Exploration and Evaluation of High-Resolution Imagery for Environmental Assessment and Wetland Classification Tool

Final Report and User Guide
July 2022

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16. Abstract

The goal of this project was to assess the potential and develop protocols for the use of high-resolution light detection and ranging (LiDAR) and multispectral imagery to evaluate environmental characteristics of Iowa Department of Transportation (DOT) project areas, with particular attention to identifying federally protected wetland areas that would require mitigation if removed or significantly altered during a road construction project.

Specifically, the research team evaluated how LiDAR and multispectral imagery can support the assessment of design alternatives and whether the data could help DOT staff select alternatives earlier and with less required fieldwork.

During the investigation, which included four objectives, an automated ArcGIS Pro tool that leverages Python and ArcGIS routines to identify potential jurisdictional wetlands based on data derived from LiDAR digital elevation models was developed.

The procedure is a first-pass screening tool that will allow Iowa DOT wetland delineation staff to focus their attention on areas likely to be wetlands, rather than having to scrutinize an entire study area with the same level of attention. The underlying classification model currently over-identifies wetland areas, but much of the overidentification has to do with where exactly the boundaries are mapped.

The final toolboxes and routines required to run the wetland classifying procedures are packaged into shareable toolboxes and have been provided and demonstrated to Iowa DOT staff. Using the automated procedure is expected to save time in wetland delineation by allowing staff to prioritize high-probability areas for further study.

The appendix to this report contains the Wetland Classification Tool User Guide that was developed as part of this project.

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EXPLORATION AND EVALUATION OF HIGH-RESOLUTION IMAGERY FOR ENVIRONMENTAL ASSESSMENT AND WETLAND CLASSIFICATION TOOL

Final Report and User Guide
July 2022

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LIST OF ACRONYMS, ABBREVIATIONS, AND INITIALISMS

DEM	digital elevation model
DNN	deep neural network
DOT	department of transportation
GIS	geographic information system
k-NN	k-nearest neighbor
LiDAR	light detection and ranging
RF	random forest
SVM	support vector machine
TAC	technical advisory committee
TPI	topographic position index
TRI	terrain ruggedness index
TWI	topographic wetness index
UTM	Universal Transverse Mercator

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EXECUTIVE SUMMARY

The goal of this project was to assess the potential and develop protocols for the use of high-resolution light detection and ranging (LiDAR) and multispectral imagery to evaluate environmental characteristics of Iowa Department of Transportation (DOT) project areas, with particular attention to identifying federally protected wetland areas that would require mitigation if removed or significantly altered during a road construction project.

Specifically, the research team evaluated how LiDAR and multispectral imagery can support the assessment of design alternatives and whether the data could help DOT staff select alternatives earlier and with less required fieldwork.

During the investigation, which included four objectives, an automated ArcGIS Pro tool that leverages Python and ArcGIS routines to identify potential jurisdictional wetlands based on data derived from LiDAR digital elevation models was developed.

The procedure is a first-pass screening tool that will allow Iowa DOT wetland delineation staff to focus their attention on areas likely to be wetlands, rather than having to scrutinize an entire study area with the same level of attention. The underlying classification model currently over-identifies wetland areas, but much of the overidentification has to do with where exactly the boundaries are mapped.

The final toolboxes and routines required to run the wetland classifying procedures are packaged into shareable toolboxes and have been provided and demonstrated to Iowa DOT staff. Using the automated procedure is expected to save time in wetland delineation by allowing staff to prioritize high-probability areas for further study.

The appendix to this report contains the Wetland Classification Tool User Guide that was developed as part of this project.

INTRODUCTION

Background and Motivation

The goal of this project was to assess the potential and develop protocols for the use of high-resolution light detection and ranging (LiDAR) and multispectral imagery to evaluate environmental characteristics of Iowa Department of Transportation (DOT) project areas, with particular attention to identifying federally protected wetland areas that would require mitigation if removed or significantly altered during a road construction project. Specifically, the research team evaluated how LiDAR and multispectral imagery can support the assessment of design alternatives and whether the data could help DOT staff select alternatives earlier and with less required fieldwork.

Current Iowa DOT methods for environmental assessment require a significant amount of manual and on-site work, driving up the costs and time associated with these initial phases of projects. This research was aimed at realizing savings through use of high-resolution imagery to pre-screen areas for further study manually or on-site. Specifically, the researchers evaluated the following three types of imagery:

- Standard (near infrared) LiDAR elevation and terrain data
- Multispectral color (blue, green, red, and near infrared) reflectance data from a satellite platform
- Multispectral reflectance data from a very high resolution drone-based platform

Project Objectives

Objective 1: Assess the utility of high-resolution color imagery and other remotely sensed data sources for wetland delineation

Objective 2: Assess the utility of the above data sources for stream corridor mapping and vegetation and tree stand characterization

Objective 3: Based on the outcomes of Objective 1, develop an automated script to identify wetlands from the above data sources

Objective 4: Create a user guide for the application developed in Objective 3

INVESTIGATION

Objective 1: Assess the Utility of High-Resolution Color Imagery and Other Remotely Sensed Data Sources for Wetland Delineation

Methods

The Iowa DOT obtained very high resolution (centimeter-level) imagery from TerraPlane, LLC, which used a drone platform to capture imagery of a project site in the Millrace Flats Wildlife Management Area (MFWMA) located north of Wapello, Iowa. Due to weather and logistical conditions, the full site's imagery was collected across several days.

Upon evaluation by the research team, it was determined that it was difficult to merge or standardize images that were collected under different ambient conditions. This makes that data source difficult to use in the development of algorithms that assess the imagery, because the images are not directly comparable from one flight mission to the next.

In the next phase of the project, then, the team focused on using remotely sensed data from a satellite platform, WorldView-3, which is a commercial earth observation satellite from DigitalGlobe with a 1.24 meter multispectral resolution. Suitable imagery (cloud-free, full coverage) was obtained for the Wapello study site, and a variety of spectral indices were created from the image.

LiDAR imagery was obtained from https://acpfdata.gis.iastate.edu/ACPF/DEM/. This version of the Iowa statewide LiDAR project data is hydrologically enforced, meaning, where culverts and below-ground surface waterways allow water to flow underneath roads or other surfaces, the LiDAR digital elevation models are altered to represent the effective elevation of the waterway rather than the surface above. This is important for studies like this one that involve the flow of water across the landscape. Several terrain indices were then generated from this elevation data.

"Ground truth" data in the form of a shapefile with the boundaries of delineated wetlands at the Wapello site were provided by the Iowa DOT. These boundaries were determined through the traditional methods currently used by the Iowa DOT. The ground truth data were segmented into training and validation data, models were built using the calibration subset, and evaluation metrics were assessed by comparing each model's output to the validation data.

Principal component analysis (PCA) was used to determine the most influential of the derived terrain and spectral indices. These indices were then used in four different machine learning techniques to create models to generate wetland delineation from the terrain and spectral indices: deep neural network (DNN), support vector machine (SVM), k-nearest neighbor (k-NN), and random forest (RF) classification.

A graphical overview of the model development procedure is shown in Figure 1.

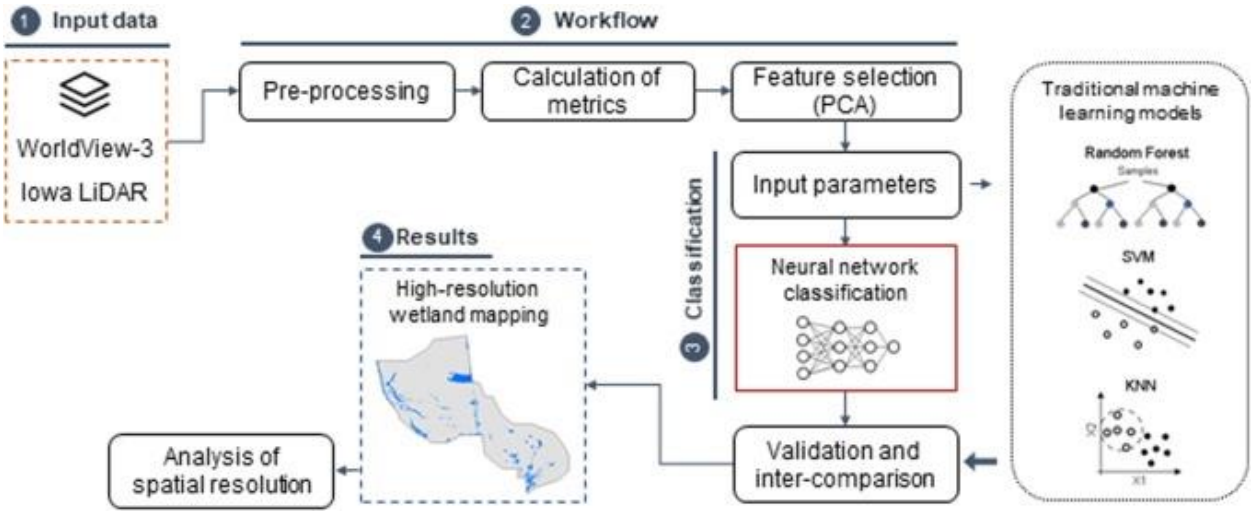

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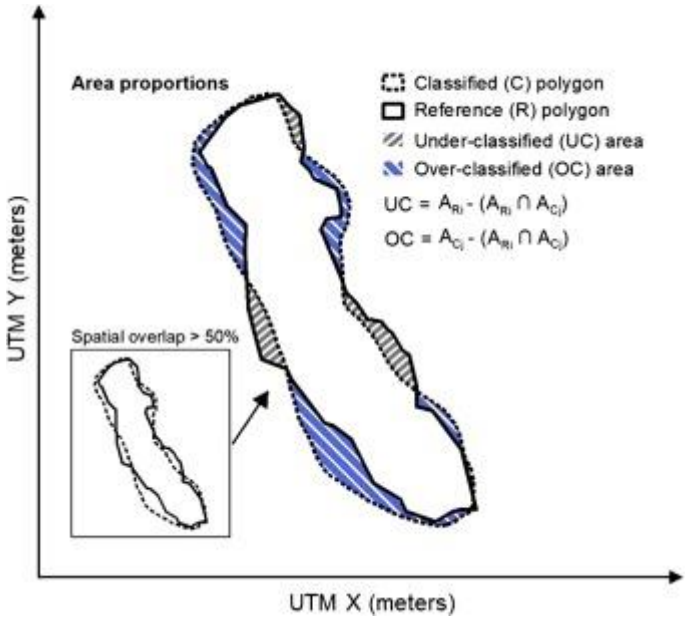
Figure 1. Framework for wetland mapping

In this phase of the research, wetland identification focused on water-holding wetlands, either those with some open water surface or those with algal and vegetative coverage over standing water. It is important to note that this is only a subset of all wetlands because the ephemeral wetlands do not hold water at all times.

Results

All three methods were successful at identifying wetlands, with the DNN and RF approaches having a slightly higher accuracy rate than the other two (SVM and k-NN). Most discrepancies in wetland classification were in identifying the precise edges of the wetland area. An example of this type of edge misclassification is shown in Figure 2, while Figure 3 illustrates the misclassification rates of the four different methods.



UTM = Universal Transverse Mercator, a coordinate system that divides the world into 60 north-south zones, each 6 degrees of longitude wide. UTM zones are numbered consecutively beginning with Zone 1, which includes the westernmost point of Alaska, and progress eastward to Zone 19, which includes Maine.

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Figure 2. Boundary mapping errors

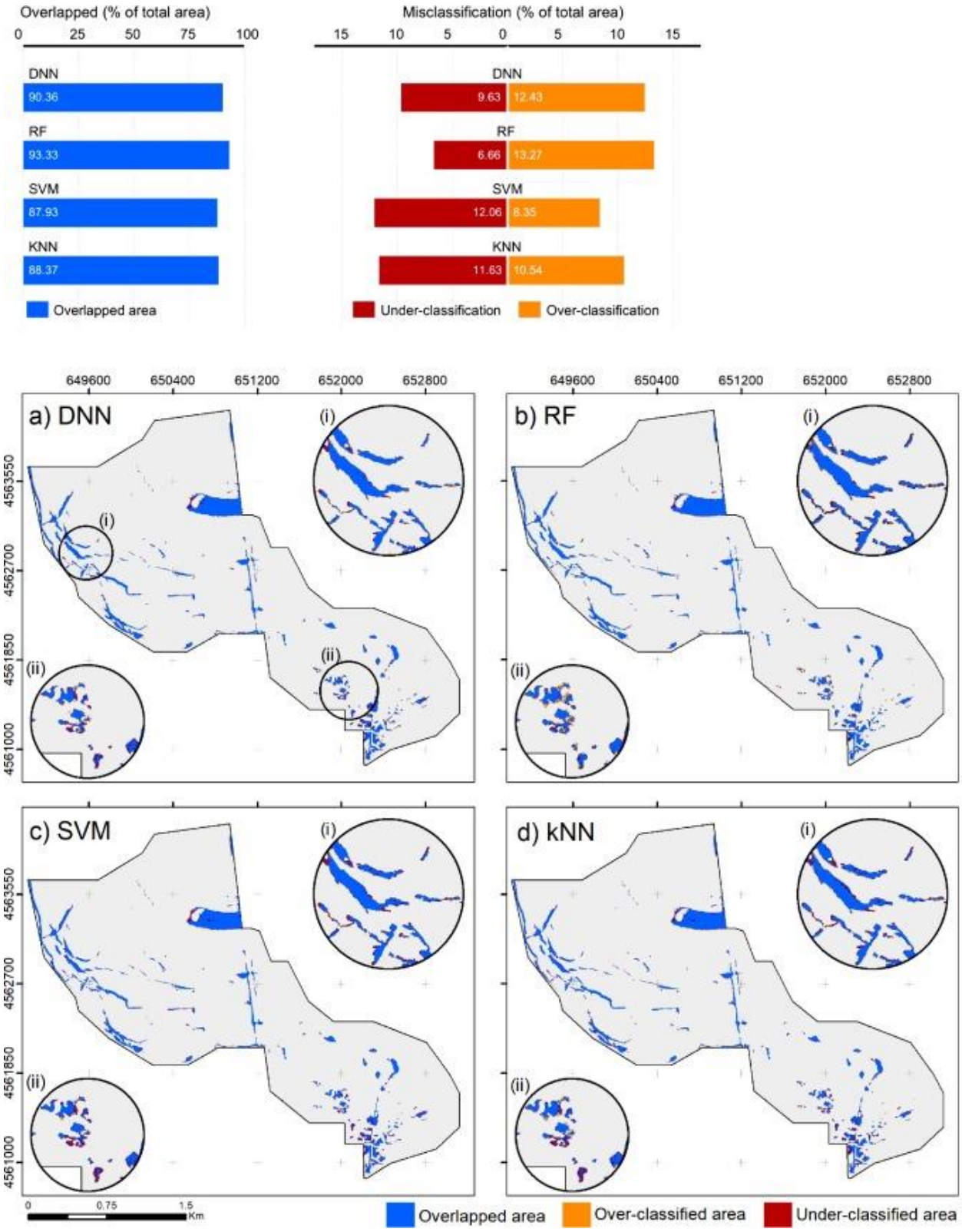

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Figure 3.Classification results of (a) deep neural network, (b) random forest, (c) support vector machine, and (d) k-nearest neighbor models

The bar graphs present the overlapped, under- and over-classified areas (%) for each method. Note that the sum of overlapped and under-classified areas is the total area of reference wetland mapping.

Objective 2: Assess the Utility of the Above Data Sources for Stream Corridor Mapping and Vegetation and Tree Stand Characterization

Methods

Unlike the wetland investigation, the researchers did not have complete ground-truth data on stream corridors, vegetation coverage, and tree stand characteristics. For this reason, evaluation of the utility of the drone-based imagery data for these purposes was only qualitative. The team informally reviewed published literature on this subject and visually reviewed the imagery to judge the utility for mapping stream corridors, vegetation, and tree stands.

Results

In the team's assessment, because the drone-based imagery is highly variable from one data collection to the next, until such time as better normalizing procedures are available, these data are more useful in a qualitative way, augmenting standard data sources where areas of confusion exist. The drone data are highly detailed, but this can also complicate analysis because the computational burden of processing very high-resolution data is non-trivial.

Regarding stream corridor assessment, the utility of imagery data is highly variable, depending on the vegetation density along the streambanks and the time of year of the imagery (e.g., leaf-on versus leaf-off conditions). For stream corridor mapping, leaf-off conditions are preferable. However, for tree stand characteristics, leaf-on conditions are valuable. Thus, the objectives are somewhat in conflict with one another in terms of what season of imagery provides the most value. This drives up the potential cost and time lag if each project requires multiple dates of imagery, each of which requires advanced mission planning and suitable illumination conditions.

Nonetheless, this data source remains a potential value-add should technology advance to the point that imagery can be standardized from one collection date to the next.

Objective 3: Develop an Automated Script to Execute the Classification and Wetland Probability Procedure

Methods

In Objective 1, the three machine learning techniques generated similar output with similar accuracy compared to the ground truth data at the Wapello site. For the purpose of building an automated procedure, the researchers selected the RF approach due to the straightforward

interpretation of how variables use the algorithm, and because it is easy to bundle into an ArcGIS-based toolbox.

Before moving forward with development and packaging of the final classification tool, the team did further testing of the RF model by expanding the evaluation to an additional three sites in addition to the Wapello site used in Objective 1. The final four sites used in model building and testing are shown in Figure 4, with site extents data given in Table 1.

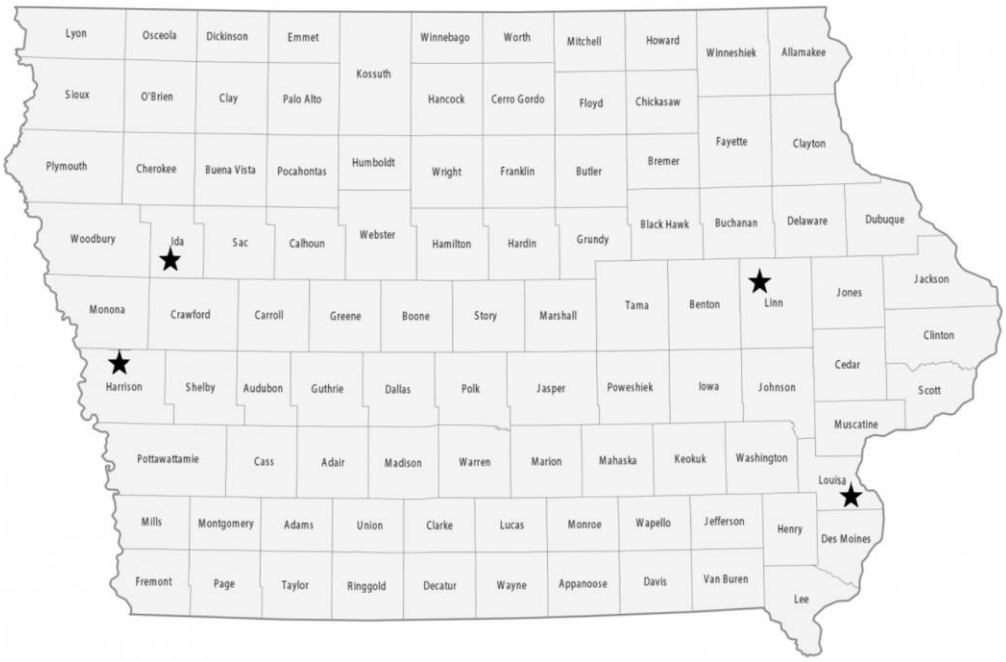


Figure 4. Wetland site locations used in development and testing

Table 1. Site and wetland area for each testing and development location

County Site	Total Study Area (acres)	Total Wetland Area (acres)	% Wetland Coverage
Louisa	1,383.18	618.77	44.41%
Ida	4,887.78	1.24	0.025%
Hamilton	4,848.22	441.78	9.11%
Linn	5,117.51	4.38	0.086%

To replicate the RF-model build of Objective 1, including the new sites, additional spectral imagery was required. While investigating the availability of images from the WorldView-3 archives, the team determined that suitable imagery was not readily available for some locations. Past images sometimes included too much cloud cover or were taken during different seasons when the ground cover was not comparable to other images, among other reasons. Because of the nuances of obtaining just the right imagery, the researchers instead explored adding additional terrain-based metrics and doing more tuning of the RF model using only the LiDAR

digital elevation model. This data source has the advantage of being consistently available at no cost for the entire state, so it is a stable and readily available data source.

Additionally, in this phase of the research, the team added all "jurisdictional" wetland types as model outputs and not just those with long-term standing water. This would therefore include classifying any wetland covered under federal guidelines requiring preservation or mitigation.

Identification of important terrain indices was repeated using the importance index in Python's RF tool and the minimum depth approach in R's RF tool. Indices that are noisy or computationally expensive and that did not add to the accuracy of the final model were disregarded.

The final terrain indices were used in the development of the RF model using the scikit-learn package in the Python programming and automation environment. Model development also included tuning the parameters and settings of the model development. The final RF model was then packaged as an executable file and exported, allowing it to be run as an automated procedure within a geographic information system (GIS) environment. Specific details of the RF parameter settings are included in an MS thesis (Gerlitz 2022).

Finally, an ArcGIS Pro toolbox was created that automates the full procedure, from digital elevation model (DEM) terrain index extraction through RF model evaluation. The toolbox returns a shapefile with the estimated likelihood of wetland presence at a dense set of randomly selected locations throughout the user-identified study area. Use of the dense network of random points, rather than all of the pixels in the original DEM data, was determined to provide suitable guidance on wetland locations while minimizing the computational time to run.

Because the Iowa DOT will be using this as a first-pass classifier to identify high-priority areas for further investigation through traditional wetland mapping methods, determination of contiguous polygons and high-resolution boundaries was not necessary.

Evaluation of final model accuracy was based on how well the model's output matched the validation data, which was, as in Objective 1, a subset of the ground truth data of delineated wetlands at the study sites provided by the Iowa DOT as determined through their standard wetland determination methods.

Results

Five indices were used in the final model. They were topographic position index (TPI), topographic wetness index (TWI), terrain ruggedness index (TRI), slope, and fill. These were identified as the best indices to improve accuracy without causing the model to be computationally expensive. Some overlap exists in the information content of each of these metrics, but they each suggest different nuances of what makes a location likely to be a wetland.

TPI is a measure of the relative elevation of a particular location compared to its surroundings. This index has a negative value in depressional areas and positive values in hilltop areas. Because this index is sensitive to the scale of the neighborhood (how large of a region around the point of calculation should be considered as its surroundings), the researchers evaluated a range of neighborhood scales and shapes and determined a roughly 90-meter (295-ft) diameter circle was most suitable.

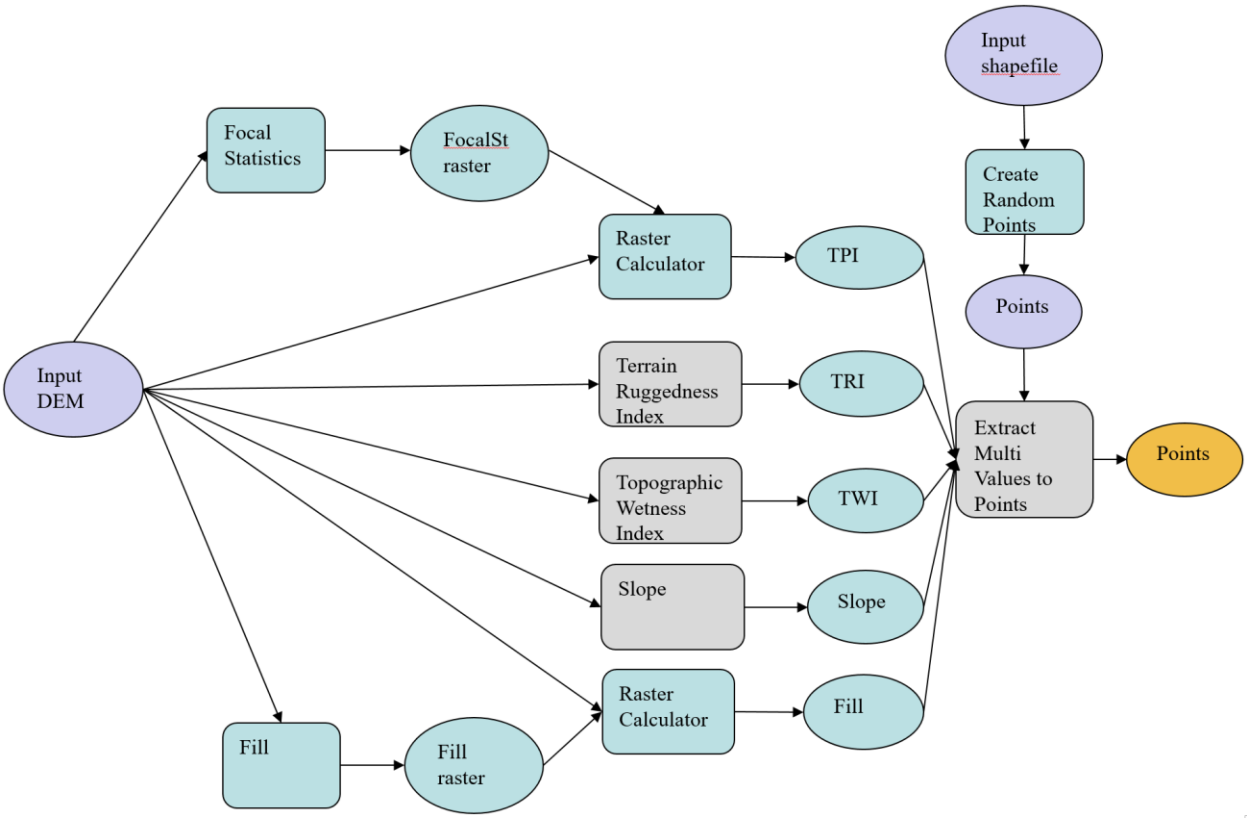
TWI uses slope and drainage area for a particular location to indicate the extent to which significant amounts of water would tend to pool at a location. A larger drainage area indicates more water likely to flow through the location, and a shallow slope indicates that water will be slow-moving.

TRI is a measure of landscape heterogeneity. A smaller TRI indicates a more homogeneous or level landscape, and a higher TRI indicates rougher landscapes.

Terrain slope affects the speed at which water will shed from an area. Depressional areas like wetlands are features with flat to shallow slopes.

Fill is a common GIS tool to identify closed depressions in the landscape. The researchers used the Fill function in ArcGIS Pro, which "fills in" closed depressions in the DEM, often for the later mapping purpose of evaluating water flow across the surface (as the presence of closed depressions will interfere with this routing). The research team then subtracted the filled DEM from the original DEM, which generates a data layer that is only those areas identified as closed depressions.

Flowcharts for the two-stage procedures developed that comprise the final tool are shown in Figure 5.



FocalSt = Focal Statistics, TPI = topographic position index, TRI = terrain ruggedness index, TWI = topographic wetness index

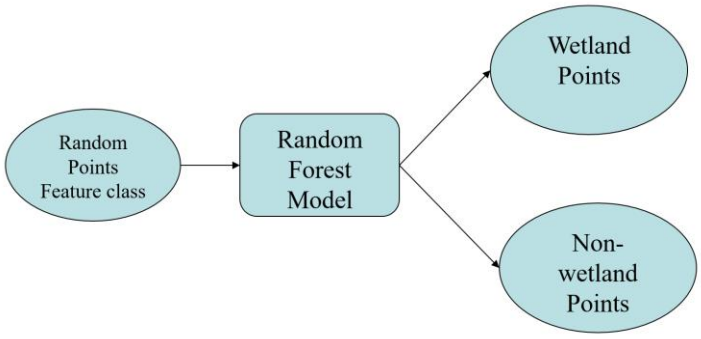


Figure 5. Flowchart of Index Extraction toolbox (top) and Random Forest toolbox (bottom)

Overall accuracy of the final RF model was roughly 75% when using a threshold where a probability of 60% or greater in wetland mapping was classified as a wetland. The final model had a tendency to over-identify wetlands (suggesting a wetland one where one does not exist). This type of error is preferable to under-identification of wetlands, because, as a first-pass screener, this tool should be more expansive rather than more limited. Areas that are overclassified as wetlands can be discarded in further detailed study, but areas that are never identified at all could be missed in further study.

A confusion matrix, which indicates the number of points correctly and incorrectly classified in the validation data compared to the ground truth data, is shown in Figure 6.

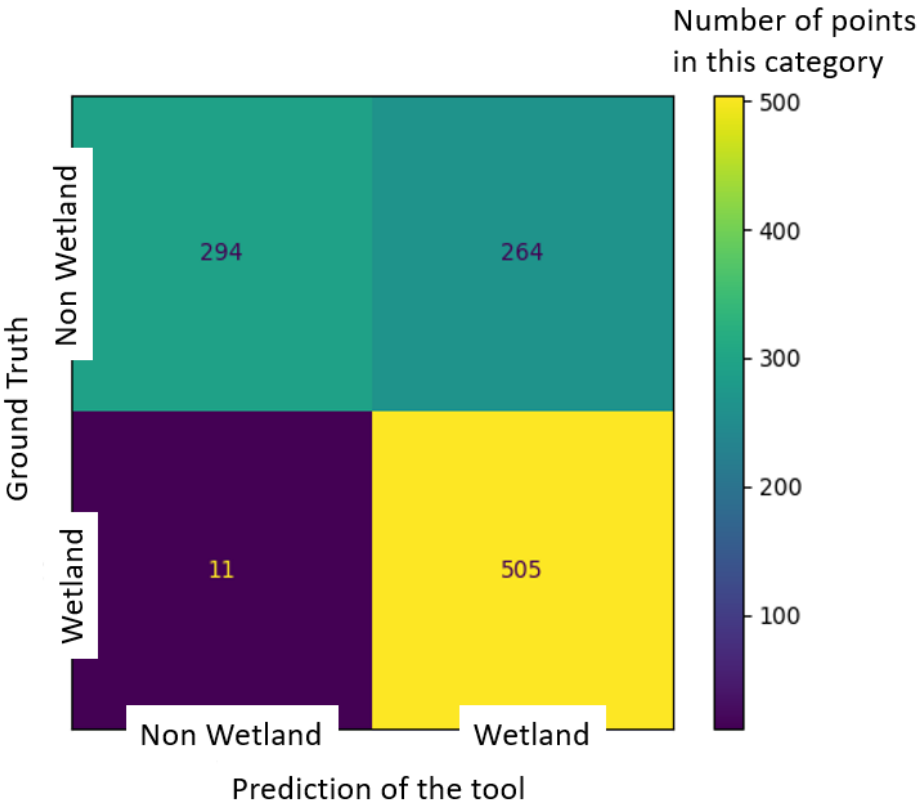


Figure 6. Confusion matrix comparing tool prediction to ground truth

The model correctly classified 97.8% of wetlands but included 4% of non-wetland areas as well. Many of the overclassified points were, as in Objective 1, located around the boundaries of the ground truth wetlands. Two examples of the results of the wetland classification are shown in Figure 7.

Figure 7. Wetland point classification by the tool (dots) compared with the Iowa DOT ground truth data (polygons) for two delineated wetlands, both from the Linn County site

Note in the image on the right, yellow dots are areas with lower wetland probability, illustrating the model's lower confidence in identifying wetland boundaries.

Objective 4: Create a User Guide

Once the final tool was developed, the procedure was executed several times from start to finish, and the necessary steps were documented with guidance and additional instruction. Once a draft user guide was prepared, the researchers met with the wetland delineation expert on the technical advisory committee (TAC) and went through the procedure in real time together. This helped to identify where the instructions were incomplete or confusing, and the draft user guide was updated based on that feedback.

The user guide, which is included in the appendix, also provides full instructions for updating the model. This is an important capability given this tool was built using only four validation sites. As future wetland delineation projects conclude, their data can be used to improve the model over time.

CONCLUSIONS

An automated ArcGIS Pro tool that leverages Python and ArcGIS routines to identify potential jurisdictional wetlands based on data derived from LiDAR digital elevation models was developed. The procedure is a first-pass screening tool that will allow Iowa DOT wetland delineation staff to focus their attention on areas likely to be wetlands, rather than having to scrutinize an entire study area with the same level of attention. The underlying classification model currently over-identifies wetland areas, but much of the overidentification has to do with where exactly the boundaries are mapped.

Implementation Readiness

The final toolboxes and routines required to run the wetland classifying procedures are packaged into shareable toolboxes and have been provided and demonstrated to Iowa DOT staff.

Benefits

Using the automated procedure is expected to save time in wetland delineation by allowing staff to prioritize high-probability areas for further study.

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Gerlitz, J. 2022. *Wetland Mapping Using LiDAR and Random Forest Machine Learning*. MS thesis. Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. https://dr.lib.iastate.edu/search?page=1&query=Gerlitz&spc.page=1&scope=&f.author=Gerlitz,%20J.,equals.

Martins, V. S., A. Kaleita, B. Gelder, G. W. Nagel, and D. A. Maciel. 2020. Deep Neural Network for Complex Wetland Mapping Using High-Resolution WorldView-3 and Airborne LiDAR Data. *International Journal of Applied Earth Observation and Geoinformation*, Vol. 93, No. 102215.

APPENDIX: WETLAND CLASSIFICATION TOOL USER GUIDE

This appendix provides the Wetland Classification Tool User Guide. It explains how to implement the Extract Indices Toolbox. Complete development documentation for the tool is available in the student's MS thesis (Gerlitz 2022),

ArcGIS Pro Toolboxes

- ArcHydro
- Spatial Analysis
- Image Analysis
- 3D
- Scikit-Learn*
- Joblib*

* These need to be manually installed in a cloned environment. Directions for how to do this are here: https://pro.arcgis.com/en/pro-app/2.8/arcpy/get-started/work-with-python-environments.htm and https://pro.arcgis.com/en/pro-app/2.8/arcpy/get-started/work-with-python-packages.htm.

Required Inputs

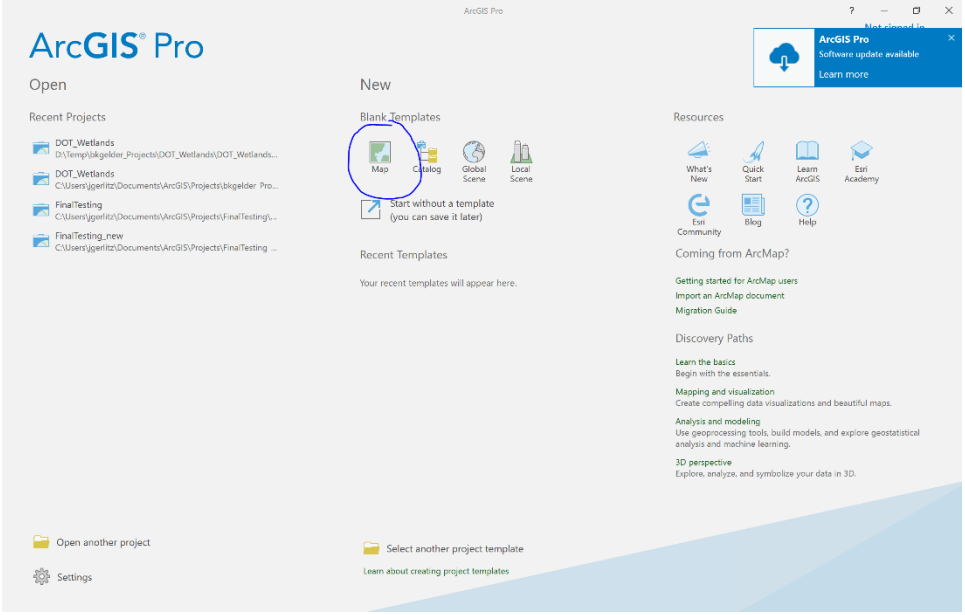
- Digital Elevation Model for area of interest
- Wetland area of interest shapefile
- .joblib file provided

Pre-Installation Instructions

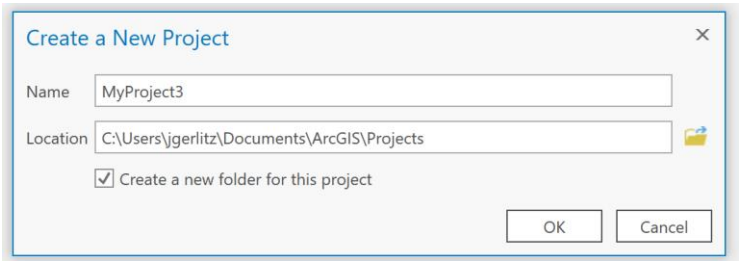
Creating a Project

1. Open ArcGIS Pro.

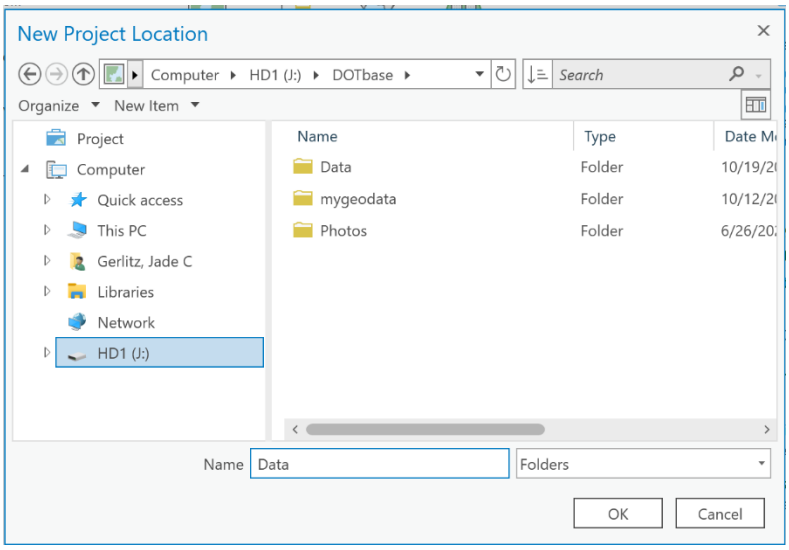
2. Click on Map under Blank Templates.



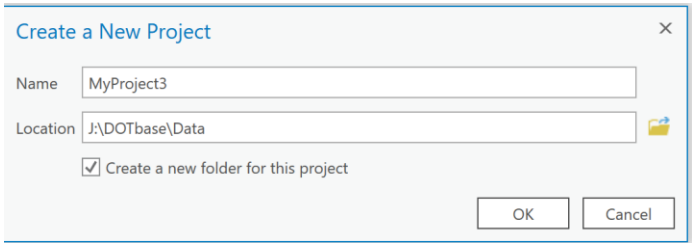
3. The Create a New Project box pops up. If the default folder is where the new project should be created, replace the name with the title of this new project; otherwise, click on the folder icon to explore other locations.



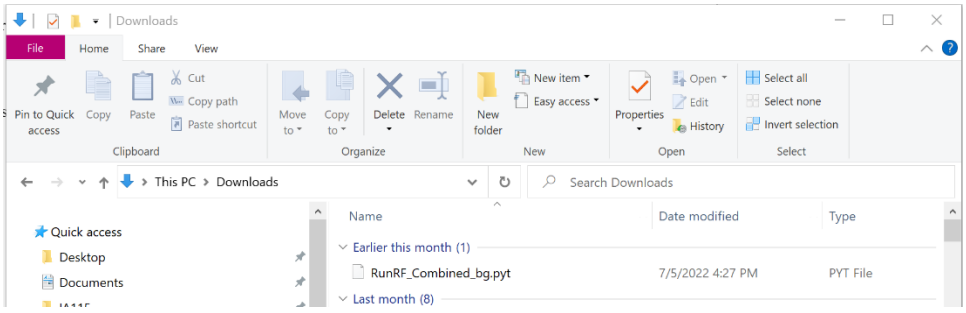
4. The New Project Location box pops up. You can navigate to your desired folder location.



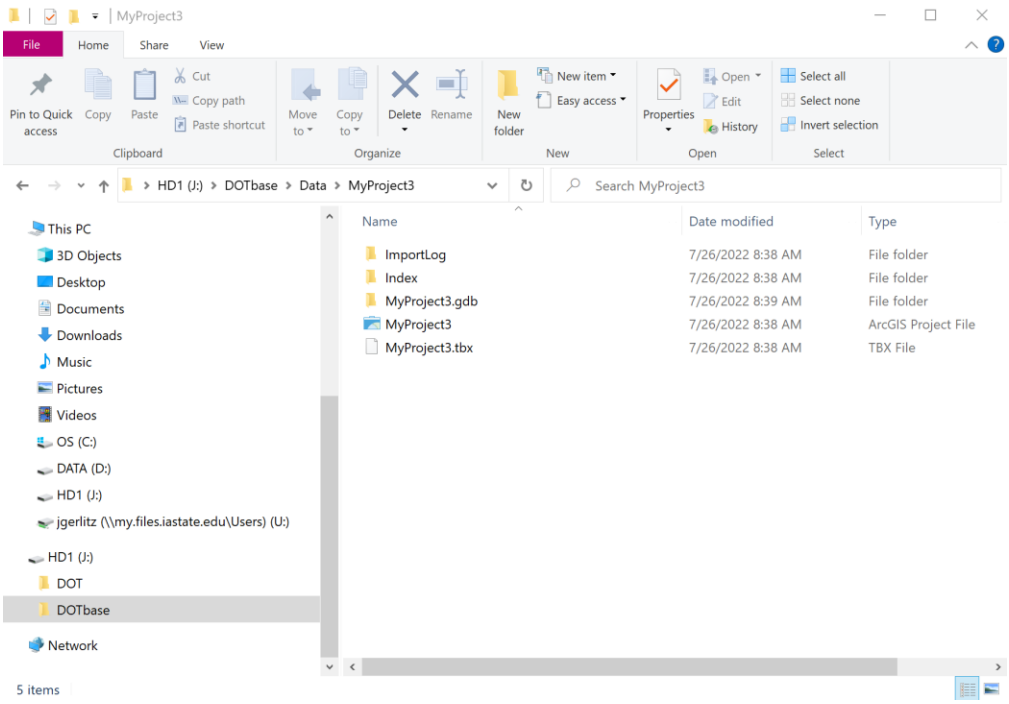
5. Click on the folder and click on OK. If you rename your project, name it something other than the folder name; otherwise, it will not create a project. Make sure the Create a new folder for this project box is checked. A new project will auto-populate on the screen.



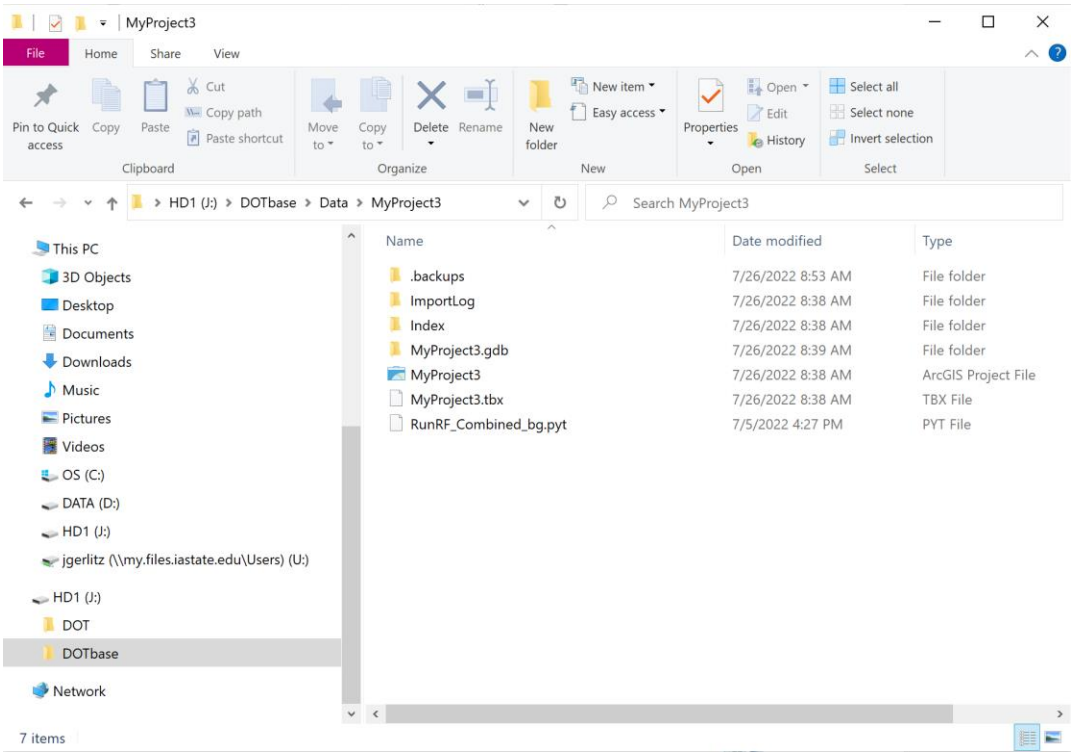
6. Next, locate and cut or copy your downloaded ArcGIS toolbox. It should be in your Downloads folder.



7. Open your project folder.

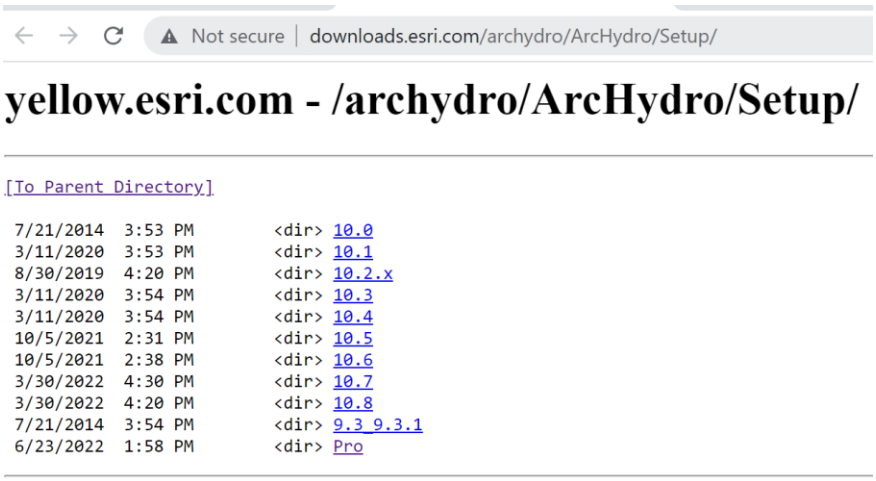


8. Paste the downloaded file directly into your folder.

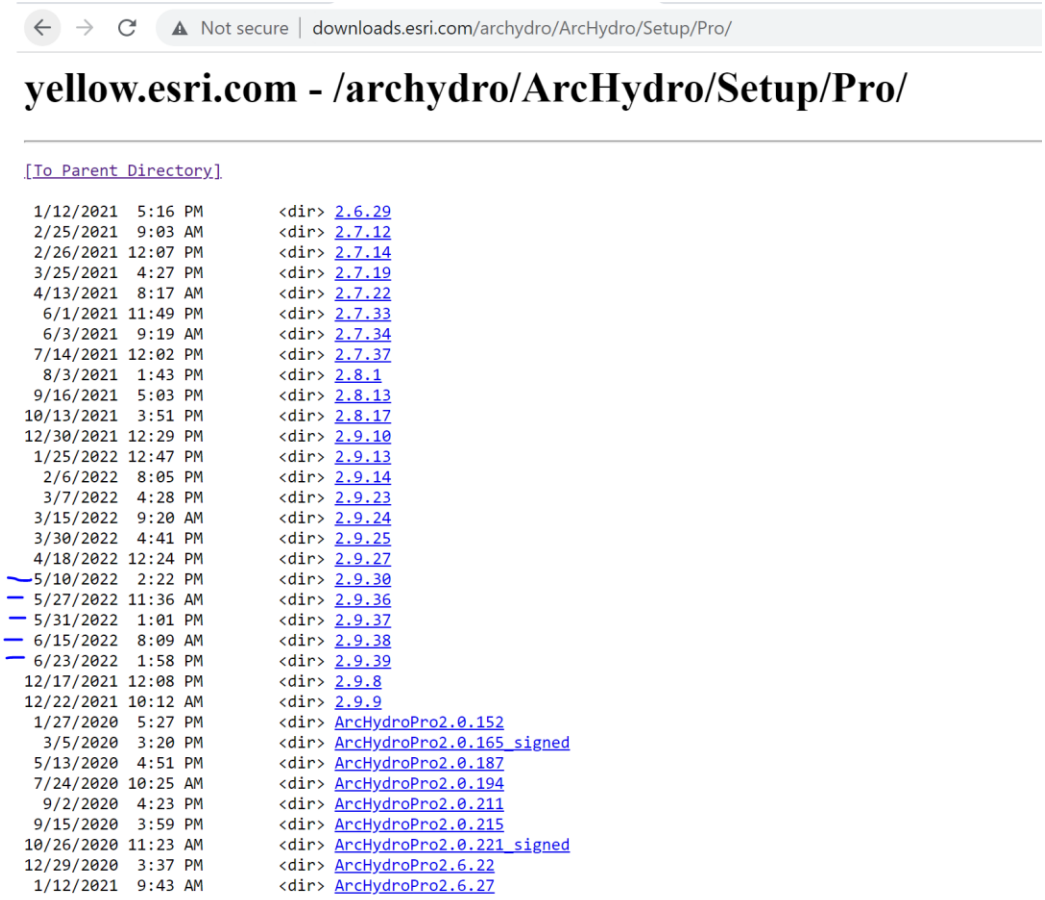


Download ArcHydro from http://downloads.esri.com/archydro/ArcHydro/Setup/

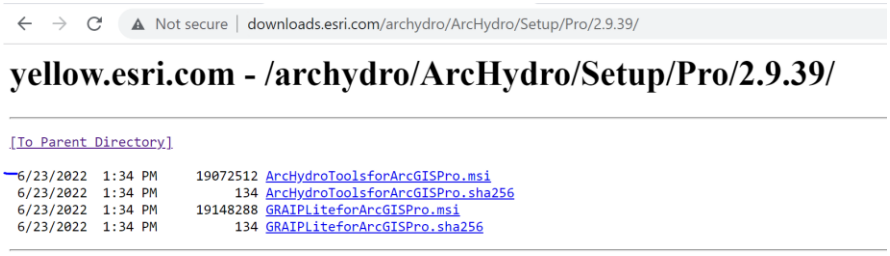
1. Click on Pro for ArcGIS Pro installation.



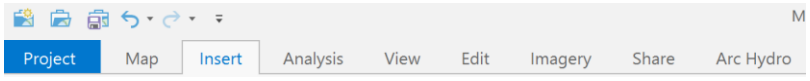
2. If your ArcGIS Pro is up to date (Version 2.9), use any of the versions 2.9.3 or above. If your ArcGIS Pro is not up to date, choose a version of ArcHydro that most corresponds with your ArcGIS Pro version.



3. Choose the top option for download. The download should automatically begin and install on your machine automatically.



4. ArcHydro can be found on the top ribbon in your project. Open the project file to verify.

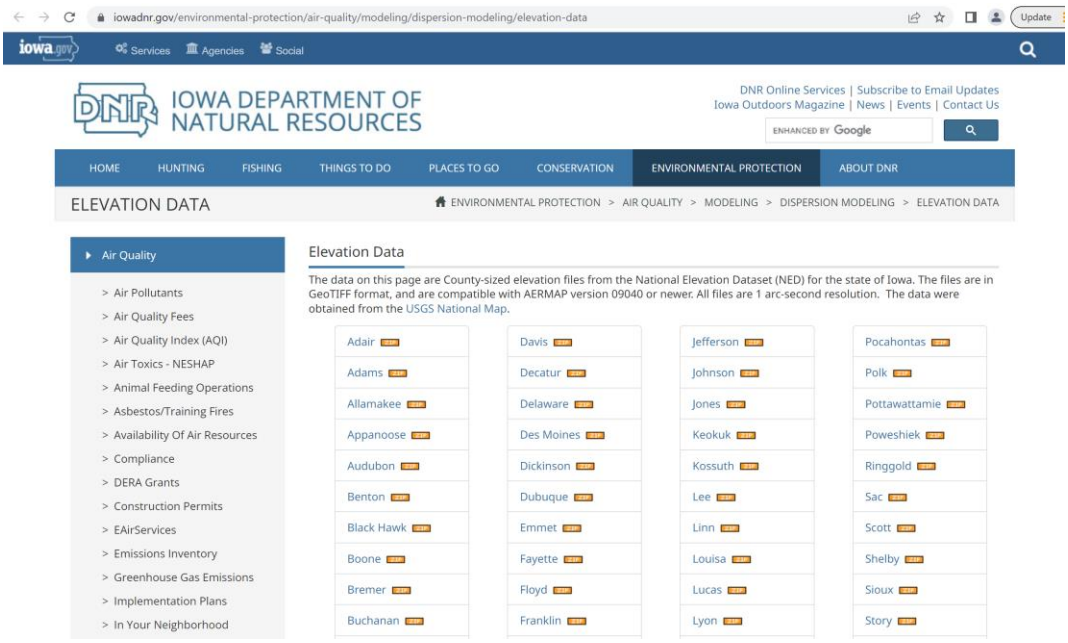


Download Digital Elevation Model (DEM) for the Study Area

Note: There are multiple locations where DEMs can be downloaded. Two of those locations are discussed here.

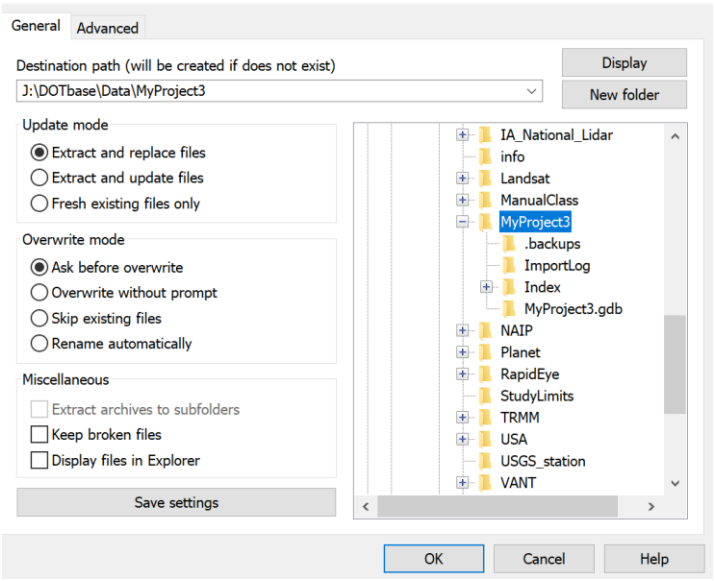
Option 1

1. Go to https://www.iowadnr.gov/environmental-protection/air-quality/modeling/dispersion-modeling/elevation-data and click on the county where your area of interest is located.

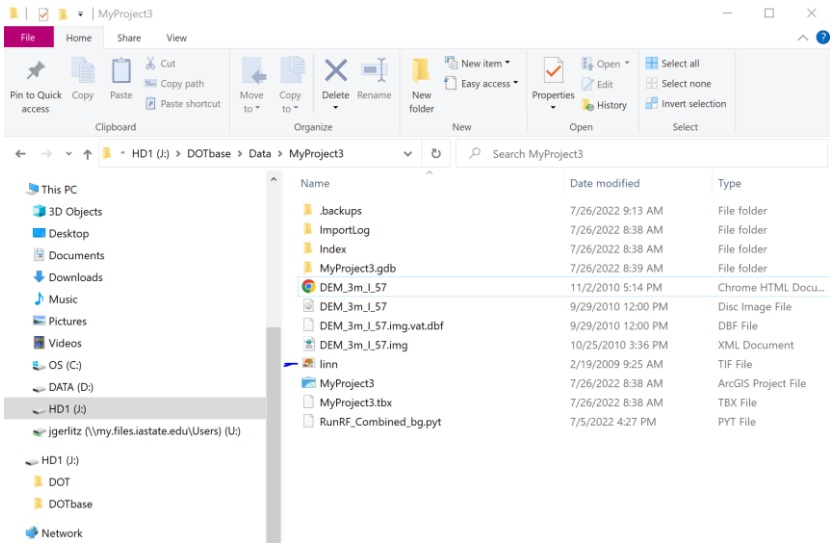


2. A .zip file will begin to download once the county has been selected.

3. Extract to your desired folder location. (This is how it looks using WinRAR). The best place to extract the files to is your project folder.

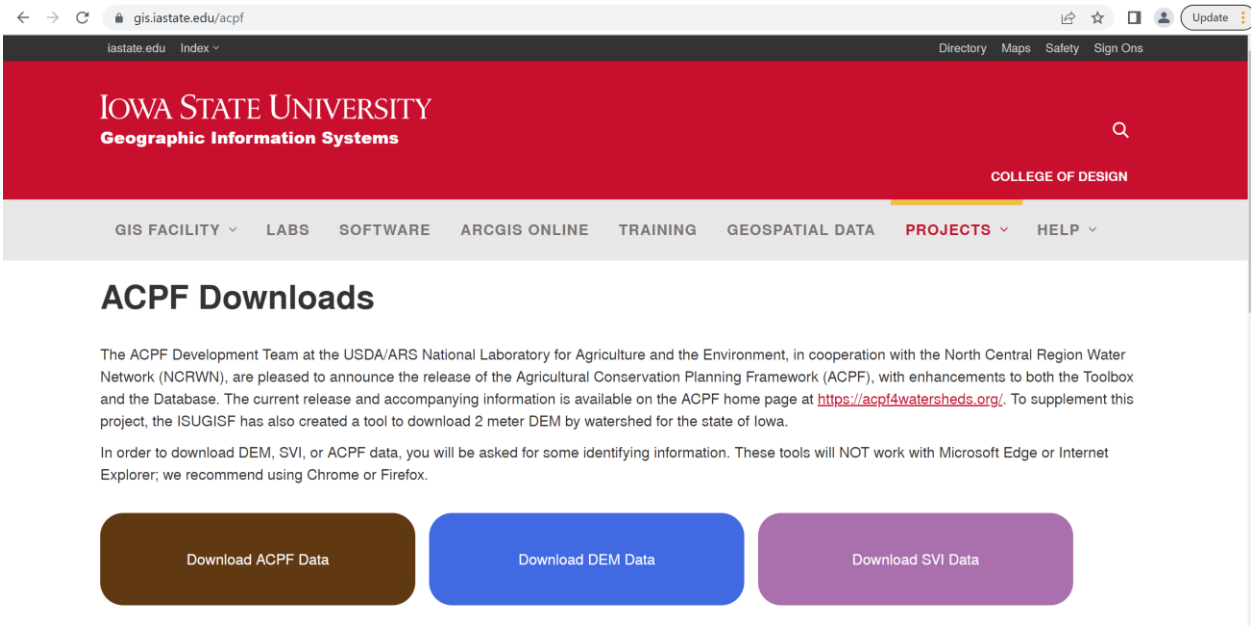


4. Verify it is in the correct location.

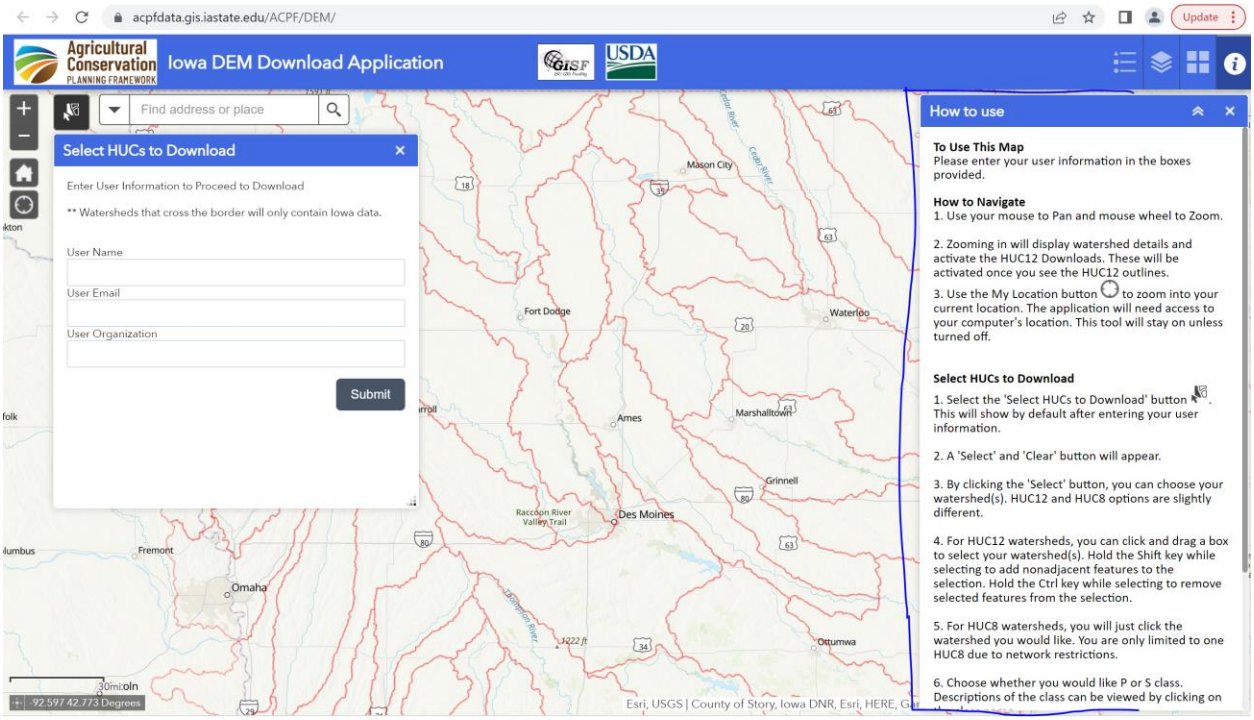


Option 2

1. Go to https://www.gis.iastate.edu/acpf and click on Download DEM Data.

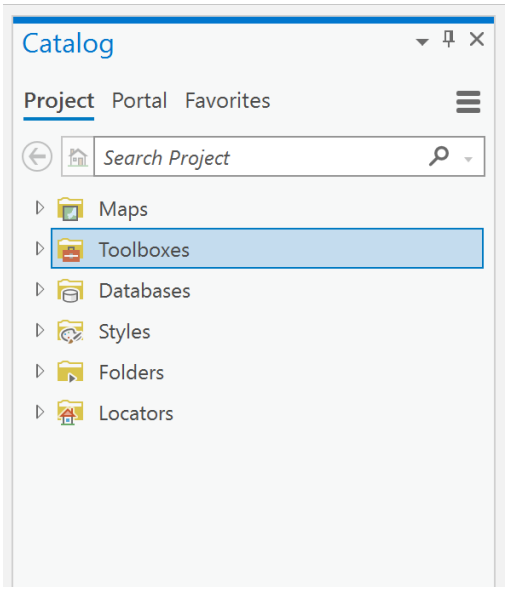


2. Follow the directions on the right side of the screen to download the DEM data provided.

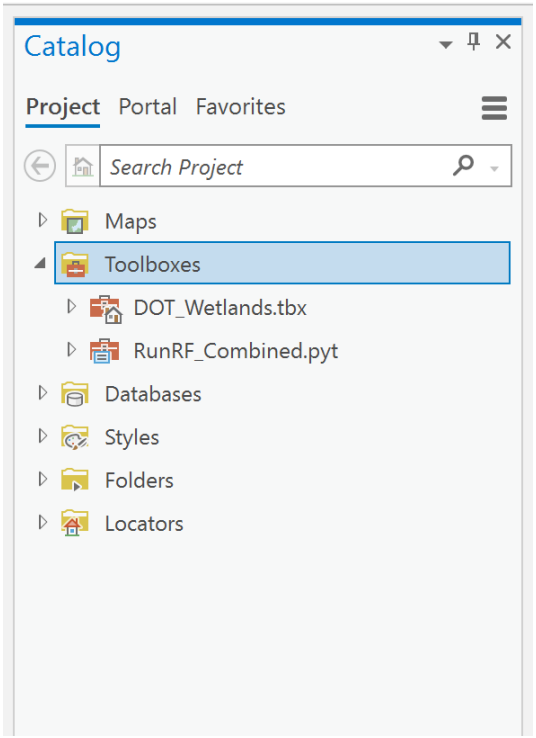


Geoprocessing Instructions

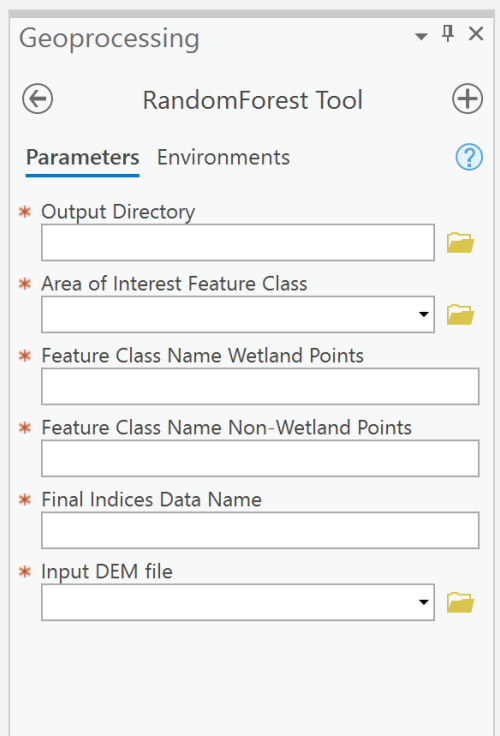
1. Navigate to the Catalog tab and find the Toolboxes drop down.



2. When Creating a Project in the previous Pre-Installation Instructions, you should have copied and pasted the provided toolbox into your project folder. When you click the Toolbox drop down, you should be able to see it there.



3. Double click to open. It should appear as below. Each input is required for the tool to work.



- The first input labeled Output Directory is a file folder where you would like the final output to exist.

- The Area of Interest Feature Class is a shapefile created by the user containing the area that is to be explored for wetland identification.

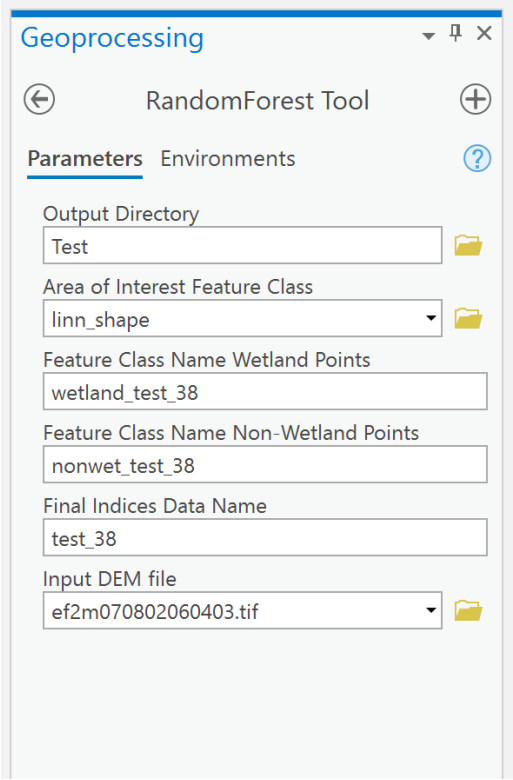
- Feature Class Name Wetland Points is the final output name for the wetland points identified.

- Feature Class Name Non-Wetland Points is the final output name for the non-wetland points identified.

- Final Indices Data Name is the final output name for the feature class of points with the indices that will be extracted for wetland identification.

- Input DEM file is the DEM covering the area of interest. This was downloaded above under Download Digital Elevation Model (DEM) for the Study Area.

4. Once everything is input, it should look like the following.



Note: Each name needs to be unique for each run. The tool will not run if it identifies a non-unique feature class name.

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