New York City Department of Environmental Protection
Bureau of Water Supply

Pilot Investigation: LiDAR Applications for Wetland Mapping and Connectivity Assessment

July 2015

Prepared in accordance with Section 4.8 of the NYSDOH Revised 2007 Filtration Avoidance Determination

NYC Environmental Protection

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Executive Summary

The New York City Department of Environmental Protection (DEP) and the U.S. Fish and Wildlife Service (USFWS) have partnered to produce and update National Wetlands Inventory Maps (NWI) for the watershed since the mid-1990s. NWI maps are traditionally produced through visual interpretation of aerial photography and various ancillary data sources.

Advances in remote sensing technology have provided DEP with high resolution orthophotography and Light Detection and Ranging (LiDAR) derived topographic datasets for use watershed-wide, when coupled with advanced automated mapping protocols, may increase the accuracy and completeness of wetland maps. This pilot study endeavored to assess the applicability of these high resolution databases towards improved wetland mapping though automated Object Based Image Analysis (OBIA).

An OBIA protocol that incorporated a LiDAR-derived topographic index and orthophotography among other data was developed for the watershed. The draft model output was manually edited in 15 pilot areas to produce an NWI-compliant product. This coverage more than doubled the extent of vegetated wetlands mapped in the West of Hudson watershed pilot areas, and increased those mapped in the East of Hudson pilot areas by 74%. Review of the database to date indicates that detection rates increased for wetlands, such as evergreen wetland forests, which lack hydrologic signatures on aerial photography and therefore were missed through visual interpretation methods alone.

The OBIA protocol was designed to over map wetlands, as errors of commission (false positives) are easier to correct than errors of omission (false negatives). While some errors of commission may remain in the final database, it is undoubtedly more complete than current NWI maps as the methodology combined both automated mapping and manual review pursuant to NWI standards. While DEP has assessed the pilot maps against field data collected to date, additional quality assurance review is underway to assess the accuracy of the pilot mapping effort.

This pilot study also demonstrated the utility of LiDAR-derived local resolution (1:1,000) stream data towards improving the assessment of wetland connectivity in the watershed. Using the local resolution National Hydrography Database (NHD) revealed that just 10% of NWI wetlands in the pilot area lack mapped surface water connections to the stream network, as opposed to the 35% predicted to lack such connections when using lower resolution stream databases. After evaluating all wetlands in the pilot areas using high resolution photography and LiDAR-derived topography, an additional 23.5 miles of streams

were digitized and amended to the local resolution NHD dataset, which further reduced the extent of unconnected NWI wetlands to just 2% of the palustrine wetland acreage in the pilot area. This is a significant finding, as connectivity to surface waters is linked to both wetland function and federal jurisdictional status.

1.0 Introduction

Through mapping and monitoring, DEP provides data on the status, trends, distribution, characteristics and functions of wetlands in the watershed. This information is critical to the implementation of regulatory, engineering, land acquisition, agricultural, stream, and forest management programs.

Previously, DEP has partnered with the USFWS to produce NWI maps for the watershed, which were most recently updated in 2005 through standard interpretation of 2003 and 2004 aerial photography. In 2009, DEP collected LiDAR data and high resolution orthoimagery for the watershed. These data improved the resolution, accuracy, and completeness of watershed hydrography, topography, and land use coverages. Cumulatively, these data may provide a richer source of wetland indicators than standard NWI photointerpretation methods alone.

Pursuant to the 2014 Filtration Avoidance Determination (FAD), DEP developed this pilot study to determine whether the 2009 orthoimagery and LiDAR derived products could improve the accuracy and completeness of wetland mapping in the watershed through automated Object Based Image Analysis (OBIA). A second objective of this pilot study was to determine whether wetland connectivity to the stream network could be more accurately assessed with the 2013 local resolution National Hydrography Data (NHD) as compared to previous lower resolution stream datasets. Improvements in wetlands mapping would benefit the numerous watershed protection programs that rely on this information. Further, the enhanced resolution of wetland connectivity would improve the ability to assess wetland function and federal jurisdictional status.

This project was conducted through a partnership with the Regional Application Center (RACNE) for the Northeast. The first objective of the pilot study was to compile and assess LiDAR and thematic GIS data sources to identify data quality issues that could negatively impact the development of automated wetland mapping protocols. Next, an automated OBIA mapping protocol was developed, implemented, and its output was manually edited to produce an NWI-compliant wetlands layer in selected pilot areas.

The connectivity assessment was applied to both current NWI wetlands and those wetlands newly mapped through OBIA. First, wetland polygons unconnected to the 2013 local resolution NHD stream network were identified. Next, the potential connectivity of these polygons was assessed, and any stream connections not captured by the local resolution NHD layer were digitized. The extent of wetlands connected to previously available lower resolution stream data (medium resolution NHD, 1:100,000) was compared to those connected to the 2013 LiDAR-derived local resolution NHD stream data as amended through this pilot.

2.0 Wetland Mapping

2.1 LiDAR data assessment

LiDAR data were delivered in 2,541 750 m^2 tiles for the East of Hudson Watershed and 8,910 tiles for West of Hudson. These data were evaluated for the entire East and West of Hudson collection areas to determine whether there is significant spatial variation in data quality that could negatively impact the project outcome. To this end, point density by LiDAR tile and by land cover type, void areas, number of returns, and intensity values were evaluated.

Point density refers to the number of laser returns detected by the sensor within a given tile. The overall point density by tile analysis showed a pattern of higher density along certain flight lines that is likely due to differences in sensor settings for different flights (Figure 1). After removing all but ground only points, the average point density appeared much more consistent and hence without major concern (Figure 2). The point density by land cover type analysis showed a clear pattern of fewer returns in water and mapped wetland areas (correlating generally with existing NWI). This is expected as the laser signal is absorbed by water. There was also a clear pattern of lower density ground points in conifer dominated land cover, which was also expected. The point density analysis confirmed the validity of the LiDAR data and did not indicate any major concerns over the utility of the data for use in the project.

Void area analysis is very similar to point density analysis (very low point density can mean the existence of voids), and can help in evaluating why certain areas may have few returns. While there some voids in the ground point data that are greater than one acre, there was no systemic pattern or spatial distribution that would significantly affect the wetlands modeling process (Figure 3). While it is certainly noteworthy to locate any voids that may be associated with a specific wetland or other ground feature, the existence of the voids in this instance is considered very normal and would not materially impact the wetlands mapping process.

The number of returns is a measure of how many discrete signals return to the sensor for each outgoing laser signal. Multiple returns are often indicative of vegetation cover, and multiple returns are expected in nearly all tiles except perhaps those that occur over large water bodies. Lack of multiple returns in the data can also be an indicator of sensor malfunction. The vast majority of tiles have four returns. Only one tile East of Hudson has fewer than four returns. There are a few areas West of Hudson that do not exhibit the expected number of returns in the data, but those are not indicative of either a systemic sensor condition or landscape characteristic that would materially affect the wetlands mapping process (Figure 4).

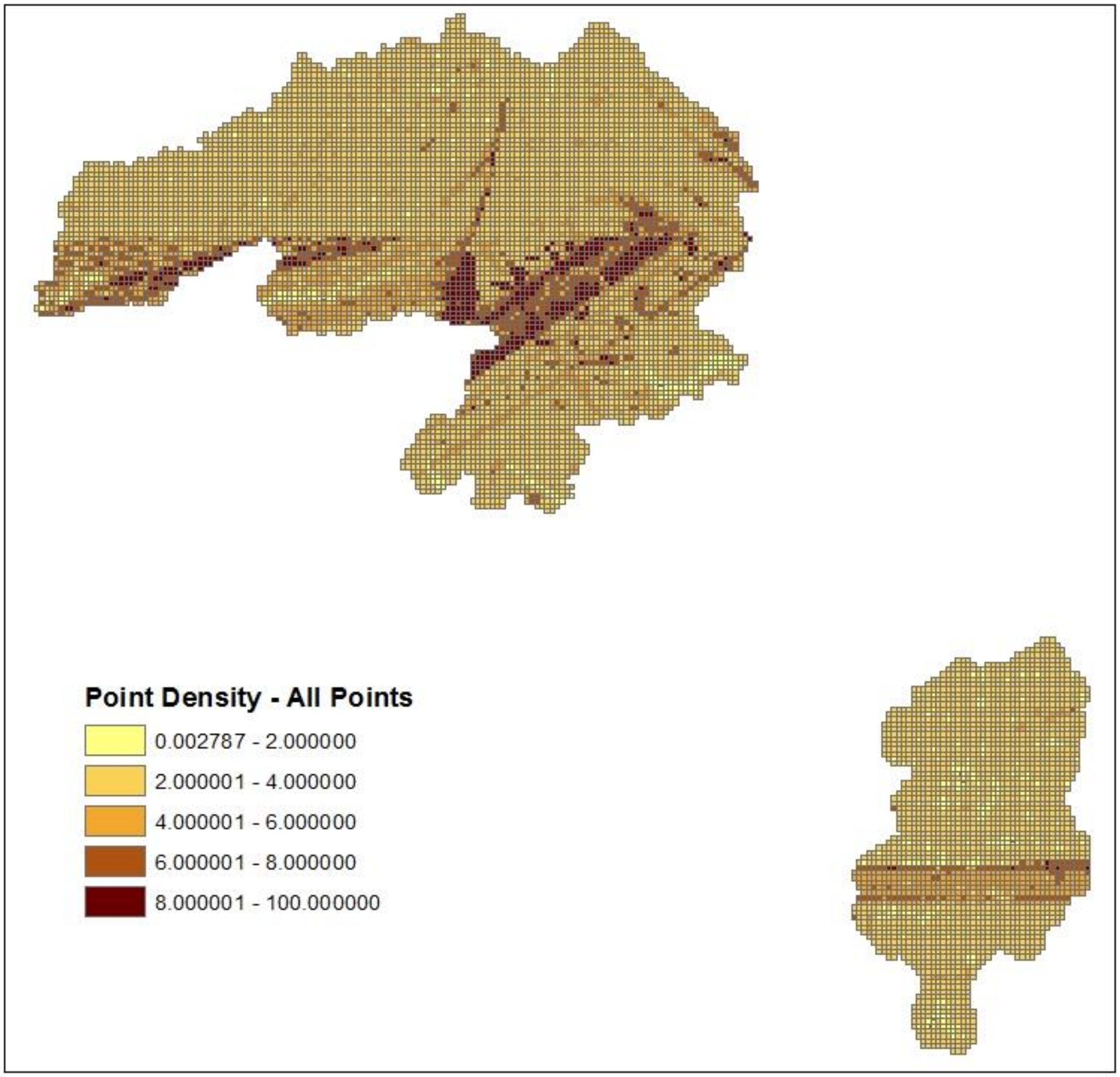

Figure 1. Point density per tile – all points.

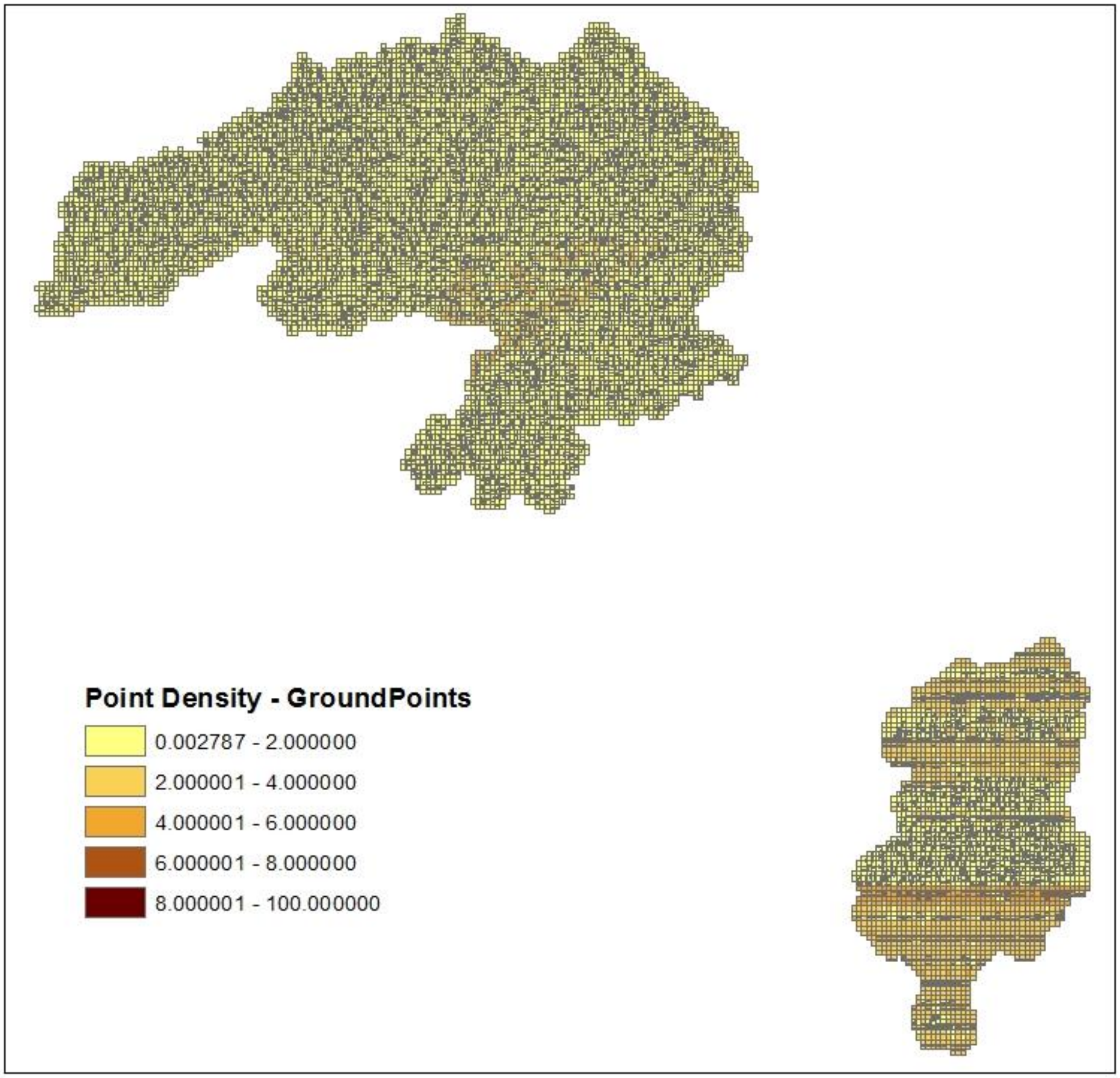

Figure 2. Point density per tile, ground points only. Ground point density is much more uniform among tiles, showing less variation with flight lines as in Figure 1.

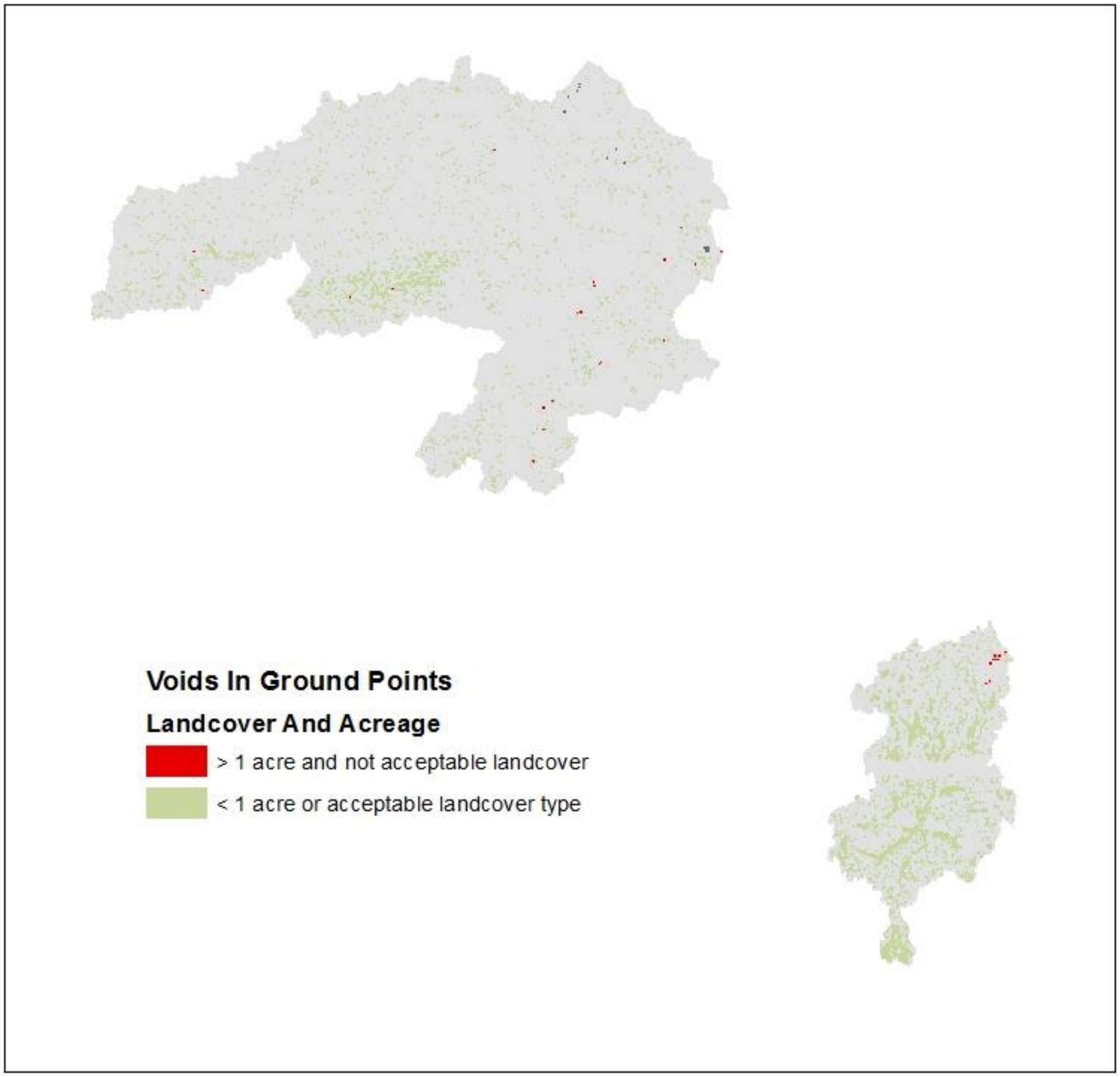

Figure 3. Voids in ground returns.

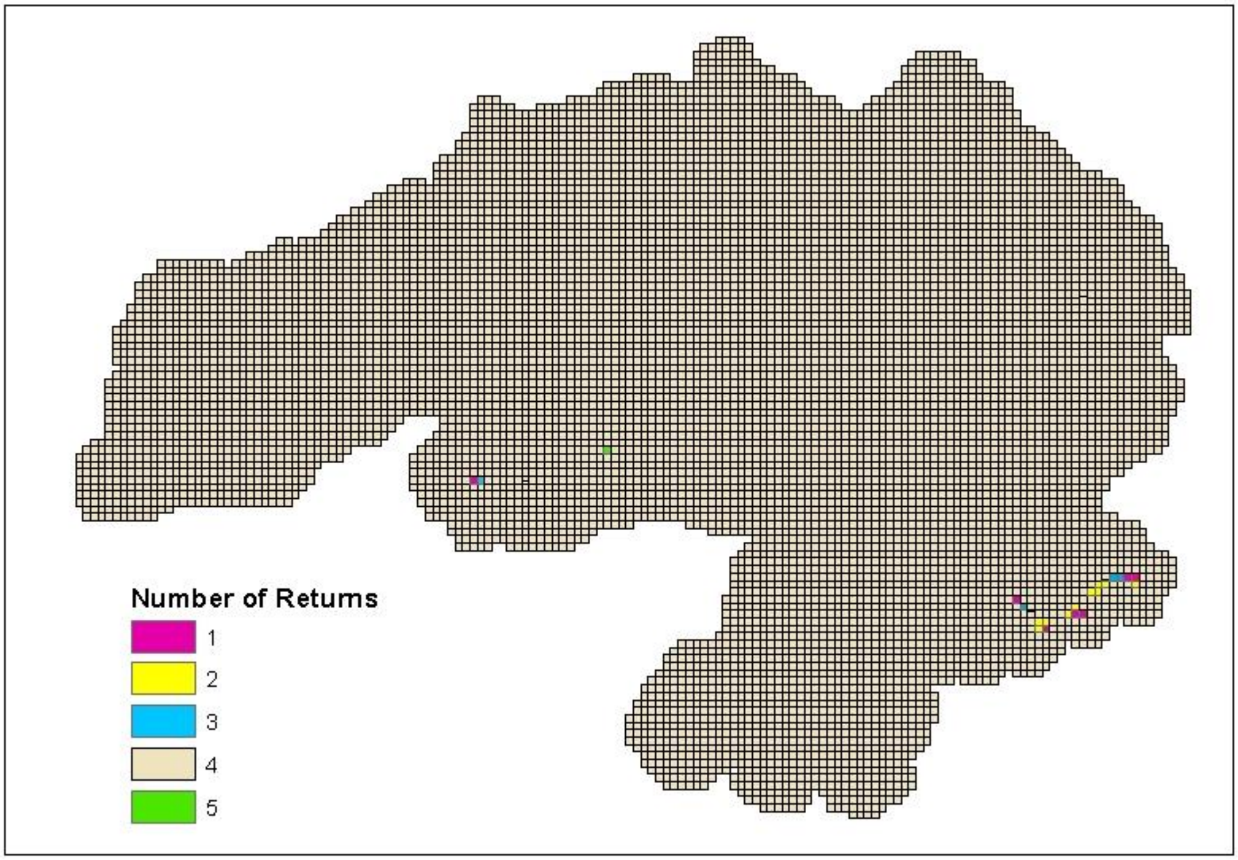

Figure 4. Number of returns by tile West of Hudson.

Research has shown that LiDAR intensity data can be strongly correlated with inundation and hence wetland occurrence. Intensity refers to the reflectance of the surface illuminated by the laser, and can be thought of as the strength of the signal. Mean intensity values showed that each data collection area exhibited distinctly different average intensity signatures (Figure 5). Causes are likely related to sensor settings as well as atmospheric and other conditions associated with data collection. A more detailed analysis of intensity values by land cover type did show distinct patterns of intensity values for predominant land cover types. However, significant overlap in intensity value distribution among land cover types make direct correlation of land cover and intensity values problematic at best and potentially misleading at worst. The combination of large standard deviations in intensity values by land cover type and the distinct differences in mean values by collection area indicate that using intensity data to support watershed based mapping in this instance would likely introduce significant additional costs without a specific guarantee of adding additional value. In the future, if flight planning can be coordinated such that the entire area can be flown in a much shorter time frame with the same sensor(s), settings and flight conditions, and if raw and normalized intensity data are included as one of the project deliverables, it is possible that such data could enhance wetland mapping updates.

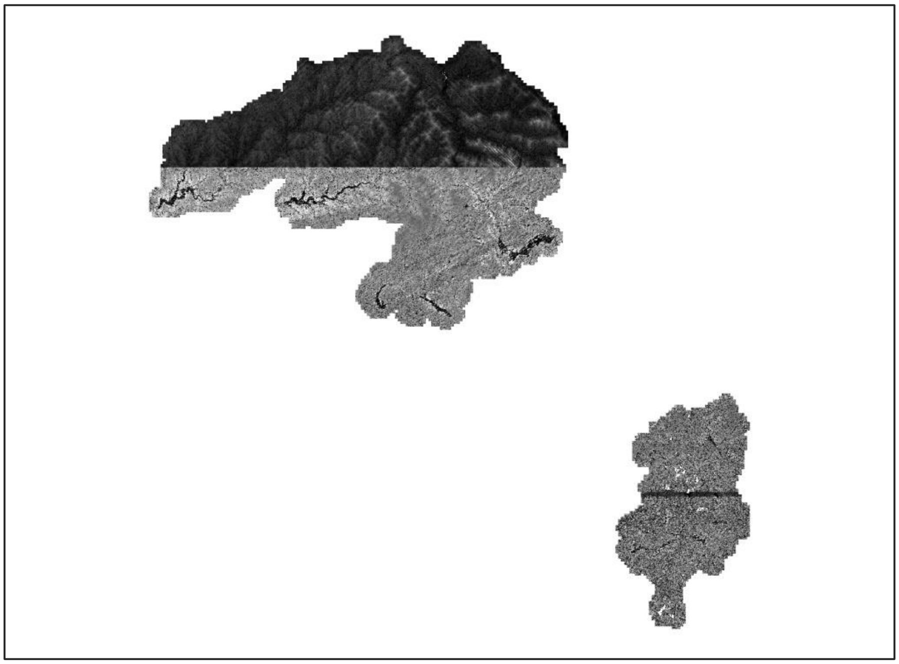

Figure 5. Bare earth intensity data. Note the differences in tone correspond to different flight lines/collection areas.

2.2 Automated Wetland Mapping Protocol Development

In addition to the 2009 LiDAR point data, several LiDAR-derivatives were compiled to support the automated mapping: digital elevation maps (DEMs), a flow accumulation layer, two-foot contour maps, a normalized digital surface model (nDSM), and a 3m Compound Topographic Index (CTI). A recent study in Minnesota successfully used a CTI in conjunction with LiDAR derivatives and high-resolution 4-band aerial photography to map wetlands in diverse eco-regions. The CTI can be calculated in ArcGIS and factors in the local upslope area and gradient contributing draining to each cell (Rampi et al. 2014).

CTI layers were calculated from both 1m and 3m DEM. Visual analysis of the CTI maps showed that wetlands in the 3m CTI appeared more highly textured and contrasted more strongly with uplands than the higher resolution 1m CTI (Figure 6). Hence, the 3m derived CTI data product was the selected input to the automated mapping protocol.

The 2009 leaf off and leaf on orthoimagery, and land-use/land-cover (LULC), and NHD datasets were also compiled to support the development the mapping protocol.

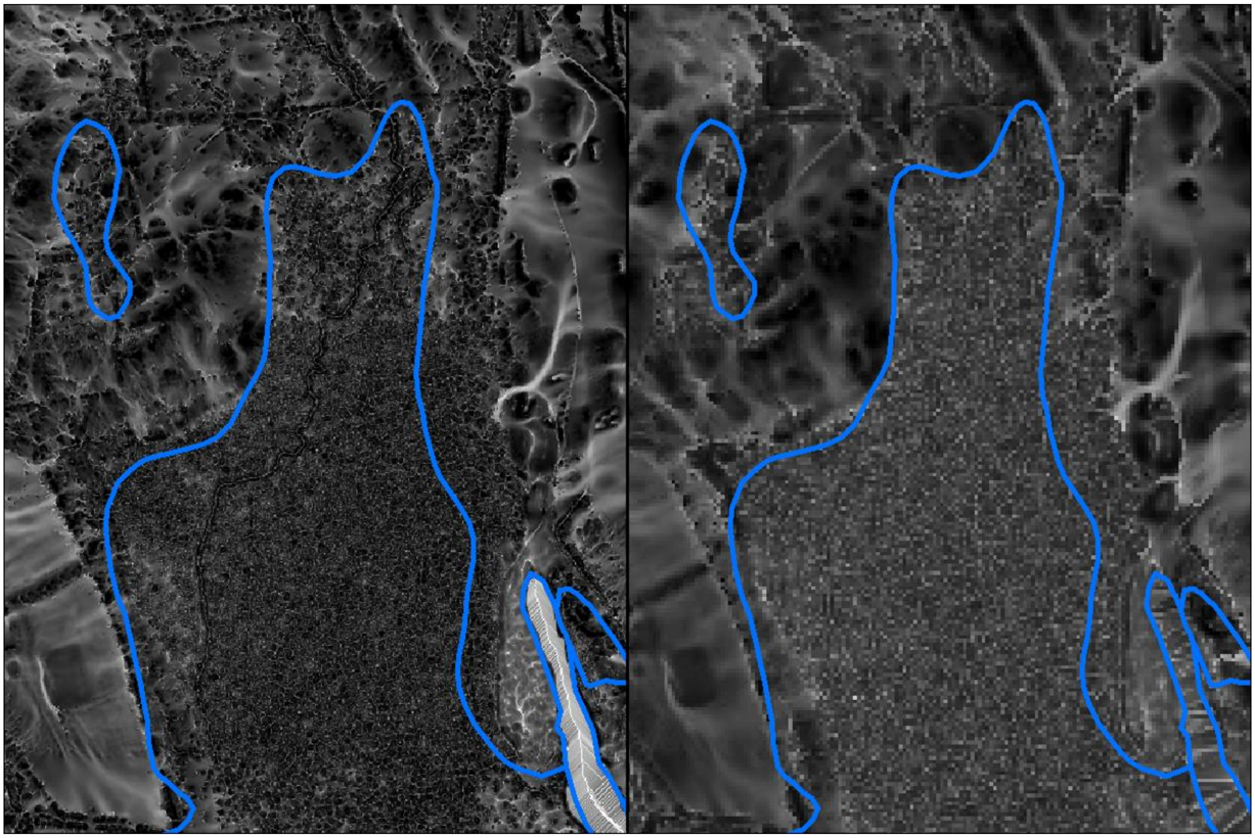

Figure 6. A forested wetland in the East of Hudson Watershed, as shown in CTI layers calculated from a 1-meter DEM (left) and a 3-meter DEM (right). NWI polygons are shown in blue. Both CTI layers show wetlands as highly textured but the lower-resolution version provides a more consistent representation and better contrasts with adjacent non-wetland features.

It was unclear *a priori* whether two separate rule sets would be needed to accommodate differences in topography and land use between the East and West of Hudson watersheds. However, review of the CTI layers suggested that similar modeling criteria could be used for both watersheds, at least initially, and use of one rule set would simplify development a standard modeling approach. Thus, only one rule set was used for all modeling in the pilot phase.

The mapping protocol was structured to first exclude all areas that are unlikely to support wetlands, including steep slopes, anthropogenic impervious surfaces, and agricultural fields. All features coinciding with NHD hydrology were also excluded from analysis by assigning them to a water class. After excluding unlikely zones, an initial segmentation was performed based on CTI texture and multispectral characteristics from the orthoimagery (e.g., Red, Green, Blue, and Near Infrared [NIR] bands). This step divided unclassified areas into objects suitable for analysis.

In a subsequent classification step, a series of temporary wetlands classes were created using definitions based on CTI texture; multispectral criteria such as NIR, Visible Brightness (average value of the Red, Green, and Blue bands), and the Normalized Difference Vegetation Index (NDVI), which is based on the relationship of the NIR and Red bands and useful for vegetation discrimination; vegetation height, and adjacency criteria (e.g., an object must have certain CTI texture values and must also be immediately adjacent to other candidate wetlands objects). Visual representation of all draft wetland features, merged into a single class, was then improved by filling gaps and smoothing edges.

Draft wetland features were further refined by categorizing them into three primary classes: forested (PFO), emergent (PEM), and scrub\shrub (PSS). Height, adjacency, and multispectral criteria drove this analysis, first segregating tall deciduous or coniferous trees from low-growing, even-textured emergent vegetation. The remaining unclassified, intermediate-height features were then assumed to be scrub\shrub features.

Because of the high resolution of the input data, the model can discern very small features as discrete cover types. As shown in Figure 7, the low generalization output delineates small gaps in the tree canopy as separate community types and may be of too fine a resolution for cover type mapping. Likewise the presence of a single shrub or tree can be mapped as a wooded community. To provide end users with multiple scale options for assessing cover types, two separate output products were created - a low generalization coverage which does not map patches with an area of less than 0.1 acres in larger polygons as discrete cover types, and a moderate generalization coverage which does not map patches with an area of less than 0.5 acres in larger polygons as discrete cover types.

All modeling was designed to err on the side of over-prediction of wetlands, to be followed by manual editing of the output. When reviewing and editing output from automated feature extraction, it is generally easier to identify and fix errors of commission than errors of omission.

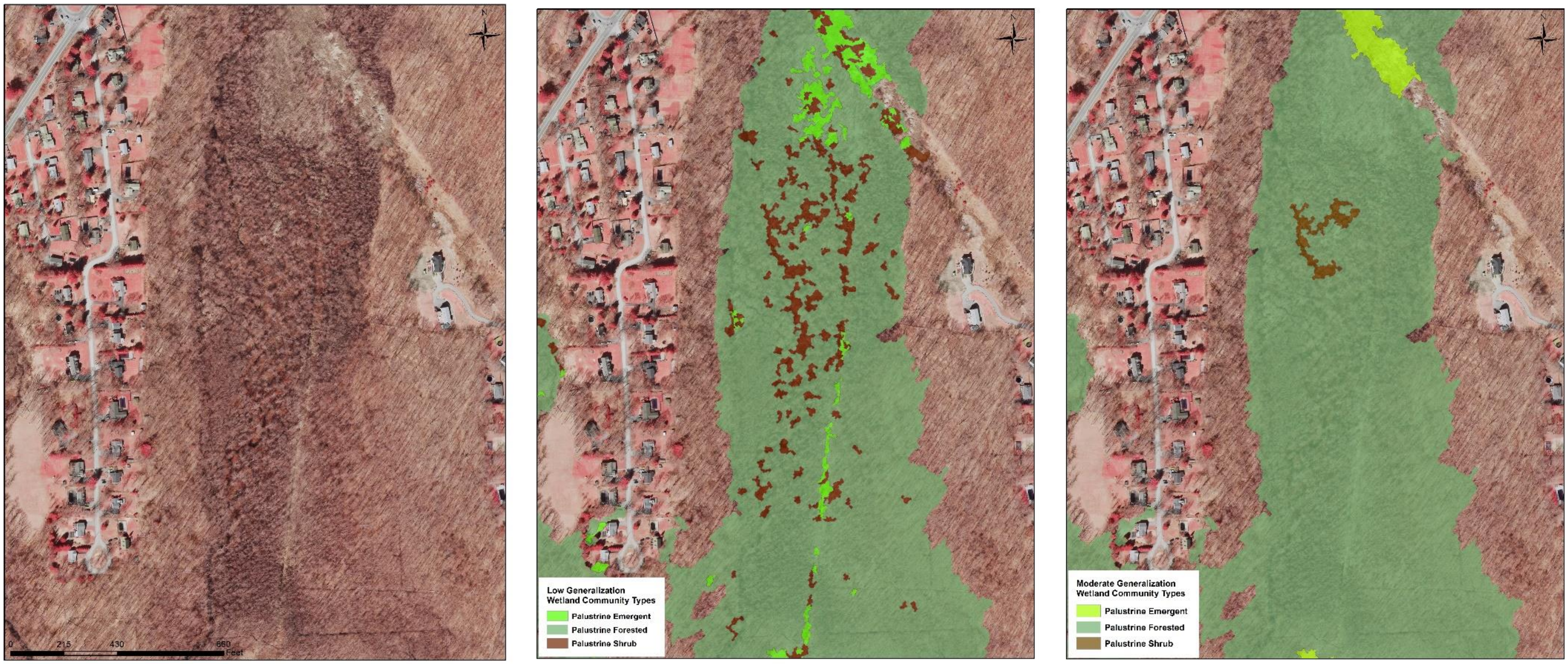

Figure 7. Two levels of generalization of cover type classification. The low generalization (center) maps features with an area as small as 0.1 acres of cover types. The moderate generalization (right) does not delineate cover types smaller than 0.5 acre.

2.3 Manual Editing

Manual editing of the moderate generalization wetland model output was conducted for 15 pilot areas, located both East and West of Hudson, and ranging from 1,500 to 2,000 acres in size (Figure 8). The pilot sites were selected to provide representatives of emergent (PEM), scrub-shrub (PSS), and forested (PFO) wetlands. Manual editing followed standard NWI protocols (Dahl et al. 2009) and consisted of wall to wall photointerpretation of the 2009 leaf off and leaf on orthoimagery within the pilot areas to refine the draft model output. The LiDAR-derived databases used in model production provided ancillary data sources, along with thematic coverages including the NWI, NHD, Soil Survey Geographic Database (SSURGO), and DEP field delineations. DEP's field delineation coverages included a compilation of DEP field delineations conducted through 2014 as well as field checks of the draft model output at 50 wetlands in pilot areas conducted in November 2014 (Figure 9).

Manual edits removed errors of commission, added or extended wetland polygons to correct errors of omission, while retaining confirmed wetlands. Following standard NWI protocols, attributes for NWI systems (Lacustrine, Palustrine, Riverine), water regime, and special modifiers were added during the manual edit phase as well. While the model generated NWI vegetation cover classes (EM, SS, UB), unconsolidated bottom (UB) cover classes were added for NHD waterbodies that were imported during modeling. Vegetation subclasses were added to forested and scrub-shrub wetlands. Pursuant to NWI revision standards, linear riverine wetlands were converted to meet the NWI program goals of removing point and line features from the NWI database.

To ensure strict compliance with USFWS NWI standards, polygons smaller than the specified 0.5 acre NWI target mapping unit (TMU) were deleted from the database during the manual edit phase (Dahl 2009). However, the Federal Geographic Data Committee's 2009 Wetland Mapping Standards allow mapping below the specified TMU, and that wetland data that exceed the TMU will be accepted. Deletion of <0.5 acre polygons from the pilot area removed only 28 acres of wetland from 2,225 acres of wetlands mapped in the pilot. Nonetheless, wetlands smaller than 0.5 acres whose presence can be confirmed will not be deleted in future work. Many of these smaller wetland areas are also included as small ponds in the NHD waterbody coverage.

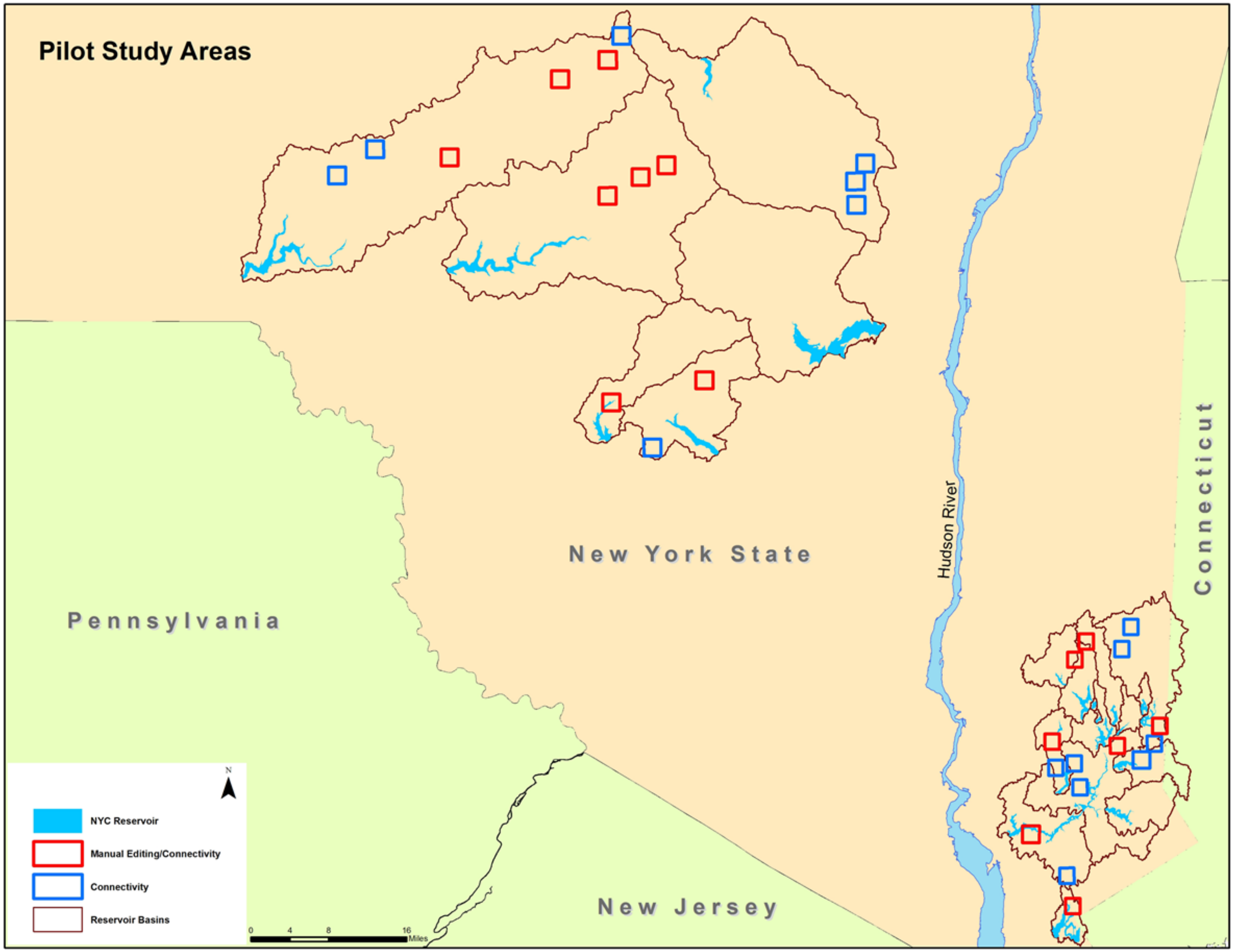

Figure 8. Pilot sites for the pilot project. Manual editing of the model output was conducted in the red pilot areas. Wetland connectivity assessment was completed for all pilot areas shown (see Chapter 3).

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Figure 9. Field check sites. Photos 1 and 6 show wetland areas that were not included in the draft model output (errors of omission). Photos 2, 3, and, 4 show areas where the model correctly predicted wetland presence. Photo 5 shows an area where the draft model incorrectly mapped a wetland (error of commission).

The final edited version was saved into a database entitled *Product1_NWI Compliant Wetlands*. A second database entitled *Product2_DEP Potential Wetlands* was created by performing a union of the NWI-compliant database with the low generalization model output. This database retains all original model output, including polygons smaller than 0.5 acres. The polygons are coded as 1 – Agreement to indicate where the NWI-compliant product and low generalization model output agree on wetland presence, 2 – Omission to indicate where the NWI-compliant database identifies a wetland but the model did not (determined through manual editing), and 3 – Commission identifies area where the low generalization model output identified a wetland that was included in the NWI-compliant database (could not be confirmed in manual review process, or was excluded based on TMU (< 0.5acre)) (Figure 10).

Category 3 includes areas where the automated ruleset indicated wetland characteristics that could not be confirmed through photointerpretation or ancillary data sources. A subset of these areas may prove to be wetlands based on detailed field investigation, particularly in areas with coniferous cover or slopes where photographic and topographic clues are not apparent in ancillary data sources. Hence, they were retained in Product 2 for future, site scale investigations that could inform future mapping efforts.

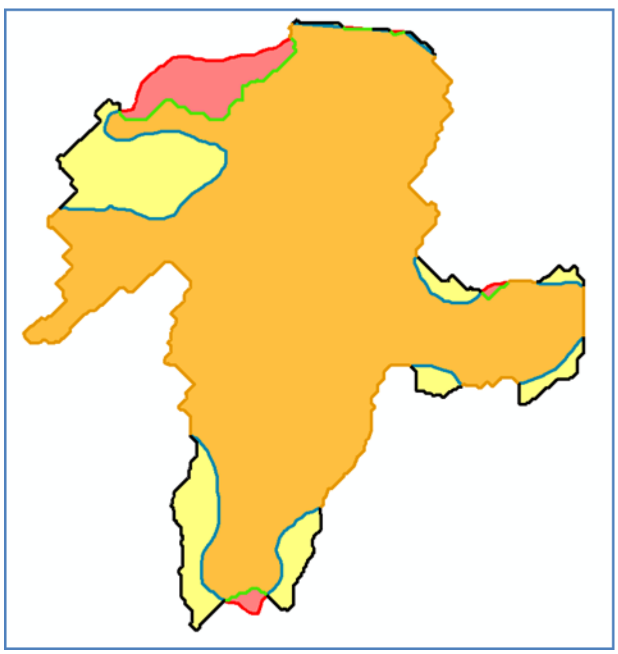

Figure 10. Polygon demonstrating Product 2 – DEP potential wetlands. The orange polygon shows areas are attributed as category 1 (agreement), red polygons as category 2 (errors of model omission) and yellow polygons as category 3 (errors of model commission). The black and blue lines represent line work required to correct the model's errors of commission, the red and green lines show line work required correct the model's errors of omission.

2.4 Wetland Mapping Results

The 2005 NWI mapped 1,566 acres of wetlands and waters in the 15 pilot areas. The NWI-compliant coverage produced for the pilot study mapped 2,224 acres in the pilot areas for a 42% increase in mapped acreage.

The mapped acreage of vegetated wetlands in the pilot study was nearly double (93% increase) that mapped in the NWI, with a 136% and 74% increase in mapped wetlands West and East of Hudson, respectively. Forested wetlands West of Hudson had the largest increase in mapped acreage, with a 220% increase (Figures 11 and 12, Table 1). This was largely due to increased detection of evergreen wetlands by the model (PFO4), whose mapped acreage increased by nearly 400% West of Hudson (Figure 13). Evergreen canopy typically masks evidence of wetland hydrology on orthoimagery. Hence, standard NWI photointerpretation alone is often unable to detect these systems. Because the pilot mapping protocol relied heavily on the CTI which accounts for topography and flow accumulation, more wetlands were detected in evergreen areas.

Improved detection of evergreen wetlands in the pilot study is further confirmed through examination of DEP's field data as compared to the draft model output for the entire watershed. DEP's GIS layer of field-delineated wetlands included 19 evergreen forested wetlands, 68% of which were detected by the pilot model, compared to 10% detected by the NWI (Figure 14).

Examination of the data by cover type and region reveals that there was little difference in the acreage of waters and unvegetated systems between the original NWI and pilot NWI-compliant coverage, with only a 5.2% increase East of Hudson and an 8.8% increase West of Hudson. This is largely due to the inclusion of portions of the New Croton, Kensico, and Neversink reservoirs in the pilot areas and the exclusion of polygons smaller than 0.5 acres. The exclusion of small polygons removed several small water bodies and erroneously resulted in a decrease in the mapped acreage of the palustrine unconsolidated bottom (PUB) class. This will be corrected in any future updates of this pilot work. The exclusion of pond acreage was partially offset by the addition of riverine wetlands pursuant to NWI standards (Table 1).

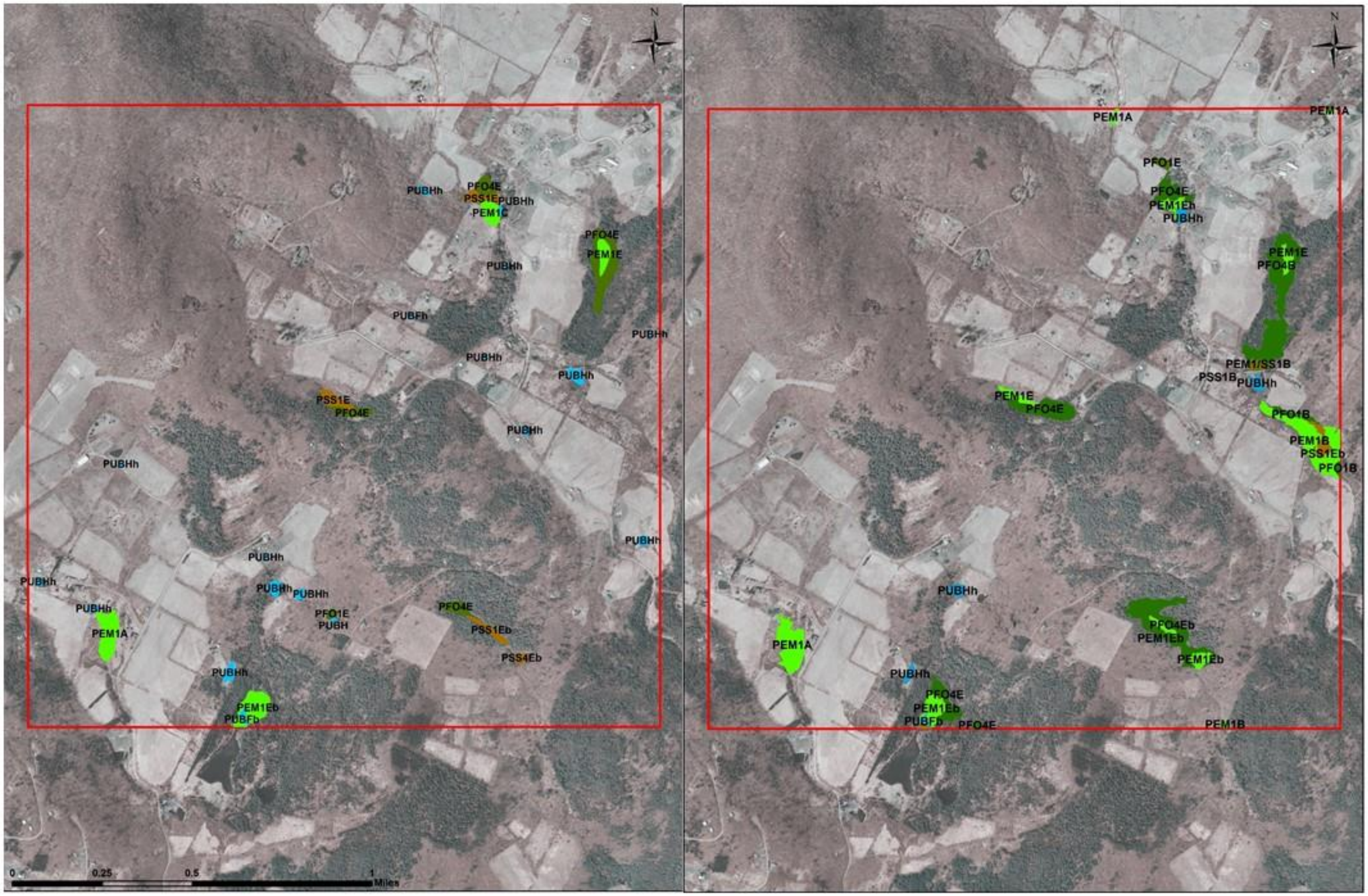

Figure 11. USFWS 2005 NWI map (left) and the pilot NWI-compliant map produced for a West of Hudson pilot area. Increases in mapped wetland area are evident in the eastern portion of the study area. NWI mapping codes are defined in Classification of wetlands and deepwater habitats of the United States (Federal Geographic Data Committee, 2013).

Table 1. Acreage comparison of the original NWI and the Pilot NWI-compliant layers. Refer to Classification of wetlands and deepwater habitats of the United States for NWI mapping codes (Federal Geographic Data Committee, 2013).

	West of Hudson			East of Hudson		
	Original NWI	**Pilot NWI-Compliant Layer**	**Percent Change**	**Original NWI**	**Pilot NWI-Compliant Layer**	**Percent Change**
Waters/Unvegetated Systems						
RUB/RSS	58.6	98.5	68.2	0.0	12.4	NA
L1UB	157.5	165.8	5.3	523.6	551.4	5.3
PUB	46.6	21.4	-54.1	139.5	134.1	-3.9
Total	262.6	285.7	8.8	663.1	697.9	5.2
Vegetated Wetlands						
PEM	115.6	236.3	104.3	41.0	63.4	54.7
PSS	40.2	95.0	136.6	52.9	147.8	179.2
PFO	43.7	139.8	220.2	347.1	558.3	60.8
Total	199.5	471.2	136.2	441.0	769.5	74.5
Grand Total Waters and Vegetated Wetlands	462.1	756.9	63.8	1104.1	1467.4	32.9

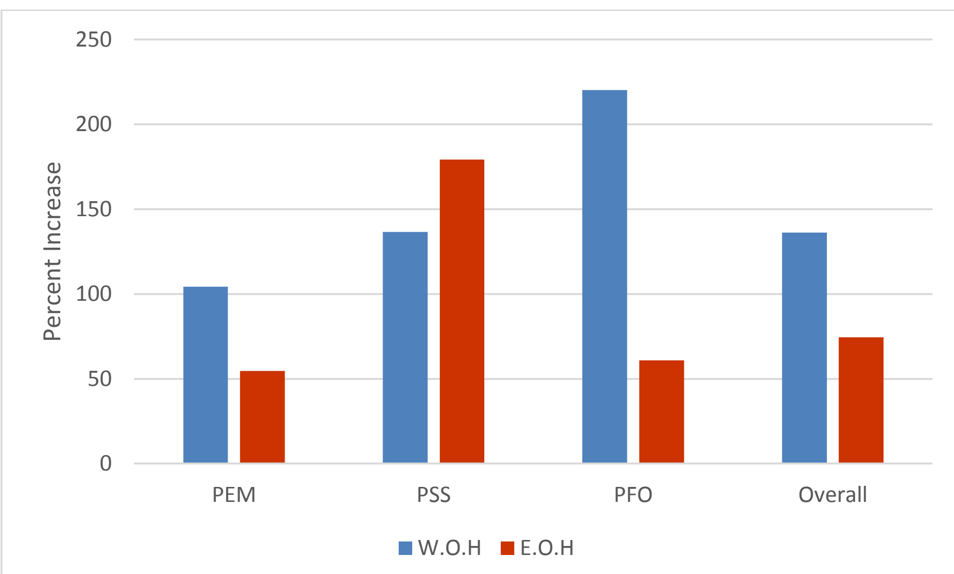

Figure 12. Increase in mapped wetland acreage in the pilot NWI-compliant coverage as compared to the 2005 NWI.

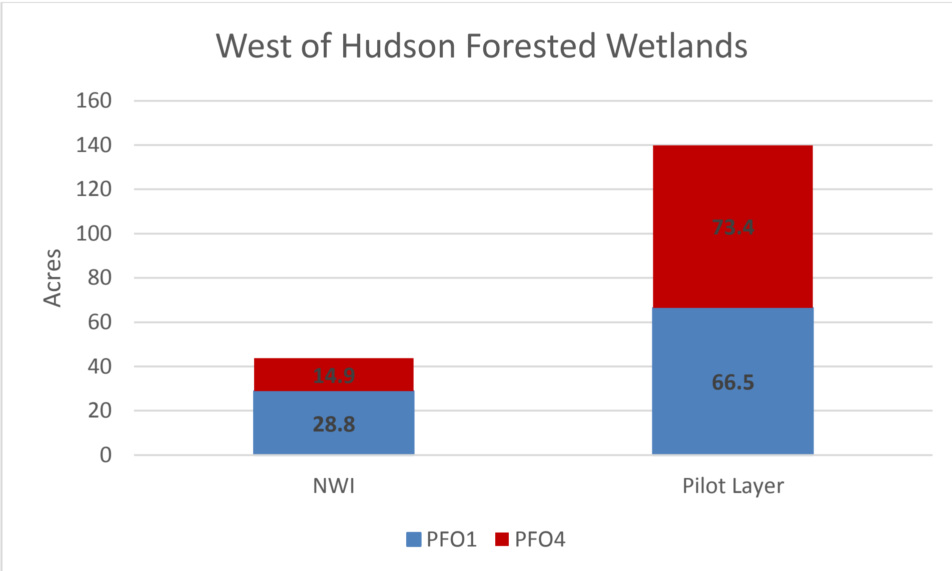

Figure 13. Comparison of acreage of deciduous (PFO1) and evergreen (PFO4) forested wetlands mapped by the original NWI and the pilot NWI-compliant layers.

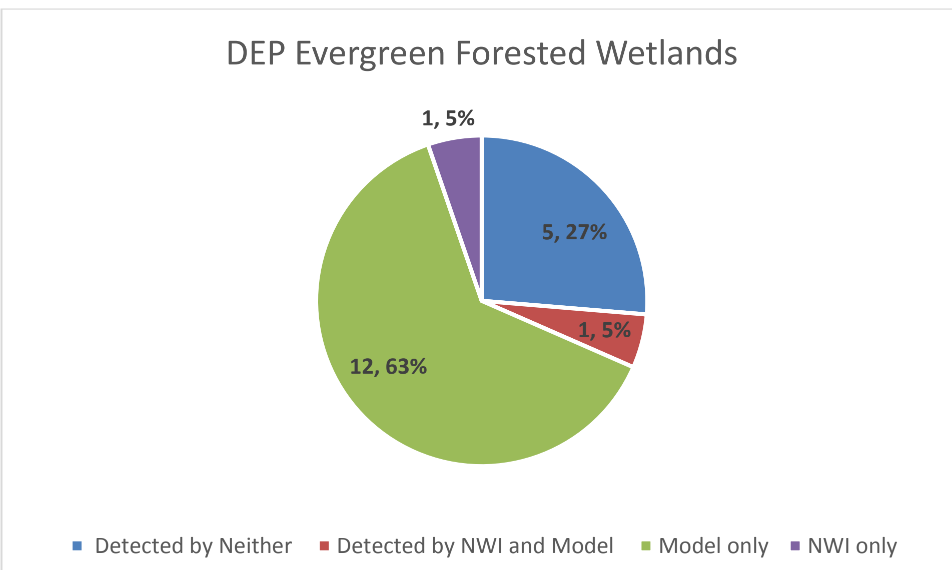

Figure 14. The number of DEP-delineated evergreen forested wetlands detected by the pilot model and the original NWI.

3.0 Wetland Connectivity Assessment

In 2013, DEP acquired a local resolution NHD coverage for the watershed developed from 1 meter resolution LiDAR. As compared to previous, lower resolution stream data layers, this local resolution data enabled detection of an additional 655 stream miles in the watershed, for a 17.8 and 9.3 percent increase in the Catskill/Delaware and Croton watersheds, respectively. However, wetland connections were not evaluated when developing the 2013 NHD update. As such, this pilot project also endeavored to determine if wetland connectivity to surface waters could be more accurately assessed using the 2013 NHD database, and to determine if additional wetland connections could be identified and digitized according to NHD protocols.

3.1 Connectivity Assessment Methods

Connectivity analysis was conducted for both the 2005 NWI data as well as the moderate generalization model output for the 30 pilot study areas shown in Figure 8. First, feature classes identifying polygons from the NWI and moderate generalization model coverages that are unconnected to medium and local resolution NHD lines were created. Wetlands directly connected to the NHD stream network were identified using the Select by Location tool in ArcGIS. The selection was reversed to include only unconnected polygons, which were exported to a new coverage. Any of these 'unconnected' polygons adjacent to the directly connected polygons were attributed as indirectly connected, and were removed from the unconnected polygon coverage. Next, polygons adjacent to these indirectly connected polygons were identified through Select by Location and removed from the coverage. This process was repeated until polygons with no direct or indirect connections to the NHD network remained. This resulted in four feature classes 1) NWI polygons unconnected to medium resolution NHD 2) Low generalization model polygons unconnected to medium resolution NHD 3) NWI polygons unconnected to local resolution NHD 4) Low generalization model polygons unconnected to local resolution NHD.

Next, the polygons in the unconnected feature classes were evaluated using orthoimagery and LiDAR elevation data to determine whether they could be connected to the 2013 local resolution NHD. The protocol used to develop the 2013 NHD was followed to create new hydrography features so they may be submitted for amendment to the local resolution NHD data. New hydrographic connections were not assessed for the new NWI-compliant layer produced through OBIA for the pilot, as it was not completed at the time of the connectivity assessment work. However, the NWI-compliant data layer is a revision of the moderate generalization product, so any connections detected for the moderate generalization polygons would apply to features in the NWI-compliant product. Any features in the moderate generalization layer that could not be confirmed as wetlands in the connectivity study were not evaluated for hydrographic connections.

Metrics were then calculated to compare the extent of unconnected wetlands as determined by using medium, local, and amended local resolution NHD data. The amended local resolution NHD data includes the new hydrographic features digitized in the pilot study. These calculations were provided for both the current NWI and the NWI-compliant layers.

3.2 Connectivity Results

An additional 23.5 miles of streams connecting wetlands from the NWI and moderate generalization layers to the local resolution NHD stream network were identified and digitized for the 30 pilot areas (Figure 15).

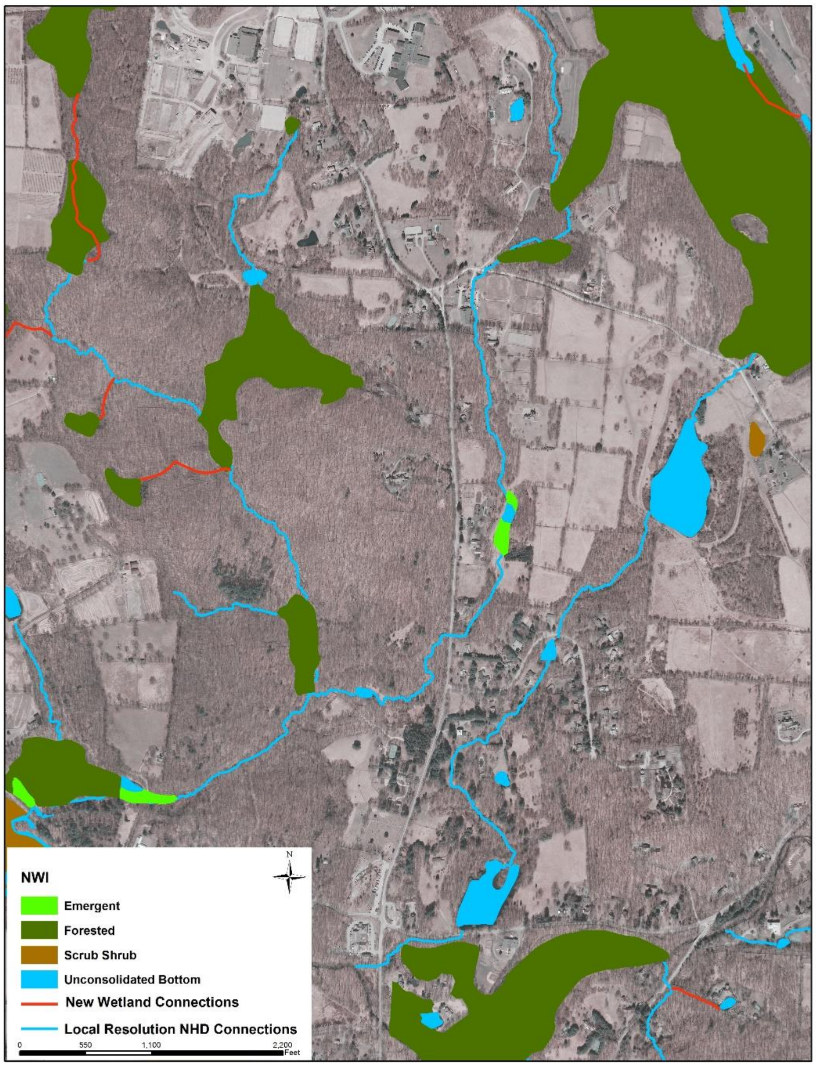

Figure 15. New surface water connections (red) to the 2013 NHD stream network digitized in an EOH pilot area.

The NWI maps include 2,223 acres of palustrine wetlands in the 30 pilot areas, 779 acres (35%) of which are unconnected to the medium resolution NHD dataset. Analysis against the 2013 local resolution NHD dataset reduced the extent of unconnected wetlands by over 70%, with 221 acres (10%) of unconnected palustrine wetlands. Amendment of the local resolution NHD data with additional streams digitized in this pilot study reduced the extent of unconnected palustrine wetlands to 44 acres, just 2% of the wetland acreage in the study area (Figure 16).

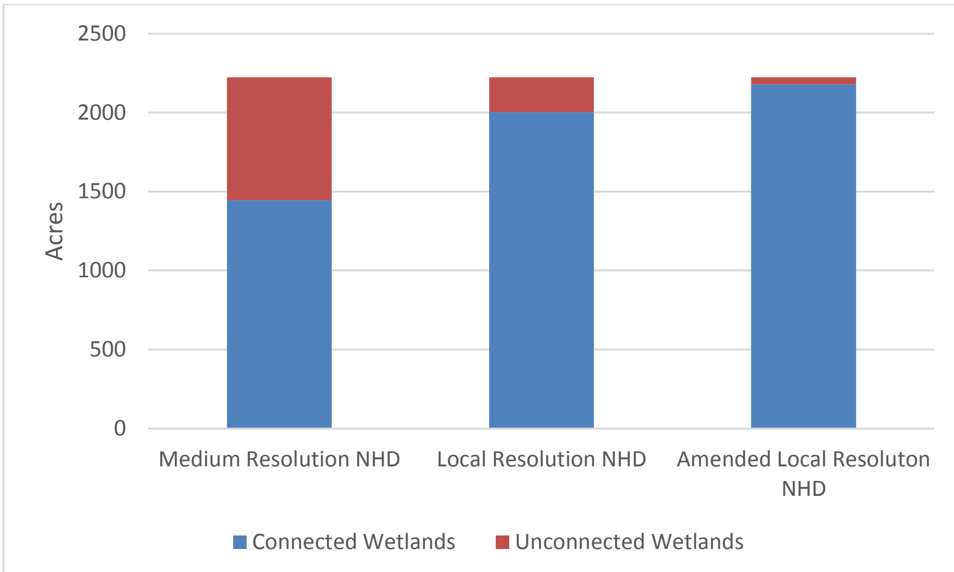

Figure 16.   Acreage of NWI palustrine wetlands connected and unconnected to medium, local, and amended local resolution stream data.

The NWI-compliant layer, produced through OBIA and manual editing as described above, included 1442 acres of palustrine wetlands in the 15 pilot areas. Of these, 590 acres (41%) are unconnected to the medium resolution NHD data. Similar to the findings for the NWI database, there is a significant reduction in the extent of unconnected wetlands when using the local resolution NHD with the NWI-compliant layer. In the pilot areas, the extent of unconnected wetlands dropped by approximately 80% to 108 acres (7%) when considered against the local resolution NHD. Amending the local resolution NHD with the streams digitized for the pilot study, reduced the extent of unconnected wetlands to 93 acres, which is 6% of the palustrine wetland acreage in the NWI-compliant database. An additional reduction in the extent of unconnected polygons would be expected if all features from the NWI-compliant database were assessed for hydrographic connections. The current analysis is based on assessment of low generalization model output prior to manual clean up. Any future connectivity studies would be completed for the final NWI-compliant product, rather than for intermediate products.

4.0 Summary and Conclusions

This pilot study assessed the current LiDAR and LiDAR-derived layers to determine their suitability for wetlands mapping using an automated OBIA protocol. No systematic issues in data quality were found in LiDAR point density, voids, or returns that would significantly impact this effort. The intensity signal did vary with collection area, so intensity strength was not used in the modeling protocol. It is likely that the intensity values with the new LiDAR datasets would be more consistent and potentially valuable. Incorporation of intensity into OBIA wetland mapping protocols would require additional research. Moreover, the automated wetland delineation relied heavily on the elevation values for the compound topographic index and which is unlikely to change significantly in a new LiDAR collection. Given the limited extent of issues identified with the LiDAR data, the value of rerunning the automated analysis with a newer LiDAR data is unclear.

The combination of automated mapping followed by manual editing that strictly adhered to the NWI protocol more than doubled the acreage of vegetated wetlands mapped in the West of Hudson watershed, and increased those mapped in the East of Hudson watershed by 74%. Because the model was strongly influenced by LiDAR-derived topography and flow accumulation, it improved detection of wetlands, such as evergreen forested systems, that typically lack hydrologic signatures on orthophotography.

The model was designed to over predict wetland acreage, as errors of commission are easier to edit than errors of omission. While DEP has assessed the pilot maps against field data collected to date, additional quality assurance review is underway to assess the accuracy of the pilot mapping effort. While some errors of commission may remain in the final database, it is undoubtedly more complete than current NWI maps as the methodology combined both automated mapping and manual review pursuant to NWI standards.

This pilot study also demonstrated the value of the LiDAR-derived local resolution NHD stream data at determining wetland connectivity on a watershed scale. The percentage of NWI wetlands unconnected to surface water was reduced from 35% to 10% by using local rather than medium resolution NHD data. Evaluation of the remaining unconnected wetlands against high resolution orthophotography and elevation data further reduced the percent of wetland unconnected to surface waters to just 2%. Similar reductions occurred when analyzing the pilot NWI-compliant layer.

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List of Acronyms

CTI	Compound Topographic Index
DEM	Digital Elevation Model
DEP	New York City Department of Environmental Protection
EOH	East of Hudson
FAD	Filtration Avoidance Determination
LiDAR	Light Detection and Ranging
LUB	Lacustrine Unconsolidated Bottom
LULC	Land Use/Land Cover
nDSM	Normalized Digital Surface Model
NDVI	Normalized Difference Vegetation Index
NHD	National Hydrography Dataset
NIR	Near Infrared
NWI	National Wetlands Inventory
OBIA	Object Based Image Analysis
PEM	Palustrine Emergent
PFO	Palustrine Forested
PSS	Palustrine Scrub-Shrub
PUB	Palustrine Unconsolidated Bottom
RACNE	Regional Application Center for the Northeast
RSS	Riverine Scrub-Shrub
RUB	Riverine Unconsolidated Bottom
TMU	Target Mapping Unit
USFWS	United States Fish and Wildlife Service
WHO	West of Hudson