Pennsylvania Department of Environmental Protection Remote Sensing Pilot Project

Phase 1 Methodology Development Plan for Remote Sensing Verification of Conservation Tillage BMPs

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Contents

Executive Summary

Conservation tillage best management practices (BMPs) contribute substantially to sediment and nutrient reductions in the Chesapeake Bay Watershed. Accordingly, the Chesapeake Bay Program (CBP) requires reporting agencies, such as the Pennsylvania Department of Environmental Protection (PA DEP), to provide annual reports of conservation tillage BMP implementation throughout each jurisdiction of the Chesapeake Bay Watershed. Transect surveys are currently the predominant methodology used for conservation tillage BMP verification and reporting in Pennsylvania. While this methodology accurately estimates county-level summaries of conservation tillage BMP implementation, transect surveys are time and cost-intensive and fail to provide a detailed view of the spatial distribution of tillage practice implementation within an individual county. Remote sensing-based conservation tillage BMP verification methodologies offer potential opportunities to overcome these limitations.

In various reports, including the "Conservation Tillage Practices for Use in Phase 6.0 of the Chesapeake Bay Program Watershed Model" and Appendix B of the Chesapeake Bay Program's BMP Verification Guidance document, the CBP has highlighted the potential utility of remote sensing methods for verifying conservation tillage BMPs. Despite report recommendations for research into remote sensing BMP verification methods, the CBP currently does not offer specific guidance on how to use remote sensing for conservation tillage BMP verification. For this reason, PA DEP has initiated a remote sensing pilot project with Resolve Hydro LLC to develop a methodology and model for satellite-based conservation tillage BMP verification in the Chesapeake Bay Watershed.

PA DEP's remote sensing pilot project has been divided into three distinct phases, which encompass planning (Phase 1), development (Phase 2), and implementation (Phase 3) activities. This report represents the primary work product of Phase 1 and details an approach for model and methodology development in Phase 2.

As described in the following report, the proposed technical approach for Phase 2 consists of five tasks:

- Task 1 – Data Collection and Pre-Processing
- Task 2 – Satellite Data Acquisition
- Task 3 – Model Development
- Task 4 – Model Evaluation and Performance Characterization
- Task 5 – Method Development and Reporting

Task 1 will include data validation, geolocation, and field delineation steps to clean and pre-process historical transect survey data collected by Capital RC&D in over thirty counties in Pennsylvania from 2020 to 2024. Following data compilation and pre-processing, imagery from three satellite platforms—Landsat 8/9, Sentinel-2, and the Planet SuperDove constellation—will be acquired in each area of interest delineated during Task 1. In Task 2, the resulting satellite/in-situ matchup dataset will be further processed to remove invalid pixels, compute relevant band indices, and address gaps in satellite coverage through time bucketing and interpolation methods.

In Task 3, the cleaned satellite/in-situ matchup dataset will be subdivided into datasets for model training, validation, and testing. An iterative development process will be employed to train and fine-tune machine learning models that classify conservation tillage practices based on satellite remote sensing data in the training and validation datasets. At the end of Task 3, three to five candidate models will be selected for performance characterization in Task 4. The Task 4 performance characterization will quantify the developed models' overall accuracy and generalizability using the held-out testing dataset. During Task 4, model performance in different contexts, such as in different hydrogeomorphic regions, will be evaluated and reviewed to identify potential causes of model error and inform later model implementation.

Finally, in Task 5, a model development report will be prepared to describe the process used to train, test, and identify the best-performing machine learning model developed for classifying conservation tillage BMPs. Additionally, a standard operating procedure (SOP) will be prepared and presented to the Agriculture Workgroup as a proposed remote sensing-based conservation tillage BMP verification methodology.

Throughout this project, PA DEP and Resolve Hydro LLC will coordinate regularly with the CBP Program Office, CBP Agriculture Workgroup (AgWG), and other stakeholders (e.g., the CBP Watershed Technical Workgroup) to report on and solicit feedback regarding project progress. For this project, a nine-member project advisory committee (PAC) consisting of experts in machine learning, remote sensing, and conservation agriculture has been established to guide and critically evaluate project outcomes. Overall, this project aims to employ the methods described in this Phase 1 report to develop tools and data products that will enhance current capabilities for tracking conservation tillage BMP implementation in the Chesapeake Bay Watershed.

Introduction

In March 2024, Pennsylvania Department of Environmental Protection (PA DEP) engaged Resolve Hydro LLC to develop a machine learning model and verification methodology for reporting conservation tillage best management practice (BMP) implementation using high-resolution satellite data. This report summarizes the findings and recommendations from Phase 1 of a comprehensive three-phase strategy toward this goal. The following report sections include a brief project overview, background information on remote sensing and conservation tillage, and a proposed technical approach for the project's second phase.

Purpose

The intent of this report is to furnish stakeholders with an overview of the trajectory for model and method development to encourage early feedback on the suggested approach as part of an iterative and collaborative process design. The report outlines a high-level roadmap for the subsequent project phase (Phase 2). Further, the report identifies key datasets and metrics that will be used during model development and evaluation. By providing this information to stakeholders prior to model development, the project team intends to solicit feedback to guide the data processing workflow and proposed model application approach. This report is not intended to define the final technical process for model and methodology development. Instead, it is intended to frame a development process that is refined in Phase 2 with stakeholder input.

Pilot Project Overview

In this pilot project, PA DEP and Resolve Hydro LLC have partnered to use remote sensing methods to enhance the verification of conservation tillage BMPs throughout the Chesapeake Bay Watershed. Verifying and reporting conservation tillage BMP implementation throughout Pennsylvania is critical to tracking the state's progress toward Total Maximum Daily Load (TMDL) goals and prioritizing farm outreach efforts. Traditionally, conservation tillage BMP verification in Pennsylvania has been conducted biannually using cropland roadside transect surveys, which require surveyors to drive thousands of miles throughout the state to gather field data. The intention of this project is to develop and evaluate an alternative BMP verification option that could reduce the time, costs, and direct emissions of current methods while potentially enhancing BMP verification accuracy and replicability.

In this project, data collected from past transect surveys will be paired with coincident satellite measurements to develop a model for identifying conservation tillage BMP implementation in agricultural fields. The key findings from remote sensing model development and implementation will be synthesized in a report and verification methodology for use by PA DEP and other reporting agencies in the Chesapeake Bay Program (CBP). The developed verification methodology will be submitted to the CBP Agriculture Workgroup (AgWG) for methodology approval prior to broader implementation in Pennsylvania. As shown in Figure 1 and outlined below, this work has been divided into three distinct project phases:

Phase 1: Methodology Development Plan

- Develop a comprehensive plan and written report documenting how to develop and evaluate a method for remote sensing-based verification of conservation tillage practices.

Phase 2: Method Development and Evaluation

- Train and test machine learning models that use satellite imagery to classify the degree of conservation tillage in a field.
- Develop and evaluate a BMP verification methodology for CBP approval.

Phase 3: Implementation

- Employ the model and method generated in Phase 2 to characterize conservation tillage implementation in agricultural areas located in the PA jurisdiction of the Chesapeake Bay Watershed during the 2025 season.

Figure 1. PA DEP Pilot Project timeline overview.

Phase 1 Objectives

The overarching goal of Phase 1 was to establish a project team and framework that would provide guidance for the subsequent phases of the pilot project. Specifically, Phase 1 efforts aimed to accomplish the following objectives:

- Gather and synthesize available data regarding conservation tillage surveys from 2015 to the present
- Establish a core project team, advisory committee, and engagement structure
- Generate a written report documenting a proposed technical approach for subsequent project phases
- Collect and incorporate feedback from the CBP Agriculture Workgroup to refine the overall project approach

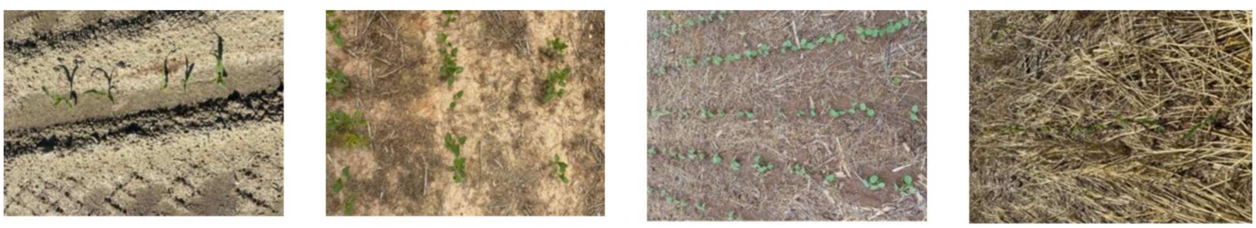
The results of the Phase 1 work are described in the report sections that follow.

Background

Definition and Importance of Conservation Tillage

As shown in Figure 2, the Chesapeake Bay Program identifies four types of tillage regimes based on the magnitude of crop residue coverage on fields immediately following crop planting.[1] The Chesapeake Bay Program's definitions for these tillage regimes are as follows:

- **Conventional Tillage**: Any tillage routine that does not achieve 15% crop residue coverage immediately after planting is considered conventional tillage and does not qualify as a BMP.
- **Low Residue Tillage**: A conservation tillage routine that involves the planting, growing, and harvesting of crops with minimal disturbance to the soil in an effort to maintain 15% to 29% crop residue coverage immediately after planting each crop.
- **Conservation Tillage**: A conservation tillage routine that involves the planting, growing and harvesting of crops with minimal disturbance to the soil in an effort to maintain 30% to 59% crop residue coverage immediately after planting each crop.
- **High Residue, Minimum Soil Disturbance Tillage**: A conservation tillage routine that involves the planting, growing and harvesting of crops with minimal disturbance to the soil in an effort to maintain at least 60% crop residue coverage immediately after planting each crop.



Conventional Tillage | **Low Residue Tillage** | **Conservation Tillage** | **High Residue, Minimum Soil Disturbance Tillage**

Figure 2. Examples of tillage practices in agricultural fields. Only fields with over 15% crop residue coverage immediately after crop planting are considered BMPs in the CBP. Specific land use types that are eligible for conservation tillage BMPs in the CBP include full season soybeans, grain with manure, grain without manure, silage with manure, silage without manure, small grains and grains, double cropped land, and specialty crops. Images from "Virginia Tillage/Residue Survey – Using an Alternative Approach for Verification."[2]

Although the CBP defines conservation tillage specifically as a routine associated with 30% to 59% crop residue coverage remaining on the field immediately after planting, the term conservation tillage is more colloquially used to describe any non-conventional tillage regime

[1] https://www.chesapeakebay.net/what/publications/quick-reference-guide-for-best-management-practices-bmps
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/VA_DCR_2022_Tillage_Survey_AgWG_7-20-2023.pdf
https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/VA_DCR_2022_Tillage_Survey_AgWG_7-20-2023.pdf

that minimizes soil disturbance during crop planting and cultivation. Accordingly, in this report, low residue tillage, conservation tillage, and high residue minimum soil disturbance tillage are collectively referred to as conservation tillage practices/BMPs.

Conservation tillage practices offer extensive field and ecological benefits by helping maintain soil structure, increasing soil organic matter content, enhancing water infiltration, and reducing the loss of soil nutrients.[3] Due to the efficacy of conservation tillage practices in reducing nutrient and sediment loading, farmers throughout the Chesapeake Bay Watershed have been encouraged to adopt and implement conservation tillage practices.[4] These efforts have resulted in substantial reductions in agricultural loads to Bay waters and have significantly contributed to overall progress toward reaching total maximum daily load (TMDL) goals. For example, in Pennsylvania, conservation tillage practices account for approximately 74% of sediment load reductions and 50% of phosphorus load reductions coming from agricultural BMPs. Across all agricultural BMPs Bay-wide, conservation tillage practices are responsible for approximately 66% of sediment load reductions and 34% of phosphorus load reductions (see Figure 3).[5]

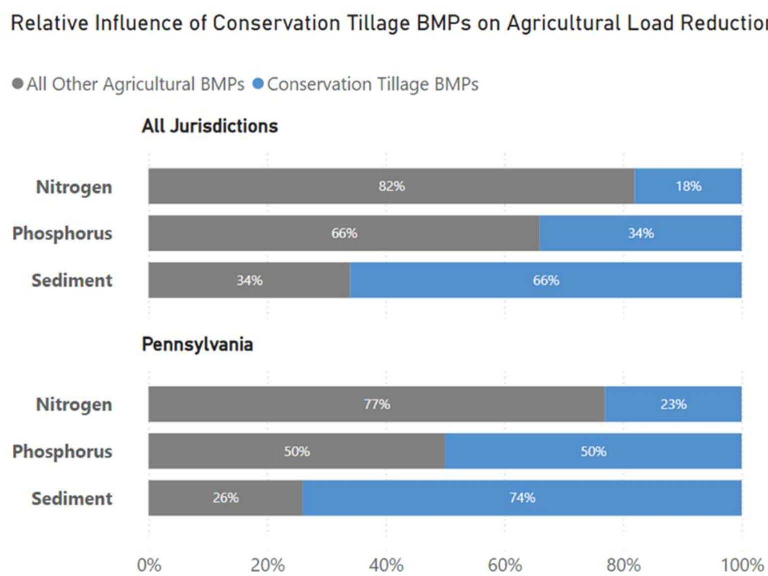


Figure 3. Relative influence of conservation tillage BMPs on nutrient and sediment load reductions from agricultural BMPs per the 2023 Edge of Tide Chesapeake Assessment Scenario Tool (CAST) model. Notably, in Pennsylvania's jurisdiction of the Chesapeake Bay Watershed, approximately three-quarters of the sediment load reduction from agricultural BMPs is attributable to conservation tillage BMPs.

Current Conservation Tillage BMP Verification Methodology

To receive TMDL credit for the nutrient and sediment reductions afforded by conservation tillage BMPs, PA DEP must regularly survey and quantify conservation tillage BMP implementation in

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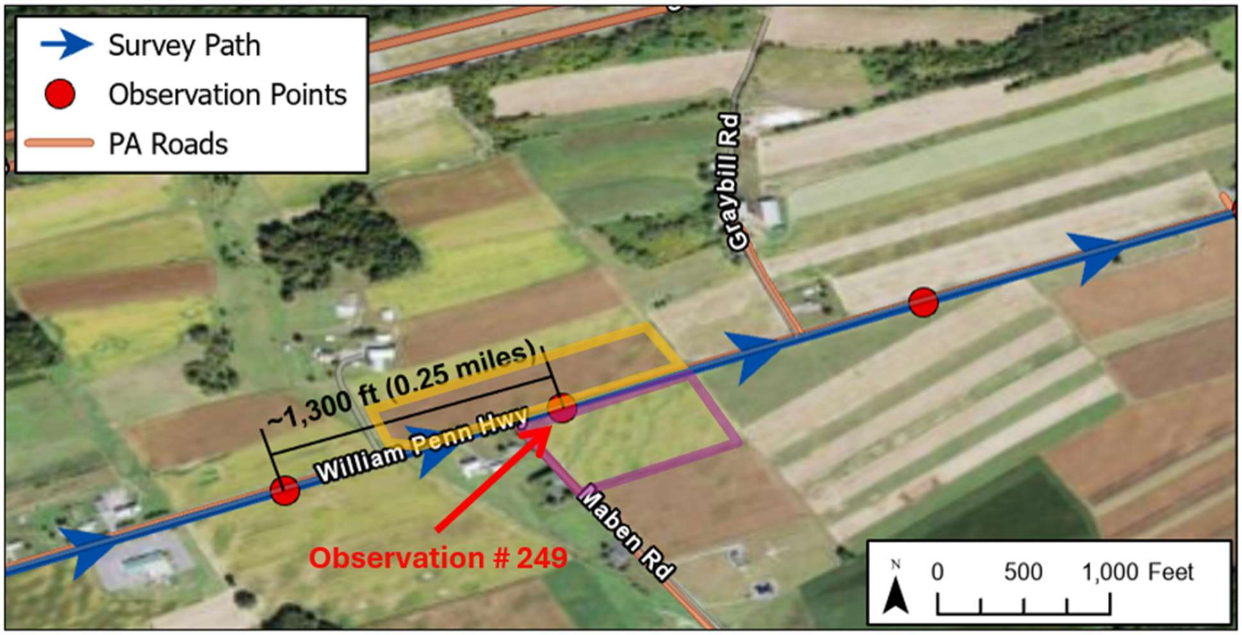
[3] https://www.sciencedirect.com/science/article/pii/S2095633915300630
[4] https://www.fsa.usda.gov/news-room/news-releases/2022/usda-announces-initiative-invests-225-million-in-water-quality-improvements-in-chesapeake-bay
[5] https://d38c6ppuviqmfp.cloudfront.net/documents/Appendix+B+-Ag+BMP+Verification+Guidance+Final.pdf

accordance with the procedures set forth in the Chesapeake Bay Program's BMP Verification Guidance document. According to Appendix B of the BMP Verification Guidance document, conservation tillage BMPs are categorized as single year visual assessment BMPs. Consequently, conservation tillage BMPs must be verified and reported on an annual basis to ensure associated load reductions are accurately accounted for in TMDL calculations. In Pennsylvania, transect surveys are the primary verification methodology for reporting conservation tillage BMPs for use in TMDL calculations.

Pennsylvania's annual conservation tillage transect surveys are conducted by Capital RC&D and follow the procedures established by the Conservation Technology Information Center (CTIC) and approved by the CBP's AgWG. Each transect survey involves three trained individuals driving several hundred miles through each county along planned survey routes that include approximately 460 observation points per county. At each observation point, surveyors record the planted crop type, the visual estimate of the amount of crop residue (<15% crop residue, 15-30% crop residue, 30-60% crop residue, or >60% crop residue), and other land use information for parcels on either side of the road. Independent verification of the data collected is then conducted for 10% of the reported crop observations. An example of a transect survey data record is shown in Figure 4.[6]

Over the study period (2020-2024), Capital RC&D has conducted multiple transect surveys in over thirty counties in Pennsylvania, including twenty-seven counties located entirely within Pennsylvania's jurisdiction of the Chesapeake Bay Watershed as well as in the Chesapeake Bay drainage area of four counties partially located within the Bay Watershed. Additionally, in 2023, new transect survey routes were added for two counties located entirely within the Chesapeake Bay Watershed and for the Chesapeake Bay drainage area of one county partially located within the Bay Watershed. In total, Capital RC&D has surveyed thirty-four counties within Pennsylvania's jurisdiction of the Chesapeake Bay Watershed on a roughly two-year cycle (approximately fifteen surveys are conducted each year).

[6] https://files.dep.state.pa.us/Water/ChesapeakeBayOffice/Final_QAPP_2023_PADEP_BWRNSM_Revised_1-25-2024signed.pdf



Obs. #	Left/ Right	Planted Crop	Cover Crop Kill	<15% Residue Coverage	15-30% Residue Coverage	30-60% Residue Coverage	>60% Residue Coverage	No-till (Yes/No)	Land Use
249	Left	Corn	*<Null>*	*<Null>*	*<Null>*	*<Null>*	X	Yes	*<Null>*
249	Right	Soybean	*<Null>*	*<Null>*	*<Null>*	*<Null>*	X	Yes	*<Null>*

Figure 4. Example conservation tillage transect survey results for an observation point in Juniata County, Pennsylvania. As shown in the map, two data records are associated with Observation # 249. The first observation record corresponds to the field on the left side of the survey path (i.e., the field outlined in yellow). The second observation record corresponds to the field on the right side of the survey path (i.e., the field outlined in purple). For each data record, tillage regime information is recorded, as well as information (if available) on the planted crop type, cover crop kill practices, no-till practices, and land use.

Capital RC&D's annual tillage survey, which began in 2014, costs approximately $150,000 per year to complete. In Spring 2022, surveyors drove an estimated 3,875 miles and slowed or stopped at over 4,600 locations to complete the tillage survey in 15 counties (Berks, Bradford, Centre, Chester, Clinton, Columbia, Lancaster, Lebanon, Luzerne, Lycoming, Mifflin, Montour, Northumberland, Schuylkill, and Tioga). Likewise, in Spring 2023, surveyors made observations at over 6,200 points to complete transect surveys in 16 counties included in the two-year survey cycle (Adams, Bedford, Blair, Cambria, Cumberland, Dauphin, Franklin, Fulton, Huntingdon, Indiana, Juniata, Perry, Snyder, Somerset, Union, and York). As reported by CTIC, "when conducted properly, this cropland transect survey procedure provides a high degree of confidence in the data summaries. Users can have 90% or more confidence in the accuracy of the results".[7] While valuable and accurate for county-level conservation tillage BMP reporting, traditional transect surveys are notably restricted in that they are costly, time-intensive, and spatially limited to roadside agricultural fields.

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[7] https://efotg.sc.egov.usda.gov/references/Delete/2003-10-06/nb_450_2_2_a1%5B1%5D.pdf

Rationale for a Remote Sensing-Based Verification Approach

Remote sensing-based BMP verification of conservation tillage practices is a promising potential verification approach that may reduce the labor, time, and costs currently invested in traditional transect surveys while simultaneously extending spatial and temporal survey coverage. Remote sensing describes the process of monitoring a distant target's characteristics by measuring the interaction of the target with electromagnetic radiation (i.e., light). In the case of conservation tillage, different combinations of crop, soil, and residue coverage predictably impact wavelength-specific values known as surface reflectance values (see Figure 5). Remote sensing platforms, such as drones and satellites, are equipped with various sensors that can measure surface reflectance values with varying spatial, temporal, spectral, and radiometric resolution (see Table 1). Thus, using in-situ crop residue coverage data and coincident satellite measurements, models relating surface reflectance and crop residue coverage may be developed to track conservation tillage BMPs.

Numerous studies have demonstrated the viability of using remote sensing to characterize the degree of conservation tillage implemented in agricultural fields. Within the Chesapeake Bay Watershed for example, Hively et al. (2018) produced high accuracy models for predicting residue coverage using from the WorldView-3 (WV3) and Landsat 8 satellites.[8] In Hively et al.'s work, WV3 band indices, including the Shortwave Infrared Normalized Difference Residue Index (SINDRI) and the Lignin Cellulose Absorption Index (LCA), were used to produce models for predicting crop residue coverage with root mean squared errors (RMSE) of 7.15% and 8.40% and coefficients of determination of 0.94 and 0.92, respectively. In this same study, the Normalized Difference Tillage Index (NDTI) calculated using Landsat 8 imagery was used to produce a crop residue coverage model with an RMSE of 12.00% and a coefficient of determination value of 0.84. Other studies have similarly shown that satellite remote sensing can provide reliable estimates of conservation tillage implementation on broad spatial scales (e.g., Azzari et al., 2019;[9] Beeson et al., 2020;[10] Gowda et al., 2008).[11]

[8] https://www.mdpi.com/2072-4292/10/10/1657
[9] https://www.sciencedirect.com/science/article/pii/S0034425718305157?via%3Dihub
[10] https://www.mdpi.com/2072-4292/12/16/2665
[11] https://www.tandfonline.com/doi/full/10.1080/01431160701581810?casa_token=d3PM0ShLpNUAAAAA%3ATcRLlpAmyeeQdT3BOiXwLGUq94h0KdbHtef7P7Av7LsdXKlWpLS2UgGxOpJwLJ9KiJ7pkMdWQc9_hA

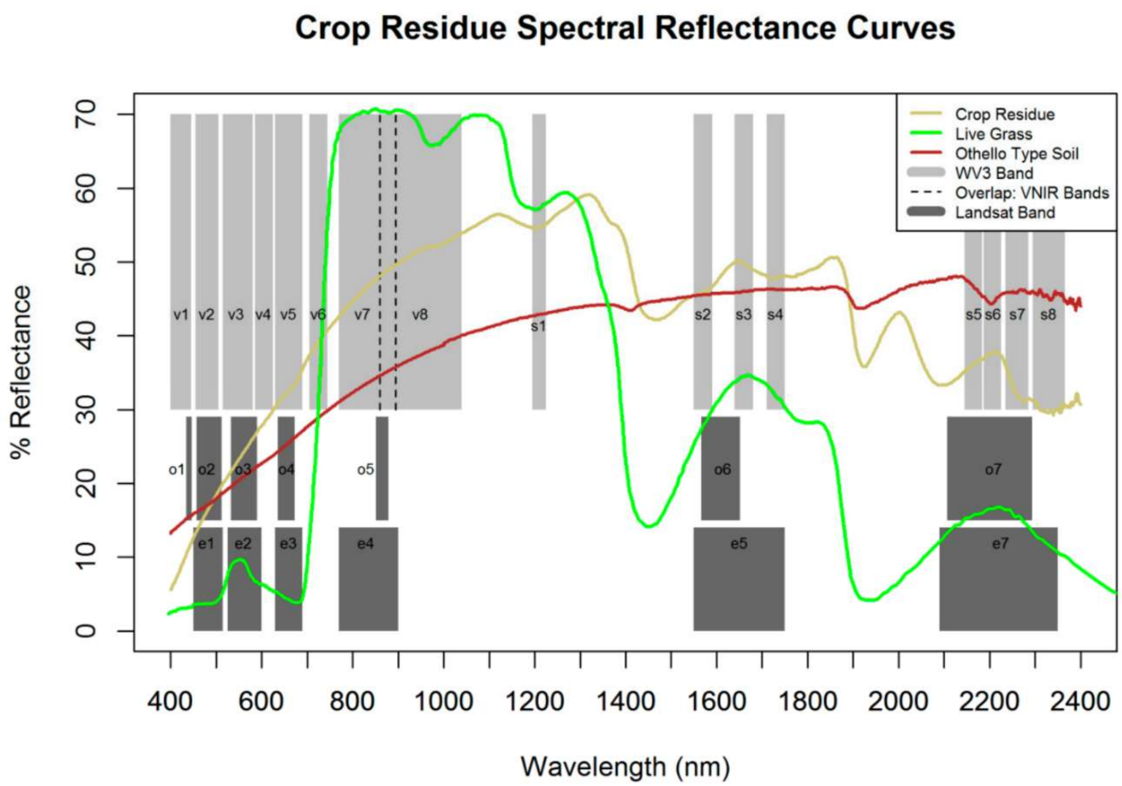


Figure 5. Reflectance curves for maize residue (tan line), live grass (green line), and an Othello silt-loam soil (red-line). The grey bars represent the spectral band widths of WorldView-3, Landat 8 Operational Land Imager (OLI), and Landsat 7 ETM. Figure reproduced from Hively et al. (2018).[12]

Table 1. Spatial, temporal, spectral, and radiometric resolution of selected satellite platforms.

Satellite	Sensor	Spatial Resolution	Effective Temporal Resolution	Number of Spectral Bands	Radiometric Resolution	Data Availability
Landsat 8/9	Operational Land Imager (OLI)	30-meter (15 -meter panchromatic band)	8 days	8	16-bit	Publicly available
Sentinel -2	Multi -Spectral Instrument (MSI)	10-meter (20 -meter or 60-meter depending on band)	5 days	13	12-bit	Publicly available
Planet SuperDove (PlanetScope)	PSB.SD	3-meter	1 day	8	16-bit	Commercially available

Although these models provide promising results, their applicability for larger-scale model training and implementation faces several limitations. For instance, the WV3 satellite generally requires expensive tasking (approximately $30 per square kilometer) to collect new imagery, and it has a relatively small historical imagery archive available for retrospective analyses.[13]

[12] https://www.mdpi.com/2072-4292/10/10/1657
[13] https://apollomapping.com/worldview-3-satellite-imagery

Additionally, while Landsat 8 data is freely available and benefits from a large historical archive, its 30-meter spatial resolution and 16-day revisit frequency (effectively 8-day since the 2021 launch of Landsat 9) presents challenges in training and deploying models using this data source alone. Specifically, Landsat 8/9's coarse spatial resolution makes it difficult to properly resolve texture information associated with different practices, and its infrequent overpass timing makes it difficult to obtain consistent cloud-free satellite data.

Recent studies have shown that newer satellite data available at high spatial and temporal resolutions may enhance classification performance for identifying conservation tillage BMPs when compared to sensors with lower spatial and temporal resolution. For example, Liu et al. (2022) showed that, machine learning models using 3-meter PlanetScope imagery had the highest classification accuracy (86.5%) for identifying conservation tillage practices in smallholder systems in India when compared to 10-meter Sentinel-1 and Sentinel-2 data.[14] Likewise, Luo et al. (2023) observed that the accuracy of convolutional neural networks (CNNs) trained to use PlanetScope imagery to identify conservation tillage practices "continuously increased with increases in both temporal and spatial resolutions."[15] This finding echoes the findings of Watts et al.[16] (2011) and Zheng et al. (2012)[17] who each observed that the use of multi-temporal imagery improved classification of conservation tillage practices.

PA DEP aims to leverage the success of recent conservation tillage remote sensing studies to develop a remote sensing-based BMP verification methodology and conservation tillage classification model. Beyond cost and time savings, a remote sensing-based BMP verification method offers the additional benefit of removing surveyor subjectivity during classification. Moreover, a remote sensing-based verification methodology enables spatially and temporally continuous classification of conservation tillage practices, which can support more effective and targeted outreach and policy decisions.

PA DEP's goals for a remote sensing-based verification methods reflect recommendations expressed in the CBP report "Conservation Tillage Practices for Use in Phase 6.0 of the Chesapeake Bay Program Watershed Model." For example, this report states, "remotely sensed (aerial/satellite) estimates are also likely feasible [for use in BMP verification] given proper calibration."[18] Additionally, the report describes in "Section 5.2 Future Verification of Conservation Tillage Practices" that the expert panel convened to develop the report "envisions that potential opportunities may exist in the future for utilizing alternative forms of BMP verification, such as remote sensing from satellite, aerial, and drone imagery."

[14] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0277425
[15] https://www.sciencedirect.com/science/article/pii/S266601722300010X#bib74
[16] https://www.sciencedirect.com/science/article/pii/S0034425710002452?via%3Dihub
[17] https://www.sciencedirect.com/science/article/pii/S0034425711003439
[18] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/CT_6.0_Conservation_Tillage_EP_Revised_Full_Report_12-14-16.2_FINAL_NEW_TEMPLATE.pdf

As noted in Table B-6 of the Agriculture BMP Verification Guidance document, remote sensing methods are "potentially eligible" for use in verification of single year visual assessment BMPs, including conservation tillage. As PA DEP and other reporting agencies in the CBP continue to promote conservation agriculture to reduce nutrient and sediment loading to the Chesapeake Bay, enhanced monitoring of tillage practices is critical for targeted outreach and reporting. Accordingly, PA DEP has decided to pursue this pilot project to develop a model and methodology for enhanced reporting of conservation tillage BMPs.

Technical Approach for Phase 2

In Phase 2 of this project, Resolve Hydro LLC will use historical Capital RC&D conservation tillage transect survey observations to develop and test machine learning models that use satellite imagery to classify the degree of conservation tillage in a field. Further, in this phase, Resolve Hydro LLC will develop a methodology for employing remote sensing models to verify and report conservation tillage BMP implementation in the Chesapeake Bay Watershed. The primary Phase 2 project objectives are as follows:

- Perform data collection, processing, and model testing/training tasks
- Quantify and qualify efficacy, costs, and other relevant parameters related to implementation of traditional and remote sensing BMP verification methodologies
- Develop written report outlining proposed BMP verification methodology
- Report back to engaged stakeholders and revise methodology based on stakeholder feedback

As shown in Figure 6, Phase 2 tasks will include five tasks—data collection and pre-processing, satellite data acquisition, model development, model evaluation and performance quantification, and method development and reporting. Further details regarding each of these tasks are provided in the sections below.

Figure 6. Proposed technical approach for Phase 2 (Method Development and Evaluation).

Geographic Scope

The geographic scope of both Phase 1 and subsequent Phase 2 work includes thirty counties in Pennsylvania's jurisdiction of the Chesapeake Bay Watershed (see Figure 7). Combined, these counties contain approximately 1.97 million acres of cropland.[19] The selection of these thirty counties was based on the availability of historical conservation tillage data spanning the period from 2020 to 2024. Within Pennsylvania's jurisdiction of the Chesapeake Bay Watershed, eleven counties do not conduct regular transect surveys. Consequently, these eleven counties will be excluded from Phases 1 and 2; however, they may be incorporated into Phase 3 (Implementation).

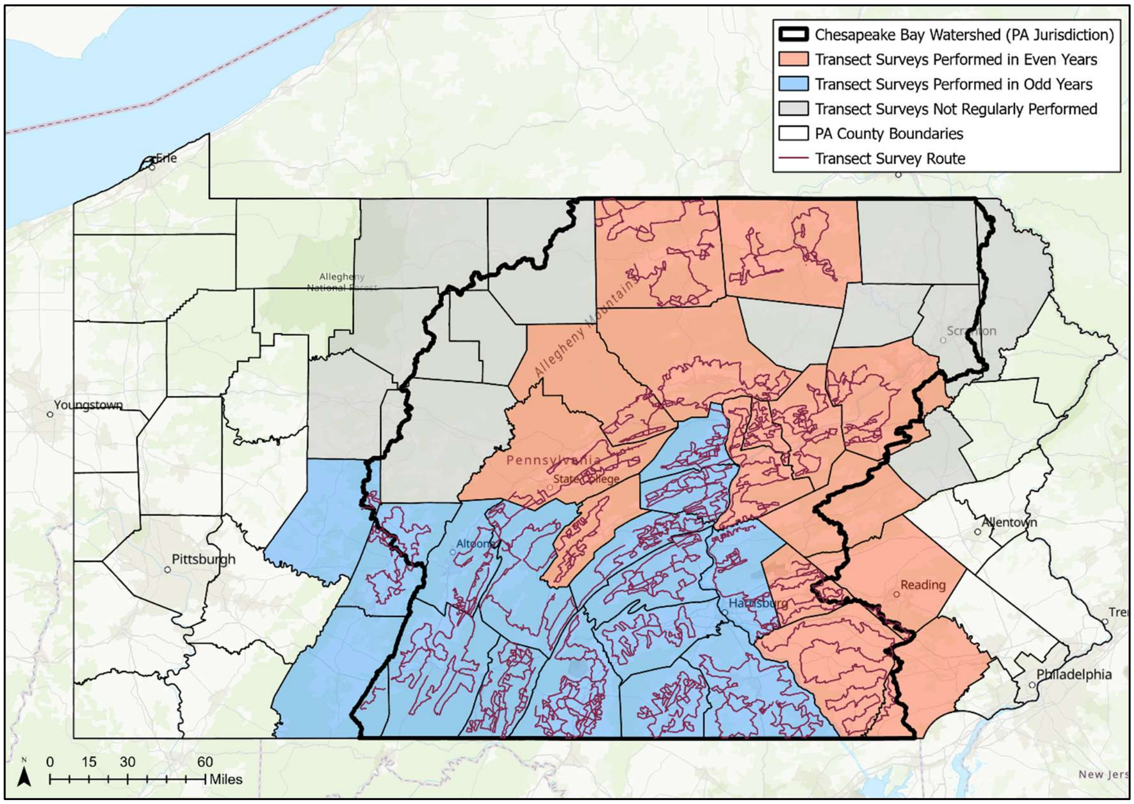


Figure 7. Map of counties and conservation tillage transect survey paths throughout Pennsylvania. Blue-shaded counties typically have conservation tillage transect surveys performed in even years (e.g., 2020). Red-shaded counties typically have conservation tillage transect surveys performed in odd years (e.g., 2021). Grey-shaded counties fall within Pennsylvania's jurisdiction of the Chesapeake Bay Watershed but are not typically surveyed.

Task 1: Data Collection and Pre-Processing

In Phase 2, Capital RC&D's observations from the 2020 to 2024 transect surveys will serve as the basis for model training and testing. Capital RC&D has provided Resolve Hydro LLC with thirty raw data files in Excel format that contain transect survey data collected throughout thirty counties in Pennsylvania. After preliminary data compilation and processing, Resolve Hydro LLC has determined that Capital RC&D has made over 40,000 observations of tillage condition at over 10,000 observation points during the 2020 to 2023 transect surveys (see Figure 8). These observations will be used in Phase 2 to train and evaluate machine learning models for

[19] https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/

conservation tillage BMP classification. Additional data from Capital RC&D's 2024 conservation tillage transect survey will also be shared with Resolve Hydro when it becomes available; 2024 transect survey data will then be used for model testing and evaluation.

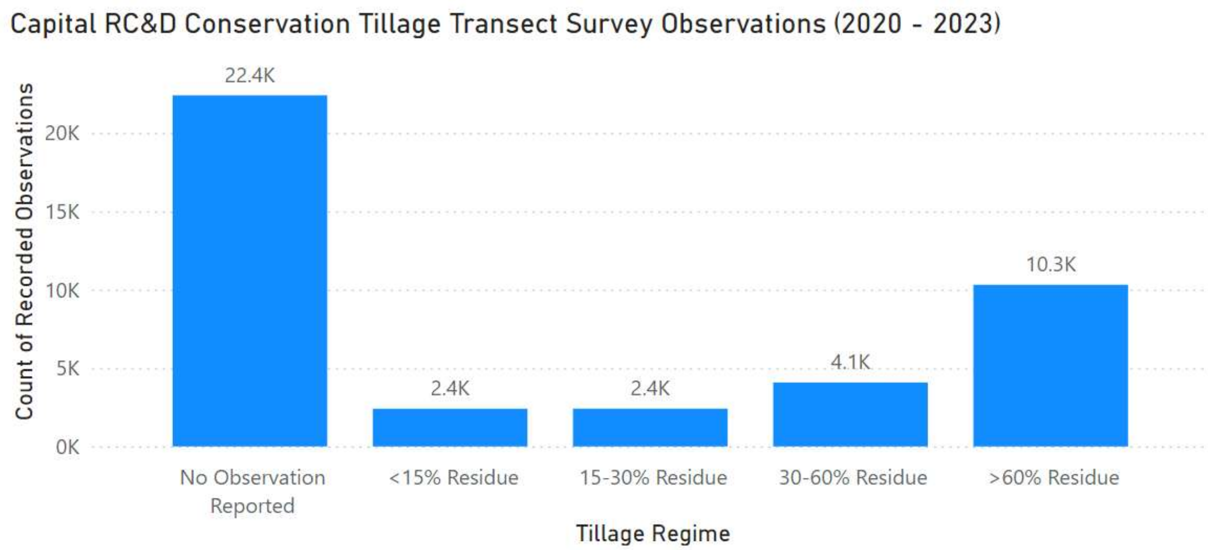


Figure 8. Distribution of tillage regime observations recorded across thirty counties surveyed in the Capital RC&D conservation tillage transect surveys from 2020 to 2023. "No Observation Reported" identifies observation points with land uses ineligible for conservation tillage BMPs (e.g., pastures and developed impervious areas) as well as abandoned observation points.

To use the data collected by Capital RC&D for model training and testing, significant pre-processing is necessary to compile, validate, and geolocate the provided information. The overall data collection and pre-processing workflow is summarized in the three steps below:

- Step 1: Transect Survey Data Compilation and Validation
- Step 2: Point Geolocation and Field Delineation
- Step 3: Route Assignment and Polygon Selection

Geolocation will be particularly challenging task because Capital RC&D reports (1) a flag that identifies the side of the road—either "left" or "right"—and (2) the latitude and longitude coordinates of the road center instead of reporting the exact coordinates of field observations. Accordingly, in Step 2, computer vision will be used to assist in delineating agricultural field boundaries in the immediate areas around these center-of-road coordinates. This delineation step will support the Step 3 assignment of observation records to specific agricultural field areas.

<u>Step 1: Transect Survey Data Compilation and Validation</u>

Using the raw data spreadsheets provided by Capital RC&D, Resolve Hydro LLC will first compile the available historical transect survey results into a central database using Power Query, a data transformation and preparation engine used to perform extract, transform, and load (ETL) data processing.[20] Resolve Hydro LLC will standardize and clean the reported data by developing automatic pre-processing routines and performing manual data review.

During pre-processing, Resolve Hydro LLC will implement data validation steps to check transect survey data for accuracy, completeness, consistency, and validity. The goal of data validation is to catch and correct errors early in the data entry process to reduce the likelihood of data inaccuracies downstream. Example data validation steps include format validation, range validation, cross-field validation, existence validation, and logic validation as shown in Table 2.

Table 2. Examples of data validation steps that will be used to pre-process and clean transect survey data.

Data Validation Type	Purpose	Example
Format Validation	Ensures data is consistently reported and has the correct format	Replace planted crop type records of "SB," "SSB," "SOYBEAN," and "SOYBEANS" with "Soybean"
Range Validation	Ensures the reported data fall within expected ranges of values	Confirm the "<15% residue coverage" field value is either "X" or blank, and correct any erroneous entries that report planted crop type in the column instead of reporting "X" or blank values
Cross-field Validation	Verifies that values across multiple fields are consistent with each other	Flag and remove records that mistakenly report both conventional and low residue tillage at a single location
Existence Validation	Confirms that required fields contain data	Remove records that provide an observation ID but leave all other fields blank
Logic Validation	Ensures reported data adhere to relevant rules and conditions	Detect logical inconsistencies, like records that report a planted crop type and a developed impervious land use type at the same point

Step 2: Point Geolocation and Field Delineation

Following data compilation and validation, the compiled transect survey data will be spatially located and used to identify agricultural field boundaries throughout the survey area. Using ArcGIS Pro, the compiled transect survey data table will be georeferenced and represented as point coordinates. As shown in Figure 9, a buffer box (300 meters per side) will then be constructed around each survey point. Within each 300-meter buffer box, high-resolution satellite or aerial basemap imagery (e.g., cloud-free Sentinel-2 imagery or NAIP imagery) will be obtained for each analysis year and later used for agricultural field boundary delineation. For each retrieved basemap image, the CBP's LULC dataset will then be used to mask regions of the

[20] https://learn.microsoft.com/en-us/power-query/

image that have land use classes ineligible for conservation tillage BMPs (e.g., developed impervious lands).[21]

Using the segment-geospatial package, instance segmentation will be performed on the masked imagery to automatically generate boundaries for the agricultural fields located within the 300-meter buffer boxes.[22] The segment-geospatial package leverages the Meta AI Segment Anything deep-learning models to create vector boundaries for input GeoTIFF files (as shown in Figure 9). If necessary, additional pre-processing steps may be applied to the basemap imagery to optimize field delineation performance. For example, multitemporal composites or principal components calculated from the imagery may be used for input files instead of RGB imagery. The overall result of this step will be a polygon layer representing agricultural fields in the vicinity of Capital RC&D's transect survey observation points.

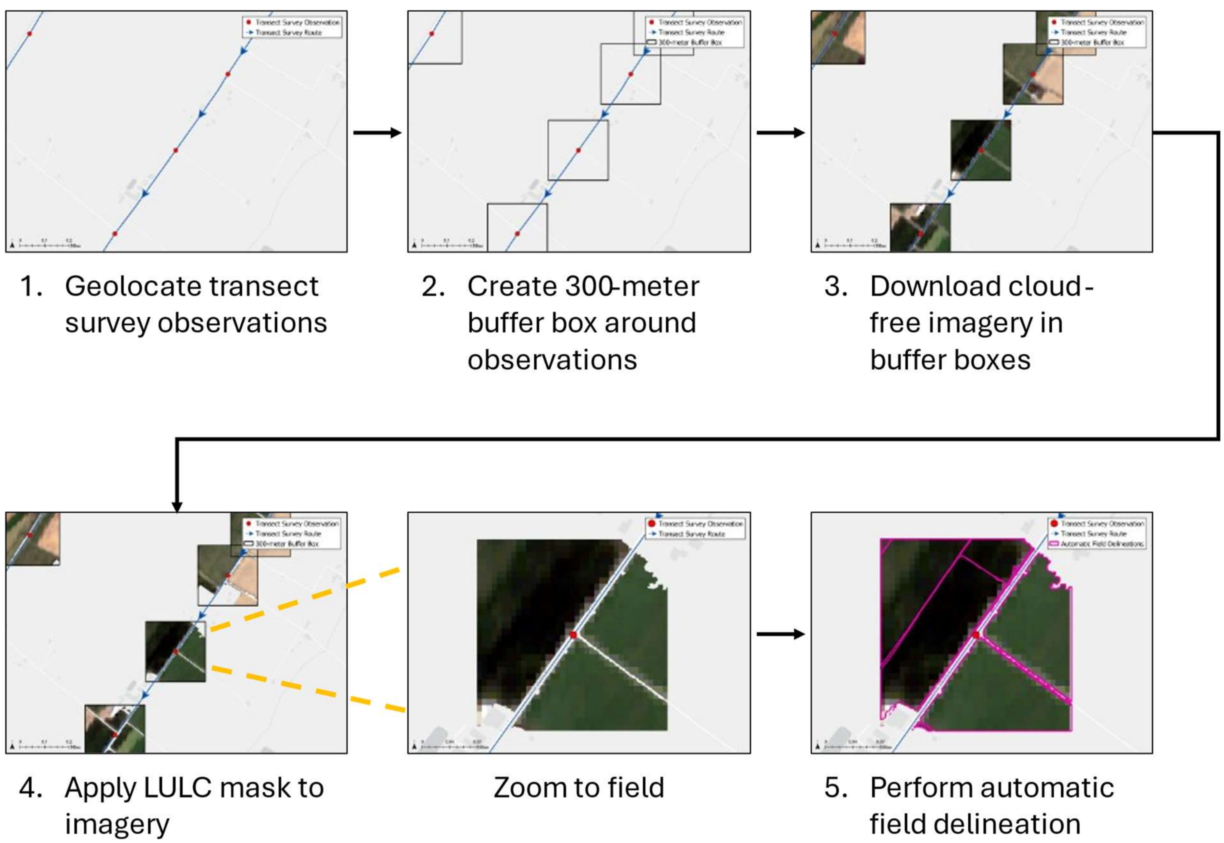


Figure 9. Workflow for automatically delineating fields in vicinity of conservation transect survey observations. The segment-geospatial package will be used to perform automatic field delineation from freely available imagery.

[21] https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/
[22] https://samgeo.gishub.org/

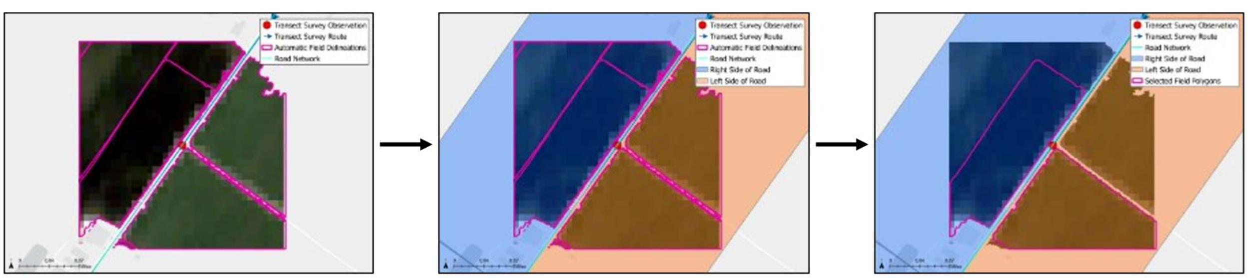
Step 3: Route Assignment and Polygon Selection

In the final step of Task 1, Capital RC&D's conservation tillage observations will be assigned to agricultural field polygons developed during Step 2.

For each county, street networks from OpenStreetMap will be downloaded using Python.[23] The survey routes provided by Capital RC&D will be used to select roads from the street network to develop a high-resolution survey route layer. The high-resolution survey route will be buffered on the left and right sides by approximately 215 meters as shown in Figure 10. The buffered route layer will be used to assign "side of the road" values (i.e., right side or left side) to the agricultural field areas delineated using the segment-geospatial model. Following assignment, the polygons closest to the observation point on either side of the road will be automatically selected in ArcGIS and enriched with the transect survey data results. Polygon/observation pairs will be manually reviewed to discard ambiguous or incorrect assignments.

A notable restriction in this method arises from the limited availability of LULC data, which is used for field masking. In areas where LULC change has occurred since 2017, the LULC mask may cause transect survey observations to be excluded. After LULC masking, the number of observation points removed from the analysis will be quantified, and, as necessary, the removed observations will be manually reviewed and potentially reintroduced to the dataset.

The completion of these steps will yield a cleaned, in-situ dataset that will be paired with satellite data (Task 2) and used in model training and testing (Tasks 3 and 4). Task 1 is critically important to the overall model development process because it will provide the basis for linking ground observations of conservation tillage BMPs to satellite measurements of reflectance.



1. Select road networks
2. Assign polygons "side of road" values
3. Perform final field selection and review

Figure 10. Process used to enrich developed field polygons with field observation data.

[23] https://www.openstreetmap.org/about

Task 2: Satellite Data Acquisition

In Task 2 of project Phase 2, satellite data from Landsat-8/9, Sentinel-2, and the Planet SuperDove constellation will be acquired for the agricultural field polygons generated in Task 1. These satellite platforms were selected due to their moderate to high spatial and temporal resolution, demonstrated potential for accurate conservation tillage classification, and accessibility—Landsat-8/9 and Sentinel-2 data are freely available, while Planet SuperDove data is available at a relatively low cost. Figure 11 illustrates the overall data acquisition and processing workflow that will be followed in Task 2.

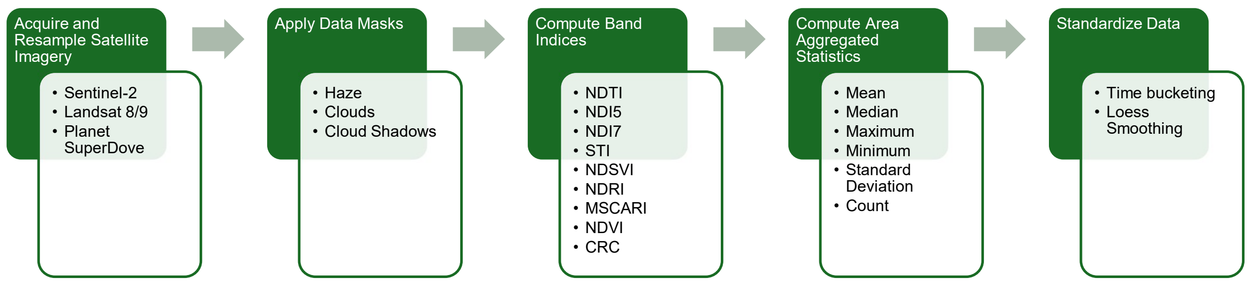


Figure 11. Workflow for Task 2 - Satellite Data Acquisition and Processing

Landsat data and Sentinel-2 surface reflectance data are freely available and can be programmatically retrieved using the Earth Search Application Programming Interface (API).[24] For each area of interest generated during Task 1, the Earth Search API (or a similar platform) will be used to search and download available Landsat 8/9 and Sentinel-2 imagery for the relevant period from 2020 to 2024. Invalid pixels (e.g., those containing clouds or cloud shadows) will be programmatically masked and relevant band indices (see Table 3) will be calculated. Additionally, data will be resampled to match the 3-meter spatial resolution of Planet SuperDove imagery for compatibility during model training and evaluation.

Similarly, Planet SuperDove surface reflectance data will be downloaded over the areas of interest generated during pre-processing using Planet's Subscriptions API. Unlike Sentinel and Landsat data, Planet SuperDove data requires commercial purchase. For Phase 2 of this project, it is recommended that up to 10,000 hectares (approximately 25,000 acres) of Planet Area Under Management (AUM) quota be acquired. AUM data subscriptions provide access to all available PlanetScope data in defined areas at least 1 hectare in size (raw data costs range from $2.50/hectare to $3.00/hectare depending on location and data purchase volume). Using Planet's Subscriptions API, all Planet SuperDove data over the selected areas of interest will be downloaded for the relevant period from 2020 to 2024. Planet's Usable Data Mask (UDM), which is available for every downloaded image, will be used to mask invalid pixels, including those with high probability of haze, clouds, and cloud shadows. Additionally, relevant band

[24] https://element84.com/earth-search/

indices that have been shown in prior studies to be related to crop residue cover will be calculated, as shown in Table 3.

After the satellite data has been acquired, area-aggregated statistics will be calculated for all spectral indices and raw band values. The computed statistics will include non-zero pixel count, mean, median, maximum, minimum, and standard deviation values. This data processing step will yield sensor-specific timeseries for every area of interest selected for analysis. Additional data bucketing and/or interpolation will then be used to standardize the length of the input timeseries data for each AOI. During Phase 2, testing will be conducted to inform the selected bucket size for each satellite dataset (e.g., 7 days) and determine the need to apply a Loess smoothing filter to interpolate missing days in the optical records.[25]

The overall output of the satellite data acquisition and processing task will be a satellite matchup dataset that will be used for model development and testing. To allow for flexibility during model training, the satellite matchup dataset will be structured such that model training may be performed using either the unaggregated or the area-aggregated reflectance values, band indices, and statistics.

Table 3. Spectral band indices relevant to satellite remote sensing of conservation tillage BMPs

Band Index Name	Reference
Normalized Difference Tillage Index (NDTI)	Van Deventer et al., 1997[26]
Normalized Difference Index 5 (NDI5)	Mcnairn and Protz, 1993[27]
Normalized Difference Index 7 (NDI7)	Mcnairn and Protz, 1993[28]
Simple Tillage Index (STI)	Van Deventer et al., 1997[29]
Normalized Difference Senescent Vegetation Index (NDSVI)	Qi et al., 2002[30]
Normalized Difference Residue Index (NDRI)	Gelder et al., 2009[31]
Modified Soil Adjusted Crop Residue Index (MSCARI)	Bannari et al., 2000[32]
Normalized Difference Vegetation Index (NDVI)	Rouse et al, 1974[33]
Crop Residue Cover (CRC)	Sullivan et al., 2006[34]

25 https://link.springer.com/article/10.1007/BF01890836
26 https://www.asprs.org/wp-content/uploads/pers/1997journal/jan/1997_jan_87-93.pdf
27 https://www.tandfonline.com/doi/abs/10.1080/07038992.1993.10874543
28 https://www.tandfonline.com/doi/abs/10.1080/07038992.1993.10874543
29 https://www.asprs.org/wp-content/uploads/pers/1997journal/jan/1997_jan_87-93.pdf
30 https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2002EO000411
31 https://acsess.onlinelibrary.wiley.com/doi/full/10.2134/agronj2007.0249?saml_referrer
32 https://ieeexplore.ieee.org/abstract/document/860296
33 https://ntrs.nasa.gov/api/citations/19740022614/downloads/19740022614.pdf
34 https://acsess.onlinelibrary.wiley.com/doi/10.2134/agronj2005.0294

Task 3: Model Development

In Phase 2, the Model Development task will include data splitting and model training, as shown in Figure 12. These activities will ultimately result in a set of candidate machine learning models that classify satellite imagery collected over eligible croplands into one of the following tillage tiers: less than 15% residue coverage, 15% to 29% residue coverage, 30% to 59% residue coverage, or over 60% residue coverage. More information on the specific model development activities is provided below.

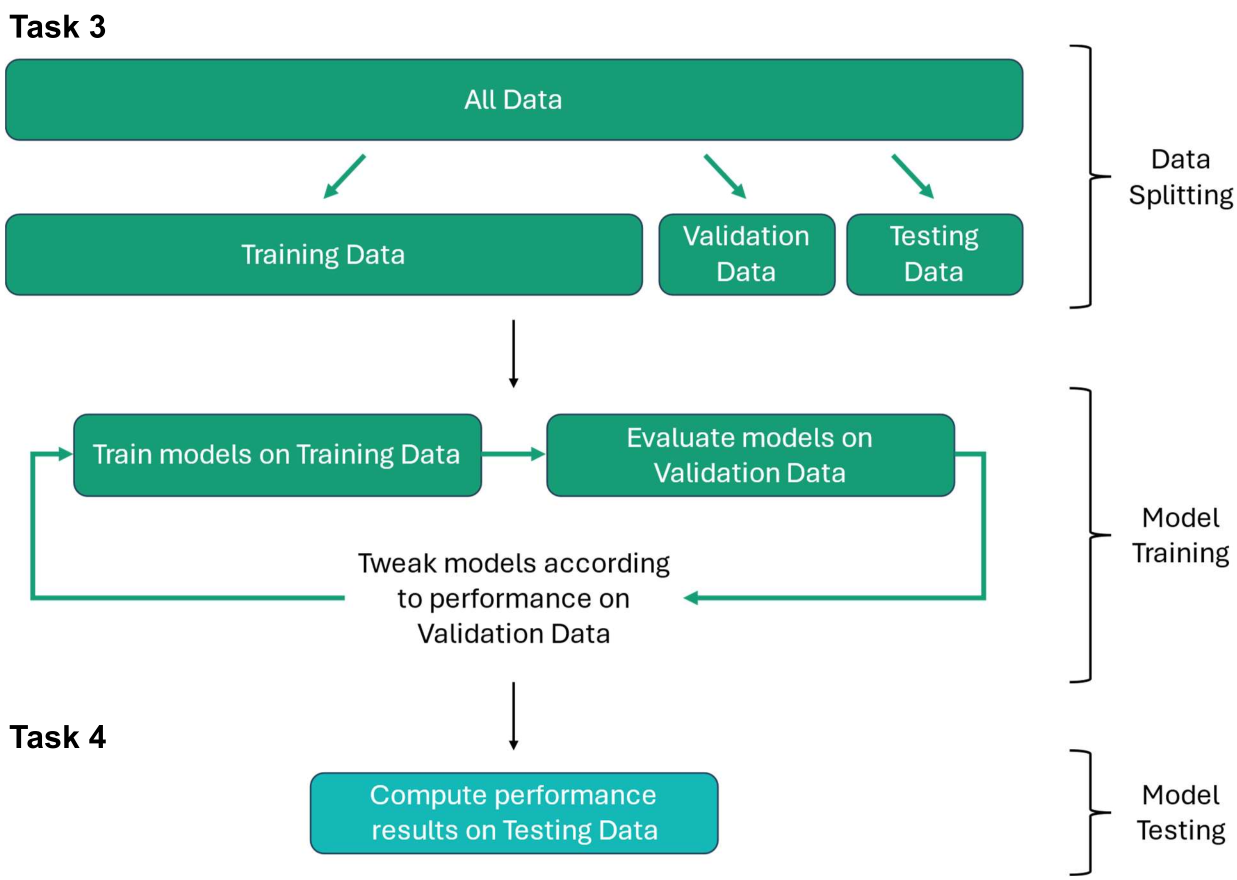


Figure 12. Diagram of major activities in Task 3 - Model Development, including data splitting and model training. Following model development, the overall performance of shortlisted models will be tested in Task 4 using the testing dataset.

Data Splitting:

Prior to model training, the satellite matchup dataset will be split into three separate datasets for training, validation, and testing. Whereas the validation dataset will be used during model development to avoid model overfitting and to tune hyperparameters, the testing dataset will only be employed after model development is fully completed to provide reliable evaluations of model performance. Data splitting prior to model training and testing is crucial to prevent "data leakage," which can bias the model development and evaluation process. Data leakage occurs when information from outside the training dataset is used during the creation of the machine learning model, leading to overly optimistic performance estimates during model testing.

In Task 4 (Model Evaluation and Performance Characterization), the model's ability to generalize to new data will be evaluated. Performance evaluation will specifically consider the questions:

(1) How well does the model perform in new field locations (e.g., how well would the model perform in identifying conservation tillage BMPs in agricultural fields that have not been included in prior transect surveys)?
(2) How well does the model perform when presented with a new year of satellite imagery (e.g., how well would the model perform in identifying conservation tillage BMPs in agricultural fields using imagery collected in 2024 if the model were trained using imagery collected only from 2020 to 2023)?

Accordingly, the training, validation, and testing dataset splits will be performed as follows:

- **Training Dataset**: The training dataset will consist of a random selection of 80% of the matchup data collected across twenty-two counties during the period from 2020 to 2023.
- **Validation Dataset**: The validation dataset will consist of matchup data collected in four counties (distinct from the twenty-two counties identified in the training dataset) during the period from 2020 to 2023 as well as 10% of the matchup data used to create the training dataset.
- **Testing Dataset**: The testing dataset will consist of all matchup data collected in 2024 (including data from four counties excluded from both the training and validation dataset) as well as 10% of the matchup data used to create the training dataset.

In the proposed data split, the testing dataset will provide opportunities to describe both spatial and temporal generalization. The exclusion of all 2024 data and all data for four counties from the training and validation datasets will allow model performance statistics to be calculated to directly answer questions #1 and #2 presented above. During Phase 2, a selection approach (e.g., random selection or expert selection) for identifying which eight counties to exclude from the training dataset will be determined after reviewing the data distributions of the full matchup dataset. Dividing the overall matchup dataset into these separate data pools and assessing the overall distributions of the subset data will allow for the objective evaluation of model performance without bias from data leakage.

Model Training:

Machine learning model training is the process of teaching a machine learning algorithm to make predictions or decisions based on data. During model training, a specific machine learning algorithm or model architecture (e.g., a decision tree or a neural network) is selected and a new instance of the untrained model is initiated. The untrained model is then presented with a training dataset that includes input values (features) and their corresponding output values (labels). As the model is trained, the model uses an optimization algorithm (e.g., gradient descent) to iteratively adjust its parameters (e.g., model weights) to minimize the error in predicting output values from the provided input values. Once training is completed, the trained model can be used to make predictions on new input data, thereby producing output predictions based on patterns it has learned from the training data.

During Phase 2 model training, several candidate machine learning models will be trained to predict crop residue coverage tier (less than 15% residue coverage, 15% to 29% residue coverage, 30% to 59% residue coverage, or over 60% residue coverage) from input satellite data. Resolve Hydro LLC will conduct several rounds of model training using the developed training dataset to identify the optimal data preparation techniques and model architectures to use for crop residue coverage tier classification. Initial model training rounds will utilize common model architectures, such as decision trees, random forests, and support vector machines. For each trained model, confusion matrices and key performance metrics, including accuracy, precision, recall, and F1-score will be computed using the validation dataset. Feature importance metrics, which describe the relative influence each input feature has on model predictions, will also be analyzed to inform enhanced selection of input features. Preliminary model performance results will be used to assess the need to perform training using more sophisticated model architectures, such as the convolutional neural network (CNN) architectures used in Luo et al.[35] Additionally, throughout model development, standard machine learning best practices will be used, such as strategies to minimize overfitting and manage class imbalances.[36]

The Phase 2 model training process will involve adaptive feature selection, feature scaling, and the application of various machine learning models to develop a shortlist of promising models. During model training, several potential models will be trained before three to five promising models are identified and fine-tuned (e.g., hyperparameter tuning) using random search cross-validation techniques.[37] To evaluate the benefit of the commercial PlanetScope data over freely available data, at least one of the shortlisted models will only contain features derived from Sentinel-2 and/or Landast 8/9 surface reflectance measurements. The overall Model Development task will thus result in a testing dataset and a set of models for evaluation in Task 4.

Task 4: Model Evaluation and Performance Characterization

Following model development, the testing dataset will be used to evaluate the overall performance of the three to five shortlisted models. For each model, confusion matrices and receiver operating characteristics (ROC) curves will be developed. Further, for each model, the key performance metrics shown in Table 4 will be computed. Micro-average and macro-average precision, recall, and F1-score will be computed, as well as Cohen’s Kappa, cross-entropy, and

35 https://www.sciencedirect.com/science/article/pii/S266601722300010X#bib74
36 https://learning.oreilly.com/library/view/hands-on-machine-learning/9781491962282/
37 https://www.jmlr.org/papers/volume13/bergstra12a/bergstra12a.pdf

Matthew's correlation coefficient. These performance metrics will be calculated globally as well as for various contexts that may potentially influence model results. The context-specific performance evaluation of each model will include the following:

- Performance by crop type, as reported by Capital RC&D
- Performance by county, as reported by the PennDOT Geographic Information Division (https://www.arcgis.com/home/item.html?id=50c2b19df296459fad5f975bb129950f&sublayer=0)
- Performance by major physiographic section, as reported by the PA Department of Conservation and Natural Resources (https://newdata-dcnr.opendata.arcgis.com/datasets/731205648bb747d396c8920fcdfea4a8_6/about)
- Performance by soil class and percent slope, as reported by USDA Natural Resources Conservation Service (https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm)
- Performance by hydrogeomorphic region, as reported by the Chesapeake Bay Program (https://gis.chesapeakebay.net/ags/rest/services/TMDL/TMDL_layers/MapServer/21)
- Performance in regions for which historical data was used for model training
- Performance in regions for which historical data was not used for model training

Context-specific metrics will be used to help explain model errors and provide recommendations regarding model application in new areas within the Chesapeake Bay Watershed.

These metrics will be reviewed to select the best-performing model and describe the overall performance in classifying conservation tillage regimes. For the best-performing model, estimates of county-specific conservation tillage BMP implementation will be prepared following the procedures outlined in "Recommendation Report for the Establishment of Uniform Evaluation Standards for Application of Remote Sensing to Identify and Inventory Agricultural Conservation Practices for the Chesapeake Bay Program Partnership's Watershed Model."[38] The overall results of the Model Evaluation and Performance Characterization task will be summarized in the Task 5 model development report and used to inform the development of the proposed remote sensing-based conservation tillage BMP verification methodology.

Table 4. Key model performance metrics to be considered during model testing.

Metric Name	Description
Accuracy (also known as proportion correct)	Accuracy is the proportion of correctly classified instances (both true positives and true negatives) out of the total number of instances. Accuracy answers the question: how often are

38 https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/recommendation_report_draft_final.pdf

	model predictions correct? Accuracy can be misleading in scenarios where there are large class imbalances.
Precision (also known as hit rate or positive predictive value)	Precision is the ratio of correctly predicted positive observations to the total number of predicted positives. It indicates how many of the predicted positive instances are actually positive. Precision addresses the question: how often are positive predictions actually correct?
Recall (also known as sensitivity or true positive rate)	Recall measures the proportion of actual positive observations that are correctly predicted by the model. Recall addresses the question: how well does the model identify all instances of the positive class?
False Positive Rate (also known as commission error or error of inclusion)	False positive rate is the ratio of the number of negative observations that are incorrectly classified as positives to the total number of actual negatives. False positive rate describes the probability that the model will return a positive result when the true value is negative.
F1-Score	The F1-score is the harmonic mean of precision and recall. The F1-score provides a balanced combination of these two metrics and is particularly useful when there is an uneven class distribution.
Critical Success Index (CSI)	The critical success index measures the proportion of correct positive predictions relative to the total number of positives that should have been predicted.
False Alarm Rate (FAR)	False alarm rate is the proportion of predicted positives that are actually negative. It is the complement of precision.
Frequency Bias (FB)	Frequency bias measures a classifier's tendency to predict the positive class more or less frequently than the actual distribution of the class. It highlights the model's inclination towards over- or underpredicting a particular class, which can be particularly problematic in imbalanced datasets.

Task 5: Method Development and Reporting

At the end of Phase 2, the results and findings from the prior tasks will be documented in a model development report. In addition to summarizing the steps taken to produce the machine-learning model, Resolve Hydro LLC will compose a standard operating procedure (SOP) describing how to use a remote sensing model for BMP verification and reporting in the Chesapeake Bay watershed. Input from PA DEP, the project advisory committee, the Agriculture Workgroup, Chesapeake Bay Program Office, and an independent review committee will be used to guide the composition of this SOP, which will be proposed to the CBP AgWG for approval as a conservation tillage BMP verification methodology.

The proposed BMP verification methodology should set guidelines for remote-sensing model documentation, performance testing, verification using in-situ data collection, and statistical review. Further, the methodology should specify an approach for how to apply a remote-sensing model for verifying conservation tillage BMPs (e.g., applying the model to sub-sample of fields or applying it to all fields in a region). Importantly, the BMP verification methodology should not provide detailed specifications on how to develop a model that is used for remote-sensing based conservation tillage BMP verification. By not detailing a specific model development process, the proposed BMP verification will be able to accommodate new models, such as those created for other states in the Chesapeake Bay Watershed or those developed using different remote-sensing platforms and/or machine-learning methods.

As outlined below, three primary model application approaches will be considered in developing the proposed methodology in Phase 2.

1) **Virtual Transect Survey (VTS):** Currently, crop residue transect surveys require surveyors to drive thousands of miles each year to observe conditions at unchanging observation points located throughout Pennsylvania. Once an appropriate model has been trained, satellite data may be used to remotely conduct these surveys at the same observation points. Using a remote sensing-based virtual transect survey (VTS) instead of an in-situ transect survey to estimate crop residue provides substantial cost, labor, and time savings. For example, all available PlanetScope imagery can be programmatically retrieved for 20,000 1-hectare sample locations for under $50,000 (approximately $2.47 per sample location for all-time data access). If model training and testing reveals only one to forty images are required per sample location per analysis year, the cost of satellite data acquisition at the 20,000 sample locations would range between approximately $1,200 and $48,000.[39] Alternatively, if model development shows freely available satellite data yield classification results with sufficient accuracy, the cost of the entire VTS would be limited to the costs of data processing and in-field verification for a subset of VTS locations. In the Phase 2 work, the benefits of a VTS method (e.g., cost and time savings and objective classification processing) will be compared to anticipated drawbacks (e.g., higher uncertainty and disruption of a ten-year, in-situ transect survey record).
2) **Virtual Field Survey (VFS):** Using a technique similar to that of the virtual transect survey, remote sensing may be used to expand conservation tillage monitoring by conducting virtual field surveys (VFS). In the VFS approach, a spatial random sampling strategy would be used to place 1-hectare monitoring points throughout agricultural lands in each county in Pennsylvania (as identified using the CBP's LULC dataset). At each of these sampling sites, satellite data will be collected, and the developed conservation tillage classification model will be applied. The VFS replicates the statistical sub-sample survey method offered by transect surveys; however, it improves the sample design by expanding the survey scope to all agricultural fields within a county, not just the roadside

[39] https://www.sentinel-hub.com/pricing/

fields. While the costs and benefits of the VTS and VFS methods are nearly identical, the VFS approach does introduce the challenge of collecting in-situ verification data for fields not immediately accessible by road.

3) **<u>Total Area Classification (TAC):</u>** The final technique that will be considered during Method Development and Reporting is an approach where the remote sensing-based classification model is applied to all agricultural lands within a county (as identified using the CBP's LULC dataset). The TAC approach leverages the broad area coverage provided by satellite imagery to identify conservation tillage BMPs without relying on statistical sub-sampling. Accordingly, the county-wide maps of conservation tillage BMP implementation produced in a TAC approach would be extremely useful in targeted outreach and policy decisions. Although the TAC approach would provide an unprecedented level of detail to support conservation tillage efforts in Pennsylvania, depending on the selected classification model, TAC data volume may present financial and logistical challenges. For example, the estimated cost to capture Planet imagery over Pennsylvania's 1.97 million acres of agricultural land is approximately $12,000 per capture, and large data volumes may require the use of cloud computing resources.

In Task 5, one of these three approaches will be selected for detailed review and proposed as a new BMP verification approach. The development of the methodology during Task 5 will be guided by the Project Advisory Committee, reviewed by an independent group, and presented as an SOP to the AgWG for discussion and voting. Pending approval, the developed methodology will be employed in this project's implementation phase.

Stakeholder Engagement

Resolve Hydro LLC has worked with PA DEP to develop a project advisory committee (PAC) to guide subsequent phases on the project (Phase 2 and Phase 3). The role of the PAC is to provide specific guidance and recommendations during the development and implementation of a remote sensing-based conservation tillage BMP verification methodology for the Chesapeake Bay Program. The PAC will be asked to evaluate and identify logistical, technical, and other pertinent factors that should inform the development of the methodology and the subsequent implementation of the model.

PAC members will be asked to attend monthly committee meetings during the period from August 2024 to July 2025. Additionally, during each project Phase, the PAC members will be asked to provide written feedback on draft reports.

Per recommendations of the Chesapeake Bay Program Office, the proposed composition of the PAC will include representatives from Delaware Department of Agriculture, Herbert, Rowland & Grubic, Inc., Upper Susquehanna Coalition, Virginia Department of Conservation and Recreation, West Virginia Conservation Agency, South Dakota State University, United States Geological Survey, and Pennsylvania Department of Environmental Protection.

Throughout the project, PA DEP and Resolve Hydro LLC will also provide regular updates on project progress during the AgWG's monthly meetings. At key points throughout the project process, presentations will be made to the CBP's Watershed Technical Workgroup and the Water Quality Goal Implementation Team to solicit further feedback on method and model development.

Conclusion

The overall outcomes of Phase 1 of PA DEP's three-phase remote sensing pilot project include the compilation of Capital RC&D transect survey data, the formation of a project advisory committee (PAC), and the development of a five-task methodology development plan to guide Phase 2 work. During Phase 2, which is set to begin in July 2024, the five outlined project tasks—Data Collection and Pre-Processing, Satellite Data Acquisition, Model Development, Model Evaluation and Performance Characterization, and Method Development and Reporting—will result in a trained machine learning model capable of identifying conservation tillage BMP implementation from satellite imagery. Additionally, Phase 2 work will produce a detailed model development report and a standard operating procedure for leveraging remote sensing for the verification of conservation tillage BMPs.

By Summer 2025, PA DEP plans to initiate Phase 3 of its pilot project and implement the developed machine learning model to report conservation tillage BMPs within Pennsylvania's jurisdiction of the Chesapeake Bay Watershed. Prior to Phase 3, PA DEP will coordinate with the CBP Agriculture Workgroup to seek peer review and approval for the proposed SOP as an official BMP verification methodology. Following method review and approval, PA DEP will verify remote sensing classification results with in-field observations of conservation tillage collected through traditional transect survey methods. These results will be summarized in a performance report to aid model development and application in other jurisdictions of the Chesapeake Bay Watershed.

The proposed methodology and model development plan represents a significant advancement in leveraging satellite-based remote sensing data to overcome the limitations of current BMP verification methodologies. Remote sensing for BMP verification not only offers the benefits of reducing verification time, labor, and cost but also promises to enable enhanced monitoring of conservation tillage BMPs. For example, a remote sensing method may be used to generate field-by-field maps of conservation tillage BMP implementation to inform targeted outreach efforts and management decisions. Given the substantial reductions in nutrient and sediment loading provided by conservation tillage BMPs, the new methods, tools, and data products produced during this pilot project are poised to significantly enhance progress toward restoration goals for the Chesapeake Bay, improve BMP reporting and outreach efforts.