic operation options for soybeans (Table 3-5) are the same as those for corn operations, but with early and late harvest dates moved up to September 5th and October 5th respectively. Small grains (

Table 3-6) are assumed to be a winter wheat or similar crop, with planting occurring in the fall (September 15th) and harvest the following year (July 15th). The tillage options are limited to fall (pre-plant) operations, with manure applications occurring prior to planting in September. Three types of hay can be simulated (Table 3-7), a grass hay, a legume hay, and an alfalfa/grass mix. The hay operations revolve around the number of hay cuttings, with the option of two to six cuttings per year for grass or legume hay and two to four cuttings for alfalfa/grass mix. Manure applications occur three days after each cutting and can be either surface applied or injected.

Table 3-4. Corn Grain and Corn Silage Agronomic Operation Options.

Operation Type	Operation Option	Operation Timing
Plant	N/A	May 15
Harvest	Early harvest	Sep. 10
Harvest	Late harvest	Oct. 10
Tillage (Spring/Fall)	No-till / None	NA / NA
Tillage (Spring/Fall)	No-till / Reduced	NA / Harvest + 3 days
Tillage (Spring/Fall)	Reduced / None	May 6 / Harvest + 3 days
Tillage (Spring/Fall)	Reduced / Reduced	May 6 / Harvest + 3 days
Tillage (Spring/Fall)	Reduced / Conventional	May 6 / Harvest + 3 days
Tillage (Spring/Fall)	Conventional and Reduced / Reduced	May 6 / Harvest + 3 days
Tillage (Spring/Fall)	Conventional and Reduced / Conventional	May 6 / Harvest + 3 days
Cover Crop	Inter-Seeded	Jul. 15
Cover Crop	Winter kill, early plant	Sep. 15
Cover Crop	Winter kill, late plant	Oct. 15
Cover Crop	Winter hardy, early plant	Sep. 15
Cover Crop	Winter hardy, early plant	Oct. 15
Manure Application	Spring, Surface Applied	May 3

Operation Type	Operation Option	Operation Timing
Manure Application	Spring, Incorporated	May 5
Manure Application	Spring, Injected	May 5
Manure Application	Fall, Surface Applied	Harvest + 2 days
Manure Application	Fall, Incorporated	Harvest + 2 days
Manure Application	Fall, Injected	Harvest + 2 days
Commercial Fertilizer	N/A	May 16

Table 3-5. Soybean Agronomic Operation Options.

Operation Type	Operation Option	Operation Timing
Plant	N/A	May 15
Harvest	Early harvest	Sep. 5
Harvest	Late harvest	Oct. 5
Tillage (Spring/Fall)	No-till / None	NA / NA
Tillage (Spring/Fall)	No-till / Reduced	NA / Harvest + 4 days
Tillage (Spring/Fall)	Reduced / None	May 6 / Harvest + 8 days
Tillage (Spring/Fall)	Reduced / Reduced	May 6 / Harvest + 8 days
Tillage (Spring/Fall)	Reduced / Conventional	May 6 / Harvest + 8 days
Tillage (Spring/Fall)	Conventional and Reduced / Reduced	May 6 / Harvest + 8 days
Tillage (Spring/Fall)	Conventional and Reduced / Conventional	May 6 / Harvest + 8 days
Cover Crop	Inter-Seeded	Jul. 15
Cover Crop	Winter kill, early plant	Sep. 15
Cover Crop	Winter kill, late plant	Oct. 15
Cover Crop	Winter hardy, early plant	Sep. 15
Cover Crop	Winter hardy, early plant	Oct. 15
Manure Application	Spring, Surface Applied	May 5
Manure Application	Spring, Incorporated	May 5
Manure Application	Spring, Injected	May 5
Manure Application	Fall, Surface Applied	Harvest + 7 days
Manure Application	Fall, Incorporated	Harvest + 7 days
Manure Application	Fall, Injected	Harvest + 7 days
Commercial Fertilizer	N/A	May 16

Table 3-6. Small Grains Agronomic Operation Options.

Operation Type	Operation Option	Operation Timing
Plant	N/A	Sep 15
Harvest	N/A	Jul 15
Tillage (Spring/Fall)	None / No-till	NA / NA
Tillage (Spring/Fall)	None / Reduced	NA /Sep 6
Tillage (Spring/Fall)	None / Conventional	NA / Sep 6
Manure Applications	Fall, Surface Applied	Sep 5
Manure Applications	Fall, Incorporated	Sep 5
Manure Applications	Fall, Injected	Sep 5
Commercial Fertilizer	N/A	Apr 15

Table 3-7. Hay Agronomic Operation Options.

Operation Type	Operation Option	Operation Timing
Plant	Grass hay	May 1
Plant	Legume hay	May 1
Plant	Alfalfa mix	May 1
Harvest	2 cuts	Jun 16/Sep 1
Harvest	3 cuts	Jun 1 / Jul 15 / Sep 1
Harvest	4 cuts	Jun 1 / Jul 15 / Sep 1 / Oct 15
Harvest	5 cuts (Grass hay/Legume hay)	May 15 / Jun 15 / Jul 15 / Sep 1 / Oct 1
Harvest	6 cuts (Grass hay/Legume hay)	May 15 / Jun 15 / Jul 15 / Aug 15 / Sep 15 / Oct 15
Manure Application	Surface Applied	Harvest + 3 days
Manure Application	Injected	Harvest + 3 days
Commercial Fertilizer	N/A	May 16

Several structural BMP options are also available. These include vegetative buffer strips, grassed waterways, and a combination of the two. All three of these options are available for corn, soybean, and small grains, while only the buffer option is available for hay. These options are summarized in

Table 3-8.

Table 3-8. Structural BMP Options.

Structural BMP	Operation Options	Relevant Crops
Buffer	Buffer Width / Length	Corn, Soybean, Small Grains, Hay
Grassed Waterway	Grassed Waterway Width / Length	Corn, Soybean, Small Grain
Buffer + Grassed Waterway	Buffer Width / Length; Grassed Waterway Width / Length	Corn, Soybean, Small Grains

The determination of crop rotations, agronomic management operations, and BMP options to simulate fields on Vermont farms sought to strike a balance between accuracy, flexibility and simplicity. This balance include the need to accurately capture the variability in practices that impact potential P losses while providing options flexible enough to reflect the actual practices of a range of growers. Simplicity was also critical—a tool must be easy and efficient to apply to a farm for its use to be accepted and practical. Experiences with tools that provide too many options have shown us that users can quickly become overwhelmed with options, leading to frustration and limited benefits of the tool.

3.2.3. Parameter Values and Sources

3.2.3.1. Crop and Tillage Parameters

The APEX model version 1501 is the current publicly available and supported APEX model version (BREC, 2018). This version is available as part of desktop user interfaces (ArcAPEX and WinAPEX) or as a standalone executable program. These APEX interfaces include a database that contains many of the parameters required for model simulations, greatly streamlining the model parameterization process. The most important tables included in the APEX 1501 database are the CROPCOM (crop data) and TILLCOM (tillage) tables. The CROPCOM table includes over 50 parameters that describe crop growth and nutrient uptake for more than 100 crops and plant species. These parameters include biomass-energy ratio, optimal growth temperature, minimum growth temperature, maximum potential leaf area index, maximum stomatal conductance, harvest efficiency, and fraction of phosphorus in yield. The TILLCOM table includes parameters that describe the effect of field operation machinery on the land and soil, as well as the costs associated with these operations. The table contains hundreds of different farm machinery, with parameters that include depth of operation (tillage depth), mixing efficiency, and the random surface roughness.

The parameters provide in the APEX CROPCOM and TILLCOM tables are generally not modified unless there is site-specific data for calibration that provides support for adjustments. The parameter values have been developed based on field data and are generally accepted to provide reasonable simulations without further calibration. The selections of APEX CROPCOM and TILLCOM records to match the crops and tillage operations used to simulate Vermont fields are summarized in Table 3-9.

Table 3-9. APEX CROPCOM and TILLCOM Assignments to Vermont Crops and Tillage Modeled.

Vermont Crop / Tillage Operation	APEX CROPCOM / TILLCOM Record
Corn Grain	CORN: Corn
Corn Silage	CSIL: Corn Silage
Soybean	SOYB: Soybeans

Vermont Crop / Tillage Operation	APEX CROPCOM / TILLCOM Record
Small Grains	WWGO: Winter Wheat
Grass Hay	FEST: Tall Fescue / BROS: Smooth Brome Grass
Legume Hay	CLOV: Red Clover / FEST: Tall Fescue
Alfalfa Mix	ALFA: Alfalfa, / FEST: Tall Fescue
Inter-Seeded Cover Crop	RYE: Rye
Winter Kill Cover Crop	OATS: Oats
Winter Hardy Cover Crop	RYE: Rye
No-Till	PLANTER NO-TILL 6 ROW
Reduced Till	TANDEM DISK PLW GE19FT
Conventional Till	MOLDBOARD PLOW REG 4-6B

3.2.3.2. Establishment of APEX Field (Subarea) Parameters

The simulation of farm fields in APEX has been organized to simulate each field as independent APEX "subareas". Subareas in APEX have homogeneous climate inputs, soils, slope, and management practices. The determinations of the parameter values required to simulate a field in APEX are based upon the datasets already described (e.g., DEM and SSURGO soils), as well as recommendations provided in the APEX model documentation (Steglich et al., 2016). The approach to setting these parameters can vary based on whether the field has a buffer or grassed waterway, and the APEX parameters for buffers and grassed waterways must also be specified. The APEX subarea parameter values and approaches for selecting these values are summarized in Table 3-10. We have not included parameters where simple model default values are chosen.

Table 3-10. Summary of APEX Subarea Input Parameter Value Determination.

Parameter Name	Parameter Description	Subarea Value	Buffer/GWW Value
INPS	Soil ID	Major component from dominant map unit	Same as field subarea
IOPS	Operation schedule ID	Selected based on crop rotation, tillage, manure, fertilizer, cover crop	Buffer/GWW specific op schedule
WITH	Daily weather station ID	Selected based on closest station to subarea	Same as field subarea
STDO	Initial standing dead crop residue (t/ha)	0.9	NA
WSA	Watershed (field) area (ha)	Calculated from field geometry	Buffer length * buffer width
CHL	Distance from outlet to most distant point on watershed (km)	1.414*sqrt(WSA)	1.1 * buffer width
CHS	Channel slope (m/m)	0.5 * average field slope	0.1 * average field slope

Parameter Name	Parameter Description	Subarea Value	Buffer/GWW Value
CHN	Manning's N for channel	0.19	0.24
SLP	Average field upland slope (m/m)	field average from DEM; or user input	Same as CHS value for buffer/GWW
SPLG	Slope length (m)	Based on lookup table versus slope; or user input	Minimum of CHS or field subarea SPLG
FFPQ	Fraction of floodplain flow	0	0.95
RCHL	Length of routing reach (km)	1.414*sqrt(WSA)	buffer width / gww length
RCHS	Routing reach slope (m/m)	Same as CHS	Same as CHS
RCHN	Manning's N for routing channel	0.19	0.24
RCHC	Crop management channel C factor	0.1	0.1
RCHK	Crop management channel K factor	0.3	0.3
RFPW	Reach floodplain width	0	User buffer length / user GWW width
RFPL	Reach floodplain length	0	User buffer width / user GWW length
IDR	Drainage code (depth of drains) (mm)	914 (3 ft)	914 (3 ft)
DRT	Time requirement for drainage system to end plant stress (d)	2	2
PEC	Erosion control practice factor	0.5 to 1.0, depending on slope	1

Slope length estimates were determined as a function of field slope (Potter, 2014) and are summarized in Table 3-11. Users also have the option of entering field measured values for both slope length and slope.

Table 3-11. Slope Length in Feet as Determined by Percent slope of Field.

Slope Range	Slope Length (ft)
<3%	200
3% -8%	150
8% - 15%	100
> 15%	75

The erosion control practice factor (PEC) was set based on an assumption of farming along the hillslope contour, a common practice that results in lower sediment and soil P loss than farming up and down the

hillslope. These PEC values were taken from Wischmeier and Smith (1987) and are summarized in Table 3-12. If future evaluations of cropping practices indicate that contour farming is not predominant, options may be added to Farm-PREP to reflect these practices.

Table 3-12. Soil Conservation Practice Factor (PEC) as a Function of Slope.

Slope Range	PEC
<= 1%	1.0
1% - 2.5%	0.6
2.5% - 8.5%	0.5
8.5% - 12.5%	0.6
12.5% - 16.5%	0.7
16.5% - 20.5%	0.8
> 20.5%	0.9

Many of the soils parameters for APEX simulations are extracted directly from SSURGO (as described in Section 3.2.2.3), while a few are provided by the user. These are all summarized in Table 3-13.

Table 3-13. Summary of APEX Soil Input Parameter Value Determination.

Parameter Name	Parameter Description	Subarea Value
SNAM	Soil name	Major component from dominant map unit
SALB	Soil albedo	SSURGO, albedodry_r
HSG	Soil hydrologic group	SSURGO, hydgrp
Z	Depth to bottom of layer	SSURGO, hzdepth_r
BD	Bulk density	SSURGO, dbthirdbar_r
UW	Wilting point (-15 bar)	Calculated by APEX using Rawls method
FC	Field capacity (-1/3 bar)	Calculated by APEX using Rawls method
SAN	Sand content (%)	SSURGO, santotal_r
SIL	Silt content (%)	SSURGO, siltotal_r
PH	Soil Ph	SSURGO, ph1to1h2o_r; or user input
WOC	Organic carbon concentration (%)	SSURGO, om_r / 1.72

Parameter Name	Parameter Description	Subarea Value
CEC	Cation exchange capacity (cmol/kg)	
ROK	Coarse fragment content (% vol)	SSURGO, 1 - sieveno10_r
SSF	Initial soluble P concentration (ppm)	User input, converted from Modified Morgan to Mehlich III
PSP	Phosphorous sorption ratio	0.5
SATC	Saturated hydraulic conductivity (mm/h)	SSURGO, ksat_r * 3.6

The APEX operation schedules also require that a land cover, treatment, and hydrologic condition be associated with the crop(s) specified in the operation schedule rotation. These characteristics are used in determining an appropriate runoff curve number. The APEX model uses standard NRCS runoff curve numbers as published in their Technical Release 55 (NRCS, 1986). To simplify the parameterization of APEX in Farm-PREP, a single representative land cover, treatment, and hydrologic condition was selected for each crop. While some refinement in runoff potential could theoretically be achieved by exposing multiple condition for each crop, increasing input options also has the potential to be misused. The assumptions associated with each crop available in Farm-PREP are summarized in Table 3-14.

Table 3-14. Land Use, Treatment, Hydrologic Condition, and Curve Number Assumptions by Crop.

Crop(s)	Land Use / Treatment / Hydrologic Condition	CN2 for Hydrologic Soil Group A/B/C/D
Corn grain/Corn silage/Soybean	Row crops/Contoured/Good	65/75/82/86
Small grains	Small grains/Contoured/Good	61/73/81/l84
Cover crop	Close seeded legumes/Contoured/Good	55/69/78/83
Grass hay/Legume hay/Alfalfa mix	Meadow/Good	30/58/70/79

The APEX model input parameters for the Farm-PREP tool have not been formally "calibrated" based on site-specific edge-of-field data surface or subsurface (tile drain) monitoring data. Rather, the parameterization was informed by previous work applying APEX in Vermont (Stone Environmental, 2015), model developer recommendations (Steglich et al., 2016), and review of field-level simulation results (see Section **Error! Reference source not found.** and Section 3.4). A formal calibration/validation with monitoring data will be conducted in a related project being led by Newtrient, LLC (entitled "Refinement of Critically Needed Assessment Tools for Tile Drainage P Loading in the Lake Champlain Basin").

3.2.4. Model Optimization Methodology

Given grower input on their current management practices, a wide range of alternative practices are simulated with APEX, resulting in a suite of P loss estimates for each field. An iterator algorithm combines the P loss from one result in the suite of alternatives for each field to generate one possible realization of the overall farm P loss. Then the algorithm tests each farm realization for whether it comes close to meeting the targeted P

reduction from the baseline farm practices. The baseline farm practices include only standard practices that would not be considered best P management. An alternative realization meets the target if it falls within a 5% tolerance around the target reduction from the baseline. If the current farm practices already exceed the target reduction from baseline, then the algorithm returns additional farm realizations that are within 5% of the reduction achieved with current conditions. The algorithm will only suggest realizations that are at least as good as the current farm practices.

The number of farm realizations grows exponentially when considering large numbers of fields and large numbers of alternative practices, making it practically impossible to test every realization. For example, considering just ten practice alternatives on six fields generates an ensemble of 10^6 or 1,000,000 farm realizations to evaluate. For this reason, an optimization algorithm intelligently filters the field-level results to a small subset before combining them into farm realizations. Using a bisection search technique on the array of field-level results sorted from highest to lowest P loss, the optimizer tests whether farm realizations are within tolerance of the target, starting at the midpoint of each array. If the midpoint realization doesn't meet the target, the optimizer bisects the array, jumping to halfway between the midpoint and one end of the array and tests the farm realization there. Whether the next move is forward or backward depends on whether the last realization was above (move toward higher P loss) or below the target reduction (move toward lower P loss). The algorithm continues bisecting the array on either side of the last move until it finds a realization between the target reduction and 5% less P loss reduction than the target (i.e., slightly more total P loss than the target). This is the starting point at which the iterator will begin testing all subsequent combinations of fields and practices. Once the bisection algorithm finds the starting farm realization, field results with higher P loss are discarded and the iterator makes combinations from the remaining subset of field results testing for realizations with passing P reduction targets. The algorithm exits when it identifies ten passing farm realizations or has exhausted all combinations.

To further expedite the search for farm management solutions, a database function divides the field-level management practices into small subsets of practices, evaluated in rounds. With each round, the number and complexity of alternative practices increase. The first round considers only changes in tillage and manure application method. The second round considers the addition of cover cropping which includes all possible combinations of cover crop varieties and planting dates. The third round includes the addition of buffers and the fourth and final round adds grassed waterways. If the optimizer finds passing farm solutions using only alternative tillage operations and cover crops, it may be that grassed waterways and buffers are never evaluated. APEX will not even run these cases, further improving simulation efficiency. To include the practices of higher rounds in farm management solutions, the user would need to increase the target P reduction. The algorithm's operating philosophy is that passing solutions should be returned with the minimal number and complexity of additional practices to the grower's current conditions. In fact, it is possible that the algorithm finds a solution where a current practice (except for grassed waterways and buffers) is removed from a field in favor of a more impactful practice elsewhere.

3.2.5. Review of Field-Level APEX Simulation Results

APEX simulations using the Farm-PREP model parameterization were conducted on a single field near St. Albans Bay to evaluate the predicted total P loss for a range of different crop rotations and practices. The simulated field had an area of 47.7 acres, a slope of 2.4%, and the dominant soil was Kingsbury silty clay soil. No tile drainage was assumed for the simulations. Crop rotations evaluated included continuous corn silage, a 4-year corn sileage / 4-year grass hay rotation, a 2-year corn sileage / 4-year grass hay rotation, and continuous grass hay. Manure was applied to corn at a rate of 20 lbs P205/acre in the spring and an additional 20 lbs P2O5/acre in the fall. Manure was applied to hay four times per year following cuttings at a rate of 10 lbs P2O5/acre. Tillage practices for corn included reduced+conventional in spring / reduced in fall, reduced in

spring / reduced in fall, and no till in spring / none in fall. Winter hardy cover crops for corn rotations planted on both 9/15 and 10/15 were also tested. Finally, all rotations and practices were evaluated with and without a 25 ft buffer. The results of these simulations are summarized in Table 3-15.

Table 3-15. Summary of APEX simulations for a range of crop rotations and practices.

Scenario	Crop Rotation	Spring / Fall Tillage	Cover Crop	Buffer	Total P-Loss (lbs / ac-yr)
1	Corn silage	Reduce + conventional / reduced	None	None	2.32
2	Corn silage	Reduce / reduced	None	None	1.59
3	Corn silage	No till / none	None	None	1.57
4	Corn silage	Reduce / reduced	Winter hardy, plant 10/15	None	1.37
5	Corn silage	Reduce / reduced	Winter hardy, plant 9/15	None	0.91
6	Corn silage (4 yr) / grass hay (4 yr)	Reduce + conventional / reduced	None	None	1.32
7	Corn silage (4 yr) / grass hay (4 yr)	Reduce / reduced	Winter hardy, plant 9/15	None	0.47
8	Corn silage (2 yr) / grass hay (4 yr)	Reduce + conventional / reduced	None	None	0.76
9	Corn silage (2 yr) / grass hay (4 yr)	Reduce / reduced	Winter hardy, plant 9/15	None	0.34
10	Grass hay	NA	NA	None	0.21
1-B	Corn silage	Reduce + conventional / reduced	None	25 ft	1.99
2-B	Corn silage	Reduce / reduced	None	25 ft	1.27
3-B	Corn silage	No till / none	None	25 ft	1.28
4-B	Corn silage	Reduce / reduced	Winter hardy, plant 10/15	25 ft	1.09
5-B	Corn silage	Reduce / reduced	Winter hardy, plant 9/15	25 ft	0.74
6-B	Corn silage (4 yr) / grass hay (4 yr)	Reduce + conventional / reduced	None	25 ft	1.13
7-B	Corn silage (4 yr) / grass hay (4 yr)	Reduce / reduced	Winter hardy, plant 9/15	25 ft	0.41
8-B	Corn silage (2 yr) / grass hay (4 yr)	Reduce + conventional / reduced	None	25 ft	0.65
9-B	Corn silage (2 yr) / grass hay (4 yr)	Reduce / reduced	Winter hardy, plant 9/15	25 ft	0.30
10-B	Grass hay	NA	NA	25 ft	0.19

The results shown in Table 3-15 follow the expected trends based no crop rotations, tillage practices, cover cropping, and buffers. The average annual total P loss rate was highest for conventional corn (Scenario 1) at 2.32 lbs/ac-yr, which falls within the range of loads for the St. Albans Bay watershed as reported in the Lake Champlain TMDL SWAT modeling (Tetra Tech, 2015a) for continuous corn on both clay and non-clay soils (see Table 3-1). The average annual total P loss rate of 1.32 lbs/ac-yr for a conventional corn / hay rotation (Scenario 6) also falls within the reported range of loads for the corn / hay rotations on clay and non-clay soils (see Table 3-1). The predicted total P loss of 0.21 lbs/ac-yr from continuous grass for this example field is also consistent with the permanent hay loading rates in the St. Albans Bay watershed. This comparison, while not exhaustive, increases confidence that the predictions from APEX based on the Farm-PREP parameterization approach are reasonable for the conventional practices assumed in the TMDL.

A comparison of the impacts of tillage practices on total P loss for corn silage also shows the expected changes. Moving from conventional tillage (Scenario 1) to reduced tillage (Scenario 2) results in a 31% decrease in P losses for the example field. A similar decrease in P losses (32%) is seen when moving from conventional to no till (Scenario 3). The reason only a minor improvement is observed between reduced till (Scenario 2) and no till (Scenario 3) is that in reduced till, manure is incorporated in both the spring and fall, while with no till, manure is not incorporated. The benefits of a cover crop are seen with Scenario 4 (late plant) and Scenario 5 (early plant), where reduction in P loss from the same scenario without cover crop (Scenario 2) are 14% and 43%, respectively.

The corn / hay rotations (Scenarios 6 – 9) demonstrate the effectiveness of reduced tillage and an early plant cover crop, where total P load reductions of 54% (for a rotation with two years of corn) to 64% (for a rotation with 4 years of corn) are seen from this example field. The impacts of shifting from four years of corn in a corn / hay rotation to two years of corn is shown by comparing Scenario 6 with Scenario 8 (a 42% reduction in P loss) and by comparing Scenario 7 with Scenario 9 (a 27% reduction in P loss).

The impact on P loss of adding a 25 ft buffer to the edge-of-field for each of scenarios 1 – 10 are reported in scenarios 1-B through 10-B. The added benefit of adding a buffer in reducing P losses ranged from a low of 10% for permanent grass scenario to 20% for several of the continuous corn scenarios.

These APEX simulation results reported in Table 3-15 demonstrate that the magnitudes of the P loss predictions across the various agronomic practice scenarios are within reason and are consistent with past modeling efforts in the St. Albans Bay watershed. The results also show relative changes in P losses that are consistent with our conceptual understanding of the conservation benefits associated with these practices. Additional more comprehensive evaluation of the model predictions across a broader range of conditions will be necessary, however this initial analysis provides promising results that give confidence in the capabilities of the APEX model predictions.

3.3. Web Tool Development and Testing

3.3.1. Description of Web Interface Development

3.3.1.1. Application Architecture

The Farm PREP application is built with industry standard web application technologies and strives to avoid vendor specific solutions that might limit its adaptability and scalability. The application is divided into four main pieces: the front-end, the application middleware, the back-end database, and the model running service (see **Error! Reference source not found.**).
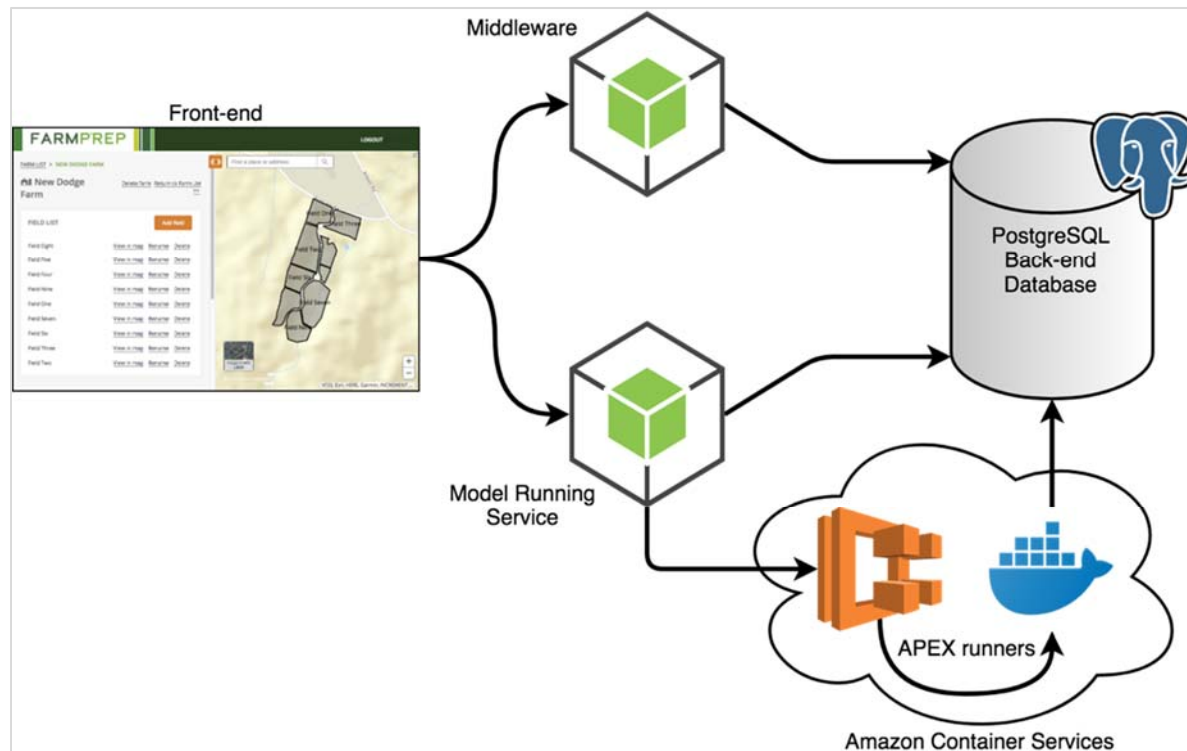
Figure 3-7. Farm-PREP application architecture

The front-end portion is comprised of the code and resources that execute inside of a web browser. The front-end is written in JavaScript, HTML5, and CSS. The front-end relies heavily on the Esri ArcGIS Javascript API, and the AngularJS framework.

The middleware is code that runs on a server and works to provide secure access to the back-end by implementing a RESTful API. The middleware is a web-accessible interface (i.e., you can access it from a web browser or web application such as the front-end) that knows how to interact with the database system. The middleware is written in JavaScript, and runs using the NodeJS engine.

The back-end is comprised of the database system and data, along with the various stored functions that are run inside the database. The database used is PostGreSQL—an open source, database system that has enterprise grade functionality and support. The PostgreSQL database includes an add-on module named PostGIS to add spatial data storage type support, as well as spatial analysis functionality such as buffer calculation, geometric intersections/unions, and more complex interactions.

The model running service is comprised of code that runs on a server that manages both preparing and running the APEX model assessments. The model running service orchestrates several functions to run APEX including remote control of cloud services at Amazon. The model running service presents a RESTful API, like the middleware, that can be accessed via a web browser, and thusly the front-end portion of the web application.

While portions of the modeling service use different languages of development code, the primary application development language is JavaScript—for the front-end, in the middleware, and in the core parts of the model running service. While the database functions are programmed in the PostgreSQL variant of SQL, the database also uses JavaScript object notation (JSON) both for some forms of data storage, and for the SQL function parameters. The broad use of JavaScript throughout the application is important as an architectural choice because JavaScript is the long-running standard language of web development. JavaScript's pervasive use in the world of internet computing means that it is known by a vast number of modern developers, and that its flaws and limitations are constantly exposed and remedied. In addition, it is fairly vendor neutral and does not lead one to platform lock-in as easily as some languages. Therefore, it is expected that the core technologies will not be obsolete for many years.

3.3.1.2. Application Workflow

Users of the application are required to login to Farm-PREP using a secure username and password. Once logged into the application, users have access only to farms, fields, assessments, and results for farms they have created.

Farms are a collection of fields and are created by adding a new farm name and then drawing each farm field on the map. To create the farm fields, the user searches for the field location by address or town name using the location search tool. As fields are saved to the database, several spatial queries are executed. The field boundary is intersected with a 10-meter slope raster and a 10-meter elevation raster to determine the average slope and elevation for the field. The field is also intersected with the SSURGO soils raster to determine the area of each SSURGO mapunit and select the mapunit representing the greatest area on the field. Finally, the weather station nearest to the center of the field is selected to establish the daily weather station for the field.

After field definition is complete, assessments can be created to define each field's inputs. When an assessment is created, the user is prompted to specify an assessment name and the percentage of farm P target reduction. Once the assessment is added, the user is provided with a list of the farm fields and can select which fields to include in the assessment. For each field included in the assessment, the user specifies soil, crop, tillage, manure, fertilizer, and buffer\grass waterway conditions. For soil and slope inputs, the user has the option to accept the defaults determined during the field creation process or enter custom inputs for slope, slope length, and field soil test results for soil P, pH, and aluminum. The user also specifies whether the field has tile drainage.

The crop\tillage\manure panel first prompts the user to select a crop and the number of years the crop is in rotation or if it's a continuous rotation. If the user selects a continuous hay crop, they are prompted to enter the hay cuttings, manure application method, manure application rate, and commercial fertilizer inputs. For corn grain, corn silage, and soybeans, the user is prompted to enter tillage, manure application method, manure application rate for spring and fall operations, commercial fertilizer in the spring, and cover crop variety and planting dates for the fall. When a user selects a rotation with two crops, they provide inputs for each crop. At any time, the user can choose to save their selections and the definition status will indicate whether the inputs are complete.

The user can then optionally complete the section on best management practices which allows for input of buffers and grass waterways on the field. The user is asked for the average width and total length in feet for a buffer and\or grass waterway.

Once all required inputs for a field are complete, the field level definition status will update to "Definition complete: Yes." The user then needs to complete all inputs for additional fields included in the assessment. For each section the user has the option of applying their defined inputs to other fields. This allows for quick field completion where inputs are the same on multiple fields.

After the definition of fields is complete, selecting the "Run Optimization" button will begin execution of the APEX model for current and baseline conditions and for all possible alternative scenarios. The user is returned to the field and assessment list page where the status of the model execution and optimization will display "Running." This status is continually updated and when complete, displays a link to the results page. An email is also sent to the user with a notification that the assessment is complete, and results are ready for viewing. While the execution of APEX simulations was designed to be efficient, it is expected for most assessments, the time required complete APEX simulations will be more than several minutes and could be as long as several hours. The intention is that once a user begins running the optimization simulations, they will come back to review the results of the assessment at a later time.

The results link opens a summary view of the assessment report. The report provides results for each scenario run at the farm-level and at the field-level. The scenarios returned include the results for a baseline scenario, the current conditions input by the user, and then up to ten alternative scenario results that are closest to the P reduction target specified by the user. The results include 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), and P input reduction percentage. These values are presented at the farm- and field-level for each scenario. The user can also view all the inputs for each field, including soils, crop/tillage/manure, and structural BMPs.

It is also possible to compare results and inputs on a field-by-field basis across scenarios by selecting scenarios of interest. The compare button then opens a separate report and displays a map of the fields, as well as a comparison of results and inputs across the selected scenarios for the currently selected field. This view allows users to easily compare what tillage, manure, cover cropping, or structure BMPs are necessary to achieve desired P reductions on a field-by-field basis.

3.3.1.3. Database Design Process

The design of the Farm-PREP database supports both the front-end user interface and the APEX model inputs. The database tables provide lookup values for the front end and store user provided input values. Database functions are used to insert the data into the appropriate database tables, return data to the front-end application, perform spatial queries to determine soils, slope, elevation, and weather stations, format data for APEX input files, and present data to users for reports.

Table 3-16 lists the base layers that store spatial data used in spatial processing to determine field appropriate values as users create farm fields in the front end.

Table 3-16 Spatial layers are used to determine field characteristics used in APEX inputs.

Table Name	Table Description
Slope	Raster of 10-meter average slope used to determine average field slope
Elevation	Raster of 10-meter average elevation used to determine average field elevation

Table Name	Table Description
SSURGO	Raster of 10-meter SSURGO mapunit values used to determine dominant field soil
Weatherstations	Daily weather station table containing latitude and longitude of station location used in determining closest weather station to centroid of field

When users create farms, fields, and assessments in the user interface, data is inserted into database tables listed in Table 3-17. The database maintains the relationships between these tables. Fields cannot be added to the database without first creating a farm, when a field is added to a farm it is simultaneously added to all existing assessments so that it is available to include if an assessment is rerun. When a field is removed, all assessments and assessment fields are removed from the database. If a user chooses to delete a farm, all fields and assessments related to that farm are removed.

Table 3-17. List of tables that store user input from user interface.

Table Name	Table Description
farms	Stores the farm name and userid of user created farms
fields	Farm fields including field name, geometry (spatial attributes), slope, slope length, elevation, soil, and elevation
assessments	Assessment name, farmid, processing target, processing status, and parameters updated after assessment is submitted for processing including average elevation, latitude and longitude of center of all included fields, monthly wind and weather station IDs.
assessmentfields	Contains all soil, crop, tillage, manure, fertilizer, cover cropping, and structural bmps input by user for the assessment. Also stores the operation schedule ID which is determined once above inputs are selected and field inputs are complete.

The options available on user input forms on the assessment details page are stored in the backend database tables listed in Table 3-18. These tables limit user options for crops, years in rotation, tillage type, manure application method, cover crop species and planting date, and number of cuts. As users save their selections, database functions determine which operation schedule has been selected for each field.

Table 3-18. List of tables that provide lookup values used by front end.

Table Name	Table Description
Lurotations	Provides crop and year options to user in selection of rotation
luopsschedules	All possible operation schedules available for selection from the application. Provides possible input options for Tillage, Manure Application Method, Cover Crop Variety, Cover Crop Planting Date, and Number of cuttings

When a user selects "Run Optimization" to submit their assessment for processing, a record for the simulation round representing baseline and current conditions is inserted for each field into inserted into a "runs" table to keep track of the processing. The "runfieldops" table tracks the run, the field, and the selected operation schedule. When additional simulation rounds are necessary to achieve the farm target P reduction percentage, the database function is executed to insert new run records and determine additional operation schedules to apply to fields. Additional tables listed in Table 3-19 provide additional input values to the APEX model.

Table 3-19. List of tables involved in execution of APEX and optimization script.

Table Name	Table Description
runs	Stores a record for each field and simulation round being run in the assessment
runfieldops	Contains a record for each operation schedule id being applied to a field in each run
Luopsmanagement	Management records used to generate APEX OPS files for each of the operation schedule ids
Lusoilcomp	SSURGO soil component data attributes selected based on the dominant field soil
Lusoillayer	SSURGO soil layer data attributes selected based on the dominant field soil
Def_run	APEX specific table used to define format of APEX run file and default values
Def_site	APEX specific table used to define format of APEX site file and default values
Def_subarea	APEX specific table used to define format of APEX subarea\field file and default values
Def_ops	APEX specific table used to define format of APEX operation schedule file and default values
Def_soil	APEX specific table used to define format of APEX soils file and default values

A series of database functions that return the APEX input data are called from a python script that writes the APEX input files for each APEX run. As APEX and the application optimization script are executed, results are returned to the database. When each APEX run completes, field results are inserted to the database. After the initial baseline and current scenario simulation round, farm results are inserted into to the database. The farm and field-level P loss values are then passed to the optimization script, previously described in Section 3.2.4. As the optimization script runs at the end of each simulation round, the combinations of field operation schedules that achieve the desired P loss reduction target are inserted into the results rank table.

Table 3-20.List of tables invlved in managing APEX optimization results.

Table Name	Table Description
runfieldresults	When an APEX run completes, field results for selected output parameters are inserted into this table
runresults	Farm level results for each round including percent reduction from current and baseline scenarios
resultsrank	Used by the optimization script to store the combinations of fields and operation schedules that achieve target P loss reductions

The Farm-PREP reporting module then combines inputs from the user inputs and operation schedule reference tables with results from APEX model runs and the optimization script to return a farm scenario comparison report and a field level comparison report.

3.3.1.4. User Interface Design Process

The Farm-PREP user interface was designed to be intuitive and efficient to use for running farm-level APEX simulations. The APEX model contains a vast number of input options to parameterize the land

characteristics and management practices associated with a farm. When all of the APEX model's input options are available to the user to define, that task of setting up a model simulation quickly becomes daunting. In addition, exposing many model inputs to users greatly increases the potential for an erroneous model setup with parameterization that can lead to incomplete model simulations or incorrect model results. These errors can be difficult to diagnose for the inexperienced APEX user. Based on past experience developing APEX user interfaces, we took an approach that resulted in a tool that collects the most important aspects of a farm's field conditions and operations that impact potential P loss, but does not overwhelm the user with too many data requirements. Taking this approach required that many of the APEX model inputs be developed and stored within the Farm-PREP database, as discussed in previous sections, and that the interface be largely driven by menu selections.

The design of the interface was arrived at through a process that involved both the project PAC and a sub-group of stakeholders that provided additional guidance. The initial layout and workflow of the interface was developed as a set of wireframes, which are a visual schematic for the design and navigation of websites. The Farm-PREP wireframes were initially designed to accommodate the APEX model inputs requirements that were arrived at through consultation with our UVM Extension and crop consultant partners. Following the December 2017 PAC meeting, a sub-group was organized to provide more extensive feedback on the interface design. The sub-group met on several occasions between the December 2017 and April 2018 PAC meeting. The wireframe design was then presented to the project PAC during the April 2018 meeting, where additional feedback and recommendations were provided. Following this PAC meeting, application design was finalized through collaborations with our UVM Extension and crop consultant partner from ACS. Involving the end-users of the Farm-PREP tool in the design process ultimately led to an interface that served the needs and met the workflow expectations of the intended users.

3.3.1.5. APEX Execution and Optimization

The APEX model running system was designed with a goal of allowing many users to execute APEX simultaneously with no impact on each other, and to also make it possible for this system to scale-up as more users started using the system. Further goals were to allow the model running system to be extendible and configurable, at least as much as possible, from the database back-end, and to allow the model runs to be executed on one, or many servers. To achieve this set of goals, we built a system that used a core RESTful web service to interact with the web application as a model-run 'job manager', internally named mPipe for model execution pipeline (see Figure 3-8).

APEX assessments are processed as "jobs" in the model pipeline. A job is defined as a series of stages of execution, each of which does a different discrete part of the processing. Some stages may initialize inputs, some may prepare output locations, some may do pre-processing for APEX, and some may do clean-up tasks. Within the database, the stages are assigned to a particular "pipe" such as the "APEX Optimization," and given a unique order of execution within that pipe. When a "pipe is run" it means that each stage of the pipe is executed in order, and that the next stage is not started until the previous stage is complete.

The mPipe server—the server that provides the model running capability—is running two services: a job manager, and a job runner. The job manager is used by the web application to start new jobs, list running jobs, and get the status of jobs. The job runner service watches the database for updates to the jobs table, and when it sees a new job has been added, it starts taking the various steps needed to run the job.

When a job is submitted, an assessment ID is passed from the front-end code, along with the user's e-mail, and which "pipe" to use, to the job manager's "submit job" function. The submit job function then inserts that information as a new record into the database's jobs table. Meanwhile, the job runner service is watching the jobs table in the database for "insert" actions. When it sees one, it fetches the list of stages that are defined for the pipe named in the job record, and follows the instructions defined for each stage.
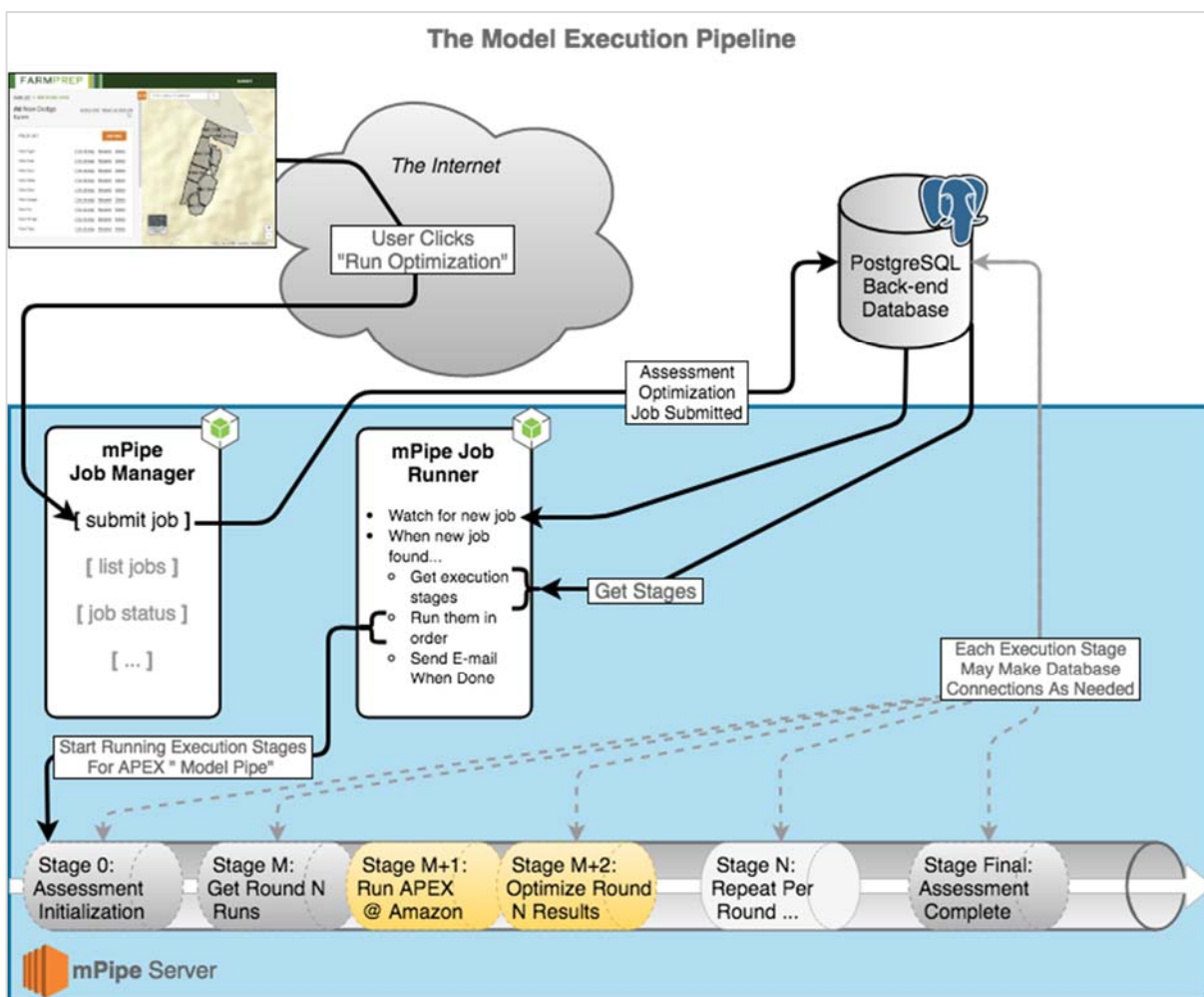
Figure 3-8. Farm-PREP model execution pipeline.

As each stage executes, the output of the stage is recorded in various ways. A stage is free to interact with the back-end database and may both retrieve inputs from the database, and store outputs to the database for use by future stages. Some stages generate console output that is stored to the job record and passed forward to the next stage. Finally, each stage is expected to exit using the standard exit code protocol, expressed as a JSON object. All stages in a pipeline will be executed no matter what happens with previous stages, so if a previous stage fails, an exit code indicating error will be passed to the next stage. Depending on how error handling is programmed in subsequent stages, the next stage may skip processing or perform job cleanup duties.

Some of the more computationally expensive stages, like running APEX and optimization, make use of Amazon's Elastic Container and Docker services to move processing off the web server and onto additional

server resources at Amazon. These stages will use one or more "containers", which are low-resource virtual computing templates, for parallel processing.

The original issue of efficiently running the APEX model "on the web" is resolved through scripted automation used by Farm-PREP. With the thoughtful use of cloud-based parallel computing, Farm-PREP's optimization modeling system is both well suited for growth in the use of the application, as well as more complex modeling approaches which make even wiser use of the vast cloud computing resources available today and in the future.

3.3.2. Farm-PREP User Guide

The Farm-PREP application has been designed to be an intuitive and user-friendly application for using APEX model simulations to help guide the adoption of farm management practices aimed at achieving reductions in P losses. This section of the report will walk through the user interface, following of the steps required to conduct a farm assessment.

Step 1: Access the Farm-PREP application at https://farmprep.net with the secure username and password provided. After entering a valid username and password, select Login (see Figure 3-9).
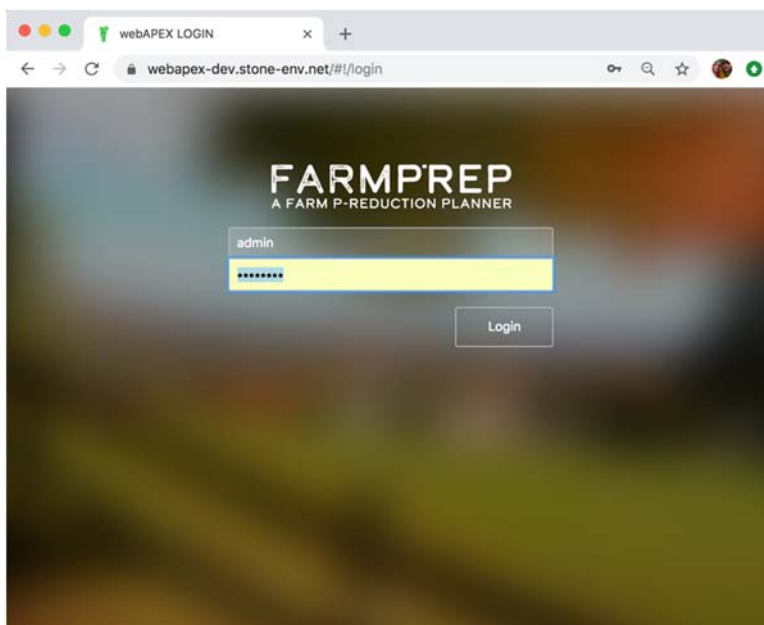
Figure 3-9. Farm-PREP login page.

Step 2: Once successfully logged in, select Add Farm, provide the farm with a name and select ADD (see Figure 3-10).
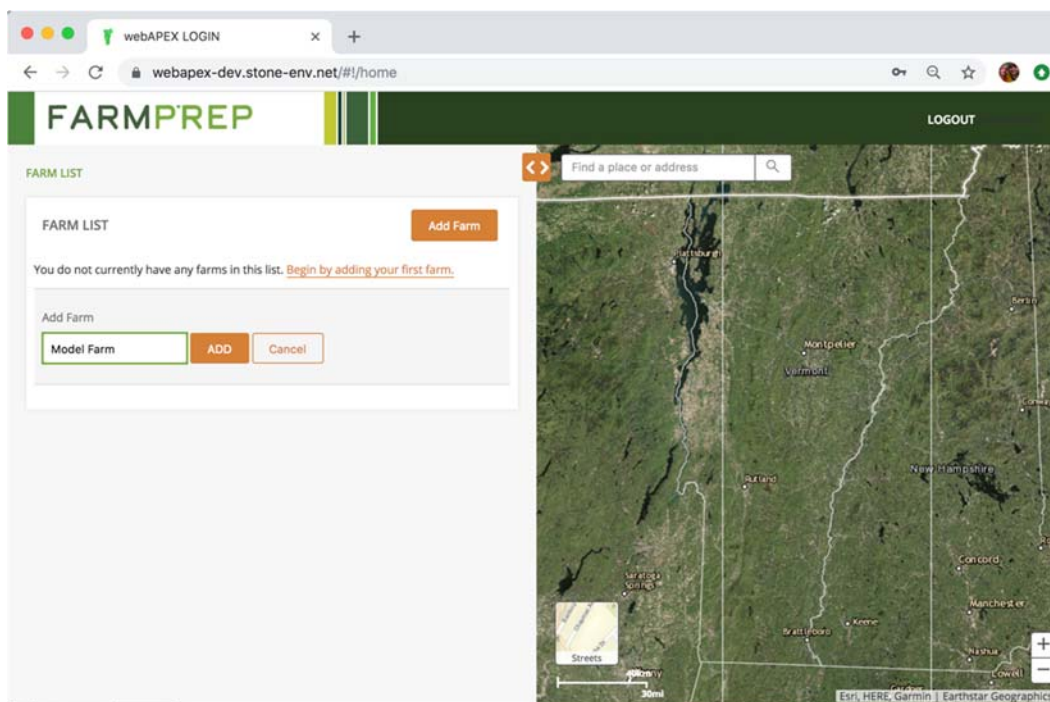
Figure 3-10. Add a new farm.

Step 3: Once the farm is created, the display will update to the field and assessment list page. Zoom to an area of interest and begin adding fields by entering an address or town name in the search box to locate the fields (see Figure 3-11).
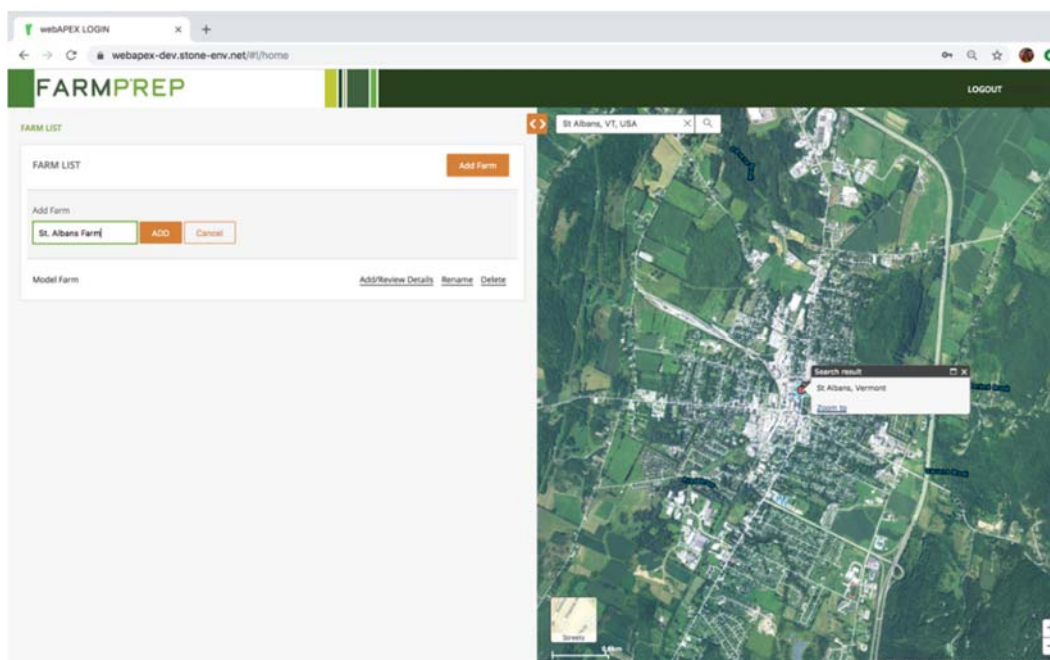
Figure 3-11. Zoom to an area of interest.

Step 4: Begin adding fields by selecting "Add Field", provide the field a name and follow the instructions provided to draw the field outline. To finalize the field creation, select "Add" and the field will be displayed on the map and inserted into the database along with the field's dominant soil, average slope and elevation, and closest weather station. There is also the option to "Cancel" creation of the field before selecting "Add" (see Figure 3-12**Error! Reference source not found.**).
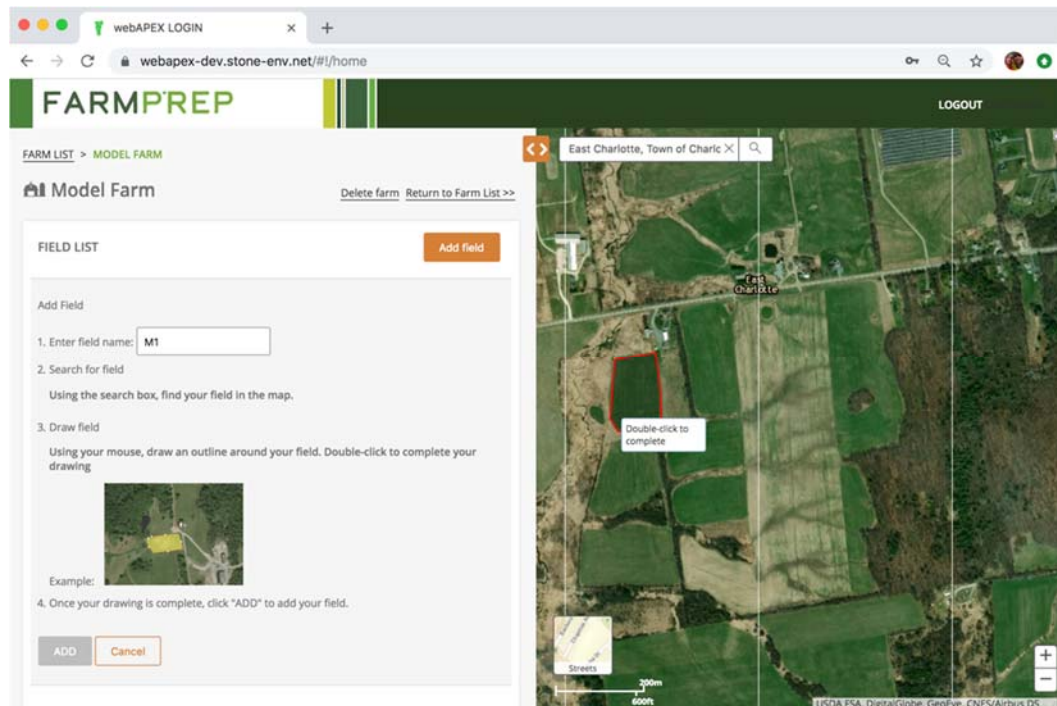
Figure 3-12. Add a new field.

As fields are added they will be listed on the left under "Field List" and displayed on the map with the field names added. If a field is not within the current map extent, select "View in map" to adjust the map extent to bring the current field into view. Fields can also be renamed by clicking the "Rename" link or deleted by selecting "Delete" (see Figure 3-13).

Note: if a field is deleted after an assessment has been created, any assessment that include the field being deleted will also be deleted.
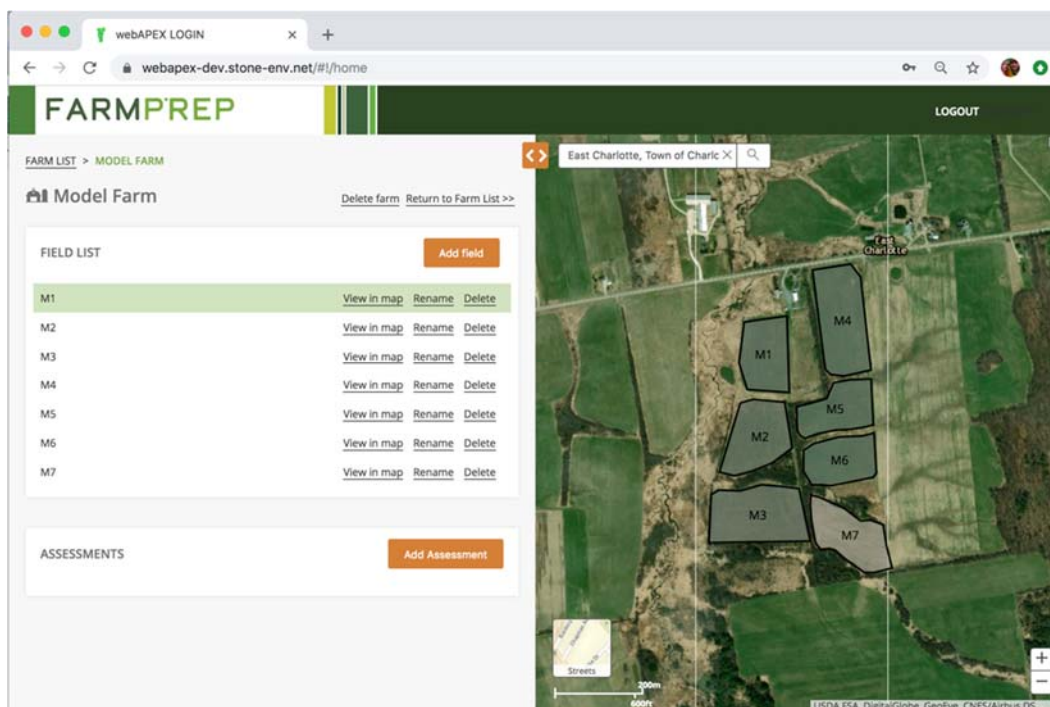
Figure 3-13. Fields can be deleted or renamed from the field list.

Step 5: After all fields have been added, create an assessment by selecting "Add Assessment." Enter an Assessment Name, Target P Reduction % and select "Add" (see Figure 3-14). To run an assessment with only current and baseline conditions (no optimization of agronomic practices), enter a Target P Reduction of 0%.
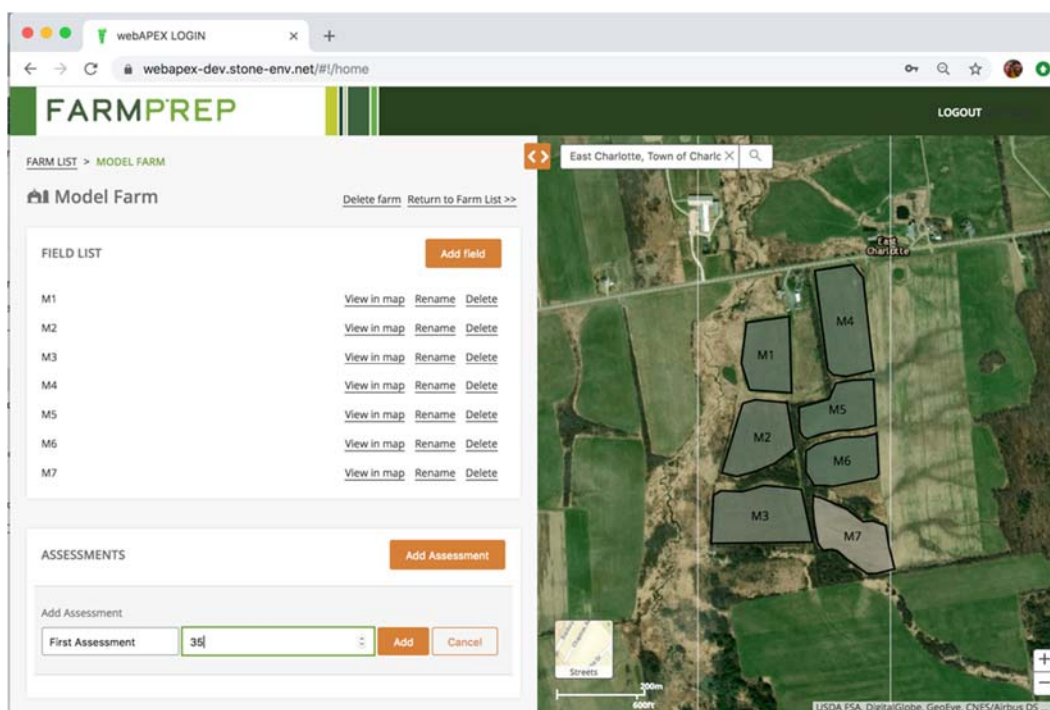
Figure 3-14. Add assessment.

STONE ENVIRONMENTAL

Step 6: After adding the assessment, the Assessment Details page will open with a listing of all fields and entry forms for soils, crop\tillage\manure, and structural BMP data. By default, all fields are included in the assessment. To include fewer fields, uncheck the "Include" check box next to a field (see Figure 3-15).

Figure 3-15. Assessment details page.

Step 7: Expand the soils panel to review default slope and soil values provided by the spatial processing results. Slope and slope length values can be modified if actual field measurements have been taken. It is also recommended that actual Modified Morgans soil P test results are entered. Only the pH value is determined from the SSURGO data; the Soil P of 5 ppm and Aluminum of 50 ppm are default values used for all soils. At the bottom of the form there is an option available to specify tile drainage on the field. Save inputs by selecting "Save and close" or "Cancel" to discard changes (see Figure 3-16).

Figure 3-16. Soils panel.

Step 8: The crop/tillage/manure information panel allows for input of field specific rotations and operations. Options in the dropdown boxes will automatically update as selections are made. Selecting grass hay, legume hay, or alfalfa mix returns an input box for the number of cuttings, manure application method and rate, and commercial fertilizer rates. After completing required fields and selecting "Save and close" the status of the data entry for this section will update from "Incomplete" to "Complete" (see

Figure 3-17). The manure application rate is represented in pounds of P2O5 per acre per year, and it is assumed that this amount is split equally over multiple applications, each occurring after cutting.

Figure 3-17. Crop/tillage/manure information panel.

Selecting corn grain or corn silage, presents the option to select the number of years in the rotation and selection of a second crop such as hay or alfalfa (see Figure 3-18). The tillage practices options are determined by the crop type and are set in the back-end database. Manure applications can be made in the spring and/or fall with the rates specified in terms of pounds of P2O5 per application.

Figure 3-18. Input forms for a two-crop rotation.

Step 9: Expanding the Best Management Practices panel displays options for entering buffer and grassed waterway dimensions for the field. By default, these options are set to indicate no buffers or grassed waterways. When details of a buffer and\or grass waterway are added, select "Save and close" and the status will change from "Optional" to "Complete" (see Figure 3-19).

Figure 3-19. Form for entering buffers and grass waterways.

Step 10: At any time when entering field information on "Soils", "Crop/Tillage/Manure Information", and "Best Management Practices", Farm-PREP provides the ability to apply those same inputs to multiple fields on the farm. This can be very useful when crop rotations and management practices are the same on multiple fields, or if you want to use those practices as a starting point. The icon in each of the sections that indicates you can to apply current field information to multiple fields looks like:

As an example, In the "Crop/Tillage/Manure Information" section, the icon is found at the top line of data where the first crop in the rotation is specified. When the icon is clicked, a window will open to allow you to select which fields to apply the information to as shown below in Figure 3-20. This action will copy all information for the given section of inputs to the selected fields.

Figure 3-20. Apply inputs to selected fields tool.

Step 11: After information has been entered for all fields, each field will display "Definition complete: Yes" and the "Run Optimization" button will be enabled (see Figure 3-21).
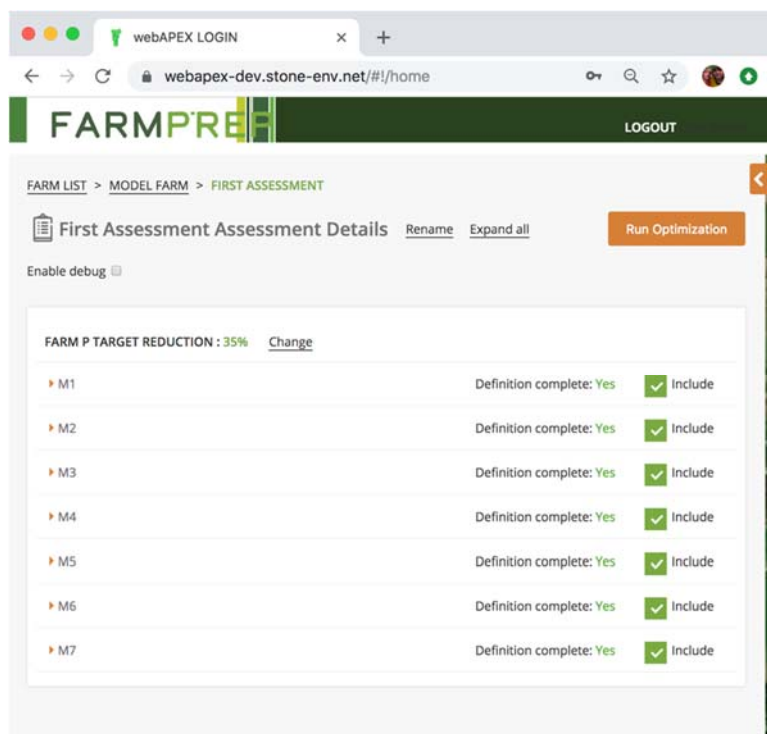

Figure 3-21. Field definition is complete, and the assessment is ready to run.

To begin processing of the APEX model and the optimization routine to determine farm best management practices that will achieve the desired Farm P Target Reduction, select the "Run Optimization" button. You will be returned to the Field List and Assessment List page and the status of the assessment just submitted will indicate "Running" (see Figure 3-22).
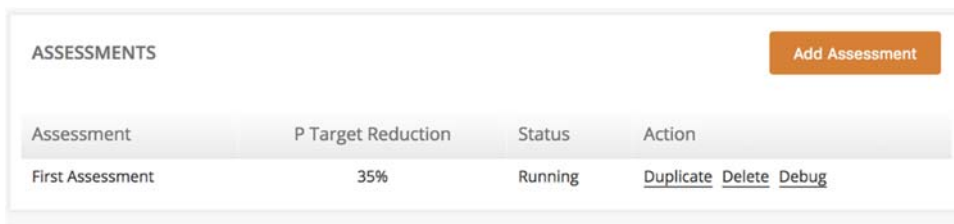
Figure 3-22. Assessment status is "running" when APEX is executing.

Step 12 (Optional): The user has the option at this point (or at any time) to select "Duplicate" to copy the assessment, enter a new name, and run the new assessment with modified inputs or a different target (see Figure 3-23). After an assessment is duplicated, it can be renamed from the assessment details page with the "Rename" button or modify the Farm P target with the "Change" (see Figure 3-21).

Step 13: Once the assessment has finished processing, the Status will update to "Complete" and provide a link to the results. Click "Results" to open the assessment report (see Figure 3-23).

Figure 3-23. The "results" link is displayed once the assessment is complete.

The Farm-PREP report includes simulation results from the baseline and current farm scenarios and the top ten farm solutions that fall within a 5% tolerance of the target P reduction from the baseline (Figure 3-24). If the current farm practices already exceed the target reduction from baseline, the report displays solutions within 5% of the reduction achieved with current conditions. Scenarios names provide a summary of the total number of BMPs applied across all fields on the farm. For this reason, the scenario names are not unique, as different combinations of practices across fields can occur. The ten alternative solutions are numbered 1–10, ordered by the percent total P reduction from baseline. This approach for naming scenarios provides the user with an indication of the type and frequency of alternative practices that led to a solution that met the target farm-scale P reduction.

The report output includes at both the farm and field level, the 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), and P Input Reduction (%).

Figure 3-24. Farm-PREP report summary view displaying farm level P reductions and P concentrations.

Step 14: To display field level results, expand the results by clicking the arrow next to one or more scenario names (Figure 3-25). This makes it possible to see which field Total P changed from current conditions (where Total P Reduction from Current (%) > 0) or baseline conditions (where Total P Reduction from Baseline (%) > 0).

Figure 3-25. Expand farm scenario results to view field level results.

Step 15. To view a field's specific inputs for the currently selected solution, further expand the field details by clicking the arrow next to one or more field names. For example, in Figure 3-26 soil, crop\tillage\manure inputs for the 4 year corn silage \ 4 year alfalfa mix rotation. soil, crop\tillage\manure inputs for the 4 year corn silage \ 4 year alfalfa mix rotation.

Figure 3-26. Expand a field to view field details for that particular scenario.

Step 16. To further compare inputs and results across multiple scenarios at the field level, select the check boxes for scenarios of interest at the far right and then select "Compare" (see Figure 3-27).

Figure 3-27. Select multiple scenarios and the "Compare" button to compare results at the field-level.

Step 17. To review results one field at a time, select a field from the list on the left or from the map view (see Figure 5-28). As the field selection changes, the results below will update. The layout for the field comparison report transposes the data viewed on the full report page with the input and output parameters on the left, scenario names across the top and results beneath each scenario.

Figure 3-28. Field comparison report. Select a field name or field from the map to update the results displayed.

This view makes it easy to see how the scenarios differ for the selected field impact the P loads. In the case of field M2, scrolling down in the report reveals that the three alternative scenarios have a change in fall tillage on Corn Silage from Reduced with Incorporated manure to No tillage with surface applied manure (see Figure 3-29). The current and alternative scenario also had a winter hardy cover crop planted on October 15th. We see from Figure 3-29 that in "Current" practices, the cover crop resulted in a 25.36% reduction in total P relative to "Baseline" conditions, which had no cover crop. The additional changes from a spring "Conventional and Recued" tillage to a "Reduced" tillage and from a fall "Reduced" tillage to "None" (no till) resulted in an additional 14.83% in total P load reduction. In the results for the example field shown (field M2), the management practices are the same for all 3 alternatives displayed. Because these represent different farm-scale solutions, we would find that differences exist across these farm scenarios on different fields.

	Baseline	Current	1 - 3 Tillage\5 Cover\1 Buffer	2 - 3 Tillage\5 Cover\1 Buffer	4 - 4 Tillage\5 Cover\1 Buffer
Total P Reduction from Baseline(%)		25.36	36.43	36.43	36.43
Total P Reduction from Current (%)		0	14.83	14.83	14.83
Total P (lbs/ac)	2.8	2.09	1.78	1.78	1.78
Soluble P (lbs/ac)	0.88	0.85	0.64	0.64	0.64
Sediment P (lbs/ac)	1.92	1.24	1.14	1.14	1.14
Tile P (lbs/ac)	0	0	0	0	0
P Input Reduction (%)	0	0	0	0	0
Crops/Tillage/Manure					
Crop	Corn silage: 4 years	Corn silage: 4 years	Corn silage: 4 years	Corn silage: 4 years	Corn silage: 4 years
Tillage	Conventional and Reduced\Reduced	Conventional and Reduced\Reduced	Reduced\None	Reduced\None	Reduced\None
Row Crop Spring Manure Application	None	None	None	None	None
Row Crop Spring Manure Rate (lbs P_2O_5/ac)	--	--	--	--	--
Row Crop Fall Manure Application	Incorporated	Incorporated	Surface	Surface	Surface
Row Crop Fall Manure Rate (lbs P_2O_5/ac)	54	54	54	54	54
Cover Crop	None	Winter hardy cover crop	Winter hardy cover crop	Winter hardy cover crop	Winter hardy cover crop
Cover Crop Planting Date	None	Late - by 10/15	Late - by 10/15	Late - by 10/15	Late - by 10/15
Crop 2	Alfalfa mix: 4 years	Alfalfa mix: 4 years	Alfalfa mix: 4 years	Alfalfa mix: 4 years	Alfalfa mix: 4 years
Hay Cuttings per Year	4	4	4	4	4
Hay Manure	Surface	Surface	Surface	Surface	Surface
Hay Manure Rate (lbs P_2O_5/ac-yr)	50	50	50	50	50

Figure 3-29. Comparison of field level AEPX model results and inputs among scenarios.

At the top right of the field comparison report it is possible to return to the full report by selecting the link "Back to full results." There is also a link to return "Home" to add a new farm or select a different farm.

3.4. Farm-PREP Application to Pilot Farm

3.4.1. Objectives

The application of the Farm-PREP tool to a farm in the St. Albans Bay watershed was designed to serve several objectives. The first objective was to evaluate whether the design and workflow of Farm-PREP was intuitive and efficient for the target user (in this case, a crop consultant) to provide the necessary information on their farm. The second objective was to identify if there were any gaps in the options provided by Farm-PREP that prevented the user from accurately representing the management operations on their farm, and if gaps did exist, identify what those gaps were. The third objective was to determine if the P-loss simulation results provided by Farm-PREP offers enough information to help in the decision-making process for identifying management strategies that meet water quality targets. The fourth and final objective was to begin evaluation of the relative magnitude of the field and farm-level P losses and reduction in losses resulting from alternative practices. The fourth objective will be addressed in much greater detail as part of an upcoming LCBP grant focused on calibrating and validating the APEX model with edge-of-field and tile drain monitoring data from Vermont fields.

3.4.2. Overview of Pilot Farm

The Pilot Farm was a conventional dairy farm located in the St. Albans Bay watershed and was representative of other medium to large dairy farms in the area. All field data, except for anonymized shapefiles for field boundary establishment, was held by the cooperating technical service provider. The farm was composed of nearly 60 fields, however to simplify the process and be respectful of the cooperators time, a subset of 13 fields was selected for the test run. The 13 fields were composed of approximately ten fields on heavy clay and three fields on a lighter soil, where fields ranged in size from a few acres to over 80 acres. Cropping on the farm was a mix between continuous corn, corn silage and hay in rotation, and corn silage and alfalfa in rotation. The Pilot Farm was comprised of both tile drained and undrained fields, and a mix of BMPs and conservation practices.

3.4.3. Farm Inputs

Farm inputs for the Pilot Farm fields were derived from the planning records of the cooperating technical service provider. Unique values of Soil Test P, Aluminum, and pH were all used to replace the default values pre-populated in Farm-PREP. The average slope of the field obtained through field measurement by the technical service provider was also used in place of the pre-populated valued in Farm-PREP obtained from the DEM. The field-measured value was assumed to be more representative of the actual field slope. Cropping records were then used to input the primary crop for each field, including the years of rotation in that crop, the years of rotation in the secondary crop, and average number of cuttings (for hay and alfalfa). Fields on this particular farm are typically rotated every four years between corn silage and grass hay or alfalfa. Planned spring and fall tillage practices were specified. Manure application methods (and whether it was incorporated) were input for the spring and fall, as well as typical P application amounts for each season. If supplemental nitrogen (i.e., commercial fertilizer) was used, this was also specified, along with the rate. Cover crop usage, and type (e.g., winter hardy), was selected for the field if they were part of the cropping plan while the field was in the corn silage rotation. Fields on the lighter soils typically were planted with a cover crop, while the heavier soils were not. Finally, average buffer width and total length were input. These were shown on the technical service provider's software, so measurements were made external to Farm-PREP and results were input. No vegetated waterways were present on the Pilot Farm, so these were not included in the sample run.

3.4.4. Simulation Results Summary

For the modeled Pilot Farm, the Current scenario (i.e., what is actually happening on the farm) had a 18.5% reduction from the Baseline scenario (i.e, no BMPs or conservation practices). A 35% reduction from Baseline scenario was also modeled, and various field management options were produced whose output met the targeted 35% reduction. This 35% reduction scenario resulted in a 20.2% reduction in P loss vs. Current scenario. Simulated changes in management included addition of cover crops on some fields, changes in methods of manure application (e.g., incorporation), and adoption of reduced or no-till practices. In general, the suite of proposed changes on the Pilot Farm to meet the 35% reduction were reasonable, but would be dependent upon the farm's resources, as further discussed below, along with more detailed feedback in the simulation output.

In general, it was clear what changes were made in respect to field operations and addition/removal of BMPs. In addition, the presentation of the actual modeling results was clear. It was simple and straight-forward to move between viewing the results for various scenarios. The output clearly states what the percent P reduction is, from the 'Baseline', and from the 'Current' farm (i.e., Pilot Farm with actual BMPs, at a % P reduction target greater than zero). The total P, soluble P, sediment P, and tile P are all given on the first page of the results, and then the user can look at results for individual fields, and go to a 'Compare' page, which shows a single fields results side-by-side between two scenarios (and the field highlighted on a map). All these features made it very easy to navigate results. Overall, the tool shows the necessary information and avoids presenting superfluous data.

We found that the farm management options that met the P-reduction targets were somewhat helpful for making management changes, but the presentation, or organization of the changes that were made in each option could be improved. For example, we needed to open each individual field and investigate it separately in order to determine what had changed in the management. A summary table would be helpful that described what particular management change was made on what field. Perhaps it is possible to do something like that the title of the management option, but their current names are not descriptive of the changes that were made. We also noticed that there were instances where conservation practices were removed in the farm options (while others were added), and we recommend that no conservation practices be eliminated from the 'Current' farm for developing the farm management options. Some guidance from the user would also be helpful for determining what conservation practices have the highest probability of being adopted by the farmer based on current equipment availability or available resources to purchase or custom hire certain operations, so that these can be included as priorities in the farm management options selected.

The relative reductions of phosphorus loss when BMPs were applied seemed reasonable in general. These reductions should likely be compared to actual EoF data, or at least data found within the literature in order to better understand where they fall in the range of reported values.

Usability was tested, but the tool was not used on an entire farm (i.e., every field managed by the farm, and receiving manure from the farm's cattle), when all the manure produced by an operation would need to be accounted for. Performing a test on a Pilot Farm and using the entire amount of manure generated would then allow us to evaluate the 'P Input Reduction' output, and if that value can be kept low, or at zero, just through the implementation of conservation practices and BMPs. This is an important next step.

3.4.5. Feedback and Recommendations from Pilot Farm Application

The cooperating technical service provider and collaborating UVM Extension faculty who performed the testing of the Pilot Farm in Farm-PREP have provided the additional feedback, along with specific suggestions for future improvements of the tool below. These suggestion and feedback, along with those from

broader testing and evaluation as part of Phase 2 of this project, will guide the next steps in Farm-PREP's development.

The Farm-PREP tool was very intuitive and easy to use. Input and navigation was straight-forward and a pleasure. We quickly became comfortable with using it after performing input for just one or two fields. The remaining fields all flowed smoothly.

For the most part, the tool provided the necessary input options necessary to describe the field operations on the Pilot Farm. The primary concern we had was the lack of the ability to control whether manure would be applied during every year of a rotation. For example, when in a four-year alfalfa rotation, our farm would not apply manure in Y1 and Y2 to avoid damaging the crowns, but would then go back and apply in Y3 and Y4. We expect this can be addressed in revised versions and was just a simple oversite in the pilot version.

In general, the level of effort/time required to provide all the necessary information to the tool is reasonable. It is easy to input, but it does take time to move around the mouse and click on boxes as much as we did. Suggestions for improvement are detailed in a separate document, but include the two key recommendations below:

- *Pre-populate as much data as possible by pulling it from the shapefile already created by the technical service provider for nutrient management planning purposes (pH, STP, Al, slope, etc.)*
- *Set up a screen with all the fields listed and columns where the soil and field info can all be input together for every field. Then do the management and BMP info on a field-by-field step process. This would limit the use of the mouse and streamline the data entry process.*

The model-predicted trends in P losses were generally sensible (see discussion above). There were, however, some instances where the trends associated with the presence or absence of buffers was not as expected and should be further investigated.

We discussed once again the fact that the P loss estimates produced by the Farm-PREP tool were from the edge-of-field, and did not represent what amount of that P would ultimately make it to a water body. This is a concern and we recommend it be addressed in future work.

4. Quality Assurance Tasks Completed

The following represents a summary of the quality control tasks completed during this study.

4.1. Quality Review of Data Collected

The project QAPP outlined that data compiled for use in the Farm-PREP tool would be reviewed for suitability and checked for accuracy in cases where transfer or transcription into a database used by the tool were required. Several datasets that were used in Farm-PREP tool required this review.

4.1.1. Precipitation and Temperature Time Series Database

The precipitation and temperature time series database for the state of Vermont was obtained from BREC (see Section 3.2.2.1). This database was obtained in "APEX ready" format for direct use in the model. To assess the suitability and accuracy of these data, summary statistics were generated for precipitation, minimum temperature, and maximum temperature. The results of these summary statistics were reviewed to look for potential outliers in the dataset. In addition, groups of stations within close proximity of one another were examined to look for similarity. The occurrence of missing days of data in the time series was also reviewed, to determine if some stations should be removed from the dataset (note that when days of data are missing, APEX estimates a value from local climate statistics). This evaluation determined that there was nothing unusual regarding the dataset and that it could be used in its entirety with the Farm-PREP tool.

4.1.2. Soil Database

The soils database used in the Farm-PREP tool to determine soil properties of fields simulated with APEX was extracted from the NRCS SSURGO 2017 dataset (see Section 3.2.2.3). In addition to the spatial data, parameters from the SSURGO tabular database were extracted and translated into the Farm-PREP soils database for use in parameterizing the necessary APEX model inputs. The cross-walk between the SSURGO soils parameters and the APEX soil inputs within Farm-PREP were checked for accuracy and consistency between the two datasets.

4.1.3. Farm Agronomic Practices

The determination of farm agronomic practices required to develop APEX model operation schedules required that the types and dates of operations (planting, tillage, fertilizer, manure applications, harvest) be specified. These agronomic practices were developed in collaboration with UVM extension faculty and our crop consultant collaborator. The final compilation of agronomic practices used to build the APEX model operation schedules was checked for by the UVM extension faculty.

4.2. Model Parameterization

The primary activities concerning quality assurance of the APEX/Farm-PREP model parameterization are described in the following sections.

4.2.1. APEX Model Inputs

The APEX model inputs used in the Farm-PREP application were described in Section 3.2.3. These parameters were set as either fixed parameters within the model database or derived from user inputs to the model specific to individual fields and farms. These parameter values and the logic required for derived values were compiled in Excel spreadsheets and translated into the Farm-PREP database. This translation and the resulting APEX model inputs files were reviewed for accuracy.

4.2.2. APEX Model Operation Schedules

The determination of farm agronomic practice options (described in Section 4.1.3) set the foundation for creating APEX operation schedules. Covering all possible combinations of practices required the creation of 173,544 unique APEX operation schedules. These schedules were built through a series of database processes conducted in the Farm-PREP database. Reviewing these operation schedules for accuracy was conducted through a series of database queries designed to determine if the correct operation dates and operation types were occurring for each possible crop rotation. Once the review of operation schedule within the Farm-PREP database was completed, the translation of operation schedule inputs from the database to APEX inputs files was checked for accuracy.

4.2.3. Field Level APEX Simulation Results

Testing of the APEX model was conducted to check that the model inputs being generated by the Farm-PREP database and tool were generating reasonable results for different field management practices. This evaluation was conducted both through the Farm-PREP tool directly, as well as off-line. This testing did not include comparison of results with monitoring data and was not intended to be exhaustive of all possible scenarios, but was rather intended to consider if the results fell within expected ranges based on previous work, such as the results from TMDL modeling (Tetra Tech, 2015a). Results from this internal review of the APEX simulation results was reported in Section 3.2.5 of this report, and were found to be consistent with TMLD modeling and follow expected trends across management practices.

Partway through this testing process, some unusual results from the model were identified as fields of widely varying sizes were evaluated. Through direct collaboration with the APEX model developers at BREC, it was determined that a "bug" had been identified in the model that required correction. The version of the APEX model (version 1501) being tested for use in Farm-PREP was the most recent upgrade from the publicly distributed version, and our analysis had uncovered an issue that required correction. Coordination with the model developers at BREC resulted in the release of an updated model version which corrected the error that had been identified and produced results consistent with both previous APEX model releases and with expectations. This is a typical process in the development and release of new model updates. Discussions in the report regarding model simulation results on the pilot farm are reflective of the updated APEX model release.

Field level APEX simulation results from Farm-PREP applied to a 13-field farm were reviewed by UVM extension faculty and the cooperating technical crop consultant as part of the pilot farm analysis reported on in Section 3.4. The fields simulated in this farm analysis included a variety of crop rotations and agronomic practices. The magnitudes and trends in P loss predictions were deemed reasonable overall. The review did observe that some results, when edge-of-field buffers were involved, did not agree with expectations and should be further investigated. This issue identified during the pilot farm testing will be addressed thoroughly during the upcoming Phase 2 component of the Farm-PREP development and implementation project.

4.2.4. Farm Level Optimization Results

The farm level optimization process in Farm-PREP identifies combinations of field practices across a farm that results in a reduction in total P loss that is as close to the specified target reduction as possible. This requires the execution of potentially thousands of APEX simulations and subsequent evaluation of the output based on the many combinations of fields and field practices. Internal checks of the aggregating of field-level results to farm-scale results were made to ensure that the analysis was identifying solutions that correctly met the target P loss reduction, within a tolerance of 5%. The results determined by the application "back-end" optimization module were then also checked for consistency with the post-processed results reported through the "front-end" user interface of the Farm-PREP application. These results were verified to be consistent.

The results of the farm P optimization module were also reviewed as part of the pilot farm evaluation described in Section 3.4. The farm level optimization was found to result in modification of operations to include a range of management practice alternatives, including reduced tillage and more extensive cover cropping. These recommendations were considered sensible overall. The pilot farm testing also noted that for some of the farm practice scenarios proposed, conservation practices that had been implemented on a field under "current practices" had been removed. This observation, while not an error in the optimization module, is something that could be changed in the logic of the optimization module. This observation from peer review of the optimization results is a topic that will require further vetting and discussion as the development of Farm-PREP moves forward.

4.3. Farm-PREP Tool Development

The primary activities concerning quality assurance of the Farm-PREP tool user interface are described in the following sections.

4.3.1. Stakeholder Involvement

Throughout the Farm-PREP application development process, a UVM Extension faculty and technical crop consultant active in the St. Albans Bay watershed were engaged in establishing the tool's input requirements and options, as well as its workflow and design. This involvement occurred through email exchanges, conference calls, and several in-person meetings.

4.3.2. PAC Involvement

The PAC involvement in the tool development was provided through two in-person PAC meetings. The initial meeting focused on the establishment of P loss reduction targets and model input options. The second meeting looked more closely at the application design, including the level of specificity of user input requirement, definition of alternative conservation practices, and the reporting of model simulation results. Feedback from these meeting helped guide Farm-PREP's design.

4.3.3. Beta Testing of Farm-PREP

The Farm-PREP tool was beta tested on a pilot farm within the St Albans Bay watershed. Feedback on the usability and functionality of Farm-PREP was provide in Section 3.4 of this report. The feedback from the beta testing offers several valuable recommendations on how the application could be enhanced.

The original vision of the beta testing of the Farm-PREP tool was that it would have been conducted over multiple farms and by multiple users. This was not accomplished to the level intended due to three primary factors. First, finding collaborators willing to participate within a relatively small geographic area such as the St. Albans Bay watershed was more difficult than expected, especially due to potential collaborators limited time availability. Second, the level of effort required to complete the technical development of Farm-PREP to a state ready for beta testing was substantially more than anticipated, resulting in a narrower window of

opportunity to conduct the beta testing. Finally, recognizing the value in more user testing and feedback, the scope of the Phase 2 project for Farm-PREP development includes a significant focus in this area. It is anticipated that the activities involving user testing and feedback during Phase 2, along with many of the other Phase 2 activities, will add greatly to quality assurance aspects of the Farm-PREP tool development.

5.   Deliverables Completed

This section provides a discussion of the deliverables completed as part of the project to develop an approach and tool to optimize farm-scale phosphorus management and achieve watershed-scale loading targets.

5.1.   Quality Assurance Project Plan
A secondary data quality assurance project plan (QAPP) was completed on September 21, 2017.

5.2.   Quarterly Reports
Quarterly reports were prepared and submitted to the Lake Champlain Basin Program and NEIWPCC on 10/10/2017, 1/10/2018, 4/10/2018, and 7/10/2018.

5.3.   Final Report and Deliverables
The final report and deliverables included a written final report (this document) and the Farm-PREP web-based application. The written report includes description of an approach to determining per-acre P loading rate targets at the farm-scale, documentation of the development of the farm P management optimization modeling approach, results from a pilot application of the Farm-PREP tool to an example farm in the St. Albans Bay watershed, and a User Guide for the Farm-PREP tool. The most important final deliverable is Version 1.0 of the Farm-PREP tool itself. The tool provides the ability to efficiently run APEX model simulations of a farm, including the identification of alternative management scenarios that meet P-loss reduction targets, designed to meet water quality objectives. The final deliverables were completed on September 30th, 2018. Screenshots of the Farm-PREP application are shown in Figure 5-1 through Figure 5-5.

The Farm-PREP web site can be accessed at: https://farmprep.net/#!/login
The application requires that a login and password be provided for secure access to an individual's farm assessments. To receive a login and password for the Farm-PREP Version 1.0 pilot application, you must contact the application administrator at: Nick@stone-env.com
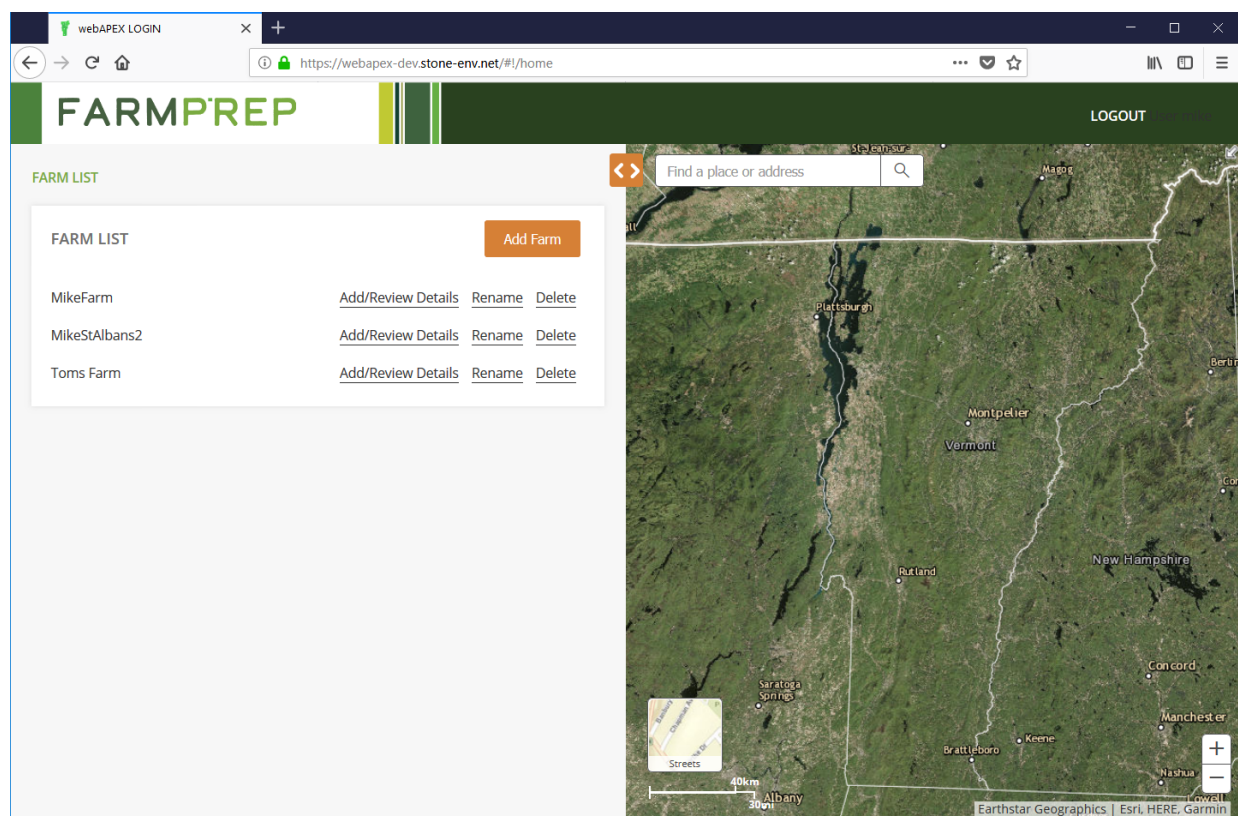
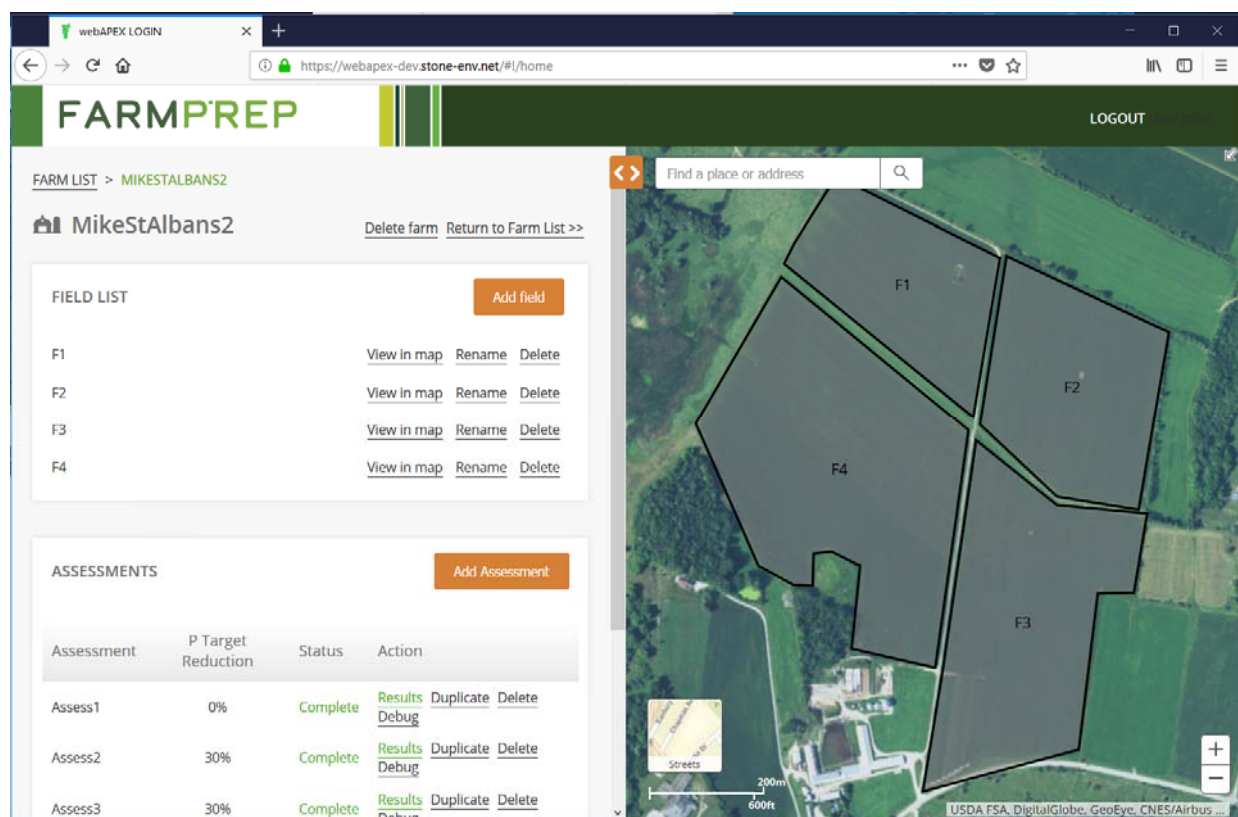*Figure 5-1. Farm-PREP create farm page.*

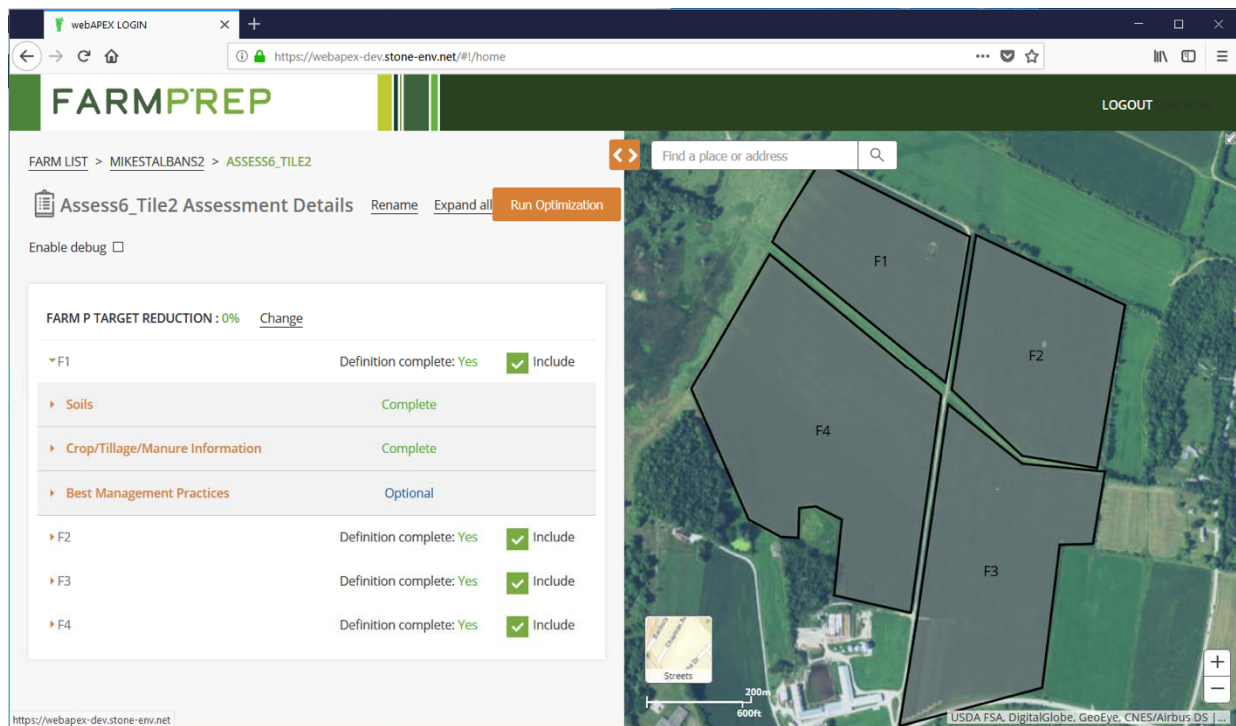*Figure 5-2. Farm-PREP farm fields and assessments page.*

STONE ENVIRONMENTAL

Figure 5-3. Farm-PREP fields information page.
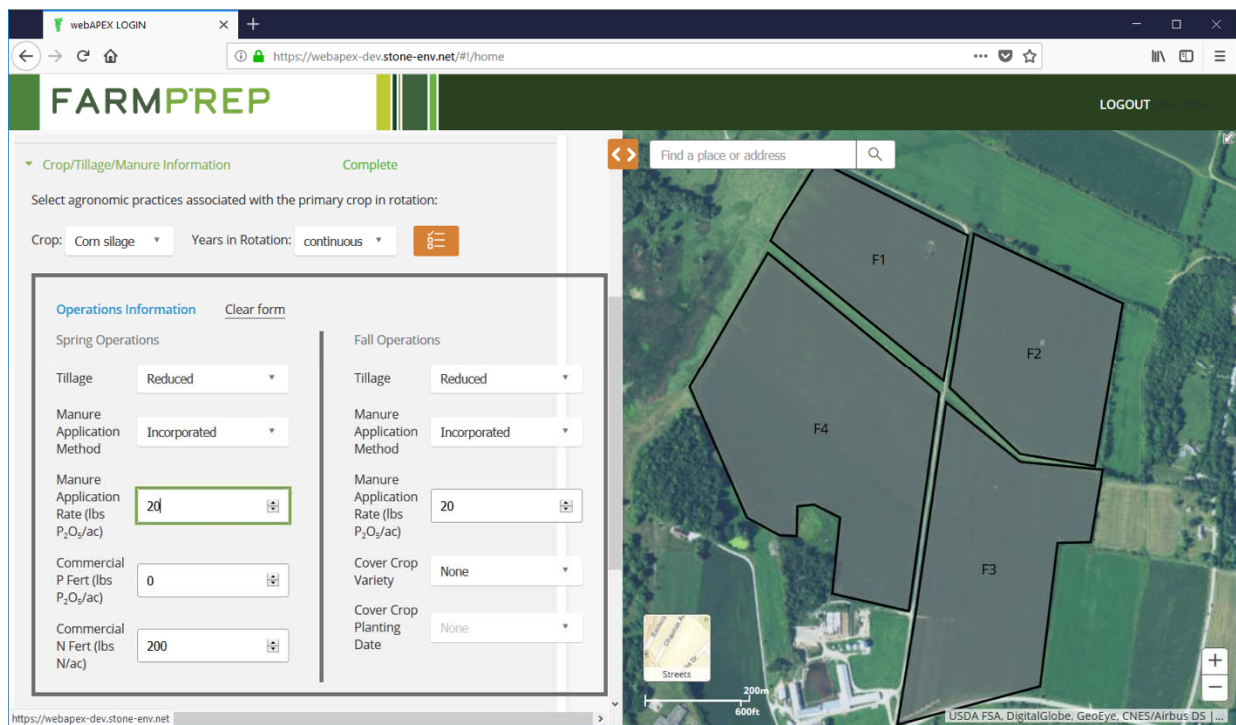
Figure 5-4. Farm-PREP Crop/Tillage/Manure data entry page.

Figure 5-5. Farm-PREP optimized results page.

6. Conclusions

The completion of this project, "Development of an Approach and Tool to Optimize Farm-Scale Phosphorus Management and Achieve Watershed-Scale Loading Targets," has significantly advanced our ability to quantify how modifications to field practices can translate to reduction of P loss from a farm. The newly developed Farm-PREP tool is unique in its ability to efficiently evaluate a broad range of field-level practices across an entire farm and identify combinations of practices that result in a predetermined farm-scale P load reduction target. This web-based application has been designed to allow expansion of use across the entire state of Vermont by implementing a scalable architecture that increases computing resources as needed. This approach will result in higher performance for the end-user together with a lower overall cost for maintenance and resources, particularly as the user base for Farm-PREP grows.

The development of Farm-PREP emphasized creating a streamlined and intuitive interface to allow farmers and their technical consultants to quickly provide the farm practice information required to generate many APEX simulations of their farm. This required that a subset of APEX input requirements, those most important for quantifying P losses, be organized into groups of field management options chosen by the user, and that other details concerning model inputs be pre-determined. This approach struck an appropriate balance between simplicity in the tool input data requirements and accuracy required to obtain realistic P loss predictions. As the tool receives more use and testing over time, we may find that field data input options increase or that some new data inputs are added, and the structure of the Farm-PREP tool has been built to allow for such updates and expansion.

One aspect of the Farm-PREP tool design, the farm-scale P load reduction target, was based upon a recommendation that farm-scale P load reductions be based on a uniform target percent reduction from baseline conditions, where the target percent reduction is specified at the lake segment level. This approach was proposed to be consistent with the TMDL load allocation objectives and required all agricultural land owners to participate in achieving the reduction. We want to emphasize that this load target determination approach was primarily intended as a demonstration of how such a water quality-based target could be implemented. We recognize that establishing farm-level targets could be a much more complicated than proposed and that multiple stakeholder groups would need to support such a program. Nevertheless, we believe that the simplicity of the approach has merit, that it integrates well with the farm optimization methods developed, and thus should be considered if quantification of farm-scale P load reductions become a required component to managing agricultural P loss improvements.

This project considered the P load results of the APEX simulations largely as a qualitative evaluation of the results and their relative variability across different crop rotations, agronomic management practices, and landscape characteristics (soils and slope). The selection of model inputs was based upon recommendations in model documentation and previous experience with application of the APEX model in Vermont (Stone Environmental, 2015). As with any physically based environmental model, the accuracy of model predictions has the potential to be improved with calibration and validation with field monitoring data. An upcoming project funded by the LCBP and led by Newtrient, LLC (of which Stone Environmental is a subcontractor), entitled "Refinement of Critically Needed Assessment Tools for Tile Drainage P Loading in the Lake

Champlain Basin" contains a substantial focus on evaluation of APEX model simulations with monitoring data, including tile drained fields. This upcoming project effort will lead to increased confidence and reduced uncertainty in the APEX-based Fam-PREP simulation results.

As this initial Version 1.0 of the Farm-PREP tool has underdone testing and application to a pilot farm, feedback provided by end-users has fostered food for thought regarding potential future enhancements to the tool (see Section 3.4 for a summary of this feedback). We anticipate that broader testing of the Farm-PREP tool will lead to additional updates or enhancements. This will require that a larger group of potential users and stakeholders become familiar with the tool and that we collectively work to refine the intended audience and objectives of the tool. These activities will largely be funded through a second LCBP grant led by Stone Environmental, entitled "Basin-Wide Implementation of a Farm Phosphorus (P) Management Optimization Web-based Tool". This project also will provide the funding necessary for hosting and maintenance of the Farm-PREP tool from 2019 – 2022. Regarding refinement in the ultimate objectives for the tool within Vermont, we believe that integration with the P Protocol and P-Credit Clearinghouse being developed by Newtrient, LLC represents an exciting opportunity to make highly quantitative use of this tool and include the additional consideration on adopting manure processing technologies as another approach to achieving desired P loss reduction targets.

The achievements from this project, "Development of an Approach and Tool to Optimize Farm-Scale Phosphorus Management and Achieve Watershed-Scale Loading Targets", are a strong foundation on which to expand and refine a consistent and scientifically valid approach for strategic farm planning aimed at reducing P losses and meeting basin-wide water quality goals. We expect that through the commitment of additional research and development support, a system for assessing P loss from all farms throughout the Vermont portion of the Champlain Basin will be realized by the end of 2019.

7.   References

BREC (Blackland Research and Extension Center). 2018. Agricultural hydrologic and water quality models supported and developed by BREC and USDA. Available at: https://blackland.tamu.edu/models/.

CARD (Center for Agricultural and Rural Development). 2018. CARD interactive software programs. Ames, Iowa: Center for Agricultural and Rural Development, Iowa State Univ. Available at: https://www.card.iastate.edu/research/resource-and-environmental/interactive-programs/.

Ford, W., K. King, M. Williams, J. Williams, N. Fausey. 2015. Sensitivity analysis of the Agricultural Policy/Environmental eXtender (APEX) for phosphorus loads in tile-drained landscapes. J. Environ. Qual. 44(4): 1099-1110.

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.

Magre, M., J.R. Williams, W.L. Harman, T. Gerik, J. Greiner, L. Francis, E. Steglich, and A. Meinardus. 2006. WinAPEX Users Guide, version 1.0. Temple, TX: Texas A&M University, Texas Agricultural Extension Service, Texas Agricultural Experiment Station, Blackland Research and Extension Center. Available at: http://winapex.brc.tamus.edu/downloads/usermanuals.Aspx.

NRCS (Natural Resources Conservation Service). 1986. Urban Hydrology for Small Watersheds, Technical Release 55. US Department of Agriculture. 164 pp.

Potter, K. 2014. Typical slope length as a function of slope steepness. Personal communication, Sep. 2014.

Saleh, A., O. Gallego, E. Osei, H. Lal, C. Gross, S. McKinney, and H. Cover. 2011. Nutrient Tracking Tool - a user-friendly tool for calculating nutrient reductions for water quality trading. Journal of Soil and Water Conservation. 66(10): 400-410.

Siemers, M., S. Plotkin, and P. Gassman. 2014. Interactive APEX (i_APEX) USER'S GUIDE USING APEX2110 and APEX0806. Technical Report 14-TR 50. Center for Agricultural and Rural Development. Iowa State University. Available at: https://www.card.iastate.edu/apex/14-TR%2050.pdf

Steglich, E.M., and J.R. Williams. 2008. Agricultural Policy/Environmental eXtender Model: User's manual version 0604 DOS and WINAPEX interface. BREC Report # 2008-16. Temple, TX: Texas AgriLIFE Research, Texas A&M University, Blackland Research and Extension Center.

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. 2011. Identification of Critical Source Areas of Phosphorus within the Vermont Sector of the Misssquoi Bay Basin. Prepared for the Lake Champlain Basin Program by Stone Environmental, Inc., Montpelier, VT. Available at: http://www.lcbp.org/techreportPDF/63B_Missisquoi_CSA.pdf.

Stone Environmental. 2015. Development of a Web-Based APEX Tool, VT STAR, for Optimizing Best Management Practices and Conservation Planning on Vermont Farms: Final Report. Prepared for the Vermont Natural Resources Conservation Service and Vermont Agency of Food and Markets by Stone Environmental, Inc., Montpelier, VT. Available at: http://www.stone-env.com/assets/resources/VT-STAR-Tool-Final-Report-13Oct2015.pdf

Tetra Tech, Inc. 2015a. Lake Champlain Basin SWAT Modal Configuration, Calibration, and Validation; April 30, 2015. Prepared for U.S. EPA Region 1. Fairfax, VA.

Tetra Tech, Inc. 2015b. Lake Champlain BMP Scenario Tool: Requirements and Design; April 30, 2015. Prepared for U.S. EPA Region 1. Fairfax, VA.

Tuppad, P., M. F. Winchell, X. Wang, R. Srinivasan, J.R. Williams. 2009. "ArcAPEX: ArcGIS Interface for Agriculrural Policy Environmental Extender (APEX) Hydrology/Water Quality Model". International Agricultural Engineering Journal, 18(1-2): 59-71.

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

VT ANR (Vermont Agency of Natural Resources). 2014. Vermont Water Quality Standards: Environmental Protection Rule Chapter 29(a). Vermont Agency of Natural Resources, Department of Environmental Conservations, Watershed Management Division, Montpelier, VT.

Weischmeier, W.H. and D.D. Smith. 1978 Predicting rainfall losses: A guide to conservation planning. USDA Agricultural Handbook No. 537. U.S. Gov. Printing Office, Washington, D.C.

Williams, J.R., J.G. Arnold, R. Srinivasan, T.S. Ramanarayanan. 1998. APEX: A New Tool for Predicting the Effects of Climate and CO2 Changes on Erosion and Water Quality, in Modeling Soil Erosion by Water. US Department of Agriculture – Agricultural Research Service, Temple, TX.