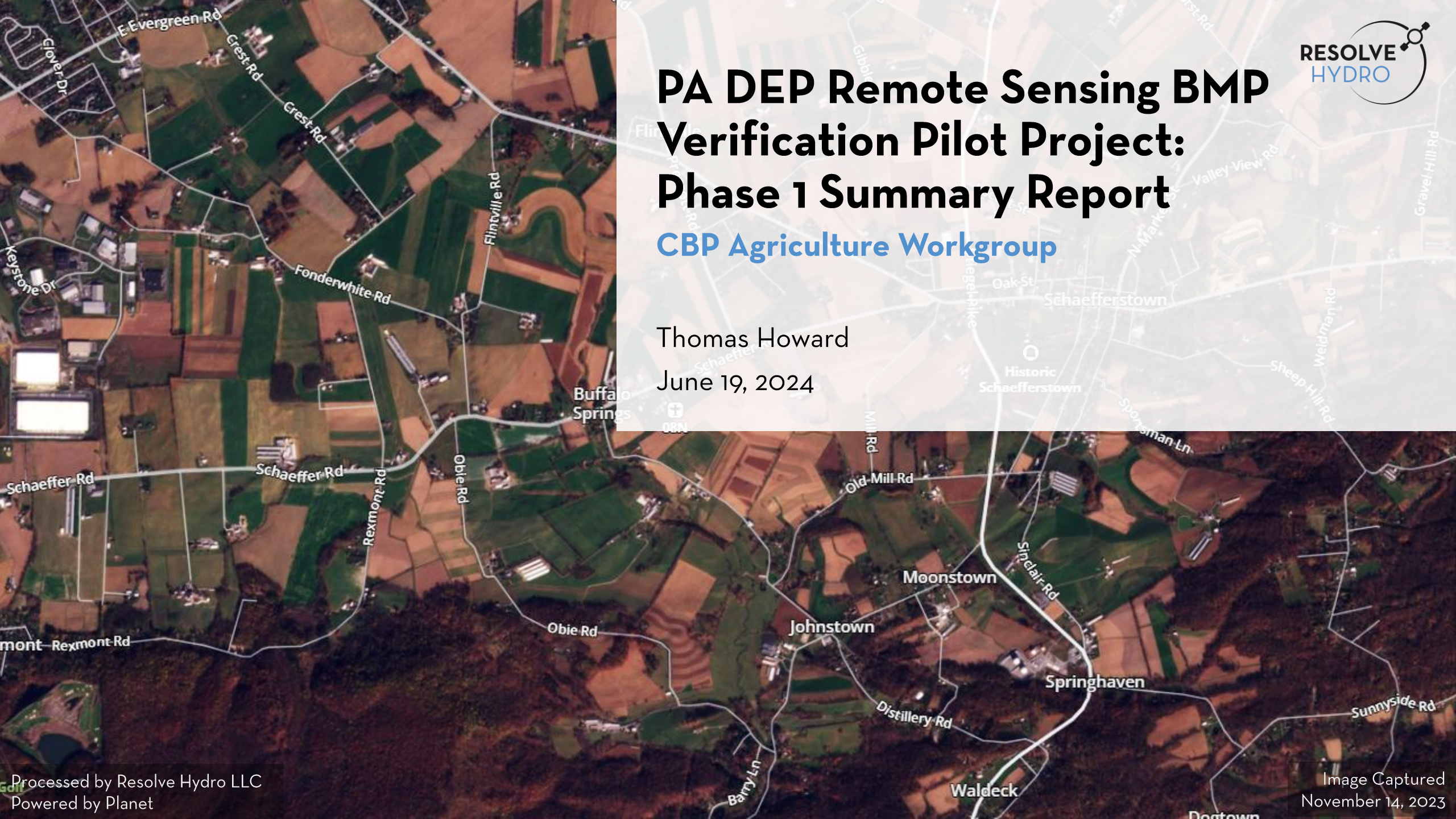
PA DEP Remote Sensing BMP Verification Pilot Project: Phase 1 Summary Report

CBP Agriculture Workgroup

Thomas Howard

June 19, 2024



PA DEP Remote Sensing Pilot Project: Phase 1 Summary Report

Thomas Howard

Founder & CEO
Resolve Hydro LLC

Agenda for Today's Presentation:

- Introduction, Motivation, and Background
- Phase I Method Development Plan Overview
- Next Steps, Future Opportunities, and Discussion

The CBP defines four tillage regimes based on crop residue coverage

The conservation tillage BMP is applicable for select land uses, including soybeans, grain, silage, small grains, double cropped land, specialty crop, and other agronomic crops

Conventional Tillage: Any tillage routine that does not achieve 15% crop residue coverage immediately after planting

Low Residue Tillage: A routine that maintains 15% to 29% crop residue coverage immediately after planting each crop.

Conservation Tillage: A routine that maintains 30% to 59% percent crop residue coverage immediately after planting each crop.

High Residue, Minimum Soil Disturbance Tillage: A routine that maintains at least 60% crop residue coverage immediately after planting each crop.

Conservation tillage minimizes disturbance to the soil and reduces nitrogen, phosphorus, and sediment loads to receiving waters

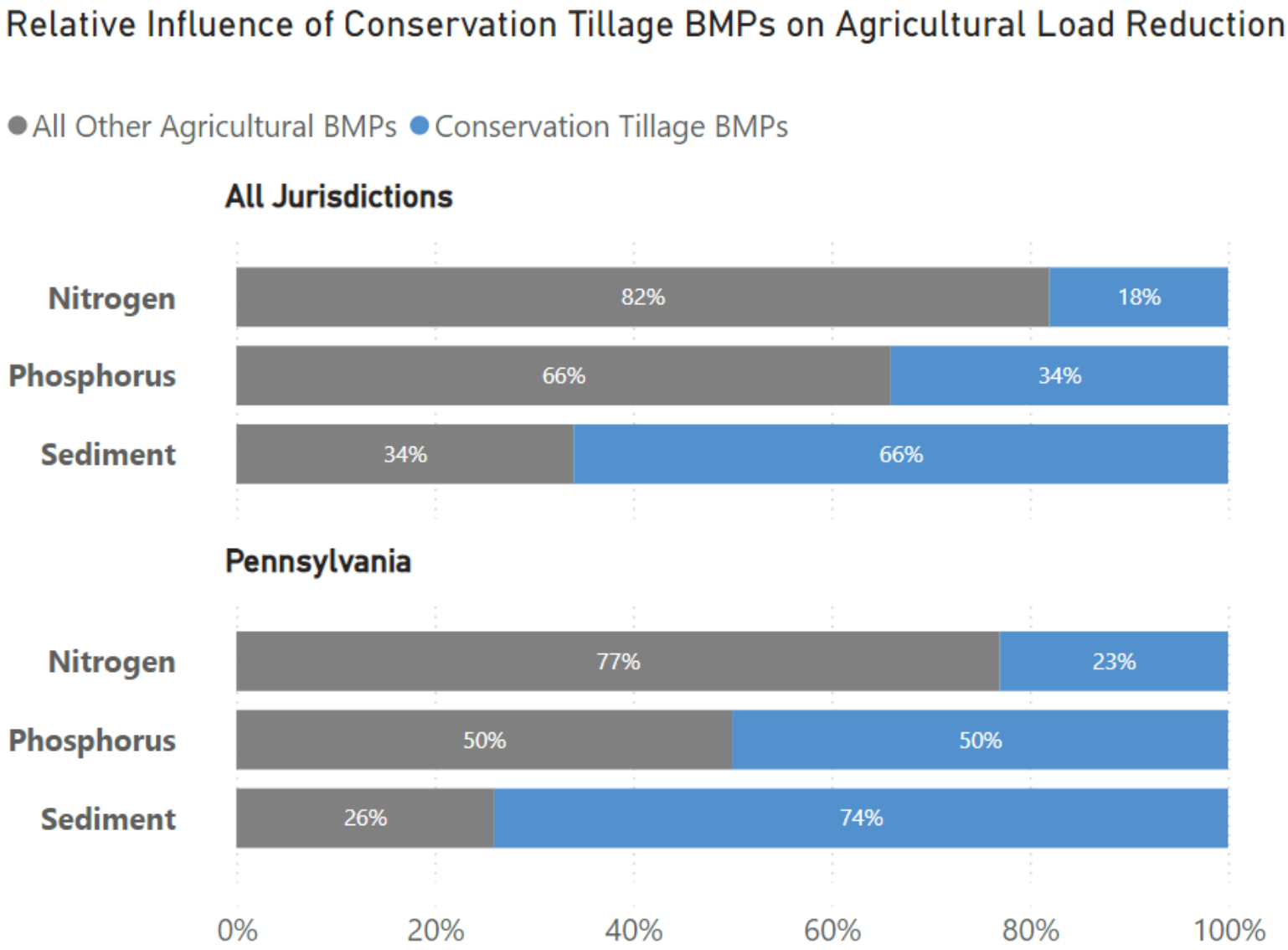
Conservation tillage offers field-level advantages as well as broader ecological benefits

- **Reduced Soil Erosion**
- **Increased Carbon Sequestration**
- **Increased Water Infiltration**
- **Reduced Labor, Time, and Costs**

	Nitrogen Reductions (%)	Phosphorus Reductions (%)	Sediment Reductions (%)
Low Residue	2 – 5	6 – 9	18
Conservation Tillage	4 – 10	2 – 60	41
High Residue	12 – 15	11 – 74	79

Nitrogen, Phosphorus, and Sediment Efficiency Value Reductions for Tillage Practices Implemented in the Chesapeake Bay Vary by Hydrogeomorphic Regions

Conservation tillage BMPs represent a significant portion of agricultural load reductions in the Chesapeake Bay



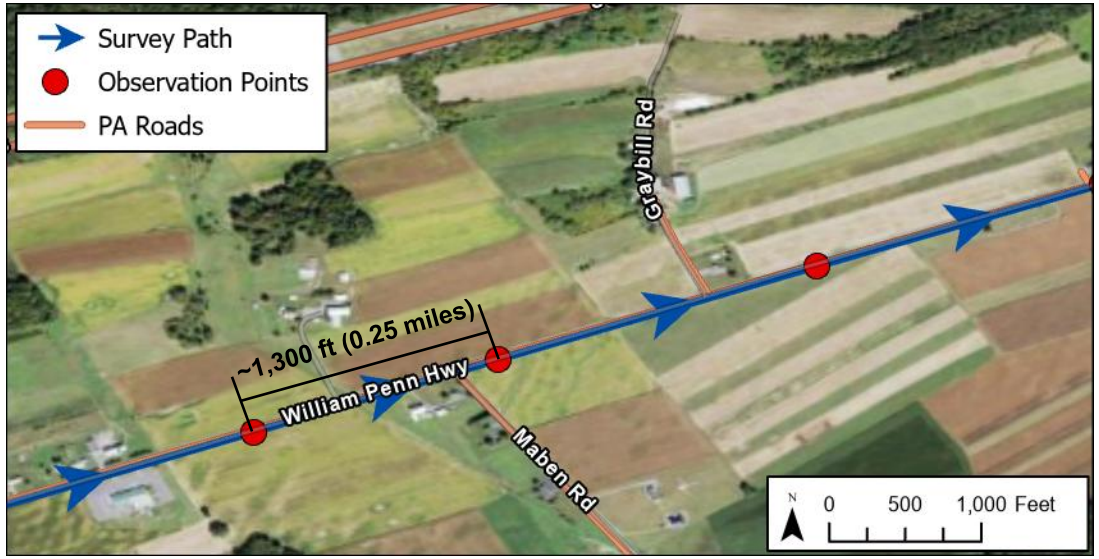
In Pennsylvania, conservation tillage is responsible for 74% of the agricultural BMP sediment load reduction!

Actively tracking and promoting tillage BMP implementation is critical to meeting TMDL goals.

*Based on 2023 Edge of Tide Progress Scenario

Roadside transect surveys are the primary method used for reporting conservation tillage practices in Pennsylvania

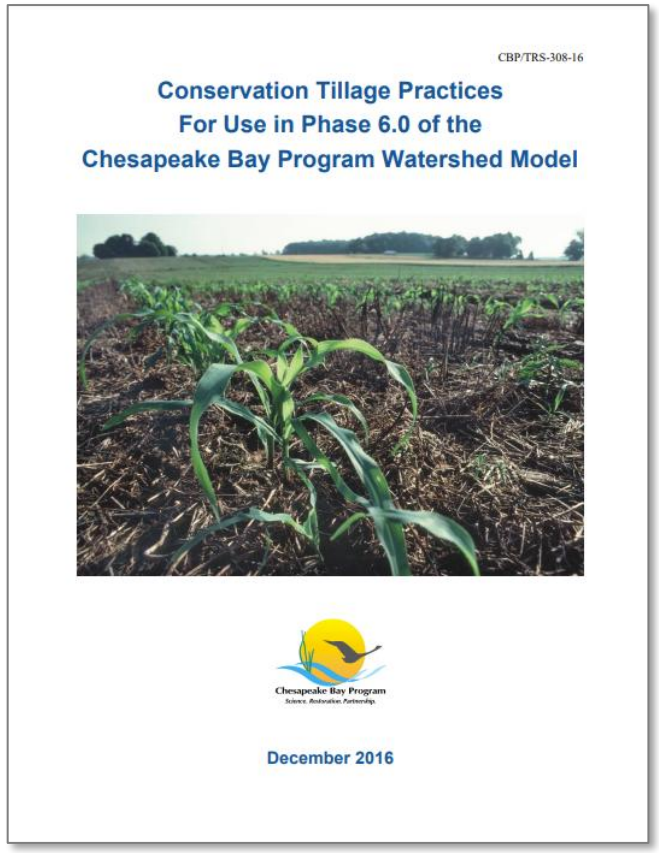
- In PA, 33 counties are surveyed over a two-year period (total cost of **~$300,000**)
- Each county survey team is staffed with at least three individuals



The 2023 Spring Tillage Survey included 800+ observations throughout Juniata County

Anticipated Mileage for 2024 Spring Tillage Survey	
County	**Miles Driven**
Bradford	286
Centre	236
Clinton	169
Columbia	221
Lancaster	437
Lebanon	215
Luzerne	256
Lycoming	221
Mifflin	322
Montour	251
Northumberland	232
Schuylkill	293
Sullivan	212
Susquehanna	180
Tioga	343
TOTAL	**3,874**

Prior CBP reports have identified the potential for remote sensing to perform BMP verification of conservation tillage practices


CBP/TRS-308-16

Conservation Tillage Practices
For Use in Phase 6.0 of the
Chesapeake Bay Program Watershed Model

Chesapeake Bay Program

December 2016

4.4 Modeling Considerations

Verification will be possible through field visits (using CTIC protocol) and records of implementation of NRCS practice codes, either 329 or 345. Remotely sensed (aerial/satellite) estimates are also likely feasible given proper calibration.

5.2 Future Verification of Conservation Tillage Practices

The Panel 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.

6 Data Gaps and Research Needs

Calibration of remotely-sensed information for residue cover data should be continued and expanded through the watershed.

PA-DEP Pilot Project Overview

Remote Sensing-Based Verification of Conservation Tillage BMPs

Phase 1: Methodology Development Plan

(Spring 2024)

- 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

(Summer 2024 – Winter 2025)

- Train and test **machine learning models** that use satellite imagery to classify the degree of conservation tillage in a field (e.g., >60% residue)
- Develop and evaluate a **BMP verification methodology** and report

Phase 3: Implementation

(Spring 2025)

- 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

Proposed Pilot Project Timeline

PA-DEP Remote Sensing-Based Verification of Conservation Tillage BMPs Pilot Project

Phase 1: Methodology Development Plan

March 2024 to June 2024

Presentation to AgWG on Methodology Development Plan

Phase 2: Method Development and Evaluation

July 2024 to February 2025

Independent Review

Vote for AgWG Approval of Developed Methodology

Phase 3: Implementation

March 2025 to July 2025

Chesapeake Bay Program
Science. Restoration. Partnership.

We seek to obtain AgWG feedback and official approval on the developed methodology at the end of Phase 2 of the pilot project.

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Phase 1 Progress Update

Phase 1 objectives were designed to position the PA-DEP team for success in later project phases

Four primary project objectives were defined for Phase 1 of the pilot project

Objective 1: Gather and synthesize available data regarding conservation tillage surveys from 2015 to the present

Objective 2: Establish a core project team, project advisory committee (PAC), and engagement structure

Objective 3: Generate a written report documenting a proposed technical approach for subsequent project phases

Objective 4: Collect and incorporate feedback from the CBP Agriculture Workgroup to refine the overall project approach

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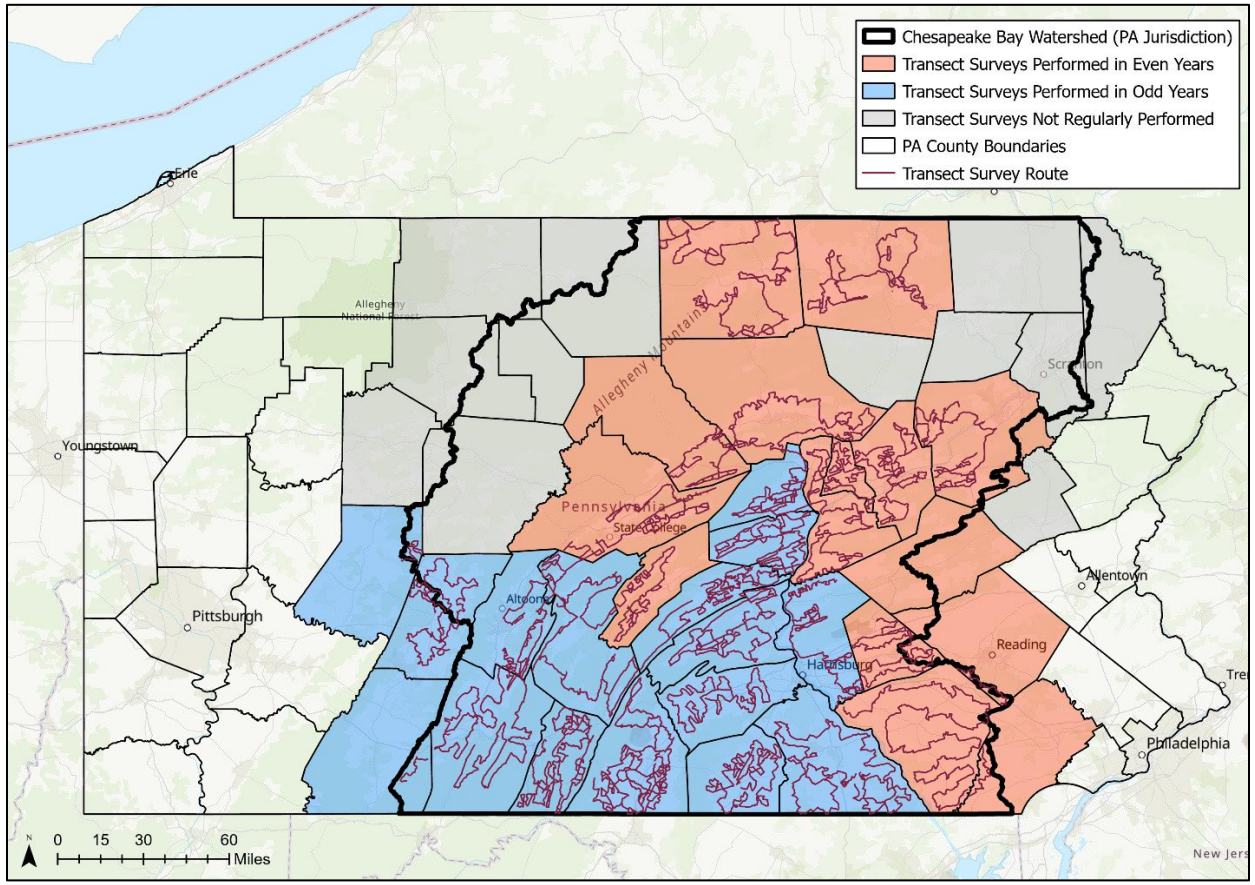
In Phase 1, Resolve Hydro reviewed historical data, past reports, and current methods for reporting conservation tillage BMPs in Pennsylvania

Objective 1: Gather and synthesize available data regarding conservation tillage surveys from 2015 to the present



Map of PA Transect Surveys

Capital RC&D provided **transect survey data across 30 counties** and demonstrated transect survey procedures in Lancaster County

Farm Survey Vehicle

*Transect route in Schuylkill County is not represented above but will be included in the Phase 1 report

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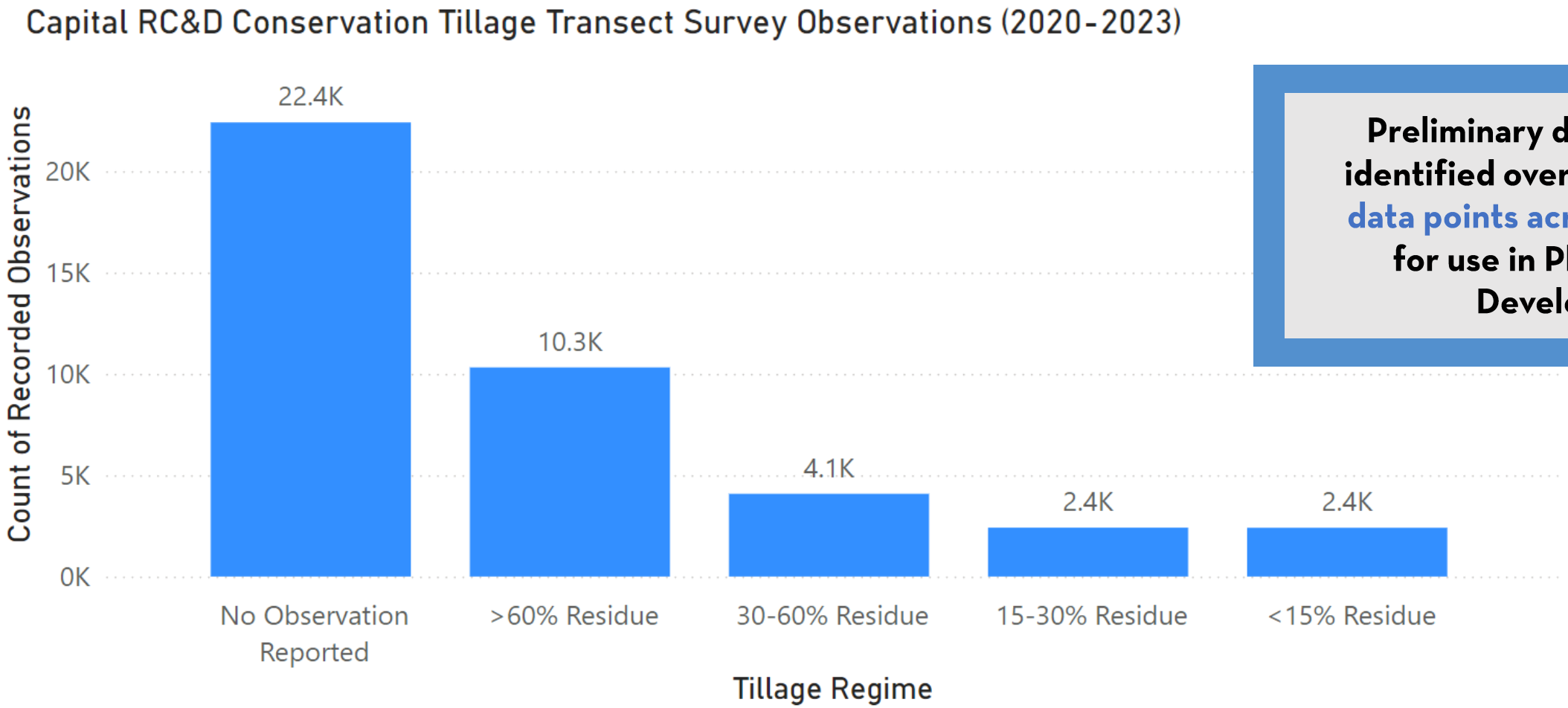

Preliminary data processing identified over 40,000 eligible data points across 30 counties for use in Phase 2 Model Development

*"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

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PA DEP's pilot project emphasizes stakeholder engagement and encourages feedback on the project approach and analysis

Objective 2: Establish a core project team, project advisory committee (PAC), and engagement structure

Core Project Team	Project Advisory Committee (PAC)	Other Engaged Stakeholders
• Scott Heidel, PA DEP • Ashley Hullinger, PA DEP • Mike Morris, PA DEP • Tyler Trostle, PA DEP • Tom Howard, Resolve Hydro	• Chris Brosch, DDA • Clint Gill, Delaware DDA • Nick Hepfl, HRA • Emily Dekar, Upper Susquehanna Coalition • Stuart Blankenship, VA DCR • Cindy Shreve, WVCA • Hankui Zhang, South Dakota State University • Dean Hively, USGS	• Chesapeake Bay Program Office and Workgroups • Conservation District Personnel • Capital RC&D • Independent Review Group (TBD)
Biweekly meetings	Monthly meetings	Regular progress updates

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The Phase 1 Methodology Development Plan outlines the Phase 2 project workflow

Objective 3: Generate a written report documenting a proposed technical approach for subsequent project phases

Proposed technical workflow for Phase 2: Method Development and Evaluation

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Proposed technical workflow for Phase 2: Method Development and Evaluation

Overview of Task 1: Data Collection and Preprocessing

Task 1
Data Collection and Pre-Processing

Task 2
Satellite Data Acquisition

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Model Development

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Model Evaluation and Performance Quantification

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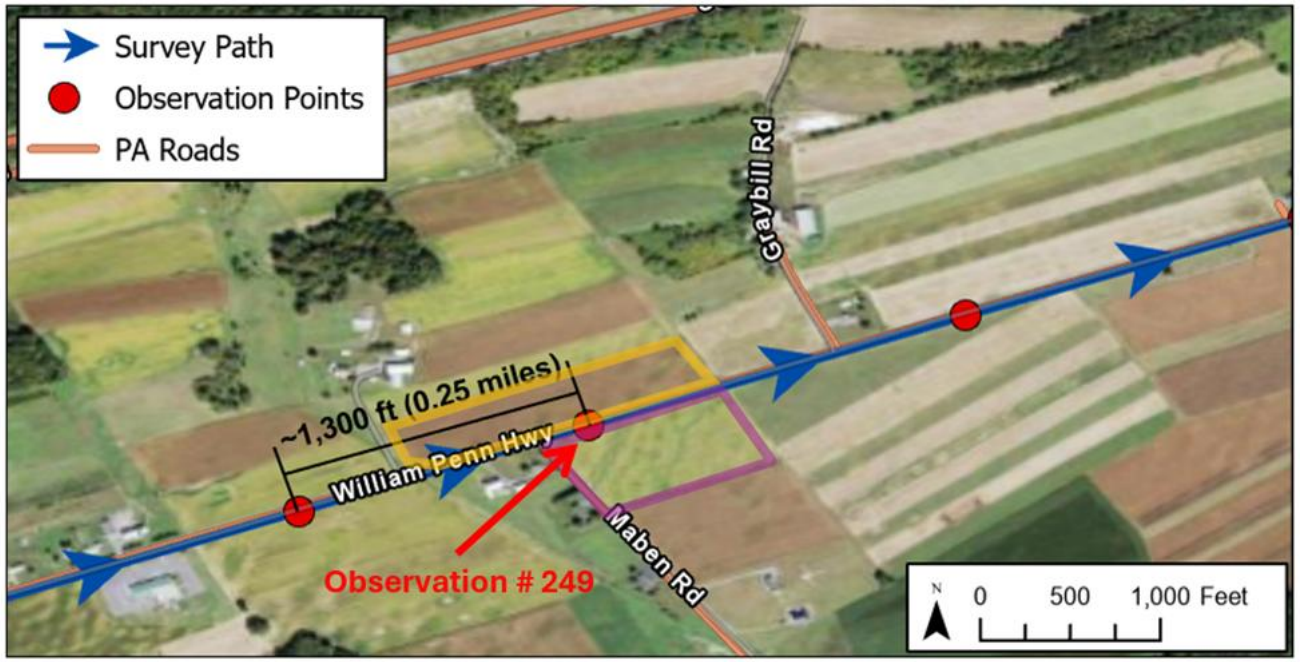
Methodology Development and Reporting



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>

Transect survey observations (available 2020 – present) are currently tabulated but not geo-referenced

In Task 1, Resolve Hydro will **compile, clean, and geolocate transect data** from 30+ county datasets provided by Capital RC&D

Overview of Task 1: Data Collection and Preprocessing

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Methodology Development and Reporting

Step 1: Transect Survey Data Compilation and Validation

- Data import
- Data validation

Step 2: Point Geolocation and Field Delineation

- Geolocate transect survey observations
- Create 300-meter buffer box around observations
- Download cloud-free imagery in buffer boxes
- Apply LULC mask to imagery
- Perform automatic field delineation

Step 3: Route Assignment and Polygon Selection

- Select road networks
- Assign polygons "side of road" values
- Perform final field selection and review

Task 1 will consist of 3 key steps

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Power Query, a data transformation and preparation engine, will be used to perform extract, transform, load (ETL) processing steps

	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

Data validation examples

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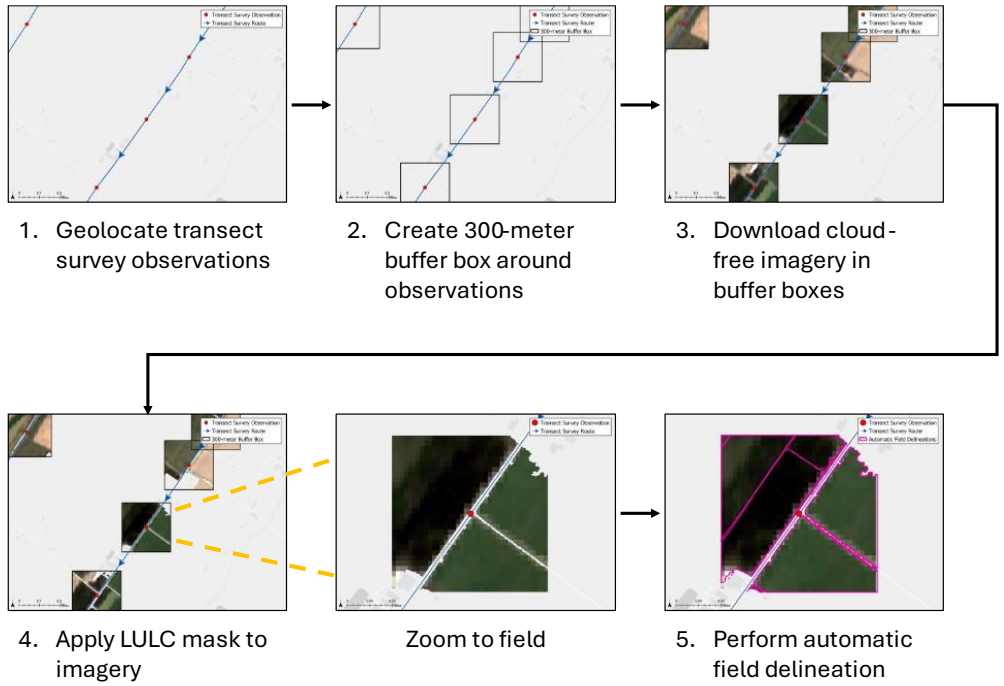
Transect survey observations are recorded at road center points; in Step 2, Resolve Hydro will use computer vision to automatically delineate field boundaries near these center points



1. Geolocate transect survey observations
2. Create 300-meter buffer box around observations
3. Download cloud-free imagery in buffer boxes
4. Apply LULC mask to imagery

Zoom to field

5. Perform automatic field delineation

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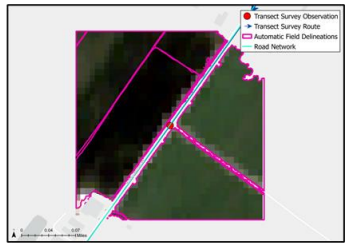
Step 3: Route Assignment and Polygon Selection

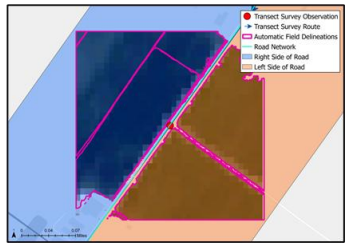
- Select road networks
- Assign polygons "side of road" values
- Perform final field selection and review

In Step 3, conservation tillage observations will be assigned to the agricultural field polygons developed during Step 2.

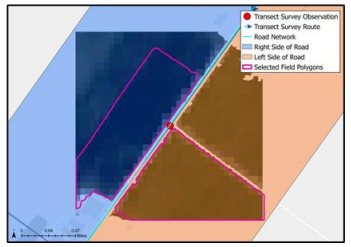
1. **Select road networks**



2. **Assign polygons "side of road" values**



3. **Perform final field selection and review**



The Phase 1 Methodology Development Plan outlines the Phase 2 project workflow

Objective 3: Generate a written report documenting a proposed technical approach for subsequent project phases

Proposed technical workflow for Phase 2: Method Development and Evaluation

Overview of Task 2: Satellite Data Acquisition

Task 1
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Model Evaluation and Performance Quantification

Task 5
Methodology Development and Reporting

In Task 2, Resolve Hydro will **acquire and process surface reflectance measurements** from Sentinel-2, Landsat 8/9, and Planet SuperDove satellites

Acquire Satellite Imagery
- Sentinel-2
- Landsat 8/9
- Planet SuperDove

Apply Data Masks
- Haze
- Clouds
- Cloud Shadows

Compute Band Indices
- NDTI
- NDI5
- NDI7
- STI
- NDSVI
- NDRI
- MSCARI
- NDVI
- CRC

Compute Area Aggregated Statistics
- Mean
- Median
- Maximum
- Minimum
- Standard Deviation
- Count

Standardize Data
- Time bucketing
- Loess Smoothing

Overview of Task 2: Satellite Data Acquisition

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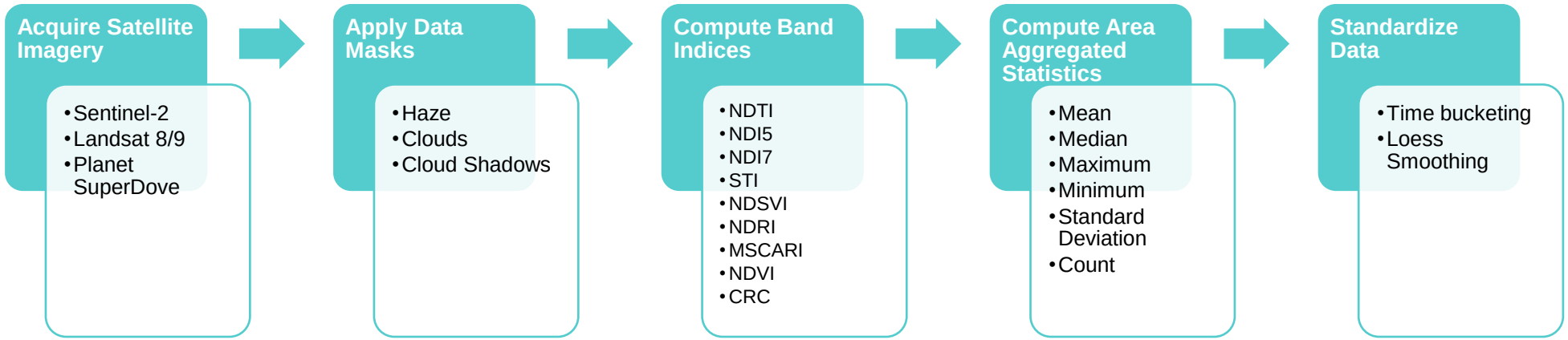

This task will develop the cleaned satellite matchup dataset used for model development and testing

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Proposed technical workflow for Phase 2: Method Development and Evaluation

Overview of Task 3: Model Development

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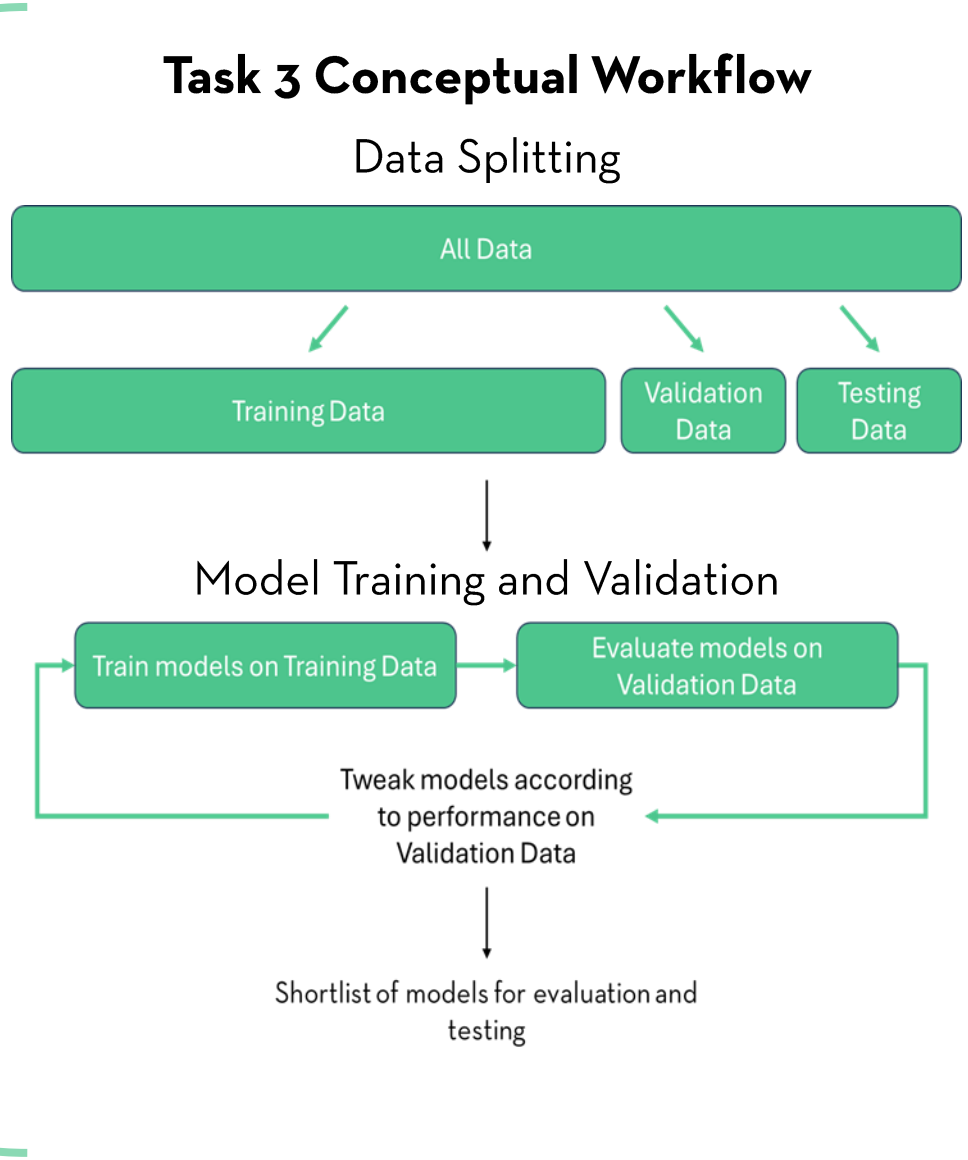

Task 3 encompasses **data splitting and model training steps**. Following model development, the overall performance of shortlisted models will be tested in Task 4.

Overview of Task 3: Model Development

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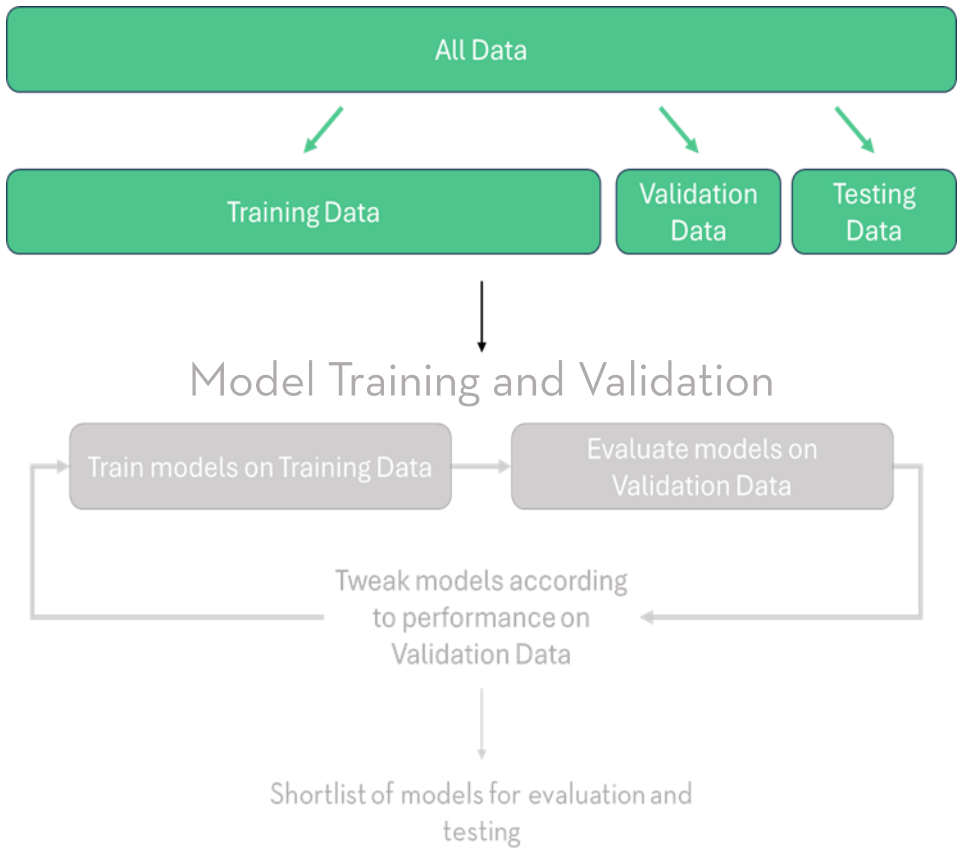
Task 3 Conceptual Workflow



Data splitting prevents data leakage and allows us to properly test how well the developed model generalizes to new data

Training Dataset:
- Random selection of 80% of the matchup data collected across 22 counties from 2020 to 2023

Validation Dataset:
- Matchup data collected in 4 counties distinct from the counties identified in the training dataset from 2020 to 2023
- 10% of the matchup data used to create the training dataset

Testing Dataset:
- All matchup data collected in 2024 (including data from 4 counties excluded from both the training and validation dataset)
- 10% of the matchup data used to create the training dataset

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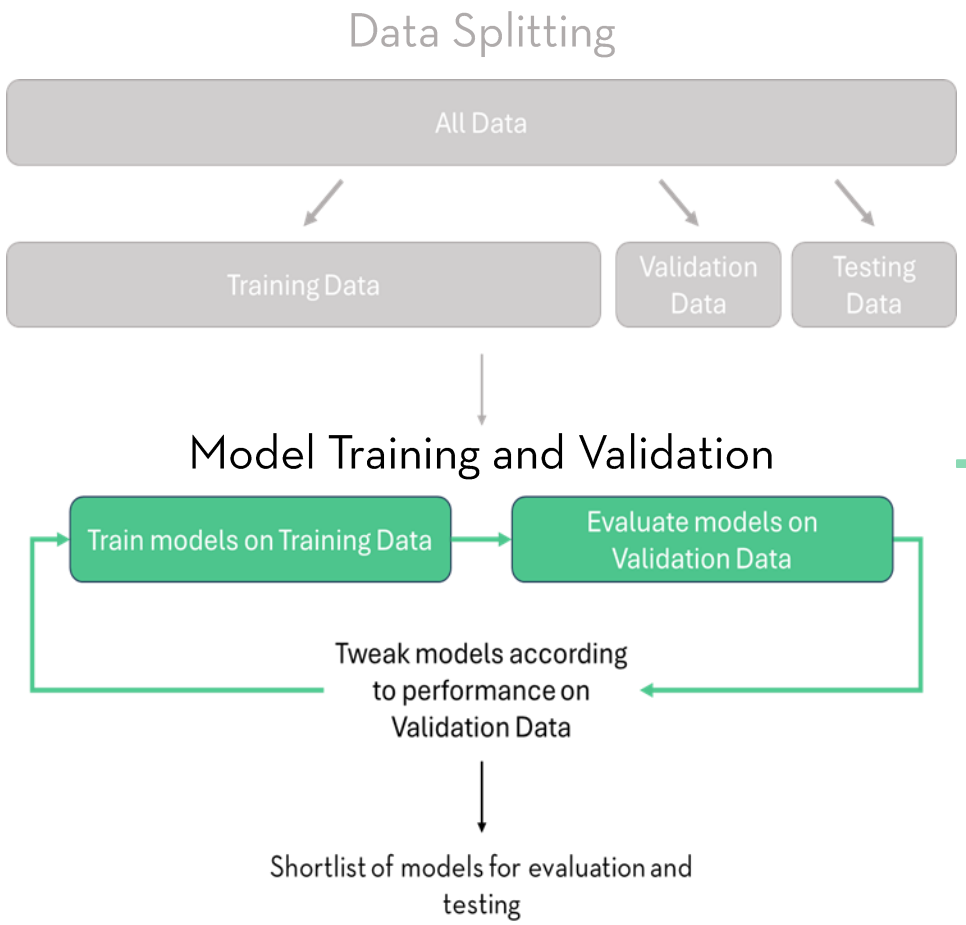
Task 3 Conceptual Workflow



Several rounds of model training and validation will be conducted to **identify optimal data preparation techniques and model architectures**

Candidate machine learning models will be trained to predict crop residue coverage tier from input satellite data:

- Less than 15% residue coverage
- 15% to 29% residue coverage
- 30% to 59% residue coverage
- Over 60% residue coverage

3 – 5 of the developed models will be shortlisted for inclusion in Task 4

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Objective 3: Generate a written report documenting a proposed technical approach for subsequent project phases

Proposed technical workflow for Phase 2: Method Development and Evaluation

Overview of Task 4: Model Evaluation and Performance Quantification

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Data Collection and Pre-Processing

Task 2
Satellite Data Acquisition

Task 3
Model Development

Task 4
Model Evaluation and Performance Quantification

Task 5
Methodology Development and Reporting

In Task 4, Resolve Hydro will use the testing dataset to **evaluate the overall performance of the shortlisted models** developed in Task 3

Key Performance Metrics:

- Micro-average and macro-average precision, recall, and F1-score
- Cohen's Kappa
- Cross-entropy
- Matthew's correlation coefficient
- Accuracy
- False Positive Rate
- Critical Success Index
- False Alarm Rate
- Frequency Bias

Key Evaluation Contexts:

- Crop type
- County
- Hydrogeomorphic region (CBP)
- Major physiographic section (PA)
- Soil class and percent slope
- In regions for which historical data was used for model training
- In regions for which historical data was not used for model training

Metrics will be used to help explain model errors, provide recommendations regarding model application in new areas, and select a "best-performing model"

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Objective 3: Generate a written report documenting a proposed technical approach for subsequent project phases

Proposed technical workflow for Phase 2: Method Development and Evaluation

Overview of Task 5: Methodology Development and Reporting

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Satellite Data Acquisition

Task 3
Model Development

Task 4
Model Evaluation and Performance Quantification

Task 5
Methodology Development and Reporting

In Task 5, Resolve Hydro will compose a **model development report** and a **standard operating procedure** for using remote sensing for BMP verification of conservation tillage

Model Development Report:

- Document and compare the assumptions and processes used to create the "best performing" and shortlisted models
- Report the model performance in accordance with CBP's *Recommendation Report*[1]

Standard Operating Procedure:

- Set guidelines for remote sensing model documentation, performance testing, verification using in-situ data collection, and statistical review
- Specify approach for how to apply a remote sensing model for verifying conservation tillage

[1] *Recommendation Report 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*

Overview of Task 5: Methodology Development and Reporting

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Satellite Data Acquisition

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Model Development

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Model Evaluation and Performance Quantification

Task 5
Methodology Development and Reporting

Primary Approaches for Remote Sensing Model Application

Virtual Transect Survey (VTS)

- Use remote sensing to classify conservation tillage at existing observation points to reduce cost, time, and labor associated with the current in-situ approach

Virtual Field Survey (VFS)

- Use remote sensing to classify conservation tillage in a random sample of agricultural fields
- Similar to the VTS approach, but not limited to roadside fields

Total Area Classification (TAC)

- Use remote sensing to classify conservation tillage over all agricultural lands identified by the CBP LULC dataset

Note: In field verification will be required for all approaches

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Objective 4: Collect and incorporate feedback from the CBP Agriculture Workgroup to refine the overall project approach

Workgroup feedback is critical to project success

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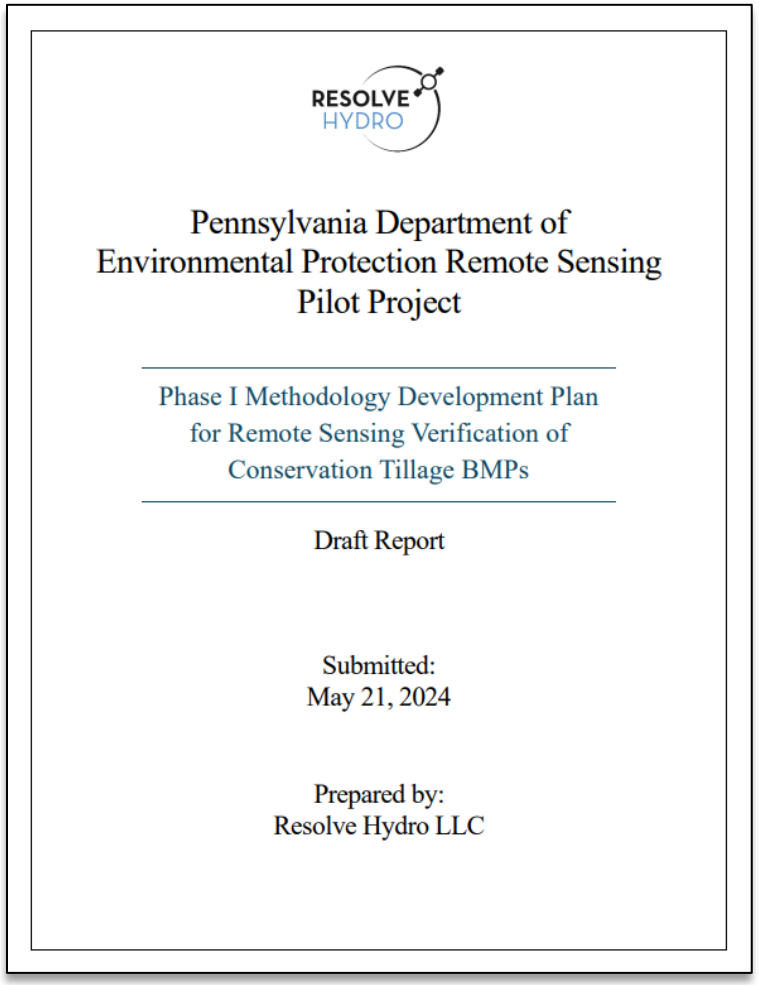

RESOLVE HYDRO

Pennsylvania Department of Environmental Protection Remote Sensing Pilot Project

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

Draft Report

Submitted:
May 21, 2024

Prepared by:
Resolve Hydro LLC

- **Email comments and feedback** on the Draft Methodology Development Plan to Eric Hughes (hughes.eric@epa.gov) and Caroline Kleis (kleis.caroline@epa.gov) by July 8th
- **Connect with PA DEP and Resolve Hydro**
  - Scott Heidel (scheidel@pa.gov)
  - Ashley Hullinger (ahullinger@pa.gov)
  - Tom Howard (thoward@resolvehydro.com)
- **Provide feedback during monthly Agriculture Workgroup updates**
- **Provide feedback during presentation to Watershed Technical Workgroup in August**

The Phase 1 report will be posted on the CBP Agriculture Workgroup website

Proposed Pilot Project Timeline

PA-DEP Remote Sensing-Based Verification of Conservation Tillage BMPs Pilot Project

Phase 1: Methodology Development Plan

March 2024 to June 2024

Presentation to AgWG on Methodology Development Plan

Phase 2: Method Development and Evaluation

July 2024 to February 2025

Independent Review

Vote for AgWG Approval of Developed Methodology

Phase 3: Implementation

March 2025 to July 2025

Chesapeake Bay Program
Science. Restoration. Partnership.

We seek to obtain AgWG feedback and official approval on the developed methodology at the end of Phase 2 of the pilot project (Spring 2025).

RESOLVE HYDRO

THANK YOU

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