Final Project Reports:
Phosphorus Index
Conservation Innovation Grant

COVER PAGE

Project Title: Refining and Harmonizing Phosphorus Indices in the Chesapeake Bay Region to Improve Critical Source Area Identification and to Address Nutrient Management Priorities

Grantee Name: The Pennsylvania State University

Project Directors: Dr. Douglas Beegle (Penn State) and Dr. Peter Kleinman (USDA-ARS)

Report Timeframe: September 20, 2012 to August 31, 2016

Agreement Number: 68-3A75-12-226

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Executive Summary:

• ***NRCS designated priorities addressed by project***

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1045272.pdf

1. *Getting More Conservation on the Ground.* By bringing together researchers and land managers with different technical expertise across nutrient management disciplines, this project was committed to developing and evaluating strategic conservation solutions while addressing current issues with the Phosphorus Index (P Index). The P Index, a field tool used in 48 states to assess potential for phosphorus (P) movement from agricultural fields to surface water is not uniformly implemented across the Chesapeake Bay states. Project accomplishments served to unify nutrient management planning recommendations within the region by harmonizing state P indices within the four major physiographic provinces of the Chesapeake Bay watershed (Atlantic Coastal Plain, Appalachian Piedmont, Appalachian Valley and Ridge, and Allegheny Plateau).

2. *Increasing Organizational Effectiveness and Efficiency*. Having a P Index that varies in methodology and adoption at state boundaries causes management practice recommendations to vary across politically defined boundaries. By combining researchers, modelers, and managers from within the four major physiographic provinces of the Chesapeake Bay watershed (Atlantic Coastal Plain, Appalachian Piedmont, Appalachian Valley and Ridge, and Allegheny Plateau), we were able to develop potential solutions to address state needs and also minimize differences across boundaries.

3. *Creating Climate Where Private Lands Conservation Will Thrive*. The P Index is easily accessed and used by private and public land managers and agricultural producers. Results of this project continue to move toward a goal where voluntary conservation can be strategically implemented. Our work has focused at the field scale for use by the producers to achieve positive environmental results.

• ***Project Objectives***

1. Establish a network of nine watersheds within the four major physiographic provinces of the Bay watershed for foundational evaluation of nutrient management site assessment tools.
2. For each physiographic province, identify site conditions and practices of priority concern and corresponding remedial practices of greatest efficacy and adaptability.
3. Evaluate P site assessment tools by comparing their output with water quality monitoring data and fate-and-transport models.
4. Use Water quality data (monitored or predicted by model) to refine P Indices, improving their prediction of P loss potential, ensuring consistency across state boundaries and Within physiographic provinces, and promoting effective recommendations for P management.
5. Predict the management impact of P indices (existing and refined) on nutrient management practices and water quality.
6. Coordinate efforts with Heartland region, Southern region, and National USDA-CIG P Index projects.

• *Project Accomplishments*

The project performed model assessments using the network of nine benchmark watersheds to test and evaluate phosphorus management and water quality outcomes in the Chesapeake Bay watershed using sub-field scale initializations using commonly used management models SWAT (Neitsch et al., 2011), SWAT-VSA (Easton et al. 2008), APEX (Wang et al., 2011) and a source model, APLE (Vadas et al., 2009). These models were run and compared at different field scale process levels in the Conewago Creek Basin and Spring Creek, as well as research basins WE-38 , FD-36, and Mattern in PA (Collick et al. 2016; Collick et al. 2014), Factory Brook in NY, the Shenandoah in VA (Sommerlot et al. 2017 in review), research farms and fields within the Manokin, MD and Riesel, TX (Fuka et al. 2016). While Factory Brook, NY and Riesel, TX are outside of the Chesapeake Bay watershed originally proposed, these two basins were chosen due to their extensive periods with precise field by field by date and implementation management practices logged. With each model initialization, work was performed to progress the automation of hydrological model initialization to become less site specific and labor intensive, as it was found early in the study that the tasks of incorporating individual management actions and incorporating sub-field-scale characterizations required a significant amount of time and learned expertise to accomplish.

For each of the physiographic provinces represented by each of the benchmark watersheds, process specific model initialization and parameterization methods were developed to incorporate site specific conditions to represent remedial practices and practices of priority concern. When possible, workflows were developed to help automate this initialization process, with methods published and workflow modules publicly shared.

As the watershed models were viewed as management tools to be used in real agricultural production areas which are often far from meteorological stations and historical soil pedon sampling, specific attention was given to how these models would be initialized in areas with limited site characterization (soils) and weather data available. Studies were performed on how to better represent soils data while automating the workflow to integrate these soils representations into the modeling frameworks (Collick et al. 2014; Fuka et al. 2016). Additionally, the best weather data for historical analysis (Fuka et al. 2014), for short term forecasting (Sommerlot et al. 2016), and for long term climatological case studies was determined.

• *Barriers to attaining project goals*

Several studies (with articles submitted for publication and in review) were able to evaluate phosphorus site assessment tools by comparing their output with water quality monitoring data and fate-and-transport models. While the project was able to evaluate the accuracy of P Indices in predicting phosphorus loss potential on a case by case within individual physiographic provinces, work still remains to be done to automate the comparisons between state specific P Indices and watershed models.

• ***Timeframe***

The project required a one year no cost extension for several reasons. The effort involved incorporating mixed levels of farm and land management information into each of the water quality models to allow direct comparison against the high frequency sampling within each of the experimental watersheds. Adding each of these specific management practice operations was beyond the current state of the art of the model initialization interfaces. As the water quality data was available on a daily basis for small basins, similar field by field daily management practice operations, often requiring custom parameterizations, were incorporated. While this would not be reflective of the needs of management tools of the future; it was required to study the effects of the each of the management practices on nutrient contributions to the streams, especially given the different physiographic provinces represented.

• ***Were project funds spent as anticipated? If not, describe major changes in the budget.***

Project funds were spent as expected without major changes.

• ***What methods were employed to demonstrate alternative technology in this project?***

The new technologies and methods were demonstrated and brought into use with a combination of local and regional conferences combined with the development and hosting of short courses to teach the new technologies to managers and producers.

• ***What were the quantifiable physical results from this project?***

This project resulted in a significant number of new tools aimed at all members of the community, from federal and university researchers and managers to agricultural producers. Quantifiable results include the simulated water quality results for the identified study watersheds, a summary of priority agricultural practices to be considered in revised Phosphorus Index tools, proposed structures for revised Phosphorus Indices, water quality model initialization procedures for integrating site specific agricultural practices, and water quality model projects developed for specific conditions of the study watersheds.

• ***Are there Federal, State, and local programs that may be used to implement this project?***

Federal programs that can implement the results of this project include US Environmental Protection, US Department of Agriculture-Natural Resource Conservation Service, and US Department of Agriculture-Agricultural Research Service. State level agencies implementing this information and results will vary by state, but generally include agencies responsible for administration, implementation, and oversight of nutrient management regulations as well as state departments of agriculture.

• ***What are the major recommendations resulting from this project?***

- A method to directly compare TopoSWAT modeling results and P Index inputs, such as soil test P levels, needs to established.
- TopoSWAT can be used to simulate P losses from agricultural watersheds with variable agricultural practices across the Chesapeake Bay watershed.
- Overall comparisons of P loss simulated by TopoSWAT and P Index values, provide guidance in modifying P Index structures through the identification and evaluation of fields that are outliers. For example, management of a field with a high P loss predicted by TopoSWAT, but a low P Index value can be examined to determine appropriate changes to the P Index.

Introduction:

The Chesapeake Bay regional project continues nearly 15 years of regionally-coordinated nutrient management activities amongst the project team. As such, this project will take advantage of long-standing activities, communications and collaborations.

Oversight and coordination. Douglas Beegle, Distinguished Professor Emeritus of Agronomy at Penn State University, and Peter Kleinman, Research Leader USDA-ARS Pasture Systems and Watershed Management Research Unit (PSWMRU), oversaw the project and were responsible for coordinating activities between the six state teams, as well as for monitoring project progress. Peter Kleinman, Doug Beegle and Zachary Easton, Virginia Tech served as liaisons between the Chesapeake project, and the National P Index coordinating project (led by Andrew Sharpley, University of Arkansas). Zach Easton, Tamie Veith, PSWMRU, and Tony Buda, PSWMRU, oversaw and coordinated modeling activities with graduate students and post-doctoral scientists employed by the grant, collaborating with modelers in the other regional and National CIG projects.

State activities. Each state had individual leaders who coordinated activities and worked to achieve the goals of each objective: Delaware, Shober; Maryland, McGrath; New York, Ketterings; Pennsylvania, Beegle; Virginia, Reiter; West Virginia, Basden. In addition, project investigators led four expert panels established for each physiographic province (anticipated chair underlined): (1) Atlantic Coastal Plain, Reiter, Easton, Coale, McGrath, Sims, Shober, Allen, Kleinman; (2) Appalachian Piedmont, McGrath, Coale, Reiter, Easton, Buda, Beegle; (3) Appalachian Valley and Ridge, Basden, Beegle, Kleinman, Buda; (4) Allegheny Plateau, Ketterings, Beegle, Kleinman, Buda, Basden, Faulkner.

- ***Project goals and objectives (including those designated in the NRCS grant request).***

1. Establish a network of nine watersheds within the four major physiographic provinces of the Bay watershed for foundational evaluation of nutrient management site assessment tools. We established a network of benchmark watersheds to test and evaluate P management and water quality outcomes in the Chesapeake Bay watershed.
2. For each physiographic province, site conditions and practices of priority concern and corresponding remedial practices of greatest efficacy and adaptability were identified.
3. Phosphorus site assessment tools were evaluated by comparing their output with water quality monitoring data and fate-and-transport models. We evaluated the accuracy of P indices in predicting P loss potential within individual physiographic provinces in order to determine what refinements were required to P indices within a physiographic province.
4. Water quality data (monitored or predicted by model) was used to refine P Indices, improve their P loss prediction, ensure consistency across state boundaries and within physiographic provinces, and promote effective recommendations for P management. State P Indices will be refined to ensure accuracy in predicting site P loss potential, efficacy in promoting nutrient management changes that enhance water quality and consistency across state boundaries.

5. Predict the management impact of P indices (existing and refined) on nutrient management practices and water quality. We evaluated the potential impacts of P Index refinements on field management and water quality. Impacts included those to field management, those to farm management (and profitability) and those to watershed water quality (local and Chesapeake Bay).
6. Efforts were coordinated with the Heartland region, Southern region, and National USDA-CIG P Index projects. We collaborated with regional and national P Index projects and coordinated under the rubric of SERA-17 to promote consistent methodology, standards and priorities across the U.S.

- ***The scope of project tasks.***

  Project tasks, protocols, and accomplishments ranged across four physiographic provinces, nine watersheds, and five states. Expertise was required in field sampling, water quality modeling, and P Index evaluation.

- ***Project Collaboration***

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  Oversight and coordination. Doug Beegle and Peter Kleinman oversaw the project and coordinated activities between the six state teams, and monitored progress. Peter Kleinman, Doug Beegle and Zach Easton served as liaisons between the Chesapeake project, and the National P Index coordinating project (led by Sharpley). Zach Easton, Tamie Veith and Tony Buda oversaw and coordinated modeling activities with graduate students and post-doctoral scientists employed by the grant and collaborated with modelers in the other regional and National CIG projects.

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- ***How the project was funded.***

  The project was funded through the USDA-NRCS Conservation Innovation Grant, Refining and Harmonizing Phosphorus Indices in the Chesapeake Bay Region to Improve Critical Source Area Identification and to Address Nutrient Management Priorities. Agreement Number: 68-3A75-12-226.

***Background*:**

A Phosphorus (P) Index is a nutrient management field tool intended to identify agricultural fields most vulnerable to P loss. Vulnerable fields are identified by evaluating the major *source* and *transport* factors controlling P movement (Lemunyon and Gilbert, 1993; Sharpley et al., 2003). Lemunyon and Gilbert (1993) proposed the P Index as a voluntary educational tool to help farmers identify fields with a high probability of P loss in runoff. In the two decades since its introduction, the P Indexing concept has evolved and expanded and there are now P Indices that serve as Best Management Practice (BMP) selection and targeting tools, manure application scheduling tools, manure application rate calculators, and as a regulatory tool in some states (DeLaune et al., 2007; Sharpley et al., 2009).

In 1999, the P Index has been integrated into the Natural Resources Conservation Service (NRCS) 590 Nutrient Management Standard (U.S. Department of Agriculture-Natural Resources Conservation Service, 2011). Also, the 2003 revision of EPA regulations for Concentrated Animal Feeding Operation (CAFOs; U.S. Environmental Protection Agency, 2003) recommends the P Index as a field-specific P loss assessment tool on permitted CAFOs. Currently, 48 U.S. states have adopted a P Index as a site assessment tool to identify critical source areas and to target practices to reduce P loss. In most of these states, the P Index is required by the NRCS 590 Nutrient Management Standard and other state and federal programs (Sharpley et al., 2003).

Despite the apparent success of the P Index concept, there remain concerns about the effectiveness of the Indexing approach for attaining water quality goals. Different versions of the P Index have emerged to account for regional differences in soil types, land management, climate, physiographic and hydrologic controls, manure management strategies, and policy conditions. Along with this development, differences in P Index manure management recommendations under relatively similar site conditions have also emerged. For instance, a survey of P Indices from 12 southern U.S. states revealed a large diversity in P Index ratings and P application guidelines for similar conditions (Osmond et al., 2006). For instance, when used to assess the identical field, some P indices would produce recommendations that no further manure be applied while others would allow N-based rates of manure to be applied.

In addition to observations of inconsistency between the P Indices of various states, there is growing concern that existing P management guidelines of some states (including the P Index) are not resulting in as great a reduction in soil P levels and runoff P loss from agricultural lands as expected or desired. For instance, several reports related to mitigation effectiveness in the Chesapeake Bay region have fueled concern that site risk assessment using the P Indexing approach was inadequate (Kovzelove et al., 2010; U.S. Environmental Protection Agency, 2010b). The lack of soil and water quality response may, in part, reflect legacy effects of past management and a slow ecosystem response to changes in state, watershed, and farm level nutrient imbalances. Nevertheless, there is a need to reassess current approaches to determine and guide P management as a component of the 590 Standard and to address problems related to nutrient imbalance.

In 2009, as part of their effort to revise the 590 Nutrient Management Standard NRCS requested that a working group of scientists within the Southern Extension-Research Activity Group 17 (SERA-17) recommend approaches to evaluate and improve P Indices (Sharpley et al., 2011). Specifically, that group concluded that a rigorous evaluation of P Indices is needed to determine if they are directionally and magnitudinally correct. While use of observed P loss data under various management scenarios is ideal, such data are not widely available and can require years of costly field research to generate. Alternatively, use of a locally relevant and validated water quality model may be the most expedient option to conduct Index assessments in the short time required by the newly revised 590 Standard. As a result of this, three regional consortiums developed and these consortiums have prepared USDA-CIG proposals to evaluate, assess, validate, and refine P Indices in the Heartland, Chesapeake Bay, and Southern Regions.

The work resulting from the Chesapeake Bay project identified priority management practices for inclusion in a revised P Index tool, developed water quality modeling approaches which integrate watershed specific management practices for comparison to the P Index, established stakeholder panel groups, and provided preliminary comparisons of P Indices and simulated water quality results.

***Review of methods*:**

- ***Modeling***

Modeling research covered all aspects of getting hydrological models functioning in the remote applied agriculture locations that the P Index would be run, taking the management model out of the research watersheds and into real production scenarios, integrating general management into modeling systems that require daily management, distributing soil at a resolution needed for modeling infield process, historical weather data, future weather/climate scenarios, short term forecasts from weather to field scale modeling, interfaces farmers and managers can use at the regional, local, to field scale levels.

For the P Indices to be evaluated against a process-based watershed model, SWAT, in lieu of measured data for all management variations, we first had to ensure that we were including the most scientifically up-to-date P process information. Incorporation of these processes into SWAT was thoroughly verified and reviewed. Relevant references: Amin et al., 2016, Liu et al., 2016, Collick et al., 2015, Collick et al., 2016, Veith et al., 2015.

Next, detailed SWAT projects had to be developed multiple watersheds. The development and analysis of the SWAT project for the Spring Creek watershed was crucial in making sure that we were accurately representing both dissolved and particulate P transport process through karst landscapes. This work has been peer-reviewed and published in Amin et al., 2016b. (Appendix 1).

- ***Establishment of stakeholder panels***

Stakeholder panels were established for the Allegheny Plateau and the Piedmont Ridge and Valley Physiographic Provinces. Meetings were held for all stakeholder panels to review the establishment and determination of priority management practices to be considered in the P Index revision process.

- ***Assessing the Subsurface Risk Components of Five Coastal Plain Phosphorus Indices (Delaware)***

Following problems related to the modeling efforts on the Coastal Plain, we shifted efforts in this region to focus on an assessment of current methods used in regional P indices, including the Delaware Phosphorus Site Index (DE-PSI), two iterations of the Maryland Phosphorus Management Tool (MD-PMT and MD-PMT2), the North Carolina Phosphorus Loss Assessment Tool (NC-PLAT), and the Virginia Phosphorus Index (VA-PI), to assign risk of P loss via subsurface processes (e.g., vertical leaching, shallow lateral subsurface runoff).

To complete this assessment, we used available estimated P load data for 1) drainage waters from six artificially drained field sites on the Delmarva Peninsula (Kleinman et al., 2007; Penn et al., 2016; Sims et al., 1996) and 2) leachate collected in undisturbed soil columns (to a depth of 50 cm) collected from six naturally drained sites on the Delmarva Peninsula (Kleinman et al., 2015). We also developed a comprehensive data set that includes soil test data (e.g., Mehlich 3, water extractable P [WEP], degree of P saturation) and site conditions (e.g., slope, runoff estimated by curve number, and map units specific data for hydrologic soil group, soil textural class, soil drainage class, etc. as available in SSURGO) for 26 agricultural fields (with a history of agronomic row crop production) from 18 locations on the Delmarva Peninsula (Fig. 1) based on the availability of detailed soil characterization data from previous soil coring campaigns conducted by researchers at the University of Delaware (UD), US Geological Survey (USGS), University of Delaware (UD), University of Maryland College Park (UMD), and University of Maryland Eastern Shore (UMES); this data set included soil and site properties for the six sites where dissolved P loads in drainage water were available.

During the soil coring campaigns, a total of 148 composite soil cores were collected from 18 fields using various sampling methods. In brief, two or three soil core samples were collected from various locations within each field (e.g., along a transect perpendicular to a ditch or within soil management grids) with a Giddings hydraulic probe (10 cm diameter; Giddings Machine Company, Windsor, CO) or bucket auger (10 cm diameter) to a depth of approximately 1 m. Soil cores were divided by horizon or by discrete depth increments and composited for a total of 4 to 16 composite core samples per field. Composited soil samples were air-dried, ground to pass through a 2 mm screen, and bagged until analyzed. Individual core composite samples were analyzed for WEP or $CaCl_2$-extractable P sels(Self-Davis et al., 2009)(with UD samples following a modified method of 4 g soil to 40 mL 0.01 M $CaCl_2$) by the molybdate blue method (Murphy and Riley, 1962) and Mehlich 3 extractable P, Al, and Fe (North Eastern Coordinating Commitee, 2011) by inductively coupled plasma optical emission spectroscopy. Sampled fields represented a wide range of soil, drainage, and management conditions across the Delmarva region, including naturally drained sites with and without irrigation and artificially drained locations of varying drainage intensities.

Phosphorus Index calculations were programmed in an Excel spreadsheet to calculate subsurface P loss risk scores for the DE-PSI (Sims et al., 2016), MD-PMT (McGrath et al., 2013), MD-PMT2 (Fiorellino et al., 2017), VA-PI (Wolfe et al., 2005), and NC-PLAT (NC PLAT Committee, 2005). In this report, subsurface P loss risk scores are denoted as DE-PSI_{sub}, MD-PMT_{sub}, MD-$PMT2_{sub}$, VA-PI_{sub}, and NC-$PLAT_{sub}$; more information on their calculation is available upon request. The accuracy of formulae in the spreadsheet were corroborated by hand calculation of each P Index or, when available, by inputting field variables into online P Index software (e.g., NC-PLAT). In order to apply the methods of NC-PLAT (NC PLAT Committee, 2005), we estimated soil transmissivity using the following equation:

$$T = \sum K$$

where K_i is the saturated hydraulic conductivity of layer *i* and D_i is the depth of soil layer *i* (NC PLAT Committee, 2005). We then calculated drainage intensity (m hr^{-1}) for each field by the method of Skaggs et al. (2004). A more detailed description of the methods used to calculate soil transmissivity and drainage intensity is available upon request.

In addition to calculation of subsurface P risk for the 18 fields, we also treated each of the 148 soil cores as individual field sites (denoted as sites from here on) when calculating subsurface P risk scores to increase the size and scope of our dataset. In order to focus on site-specific factors affecting subsurface P transport risk, we assumed no P fertilizer and manure applications across all locations.

Calculation of subsurface P index risk scores for the (Kleinman et al. 2015) leaching dataset was completed using soil test data and SSURGO data for each of the sites. At each site, scores were calculated for conditions during a 9 week leachate collection period where no manure was applied and following the application of poultry litter at a total P rate of 52 kg ha^{-1} that was surface applied to the soils followed by leachate collection for 8 weeks. We excluded two poorly drained silt loam soils from our analysis because P leaching via macropore flow tended to prevail over matrix flow (Kleinman et al., 2015); the former P leaching mechanism is poorly simulated by most (if not all) P Indices (Reid et al., 2012).

- **Establishing a Field Site to Understand Subsurface Hydrology in Drained Agroecosystems Using Electrical Resistivity Imaging and Salt Tracers (Delaware)**

We established a site for subsurface lateral flow monitoring with Electrical Resistivity Imaging (ERI) at University of Maryland, Eastern Shore (UMES) (Fig. 2). We placed 192 electrodes in a grid approximately 1 m from the ditch edge. The grid placement corresponds to the known direction of groundwater flow in the field. A shed was set up to house the ERI related equipment and power sources. A trench filled with pea gravel to 25 cm was placed within the grid as the site for application of a bromide salt tracer. Ten wells were included within the grid for monitoring of electrical conductivity, depth to water table, and temperature. Eight soil moisture probes were also placed within the grid.

Periodic monitoring of movement of the bromide in the soil was completed. Originally, it was planned to use marine batteries and solar panels to supply power to the site, but the power needs of the system exceeded the amount available with this design. For long term monitoring during storm events and periods of high water table, a more stable supply of power was secured from a nearby poultry house with electricity.

Periodic monitoring of two storm events using ERI and salt tracers was collected during two storm events using a SYSCAL Pro Switch 96 Resistivity Meter (Iris Instruments, France). For the storm events in October 2015 and February 2016, full reciprocal data sets were collected at prior to the rainfall event and again at the conclusion of the event. Fast ERI datasets were collected at approximately 1.5 or 4 hr intervals (October 2015 and February 2016 events, respectively) via a script designed to collect data continuously beginning at the onset of the rain event; a total of 1.5 hr was needed to allow for collection of each dataset which was expected to be frequent enough to catch any significant changes in resistivity as they occurred in real time. Monitoring of the field study, beyond activities associated with this project, is continuing under a recently funded USDA-AFRI grant.

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- ***Identification of priority nutrient management practices (Pennsylvania and New York)***

  In cooperation with nutrient management specialists and stakeholder panels, priority nutrient management practices for review in the P Index revision process and for inclusion in SWAT-VSA modeling were identified in both New York and Pennsylvania. Several common nutrient management practices were common to both states and to the Allegheny Plateau.

- ***Phosphorus Index and TopoSWAT comparison (Pennsylvania and New York)***

  Pennsylvania P Index and New York P Index results were compared to different forms of P loss simulated by TopoSWAT. These comparisons resulted in variable results demonstrating that comparison of TopoSWAT results and P Index values on a field-by-field basis over time may not provide the information needed to make decisions about overall changes to P Index tools and their associated management categories. However, these comparisons yielded important information about management and field properties that created outlier results where the TopoSWAT results were low for the P loss and the P Index indicated a high vulnerability to P loss or there opposite where TopoSWAT results were elevated for a field and the P Index indicated a low vulnerability to P loss. After determining the factors contributing to these situations, modifications to both the Pennsylvania and New York P Indices were recommended. However, further analysis is needed to make comprehensive P Index changes related to management recommendations and criteria.

***Discussion of quality assurance*:**

- **Data Analysis and Statistics - Assessing the Subsurface Risk Components of Five Coastal Plain Phosphorus Indices**

  We compared the subsurface P risk scores of P Indices in this study to: 1) dissolved P loads in leachate collected (to a depth of 50 cm) from intact soil cores, 2) dissolved P loads in ditch water at 6 of the 18 field sites where soil core samples were collected, and 3) soil water extractable P at near the depth to seasonal high water table as determined by SSURGO (WEP_{WT}), which previous researchers have confirmed as key a factor in P losses by subsurface flow pathways (Flores-Lopez et al., 2013; Obour et al., 2011; Vadas et al., 2007). A detailed description of WEP_{WT} calculation methodology is available upon request. Linear regression (PROC REG) was used to assess subsurface P risk scores of the P Indices against load data and soil WEP_{WT}, with stronger relationships evidencing the ability of a P Index to predict the potential for sites to lose P via subsurface flow pathways (i.e., vertical leaching or subsurface lateral flow). We also used regression analysis to determine the relationship between dissolved P in drainage water and soil WEP_{WT}. For all statistical tests, we confirmed normality assumptions were met by examining histograms of independent and dependent variables and normality plots of conditional residuals. Correlations and regression models were considered significant at $\alpha \leq 0.05$.

- **Establishing a Field Site to Understand Subsurface Hydrology in Drained Agroecosystems Using Electrical Resistivity Imaging and Salt Tracers**

  All ERI measurement data was processed using ProfileR Version 2.5 (Binley, 2003), a program designed for 2D surface array resistivity profile inversion and imaging that can handle small to moderately-sized datasets. ProfileR requires a simple input file consisting primarily of electrode coordinates and the output of the resistivity dataset. A series of two transects out of the overall grid were used for the ERI data analysis (Figure 2.4). The two transects analyzed were located in the center of the grid, running through the trench and adjacent to the storage shed. The 2D transects were extracted from larger 3D datasets using Matlab; more thorough 3D analysis will be completed by project partners at Rutgers University Newark at a later date and is beyond the scope of our study. These 2D transects were then used to create the input files for ProfileR. The input file contains information on the locations of the electrodes and the resistivity measured (voltage/impedance) for each of the electrode sets. ProfileR generates a finite element mesh containing a foreground region and a background region, which allows it to set the boundaries in the background and display the investigated area in the foreground. Surfer 13 (Golden Software LLC, 2016) was used as a contouring, gridding, and visualizing software to create the 2D images from the ProfileR output (.dat) files. In all ERI figures, a red color indicates higher changes in resistivity from the background dataset, whereas blue colors indicate little to no change. Therefore, the red color indicates the presence of an area with higher conductivity, which could be due to the presence of salt or high moisture areas within a dry profile. Water ponding on the surface could also cause the topsoil to appear more conductive.

<u>Findings</u>:

- **Assessing the Subsurface Risk Components of Five Coastal Plain Phosphorus Indices (Delaware)**

  The results of our Coastal Plain P Index assessment showed general consistencies in the accuracy of P leaching risk predictions. Specifically, we found that DE-PSI_{sub}, MD-PMT_{sub}, MD-PMT2_{sub} and NC-PLAT_{sub} were significantly ($P < 0.014$) and positively related to dissolved leachate P loads from manure amended soils experiencing matrix flow, indicating that all four P Indices exhibited the potential to accurately characterize P leaching risks from Coastal Plain soils receiving poultry litter (Fig. 3 A-D). Notably, the VA-PI_{sub} assigned values of zero to the five naturally drained soils used by (Kleinman et al., 2015), indicating an absence of P leaching risk despite measurable P losses in leachate before and after poultry litter was applied to these soils. Similarly, all P Indices except the VA-PI_{sub} were able to discern P leaching risks from edaphic P sources (i.e., the nine-week period of P leaching when no manure was applied). While the relationships of DE-PSI_{sub}, MD-PMT_{sub}, MD-PMT2_{sub}, and NC-PLAT_{sub} with dissolved P loads in leachate were positive and statistically significant ($P < 0.015$; Fig. 4 A-D), they all were heavily influenced by a single site with high soil test P. Perhaps most interesting was the inability of any Coastal Plain P Index to predict the risk of P leaching from the poorly drained Quindocqua soils accurately, where rapid P losses by macropore flow generally predominated under artificially drained conditions (Kleinman et al., 2015). Thus, even though Coastal Plain P Indices seemed to identify a risk of P leaching by matrix flows, there remains an urgent need to improve the capacity of these indices to identify and quantify rapid P losses by macropore flow (Radcliffe et al., 2015; Reid et al., 2012).

All in all, three of the five Coastal Plain P Indices we tested satisfactorily predicted the risk of subsurface P loss when ditch dissolved P loads were used as a proxy for subsurface P runoff from flat fields with artificial drainage. While the small size of the dataset (n = 6 ditches) likely prohibited significant relationships between subsurface P risk ratings and dissolved P loads in ditch drainage, DE-PSI_{sub}, MD-PMT_{sub}, MD-$PMT2_{sub}$, and VA-PI_{sub} (to a lesser extent), all showed that subsurface P loss risk increased concomitantly with dissolved P losses in ditch drainage (Fig. 5 A-D). Perhaps most important is that the positive relationship between MD-$PMT2_{sub}$ and dissolved P loads in ditches (Fig. 5 C) was nearly significant at $\alpha = 0.1$ ($P = 0.12$), even with only six observations. As such, we suggest that the subsurface drainage factor formulations in semi-quantitative P Indices, especially MD-$PMT2_{sub}$, appear to capture the potential for subsurface P losses from ditch-drained fields. Interestingly, the apparent success of the Delmarva P Indices in predicting the risk of subsurface P delivery to ditches was not matched by NC-PLAT, as indicated by the weak negative relationship between NC-$PLAT_{sub}$ and dissolved P loads in drainage waters (Fig. 5 E). As specified in Eq. [6], fields with artificial drainage (tiles and ditches) require a transmissivity factor (T_{30}/T_P) that assumes dissolved P in drainage water only interacts with the top 76 cm (30 in) of soil (Johnson, 2004). In essence, the transmissivity factor in NC-$PLAT_{sub}$ decreases the amount of P that is lost via subsurface flow despite the expected increases in subsurface discharge volumes that occur with artificial drainage (Johnson et al., 2005). The reduction in subsurface P losses triggered by the transmissivity factor seems to explain the inability of NC-$PLAT_{sub}$ to estimate dissolved P export from the six field ditches. Moreover, these findings highlight the need for further testing and calibration of mechanistic P Indices like NC-PLAT in ditch-drained systems so that runoff routing and complex interactions between water and P sources (applied and edaphic) are properly simulated.

When we compared ditch P loss data from the six ditch locations on the Delmarva Peninsula (Bachman and Phillips, 1996; Kleinman et al., 2007; Sims et al., 1998) to WEP_{WT} determined from soil cores in their respective field drainage areas, we found a statistically significant relationship (Fig. 6; $r^2 = 0.64$; $P < 0.033$). As such, we suggest that subsurface P risk scores from the five Coastal Plain P Indices evaluated in this study are likely related to WEP_{WT} across all 149 sites, with stronger relationships evidencing the ability of Coastal Plain P Indices to predict the potential for P loss via subsurface flow.

Our assessment of WEP_{WT} generally mirrored the earlier comparisons between ditch P loads and subsurface P risk scores. Regression models between soil WEP_{WT} and MD-PMT_{sub}, MD-$PMT2_{sub}$, DE-PSI_{sub}, and VA-PI_{sub} all were significant at $P < 0.0001$ (Fig. 7), indicating these four P

Indices displayed a reasonable ability to predict subsurface P risk using WEP_{WT}. Even so, there were many cases where the $DE\text{-}PSI_{sub}$, $MD\text{-}PMT_{sub}$, $MD\text{-}PMT2_{sub}$, and $VA\text{-}PI_{sub}$ scores appeared to overestimate subsurface P risk (Fig. 9 A-D) when viewed in terms of water quality criteria and our WEP_{WT} data. Using a known relationship between soil WEP and dissolved P in runoff (Vadas et al., 2005), we estimated that a WEP_{WT} of 2.95 mg kg^{-1} would generally equate to about 0.1 mg L^{-1} of dissolved P in runoff, which is the EPA eutrophication limit for total P in stream water (USEPA, 1986). Based on this approximated WEP_{WT} eutrophication threshold, we inferred that $DE\text{-}PSI_{sub}$, $MD\text{-}PMT_{sub}$, $MD\text{-}PMT2_{sub}$, and $VA\text{-}PI_{sub}$ likely overrated the subsurface P risk for at least 40, 30, 30, and 70 of the 148 soils in our dataset, respectively. These sites had WEP_{WT} values less than 2.95 mg kg^{-1} and subsurface P risk scores above 4, 50, 68, and 0, respectively, which would result in a WEP_{WT} concentration of 2.95 mg kg^{-1} based on the linear relationships developed with our soils dataset (Fig. 7). Often, these overestimations occurred at sites with deeper seasonal high water tables, and by extension, lower drainage intensity (data not shown).

The $MD\text{-}PMT2_{sub}$ exhibited the best capacity to predict WEP_{WT} and subsurface P loss risk across the soils used in this study (Fig. 7C). In contrast, $NC\text{-}PLAT_{sub}$ (Fig. 7E) grossly underestimated WEP_{WT} concentrations at many sites. It is essential to note, however, that the final NC-PLAT risk score is adjusted to the “high” risk category when Mehlich-3 P concentrations at 76 cm depth exceed 50, 100, or 200 mg kg^{-1} for organic soils, sands, and loams, respectively (NC PLAT Committee, 2005). Even so, this adjustment occurs in calculation of the total risk score, making it difficult to assess the association between $NC\text{-}PLAT_{sub}$ and WEP_{WT} quantitatively. All in all, similarly successful predictions of WEP_{WT} and ditch P loads by Delmarva P Indices, especially by $MD\text{-}PMT_{sub}$ and $MD\text{-}PMT2_{sub}$, show that WEP_{WT} may have interim merit as an indicator of subsurface P risk that could prove valuable in assessing the subsurface routines of Coastal Plain P Indices.

- **Establishing a Field Site to Understand Subsurface Hydrology in Drained Agroecosystems Using Electrical Resistivity Imaging and Salt Tracers (Delaware)**

Weather projections called for >15 cm of rainfall to occur during the October 2015 storm event (suggesting a particularly anomalous storm); however, only 3.8 cm actually fell. The water table rose rapidly during the storm event, remained elevated for the duration of the event, and dropped off immediately following the storm (Fig. 7). Peak water table height corresponded with peak rainfall. During this short storm event, water height in at least two of the wells within the study area was within the top 25 cm of the soil at the field, which corresponds with the zone of P accumulation at the site (data not shown). However, the in-situ well measurements were not corroborated with manual water table readings to determine the accuracy of these water table readings. Water table measurements were adjusted slightly to account for possible overestimation. Future hydrologic monitoring of the site should be supplemented periodically with manual readings and visual observations of the site to ensure that accurate adjustment factors can be applied to the in-situ data collected by sensors.

A 2D view of the two transects within the electrode grid at three specific times allowed for visualization of the salt tracer activation by the rainfall (Fig. 8). There was only evidence of a slight horizontal spread and vertical leaching (as indicated by red areas of high conductivity on the image) of the tracer as rain water infiltrated the trench, dissolved the salt, and moved it throughout the gravel-filled trench. Activation of the tracer was evident (the red area located in the trench) beginning at 15:10 on 1 Oct; tracer activation intensified throughout the storm, becoming most noticeable near the end of the storm on 3 Oct. Based on the ERI imaging, the tracer moved down to a depth of 0.5 m, indicating that it broke through the bottom of the 0.25 m deep trench. While some interaction between the KBr and the water table was possible and surface soils appeared to be more conductive than subsoils, there was no clear evidence of lateral movement of the tracer beyond the boundaries of the trench (Fig. 8).

Data from four time points during a second storm period were analyzed, allowing visualization of soil resistivity prior to the storm on 22 February, twice during the storm on 24 February, and after the storm on 25 February. Over 2.54 cm of rain was predicted during the February 2016 storm event. Movement of the tracer during the February 2016 storm event was expected because the antecedent moisture conditions were wet and the water table was within 0.5 m of the surface prior to the storm event (Fig. 9). Ultimately, a total of 1.25 cm of rainfall was recorded at the site (Fig. 9). Water table rose markedly, following the peak in precipitation, and began to drop immediately following the storm. The water table was very active within the top 20 cm topsoil, where P is expected to be susceptible to movement.

Similar to the October 2015 storm data, there was minimal evidence of tracer movement during this minor February 2016 storm event (Fig. 10). The tracer appeared present and fully activated in and below the trench during all four times during the event. There was ERI evidence of a small plume extending to the right of the trench about 0.5 m in both transects, suggesting that the tracer placed in the trench was moving towards the ditch along the expected flow path. Moisture was evident in the top 25 cm of the soil profile as shown by the red high conductivity levels (Fig. 10). The large blue area located in the center of both transect images indicates an area with lower conductivity, which was likely due to presence of a freshwater water table with significantly lower conductivity than the salt tracer in the trench.

Soil and water sensors, installed as part of the hydrologic monitoring stations within the plot, failed to pick up any changes in soil or groundwater EC after the tracer was applied (data not shown). Variability and uncertainty in the quality of the soil moisture and water sensor data precluded us from using that data to corroborate the ERI measurements. However, we feel confident that increases in conductivity within the ditch can be attributed to movement of KBr, which was visualized using ERI continuously over the period of a rain event (Fig. 8 and 10).

- **P loss risk characteristics across PA**

Efforts to update P site assessment tools must ensure that the tools are representative of the range of conditions to which they will be applied. We sought to identify key parameters available in public GIS data that are uniquely descriptive of critical source areas in Pennsylvania and that ensure all reasonable parameters combinations are considered in modifications of the P Index. We found that available water capacity, soil saturation, and organic matter are key for grouping near-stream PA soils. Discontinuities across soil survey boundaries prevent modeling consecutive regions larger than a single county. Two to five topoedaphic groups per county are sufficient to classify the majority of near-stream PA soils. Clustering environmental data provides a solid foundation for assessing impacts of management practices and revising the P Index. This research will help to guide the development of management guidelines as well as to prioritize new studies on nutrient management in areas that are underrepresented.

This work has been presented at the Annual International Meeting of the American Society for Agricultural and Biological Engineers (ASABE), and has been submitted to a peer-reviewed journal:

- ***Methods***

  Spatial soil and topographic characteristics of Pennsylvania were compiled for all land with less than 20% organic matter and within 90 meters of streams. This data set was grouped at a 30-m resolution based on hydrogeomorphological characteristics by using k-means and classification tree statistics for variables corresponding with the P Index or with the water quality model being used in the P Index revision (Figures 1, 2). Within counties, 2-5 groups adequately represented near-stream complexity, with available water capacity, soil saturation, and organic matter being the most important environmental variables. Discontinuities across soil survey boundaries made it impossible to develop clusterings at a broader spatial scale (Figure 3). For county-scale research and management efforts, these groupings provide a manageable approach to developing representative sites for near-stream agricultural lands. The full set of representative sites across the state enables evaluation of the P Index throughout the full hydrogeomorphic diversity of Pennsylvania. In future work, we can then combine a set of reasonable management practices with each of the main hydrogeomorphological regions resulting from this study and verify the revised P Index against expert knowledge and simulation results.

Figure 1. Classification trees for Snyder County, in the Ridge and Valley Region of PA. The tree shows a dichotomous key to class types based on the most important input variables. Each node lists: the predicted class; the probability for each class member to be found at that node (an estimate of misclassification); and the percent of total observations at that node. Class numbers and colors correspond to those in Figure 2.

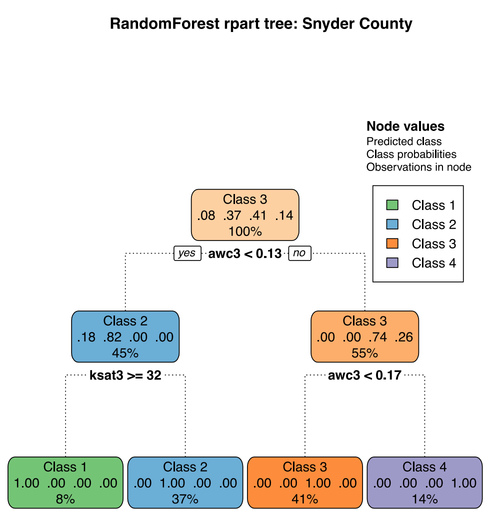


Figure 2. Mapped riparian clusterings for Snyder County, in the Ridge and Valley Region; and 2c) Clarion County, in the Appalachian Plateaus Region. County maps are shaded by elevation, such that darker shades indicate valleys and lighter indicate ridges. Class numbers and colors correspond to those in Figure 1.

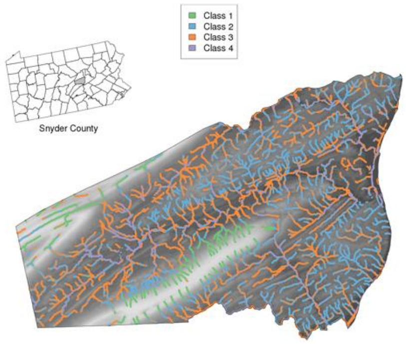
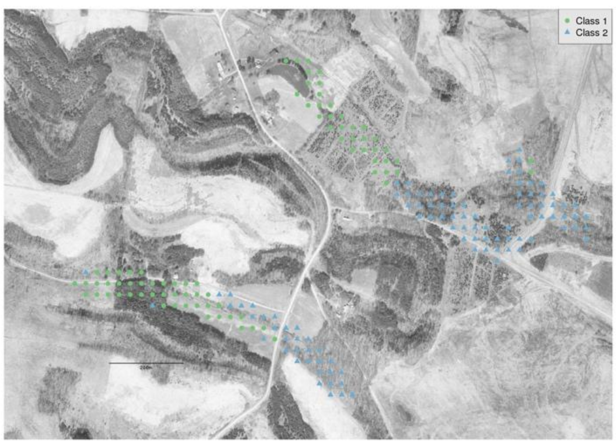


Figure 3. Close-up of near-stream classification overlaying an aerial photo (USGS Digital Orthophoto Quadrangle), in which darker shades depict forests and lighter indicates less densely-covered agricultural land.



<u>Conclusions and Recommendations</u>**:**

- **Establishing a procedure to directly compare soil test P levels in TopoSWAT and in the P Index**
  Project results allowed for a basic comparison of P Index and estimated water quality results and structural changes to P Indices. However, project results demonstrated that a method or process allowing for more direct comparison of P loss results estimated by water quality models such as TopoSWAT is needed. This will allow for the establishment of priority management scenarios that require a more complete evaluation using a water quality model such as TopoSWAT. Additionally, a method for more direct comparison can provide a basis for comparing the impact of different soil test P levels on P loss potential.

- **Assessing the Subsurface Risk Components of Five Coastal Plain Phosphorus Indices**

  While most (if not all) prior P Index evaluations have focused on overall risk scores, our study is perhaps the first to address the subsurface component risk scores of several prominent P Indices in isolation. Given the prevalence of P losses by subsurface flow in artificially drained landscapes of the Delmarva Peninsula, we consider this an important first step toward confirming the veracity of subsurface P loss predictions by P Indices used in this region. However, there are important limitations to relying solely on soil P data as a means for verifying the subsurface P loss routines of P Indices, and our study is no exception. As noted by Sharpley et al. (2012); (2013) and Nelson and Shober (2012), the ideal approach for corroborating P Indices would be to use multi-year observational datasets of P fluxes in subsurface flows. While we concur with this view, the lack of such datasets on the Delmarva Peninsula led us down an alternate path, where instead we highlighted the potential value of soil P data at the depth of the seasonal high water table as a suitable surrogate for assessing subsurface P loss risk. This contention is indeed supported by various studies of P mobilization processes (Mozaffari and Sims, 1996; Sims et al., 1998; Vadas and Sims, 1998) and subsequent losses in shallow subsurface flow (Boynton, 2000; Kemp et al., 2005; Kleinman et al., 2007; Vadas et al., 2007). As such, our results provide interim insight into the predictive ability of subsurface P loss routines in P Indices designed for the Atlantic Coastal Plain, as well as some possible avenues for improving these predictions. Certainly, longer term efforts should be directed to standardizing our monitoring of subsurface P fluxes across various hydrologic and management regimes (e.g., Sharpley et al., 2013), which should include measuring the full suite of geochemical (e.g., redox conditions) and hydrological (e.g., preferential flow paths) factors affecting P solubility and movement. These efforts would not only provide new observational data that could be applied to P Index evaluations in artificially drained landscapes, but also could build upon the preliminary findings reported herein.

- **Establishing a Field Site to Understand Subsurface Hydrology in Drained Agroecosystems Using Electrical Resistivity Imaging and Salt Tracers (Delaware)**

  In this study, ERI data provided minimal evidence for lateral tracer movement occurred during the two monitored storm events. Kleinman et al. (2007) suggested that P losses in subsurface lateral flow was occurring for brief periods of time during heavy storm events. Small storm events, such as those monitored in this study, may not be responsible for significant P transfers. Monitoring of more storm events (with various intensities and durations) over a longer period of time is necessary to confirm this hypothesis.

  Despite limited evidence for later subsurface flow at the site, the potential for ERI explore subsurface water movement at this site and other artificially drained sites in the Delmarva is promising. The process of tracer solubilization and movement throughout the trench was observed clearly during the October event (Figure 2.6). In addition, some movement outside of the trench in the direction of the ditch was seen during the February event (Figures 2.8). These results confirm the design of project to be potentially suitable for continued monitoring of tracer movement by ERI at this site and other sites. Yet sinking of the tracer due to density is a serious concern. More research is needed, perhaps using extracted lysimeters in a laboratory setting, to determine how the salt tracer is behaving in the soil to determine the appropriate tracer concentrations and application methods. Monitoring of this site will continue through a recently funded AFRI Foundational grant.

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Project Generated Publications

Peer-reviewed publications:

1. Cela, S., Q.M. Ketterings, K.J. Czymmek, M. Soberon, and C.N. Rasmussen*. 2015. Long-term trends of nitrogen and phosphorus mass balances on New York dairy farms. Journal of Dairy Science 98: 7052-7070. http://dx.doi.org/10.3168/jds.2015-9776

2. Collick, A. S., D. R. Fuka, P. J. A. Kleinman, A. R. Buda, J. L. Weld, M. J. White, T. L. Veith, R. B. Bryant, C. H. Bolster, Z. M. Easton. 2015. Predicting phosphorus dynamics in complex terrains using a variable source area hydrology model. Hydrological Processes 29(4):588-601.

3. Soberon, M., S. Cela, Q.M. Ketterings, K.J. Czymmek, and C.N. Rasmussen*. 2015. Changes in nutrient mass balances over time and related drivers for 54 New York dairy farms (2015). Journal of Dairy Science 98: 5313–5329. http://dx.doi.org/10.3168/jds.2014-9236.

4. Veith, T. L., J. E. Richards, S. C. Goslee, A. S. Collick, R. B. Bryant, D. A. Miller, B. W. Bills, A. R. Buda, R. L. Sebring, P. J. A. Kleinman. 2015. Navigating spatial and temporal complexity in developing a long-term land use database for an agricultural watershed. Journal of Soil & Water Conservation 70(5):288-296.

5. Amin, M. G., C. Ø. Pedersen, A. Forslund, T. L. Veith, M. Laegdsmand. 2016a. Influence of soil structure on contaminant leaching from injected slurry. Journal of Environmental Management 184(2):289-296. doi:10.1016/j.jenvman.2016.10.002.

6. Amin, M. G., T. L. Veith, A. S. Collick, H. D. Karsten, A. R. Buda. 2016b. Simulating hydrological and nonpoint source pollution processes in a karst watershed: A variable source area model evaluation. Agricultural Water Management 180B(31):212-223, http://dx.doi.org/10.1016/j.agwat.2016.07.011.

7. Cela, S., Q.M. Ketterings, K.J. Czymmek, J.L. Weld, D.B. Beegle, and P.J.A. Kleinman. 2016. Nutrient management planners' feedback on New York and Pennsylvania phosphorus indices. Journal of Soil and Water Conservation 71: 281-288. DOI: 10.2489/jswc.71.4.281.

8. Collick, A. S., T. L. Veith, D. R. Fuka, P. J. Kleinman, A. R. Buda, J. L. Weld, R. B. Bryant, P. A. Vadas, M. J. White, R. D. Harmel, and Z. M. Easton. 2016. Improved simulation of edaphic and manure phosphorus loss in SWAT. Journal of Environmental Quality 45(4):1215-25. Doi:10.1234/jeq2015.03.0135.

9. Liu, J., P. J. A. Kleinman, D. B. Beegle, C. J. Dell, T. L. Veith, L. S. Saporito, K. Han, D. H. Pote, R. B. Bryant. 2016. Subsurface Application Enhances Benefits of Manure Redistribution. Agricultural & Environmental Letters 1:1500900, doi:10.2134/ael2015.09.000.

10. Cela, S., Q.M. Ketterings, M., Soberon, C. Rasmussen, and K.J. Czymmek. 2017. Upper Susquehanna watershed and New York State improvements in nitrogen and phosphorus mass balances of dairy farms. Journal of Soil and Water Conservation 72: 1-11. DOI: 10.2489/jswc.72.1.1

11. Ketterings, Q.M, S. Cela, A. Collick, S. Crittenden and K.J. Czymmek. 2017. Restructuring the P Index to better address P management in New York. Journal of Environmental Quality 46:1372–1379. DOI: 10.2134/jeq2016.05.0185

12. Veith, T. L., S. C. Goslee, D. B. Beegle, J. L. Weld, P. J. A. Kleinman. 2017. Analyzing within-county hydrogeomorphological characteristics as a precursor to Phosphorus Index modifications. Journal of Environmental Quality 46(6):1365-1371. DOI: 10.2134/jeq2016.10.0416

New grant:

1. "Revising and Implementing Phosphorus Indices to Protect Water Quality in the Northeastern US". 2016 USDA Conservation Innovation Grant 69-3A75-17-26 ($994,172.00). Ketterings, Q.M., Czymmek, K., Beegle, D., Kleinman,P, Faulkner, J., Easton, Z., and Collick, A.

Extension articles:

1. Ketterings, Q.M., S. Cela, K.J. Czymmek and S. Crittenden (2016). What is the nutrient balance of your dairy farm? What's Cropping Up? 26(3): 43-45.
2. Van Almelo, J., Q.M. Ketterings, and S. Cela. (2016). Integrating record keeping with whole farm nutrient mass balance; A case study. What's Cropping Up? 26(3): 46-49.
3. Cela, S., Q.M. Ketterings, K.J. Czymmek. M. Soberon, and C. Rasmussen (2015). Trends in nutrient mass balances on four New York dairy farms. What's Cropping Up? 25(3): 25-27.
4. Cela, S. Q.M. Ketterings, K.J. Czymmek, M. Soberon, and C. Rasmussen (2015). Feasible whole farm nutrient mass balances for New York dairy farms. What's Cropping Up? 25(2).
5. Soberon, M. Q.M. Ketterings, K.J. Czymmek, S. Cela, C. Rasmussen (2015). Whole farm nutrient mass balance calculator for New York dairy farms. What's Cropping Up? 25(2).
6. Cela, S. Q.M. Ketterings, K.J. Czymmek, M. Soberon, and C. Rasmussen (2014). Whole farm nutrient balance benchmarks for New York dairies. Cornell Nutrition Conference Proceedings. Syracuse NY, October 21, 2014. http://ecommons.library.cornell.edu/bitstream/1813/37980/1/CNC2014_16_Ketterings.pdf.

Abstracts and presentations at scientific meetings:

1. Crittenden, S., S. Cela, Q.M. Ketterings, and K.J. Czymmek (2016). Developing a new P index for New York with stakeholder input. The Northeastern Plant, Pest, and Soils Conference. 2016. Philadelphia, PA. January 3-7, 2016. Abstract and poster presentation.
2. Kleinman, P.J., T.J. Basden, D.B. Beegle, Z. Easton, Q. Ketterings, A. Shober, and J. Weld (2016). Phosphorus index project overview: Refining and harmonizing phosphorus indices in the Chesapeake Bay region to improve critical source area identification and to address nutrient management priorities. 71st International Annual Conference Soil and Water Conservation Society. *Managing Great River Landscapes.* July 24-27, 2016. Louisville, Kentucky. Abstract and oral presentation.
3. Ketterings, Q.M., S. Cela, M. Soberon, C. Rasmussen, S. Crittenden, and K.J. Czymmek (2016). Whole farm nutrient mass balances for improvements in agriculture and environmental management of dairy farms. The Northeastern Plant, Pest, and Soils Conference. 2016. Philadelphia, PA. January 3-7, 2016. Abstract and oral presentation.
4. Cela, S., Q.M. Ketterings, K.J. Czymmek and S.J. Crittenden (2015). A new and more intuitive structure for the New York phosphorus index. Annual Conference of the Agronomy, Soil and Crop Science Societies of America. Minneapolis, MN. November 15-18, 2015. Abstract and poster presentation.
5. Cela, S., Q.M. Ketterings, K.J. Czymmek, M. Soberon and C. Rasmussen (2015). Nutrient mass balances trends for dairy farms in New York and in the Upper Susquehanna watershed. Abstract and oral presentation. Annual Conference of the Agronomy, Soil and Crop Science Societies of America. Minneapolis, MN. November 15-18, 2015.
6. Ketterings, Q.M., S.J. Crittenden, S. Cela, and K.J. Czymmek (2015). Evaluation of the New York phosphorus index. Abstract and oral presentation. Annual Conference of the Agronomy, Soil and Crop Science Societies of America. Minneapolis, MN. November 15-18, 2015.
7. Cela S., Q.M. Ketterings, K.J. Czymmek, M. Soberon and C. Rasmussen (2014). Characterization of nutrient mass balances on New York dairy farms. ASA/SSSA/CSSA meeting, Long Beach, California, November 2-5, 2014. 260-10. Abstract and poster presentation.
8. Cela S., Q.M. Ketterings and K.J. Czymmek (2014). Ten years of the New York phosphorus index: Nutrient management planners' feedback. ASA/SSSA/CSSA meeting, Long Beach, California, November 2-5, 2014. Abstract and poster presentation.
9. Cela, S., Q.M. Ketterings, K.J. Czymmek, M. Soberon and C. Rasmussen (2014). Evolution of N and P mass balances over time on four dairy farms in NY. ASA/SSSA/CSSA meeting, Long Beach, California, November 2-5, 2014. 353-1 Oral Presentation and Abstract.
10. Cela, S., Q.M. Ketterings, M. Soberon, S. Swink and K.J. Czymmek (2013). State, regional and farm-scale nutrient balances: tools for enhanced efficiency of whole-farm nutrient use. ASA/SSSA/CSSA meeting, Tampa, FL, November 3-6, 2013. Abstract and oral presentation.

Extension talks:

1. Ketterings, Q.M., S. Cela, K.J. Czymmek, and S. Crittenden (2016). Developing a new P index for New York with stakeholder input. Phosphorus index meeting with OMAFRA, Canada. June 16, 2016. ~10 people. 1 hr.
2. Ketterings, Q.M., S. Cela, K.J. Czymmek, and S. Crittenden (2016). Developing a new P index for New York with stakeholder input. 2016 International Association of Great Lakes Research (IAGLR) conference, Guelph, ON, June 6-10, 2016. ~50 people. 30 min.Ketterings, Q.M., K.J. Czymmek, S. Cela and S. Crittenden (2016). New York P index – Stakeholder input session. Canton, NY. April 12, 2016. 18 people. 4 hours.
3. Ketterings, Q.M., K.J. Czymmek, S. Cela and S. Crittenden (2016). New York P index – Stakeholder input session. Walton, NY. April 7, 2016. 25 people. 4 hours.

4. Ketterings Q.M., and K.J. Czymmek (2016). P index evaluation for New York. 15 people. 30 min. Tabaco Barn Meeting, Lexington, KY. March 29, 2016.
5. Ketterings, Q.M., K.J. Czymmek, S. Cela and S. Crittenden (2016). New York P index – Stakeholder input session. Canton, NY. March 11, 2016. 15 people. 4 hours.
6. Ketterings, Q.M., K.J. Czymmek, S. Cela and S. Crittenden (2016). New York P index – Stakeholder input session. Warsaw, NY. February 26, 2016. 15 people. 4 hours.
7. Ketterings, Q.M., S. Cela, M. Soberon, C. Rasmussen, S. Crittenden, and K.J. Czymmek (2016). Whole farm nutrient mass balances for improvements in agriculture and environmental management of dairy farms. Center for Dairy Excellence Seminar Series. February 8, 2016. ~30 people. 50 min.
8. Ketterings, Q.M., K.J. Czymmek, S. Cela, and S. Crittenden (2016). Phosphorus index update from New York. NRCS-CIG nationwide project. Webinar invited by Andrew Sharpley. ~10 people. 60 min.
9. Ketterings, Q.M., K.J. Czymmek, S. Cela, and S. Crittenden (2015). Phosphorus Index update; new ideas for New York. Northeast Region Certified Crop Advisor annual Training. December 1 and 2, 2015. East Syracuse, NY. 2x50 min. 89 people.
10. Ketterings, Q.M. (2015). Whole farm nutrient balances; what do they say? Field Crop Dealer Meetings. November 11, 2015. Syracuse, NY. 40 min. ~80 people.
11. Ketterings, Q.M. (2015). Tightening nutrient cycles for dairy farms: cover crops, double crops, and whole farm balances. Stockbridge School of Agriculture, University of Massachusetts-Amherst, CT. October 5, 2015. 1 hr. ~25 people.
12. Ketterings, Q.M. (2015). Whole farm balances. SAI Platform Meeting in NY. Cayuga Milk Ingredients Plant, Auburn, NY. September 2, 2015. 15 min. ~20 people.
13. Cela S., M. Soberon, C.N. Rasmussen, K.J. Czymmek, J. Burke, R. Jerauld, A. Ristow and Q.M. Ketterings (2015). Nutrient Mass Balances: Definition, importance, feasible levels and trends over time. Nutrient Reduction Workgroup USC Final Wrap-up Meeting. Cortland, NY. April 29, 2015. ~30 people.
14. Cela, S., K.J. Czymmek and Q.M. Ketterings (2014). Whole Farm Nutrient Mass Balances; Benchmarking. Northeast Region Certified Crop Advisor Annual Training. East Syracuse. December 3, 2014. 50 min.
15. Beegle, D., S. Cela, Q.M. Ketterings, and K.J. Czymmek (2014). P Index; Beyond States. Northeast Region Certified Crop Advisor Annual Training. East Syracuse. December 2, 2014. 2x50 min.
16. Ketterings, Q.M., and K. J. Czymmek (2014). Phosphorus research update. Cornell P research meetings, Ithaca NY. 30 min. 6 people.
17. Ketterings, Q.M. and S. Cela (2014). Whole farm mass balances; why we should care. Soil and Water Conservation Society Empire Chapter Annual Meeting. Auburn, NY. November 21, 2014. 30 min. ~45 people.
18. Ketterings, Q.M. and S. Cela (2014). New York Phosphorus Index; what planners really think. Soil and Water Conservation Society Empire Chapter Annual Meeting. Auburn, NY. November 21, 2014. 30 min. ~45 people.
19. Ketterings Q.M. and S. Cela (2014). Whole-farm nutrient mass balance benchmarks for New York dairies. Cornell Nutrition Conference. Syracuse, NY. October 23, 2014. 40 min. ~200 people.
20. Ketterings, Q.M. and S. Cela (2014). Results of the NY P index survey. Allegany Plateau expert panel meeting, April 8, 2014. 20 min. ~20 people.
21. Czymmek, K.J., S. Cela, and Q.M. Ketterings (2013). P index: 10+ years. What works? What doesn’t? What’s next? Northeast Region Certified Crop Advisor Annual Training. Advanced Training. December 3 and 4, 2013. Syracuse, NY. 2*50 min. 100 people.