Rhode Island Freshwater Wetlands Monitoring and Assessment Program:

MAPPING OF POTENTIAL VERNAL POOLS IN RHODE ISLAND USING A LIDAR MODEL AND PHOTOINTERPRETATION, PILOT 2

Quality Assurance Project Plan for Secondary Data
January 19, 2024

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1.3 Distribution List

- Signatories (Title Page)
- Beth Alafat, EPA Region 1 Wetlands Protection Section
- Erica Sachs-Lambert, EPA Region 1 Wetlands Protection Section
- Charles LaBash, URI Environmental Data Center
- Dr. David Gregg, Rhode Island Natural History Survey
- Thomas Kutcher, Rhode Island Natural History Survey

1.4 Project Organization

The Department of Environmental Management (DEM) Office of Water Resources will be the lead agency to administer this work. DEM has contracted with the University of Rhode Island Environmental Data Center (EDC) who employ qualified and experienced personnel to execute the work. The following people will participate in this project:

- Richard Enander, RIDEM Deputy Administrator, Office of Technical Assistance: Responsible for administration of and project consistency with the RIDEM Quality Management Plan
- Susan Kiernan, RIDEM Administrator, Office of Water Resources: Responsible for contract agreement and fiscal grant management and general program oversight.
- Carolyn Murphy, RIDEM Environmental Scientist III, Office of Water Resources: Responsible for technical project oversight and quality assurance and communication. RI Vernal Pool Team member.
- Anthony Pepe, EPA Region 1: Quality Assurance Reviewer.
- Donna Smith-Williams, EPA Region 1: Wetland Program Development Grant Project Officer, Award CD 00A00607.
- Erica Sachs-Lambert, EPA Region 1: Responsible for technical consultation and assistance. RI Vernal Pool Team member.
- Charles LaBash, Director, URI EDC: Responsible for contract agreement and mapping oversight.

- Jason Parent, PhD., Professor of Geographic Information Systems (GIS), University of Rhode Island (URI): Responsible for providing technical advisement regarding mapping methods.
- Michael Bradley, GIS Analyst, URI EDC: Responsible for conducting the GIS mapping, including model development and deployment, and photointerpretation. Mr. Bradley has over 20 years' experience developing and conducting geospatial mapping and aerial photointerpretation of natural resources in Rhode Island.
- Thomas Kutcher, Wetlands Scientist, RINHS: responsible for drafting this QAPP in consultation with the URI project principal. RI Vernal Pool Team member.

1.5 Problem Definition/Background

The DEM Office of Water Resources has been working with state and local partners to develop methods to characterize freshwater wetlands and inform the goals and objectives of the Rhode Island Freshwater Wetland Monitoring and Assessment Plan (WMAP; NEIWPCC and DEM 2006) with support and guidance from the United States Environmental Protection Agency (U.S. EPA 2006). Vernal Pools are listed in the WMAP as among wetlands that are vulnerable to loss and degradation and have been recognized in Rhode Island as wetlands of high ecological value (Leeson et al. 2018). Vernal pools are seasonal ponds that support certain obligate amphibians and invertebrates, and they are afforded specific protections under new state wetland rules (250-RICR-150-15-3) that took effect on July 1, 2022. DEM has identified statewide mapping and verification of vernal pools as a priority for wetland program development and has contracted with the Rhode Island Natural History Survey (RINHS) to assemble a team of mapping and vernal-pool experts (hereafter the *VP Team*) to recommend mapping and verification methods.

In Spring of 2022, RINHS worked with DEM and Dr. Jason Parent (URI, Parent Lab) to map potential vernal pools (PVPs) remotely, using a geographic information system (GIS), which is typically the first step in a vernal pool mapping and verification process. The mapping followed recommendations of the VP Team to pilot two potential methods of mapping potential vernal pools; these included (1) the visual interpretation of multiple years of two-dimensional leaf-off aerial photographic imagery (photointerpretation or PI), and (2) the development and application of a model based on light-detecting aerial radar (LiDAR) to detect small wetland depressions in the landscape. Aerial photo interpretation has been the most common method for locating PVPs in the landscape, but errors of omission (pools missed in the mapping process) and commission (features that are mapped, but are not actually pools) are inevitable, particularly in landscapes dominated by coniferous forest (Calhoun et al. 2003). Mapping using photointerpretation is also time-consuming and labor-intensive (Burne 2001, Dibello et al. 2016). Research has indicated that LiDAR modeling can be more efficient and accurate than photointerpretation for identifying PVPs, with lower errors of commission and omission (Julian et al. 2009, Wu et al. 2014, Bourgeau-Chavez et al. 2016, Dibello et al. 2016, Varin et al. 2021).

Using aerial photointerpretation (PI), graduate students in the Parent Lab volunteered and mapped 334 PVPs across 11,000 acres of mostly-forested land located in central Rhode Island on properties owned by the State of Rhode Island and the Audubon Society of Rhode Island. Of the 334 PVPs identified through PI mapping, 192 were field-surveyed by RINHS and trained partners from the VP Team (under the 2022 EPA-approved QAPP titled "Mapping and Verification of Vernal Pools"). One hundred and fourteen (114) of these were aquatic depressions (the mapping target). Sixty five of the 114 were field verified to be supporting vernal-pool-dependent amphibians; and 52 features were verified to be isolated vernal pools (aquatic depressions that supported VP amphibians and were not located within a larger wetland). This information was used by the Parent Lab in the development of a model to predict the presence of PVPs on the landscape using existing statewide LiDAR (USGS, 2011).

As part of the 2022 project, 98 acres of the study area were field-surveyed (searched) for aquatic depressions to determine errors of omission and commission. The mapping errors for the volunteer photointerpretation were similar to results reported from other studies in the region, whereas mapping errors for the LiDAR model were somewhat higher. Based on the combined results from the 2022 pilot, the VP Team advised DEM that neither method, as tested, was ideal for statewide implementation, because photointerpretation was not efficient enough and LiDAR accuracy was less than desirable. The VP Team suggested that mapping efficiency and accuracy could be significantly improved by using a revised strategy. Development and demonstration of a revised strategy for statewide PVP mapping (the Project) is the subject of this new Quality Assurance Project Plan (QAPP).

1.6 Overview of Project Tasks

The VP Team predicts that PVP mapping efficiency and errors could be improved over the 2022 effort by using the strategy outlined below. This strategy will be piloted in the Winter-Spring of 2024 across the Rhode Island portions of the Upper Five-mile and Clear River watersheds in northwestern Rhode Island, and may be expanded to the Chepachet River and Branch River watersheds, if time allows (Fig. 1).

Project Tasks:

1. Use a *hybrid strategy* that uses an improved LiDAR modelling approach (see Task 2 below) to identify PVPs, followed by photointerpretation of those mapped PVPs (rather than searching the entire landscape) to finalize the PVP maps. The LiDAR model will be calibrated to include more areas and features that may not be actual vernal pools. This approach will reduce errors of omission, but may also increase errors of commission. Targeted photointerpretation of those LiDAR-mapped features will then remove obvious mapping errors, serving to lower the errors of commission. The VP Team predicts that

this method will be more efficient than photointerpretation alone across the entire area, while providing lower errors of omission or commission than LiDAR mapping alone.

2. Update the prior LiDAR model by using two years of LiDAR data, including higher-resolution and updated statewide LiDAR data collected in 2022. The USGS 2011 dataset will be used to reduce uncertainties arising from gaps inherent in the datasets. The LiDAR data were collected during the winter and spring seasons to reduce interference from deciduous leaves, and this is also a time when vernal pools are typically flooded. Flooded pools can often appear as gaps in the LiDAR data, as the water does not efficiently reflect the radar used by LiDAR. Using both years of data will reduce the number of erroneous gaps coded as PVPs.

3. URI-EDC will conduct the photointerpretation using multiple years of high-resolution aerial photographic imagery available from the Rhode Island Geographic Information System (RIGIS). The 2022 effort used inexperienced students to detect the PVPs, resulting in higher-than-expected errors of commission. A single, experienced GIS Analyst (Mr. Bradley) will interpret the data. In addition to interpreting PVPs generated by the LiDAR model (see Task 1, above), the GIS Analyst will photointerpret imagery from 10 randomly-selected polygons (50 to 100 acres, depending on the number of PVPs detected) located within the study area to detect PVPs without the aid of the model; this will provide a GIS-based proxy for errors of omission produced by the model.

4. Use existing RIGIS Community Classification (2011) data to identify large wetlands that will be excluded from the PVP mapping effort in order to focus on confined vernal pools that are more vulnerable to being overlooked during the regulatory process. There are three main justifications for this decision. (1) Vernal pools and their buffers located within larger wetlands are most-often protected by the protections given to the larger, more obvious wetlands, so mapping them is less critical for their protection. (2) Identifying aquatic depressions within larger flooded or depressional areas poses challenges in feature discrimination for modeling and photointerpretation; focusing on isolated pools should reduce the challenges and associated errors. (3) Earlier work found that isolated pools were almost twice as likely to support vernal-pool-dependent amphibians (86% versus 43% respectively; Kutcher and Parent 2023).

5. Resulting mapped PVPs will be field-surveyed by the RINHS using existing methods detailed in an addendum to the Dec. 2022 EPA-approved QAPP. Analysis between the GIS and field datasets will reveal errors of omission and commission to inform statewide mapping for the remainder of Rhode Island.

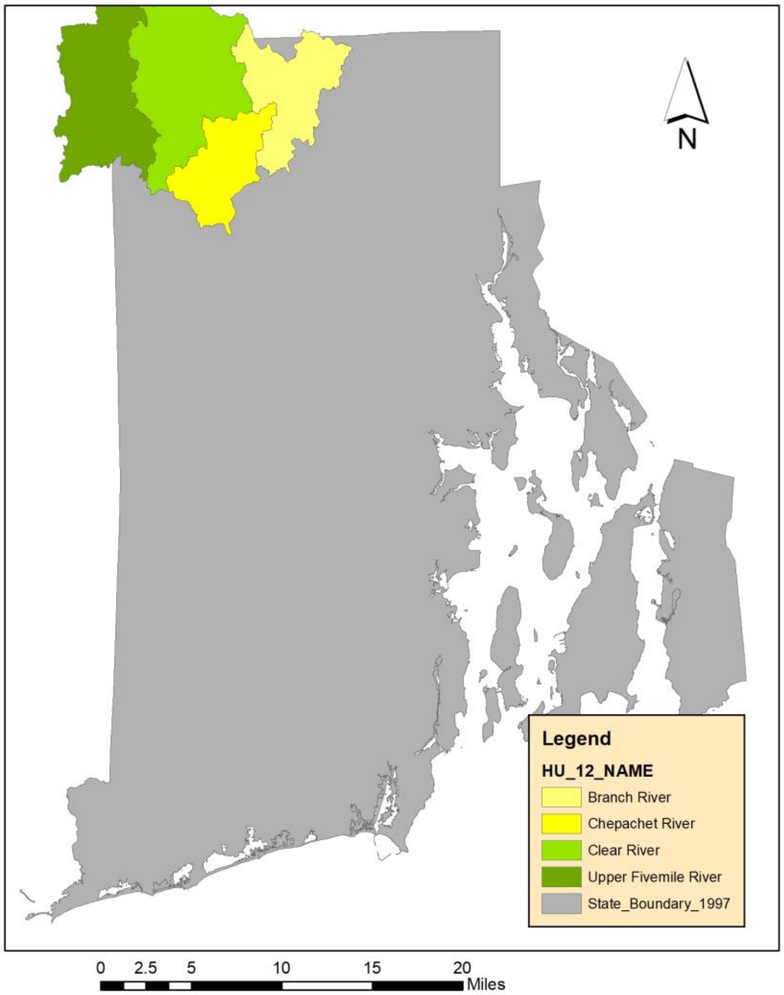

Figure 1. HUC 12 watersheds to be mapped* for PVPs during this Project. Watersheds depicted as green are focal mapping areas. Watersheds depicted as yellow will be mapped if time allows. *Only areas falling within the Rhode Island boundary will be mapped for this Project.

LiDAR Modeling Methods

LiDAR modeling will be conducted by the URI Environmental Data Center (EDC). In the prior mapping effort, the Parent Lab (URI) developed a LiDAR model to identify PVPs based on elevation information derived from RIGIS 2011 LiDAR, and spectral information from RIGIS April 2020 aerial imagery (Kutcher and Parent 2023). That model will be refined using Esri's ArcGIS Pro software and applied to the study area. Newly-released 2022 LiDAR data will be used in addition to the 2011 data to refine the Parent Lab's model (available at RIGIS.org). The modeling will use a heuristic approach guided by field-verified vernal-pool data from prior studies in the nearby Wood-Pawcatuck watershed in RI (DEM 2011) and the Big River watershed (Kutcher and Parent 2023). The model will consider the following factors in classifying PVPs: 1) depressions, 2) low density of LiDAR points, 3) low spectral brightness across all bands, 4) low to moderate normalized difference vegetation index (NDVI) in leaf-off imagery, and 5) land cover type.

The mapping process will use digital terrain models (DTM), created from the 2011 and 2022 LiDAR datasets, to identify depressions in which vernal pools could form. Depressions will be filled by using ArcGIS's *Fill* tool and then subtracted the original DTM to calculate depression depth. Depressions with depths > 5 cm (2 inches) will be considered to correspond to PVPs. Because LiDAR typically generates few data points from water features, voids in the point cloud dataset in which there were no ground return points will be flagged. Pixels that contain no LiDAR ground returns will be extracted and used to calculate the percentage of area within a 3 m radius that consisted of void space. The model will consider pixels to be PVPs if > 90% of the area within these neighborhoods contains no LiDAR ground returns. Water has low reflectance at visible and NIR wavelengths; thus, pixels with low reflectance will be classified using the iteratively self-organized data (Iso Data) algorithm in ArcGIS. This algorithm classifies image pixels into classes that have similar spectral properties with very dark pixels typically assigned to a single class. Pixels that are not classified as the darkest of the Iso Data classes will be excluded from consideration as PVPs. To help further reduce commission errors, pixels that have high NDVI values, corresponding to coniferous vegetation in our leaf-off imagery, will also be excluded. Finally, pixels falling within areas that are defined as wetlands by the RIGIS Ecological Communities Classification 2011 dataset and are > 1 acre (0.405 ha) will be excluded. The remaining PVP pixels will be grouped into contiguous patches, and patches smaller than 20 m^2 will be discarded.

Photointerpretation Methods
URI-EDC will photointerpret leaf-off multispectral imagery from April 2018, 2019, and 2020 (available through RIGIS.org), viewed on-screen using ESRI ArcGIS software. The April 2018, 2019 and 2020 imagery have a 3-inch digital resolution and are not traditionally orthorectified; The imagery will be visually scanned by the GIS Analyst and all non-linear features that appeared to be aquatic depressions (e.g., distinct depressions holding shallow water) will be marked with a point feature as potential vernal pools (PVPs). During the photointerpretation, screen scale will be adjusted (zoomed in or out) as needed to best discriminate PVP features in the landscape. Other similar-quality RIGIS aerial imagery may be used if it is found to improve photointerpretation efficiency; any such data will be specified in the final report.

1.7 Quality Objectives and Criteria

The objective of the Project will be to produce a map of isolated PVPs in an unmapped area of the state (the study area, see Fig. 1) and evaluate the accuracy of the above-described "hybrid" PVP mapping approach by field inspecting the PVPs (Sec. 1.6). Isolated PVPs are defined as aquatic depressions in the landscape that are not located within a larger wetland and are flooded during spring imagery in most years, as determined though inspection of the remote data (leaf-off imagery and LiDAR). The quality objective is to produce a spatially useful map of isolated PVP locations that improve upon the former mapping effort (Kutcher and Parent 2023) in mapping accuracy (lower errors of omission and commission to those reported in Table 1), and provide a mapping efficiency (i.e., labor and cost) that is acceptable for statewide application, at the discretion of DEM. PVP maps will be produced using the *best-available* data from RIGIS to produce the most accurate maps possible, given the resources.

While the quality objective of the mapping is to exceed the prior PVP maps in accuracy and efficiency, the overall mapping accuracies will not be determined until after the mapping is complete. However, adjustments to the model will be made in the process of model development and photointerpretation to optimize mapping accuracies and efficiency. For example, the LiDAR model may be adjusted to detect fewer or more features based on preliminary photointerpretation to balance errors of commission against errors of omission, leaning toward higher commission errors that can be rectified through photointerpretation. Also, aerial imagery may be deemed only somewhat useful based on preliminary photointerpretation. Datasets deemed to be less than optimal may still be utilized to check primary data sources, or may be replaced with imagery that meets the requirements of this QAPP.

Spatial accuracy will be assessed by matching newly-utilized data (e.g., 2022 LiDAR, Ecological Communities Classification 2011) against the known-accurate datasets being reused (e.g. 2020 imagery and 2011 LiDAR). If inconsistencies of greater than 10m on the ground are discovered between datasets or between the datasets and high-resolution GPS in the field, the PVP maps will be georectified by the GIS analyst to be within 10m of true location at the most appropriate and efficient stage of the mapping procedure.

Table 1. Errors of commission and omission in the mapping of PVPs by two-dimensional photointerpretation and LiDAR modeling, as reported by (Kutcher and Parent 2023).

Mapping Method	Errors of Commission	Errors of Omission
Aerial Photointerpretation	44%	29%
LiDAR Modeling	70%	33%

2.0 DATA SELECTION AND MANAGEMENT

2.1, 2.2 Sources of Existing Data and Intended Use

The Project will use electronic digital aerial imagery, LiDAR data, and secondary data available from RIGIS (available at rigis.org). RIGIS is a clearinghouse for geospatial data in Rhode Island. All RIGIS Data are quality inspected and include descriptions of data collection methods and overviews of expected accuracies. When available, Federal Geographic Data Committee (FGDC) compliant metadata for the data is available at the RIGIS website (RIGIS.org 2023). The following datasets (publication dates in parentheses) and other RIGIS data may be used as needed:

- *Digital Aerial Photography* (2018, 2019, 2020, and possibly other datasets)
- *RIGIS Statewide LiDAR* (2011, 2022)
- *RI Ecological Communities* (2011)

Digital Aerial Imagery
RIGIS 2020 Rhode Island Digital Aerial Photographs (hereafter April 2020 imagery) was used in the 2022 vernal pool mapping effort and was found to have exceptional visible contrast, clarity and resolution for identifying potential vernal pool features on-screen and an accuracy satisfactory for locating features in the field using geospatial locating software and a global positioning system (GPS) (Kutcher and Parent 2023). Other RIGIS aerial imagery datasets (example, 2018 Spring Rhode Island Digital Aerial Photographs) were used in the prior project and were found to be similarly spatially accurate and useful. Multiple RIGIS imagery datasets, including the 2020 imagery described below, may be used to discriminate whether LiDAR-mapped features are likely to be vernal pool before coding them as PVPs for field inspection. Any new aerial imagery utilized will be evaluated in areas to be mapped by locating features against the known datasets on-screen. Any aerial imagery found to be spatially-inconsistent with the April 2020 imagery will not be used to spatially locate the PVPs. All RIGIS aerial imagery is quality inspected similarly to below, as reported by RIGIS for April 2020 aerial imagery, as an example:

"Image service. Capture date range: April 12 - 25, 2020. Statewide, true color, 3-inch spatial resolution, leaf-off aerial photographs of Rhode Island. This image service features aerial photographs collected April 12 - 25, 2020 by Eagle View Technologies, Inc, under contract to the Rhode Island Department of Transportation. The source images are 3-band true color, have a 3-inch spatial resolution, and are leaf-off. These images are not traditionally orthorectified. Their horizontal accuracy may vary throughout the state. Potential users are encouraged to carefully evaluate the suitability of these images before use." RIGIS (accessed November 2023)

LiDAR Data
RIGIS 2011 LiDAR data were used as a basis of a GIS model to map vernal pools in the 2022 PVP mapping project and were found to be spatially accurate compared with the 2020 aerial imagery and GPS locations documented in the field (Kutcher and Parent 2023). According to RIGIS descriptions (App. 1), the new 2022 LiDAR dataset exceeds the 2011 data in resolution and should therefore produce a more practically accurate product.

Ecological Communities Classification 2011
Prior freshwater monitoring and assessment work undertaken by DEM and RINHS have utilized this statewide dataset which is suitable to distinguish between freshwater wetlands and upland habitat types which is necessary for this mapping project. A description of the Ecological Communities Classification 2011 dataset according to RIGIS.org (accessed November 2023) is shown below:

"This is a statewide, seamless digital dataset of the ecological communities for the State of Rhode Island, which was derived using automated and semi-automated methods and based on imagery captured in 2011. The project area encompasses the State of Rhode Island and also extends 1/2 mile into the neighboring states of Connecticut and Massachusetts or to the limits of source orthophotography. Geographic feature accuracy meets the National Mapping Standards for 1:5000 scale mapping with respect to base level data (roads, hydrography, and orthos). The minimum mapping unit for this dataset is .5 acre. The ecological communitiesjk classification scheme used for these data was based on the Rhode Island Ecological Communities Classification document created by Richard W. Enser on October 4, 2011. Geography for the dataset was based on ground conditions of 2011 four-band orthophotography with a spatial resolution of 0.5 ft and 2011 LiDAR data and data derivatives with a nominal post spacing of 1m. Additional ancillary data used in the production of this dataset were provided by the State of Rhode Island and included 2011 land cover/land use, 2011 impervious, road centerline, hydrography, railroads, state boundary, municipal boundary, coastline, location of schools, hospitals, governmental facilities, waste disposal sites, etc."

2.3 Limitations of Existing Data

All data used will be quality-inspected data from RIGIS. The utility and accuracy of RIGIS 2011 LiDAR and April 2020 imagery datasets have been demonstrated in a prior mapping effort (Kutcher and Parent 2023).

Limitations on the 2022 LiDAR data:

1. Must be spatially compatible with the RIGIS 2011 LiDAR data and April 2020 imagery within 10m; and
2. Must be as capable as the 2011 LiDAR data of identifying features to be later photo interpreted as PVPs.

Limitations of aerial imagery data:

1. Must be spatially compatible with the RIGIS April 2020 imagery within 10m; and
2. Must provide clear visible information to compliment or supplement the April 2020 imagery.

Limitations of RIGIS secondary data:

1. Must be spatially compatible with RIGIS April 2020 aerial imagery within 10m; and
2. Any obvious errors in community classification, as deemed through photointerpretation of the GIS analyst, will be noted and corrected in the mapping process, as possible and limited to the errors' impact on identifying isolated PVPs.

3.0 ASSESSMENT AND OVERSIGHT

3.1 Assessments/Oversight and Response Actions

Project oversight will be provided through regular correspondence between the RI DEM Project Manager/Quality Assurance Officer, directly or through correspondence with RINHS, no less than once per month. Correspondence will be in the forms of email and telephone correspondence, review meetings, memoranda, and the exchange of key data and documents according to the schedule herein. Assessment-oversight will involve review of all aspects of the project and its progress. Technical advisors, including Dr. Jason Parent (URI), RI DEM scientists, EPA scientists, and other expert PVP-mapping stakeholders will be consulted throughout the project.

3.2 Reports to Management

Brief memoranda and final reports will be submitted by the EDC to the DEM Project Manager/Quality Assurance Officer at the following project milestones: (1) following PVP generation via LiDAR modeling, (2) following photointerpretation, (3) following analysis of errors and efficiencies, (4) the Draft Report, (5) the Final Report.

3.3 Resolving Problems

According to the schedule herein, RI DEM and EDC will respond to input as necessary to ensure the efficient use of project resources to meet State reporting and Project requirements. The RI DEM Wetland Program Manager has the authority to issue a stop work order if something is not going right and to document corrective actions that need to be taken.

4.0 DATA REVIEW – VERIFICATION, VALIDATION, AND EVALUATION

4.1 Data Review, Verification, and Validation Requirements

Data limitations will be assessed during the model-development and photointerpretation processes by the GIS analyst in consultation with J. Parent, DEM, and RINHS. The validity and utility of data produced by this Project will be validated against field data collected by RINHS under a separate addendum to the 2022 EPA-approved QAPP for the initial pilot project titled "Mapping and Verification of Vernal Pools". The addendum will be prepared in advance of the spring 2024 field season. EDC will work with RINHS to interpret the outcomes of the analyses. Outcomes of the validation, in terms of mapping errors and mapping efficiency will be compared with the 2022 mapping effort to assess whether improvements have been made to qualify the method as suitable for statewide implementation by DEM. Secondary data (PVP maps) will be quality assured by EDC and RINHS to be complete throughout the study areas, without spatial gaps or other inconsistencies. This will be done by selection of random areas within the study area and inspecting them via photointerpretation for mapped and unmapped features. Any gaps in the dataset will be rectified by rerunning the LiDAR model and photointerpretation process.

4.2 Verification and Validation Methods

The GIS Analyst will review the data for inconsistencies and outliers. Any inconsistencies or outliers found will be corrected in the electronic datasets. Any data outliers or other logical inconsistencies that cannot be corrected through this review process will be removed from the dataset prior to analysis, and this action will be documented in the Project reports.

Protocols for data analysis, development, and implementation methodologies may be adjusted for future applications of PVP mapping based on comments from the technical advisors and the project participants. DEM holds ultimate authority in the adjustment of the protocols according to review feedback. Any adjustments to PVP mapping methods based on validation analysis outcomes and internal and workgroup feedback will be documented in the draft and final Project reports.

5.0 PROJECT SCHEDULE

The Project will be conducted from January 2024 through September 2024. The task descriptions and schedules are planned as follows.

Tasks		**Deliverables**	**Month**
1	Project setup	Map containing the study areas to be mapped and % cover of land cover types	Jan-Feb 2024
2	LiDAR model development	At the end of the project, a LiDAR model using a subset of the 2011 and 2022 datasets will be delivered as a geoprocessing tool in ArcGIS.	Jan-Sept 2024
3	LiDAR mapping and Aerial Photointerpretation	A digital map of georeferenced PVP points ready for field surveys. Time estimates for completion of the study area will be submitted as a MS Word table.	Feb 2024
4	Analysis of data	Errors of omission and commission for main cover types and overall will be submitted as a MS Word table; estimates for mapping time by acre and	June 2024

		statewide will also be included as a MS Word table.	
5	Report writing	Draft and final Project reports	June-Sept 2024

6.0 PROJECT REPORTING

The Project Report will be written by EDC and RINHS and will include sections as follows:

1) Introduction:
   a) Background, justifications, and context of the Project
2) Methods:
   a) Study Site description
   b) Data used to generate PVP maps
   c) The specific operations involved in site selection, LiDAR modeling, and photointerpretation
   d) Estimating the time commitments for each process
   e) Analyses used to determine accuracies and efficiencies for various community and land cover types (e.g., coniferous forest, deciduous forest, open land, developed land) and overall.
   f) Quality assurance procedures
3) Results:
   a) The area of wetland versus upland in the study area (areas searched vs not searched)
   b) The number of isolated PVPs generated by each method
   c) The time the mapping took per acre and an estimate of how that may translate to a statewide effort
   d) Mapping error outcomes for various community types and overall
4) Discussion:
   a) Recommendations for or against using the method for statewide mapping
   b) Adjustments to the model or methodology needed for statewide mapping
   c) Recommendations for a statewide mapping strategy

DEM will provide written comments on a draft Report for the Project. A final Report, which will be completed by EDC, will incorporate responses to revisions based on DEM comments.

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Appendix 1. Data collection methods and specifications for LiDAR data used in the Project (verbatim from RIGIS.org accessed November 7, 2023)

2011 Rhode Island Statewide Lidar

Detailed elevation data were collected with airborne lidar technology for the entire area of Rhode Island between April 22 and May 6, 2011.

This data collection was a component of the larger Northeast Lidar Project. This multi-state regional initiative was primarily funded by the American Recovery and Reinvestment Act and is lead by the Maine Office of GIS, facilitated by the USGS Geospatial Liaison Network, and managed by the USGS National Geospatial Technical Operations Center. Locally, this project was coordinated by RIGIS and the URI Environmental Data Center.

Specifications:

- 1 meter nominal pulse spacing
- National Spatial Standard for Spatial Data Accuracy (NSSDA) Fundamental Vertical Accuracy (FVA) 29.4cm @ 95% confidence, based on 15cm RMSEz in open terrain land cover.
- Horizontal coordinate system: NAD83 UTM Zone 19 North, meters
- Vertical reference: NAVD88 (GEOID09), meters
- No tidal coordination
- Meet or exceed standards defined in version 12 of the USGS National Geospatial Program Base Lidar Specification (PDF).

Deliverables:

- Raw point cloud data, delivered as flight swaths (LAS 1.2 file format)
- Partially classified point cloud data, delivered as 1500x1500 meter tiles (LAS 1.2 file format; includes intensity data and the following classes:
    - 1 (unclassified); 2 (ground); 7 (noise); 9 (inland water hydro-flattened with the assistance of breaklines); 10 (ignored ground - 1m buffer around hydro-flattened and bare water features); 14 (bare water - estuarine and marine water, not hydro-flattened).

Total file size for all partially classified LAS files for Rhode Island is 258 GB, representing a total of 1553 tiles. 1-meter resolution bare earth digital elevation model, delivered as 1500x1500 meter tiles (ERDAS IMG format, total file size for all DEM files for Rhode Island is 13 GB). Supporting documentation, including QA/QC results and metadata.

The expanded Lidar collection coverage for this project (entire state vs just coastal communities) and higher sampling density (1m nominal point spacing vs 2m) are both upgrades over what was specified for the standard regional product project deliverables. These upgrades were made possible by the coordination of contributing funds from the Rhode Island Statewide Planning Program (Federal Highway Administration), Rhode Island

Chapter of The Nature Conservancy, and USDA Natural Resource Conservation Service Rhode Island State Office. Credit is also due to all the agencies and organizations that contributed their time to help build support for the Rhode Island component of the Northeast Lidar Project.

2022 Rhode Island Statewide Lidar Data Project

Quality Level 1 statewide aerial lidar elevation data acquired March 26-30, 2022.

Developed through the USGS 3D Elevation Program (3DEP) and jointly funded through the US Department of Agriculture Natural Resources Conservation Service (NRCS) and US Geological Survey (USGS)

Specifications:

- Aggregate nominal pulse spacing (ANPS) of 0.35 meters (8ppsm).
- Horizontal projection/datum, NAD83(2011) State Plane Rhode Island FIPS 3800 US Survey Feet
- Vertical datum of NAVD88 (GEOID18)

Deliverables:

- Processed and classified LAZ (v1.4) file format, organized into individual 2500ft x 2500ft tiles
- Raster bare earth DEMs; all tiled to the same 2500ft x 2500ft schema