Relative Densities of Tree Canopy

in Butler, Clermont, Hamilton and Warren Counties, Ohio

June 2014

Ohio · Kentucky · Indiana Regional Council of Governments

Ohio Environmental Protection Agency

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Introduction

Purpose

The purpose of *Relative Densities of Tree Canopy in Butler, Clermont, Hamilton and Warren Counties, Ohio* is to develop a field-tested, digital methodology for analyzing and mapping forest areas, based on remotely sensed tree canopy. For this study, the methodology is also designed to characterize areas where riparian (streambank) tree canopy appears to be threatened by encroaching development, when such development is not properly designed and managed. A major goal is to create an analytic process that is transferable to other parts of Ohio, where it can be shared with local and state government for consideration in policy development. A geographic information system (GIS) is the essential component of tree canopy analysis, but is by no means the only factor behind a replicable methodology with multiple applications. Beyond the computers and GIS software, this project relied on a variety of other tools and techniques, including a global positioning system (GPS), clinometers, a 100-foot tape measure, desktop planning and outdoor cross-checking.

Funding

This product was financed through a grant from the Ohio Environmental Protection Agency (Ohio EPA). The contents and views, including any opinions, findings, conclusions or recommendations contained in this product are those of the authors and have not been subject to any Ohio Environmental Protection Agency peer or administrative review and may not necessarily reflect the view of the Ohio Environmental Protection Agency, and no official endorsement should be inferred. OKI has a long-standing working relationship with Ohio EPA because OKI was designated by the governors of Ohio, Kentucky and Indiana as the water quality management planning agency for the region in 1974, after such planning was required by Section 208 of the Federal Water Pollution Control Act Amendments of 1972.

Scope of Work

The scope of work for this project calls for OKI to use the 2007 State of Ohio LiDAR (Light Detection and Ranging) and color infra-red datasets to create a GIS layer that shows the relative densities of tree canopy along riparian corridors and in the HUC12 watersheds of Butler, Clermont, Hamilton and Warren Counties. (The LiDAR data are useful for determining the elevation of features on the surface of the earth, and the color infra-red data are useful for detecting the presence of vegetation.) OKI agreed that after a GIS layer was produced by analyzing these datasets, field checks would be performed in at least three watersheds where riparian tree canopy appears to be threatened by encroaching development, because such development may not always be properly designed or managed. The GIS layer would then be finalized and available to use in the future with other data for both riparian corridor level analysis and watershed level analysis, and could be shared with local and state government for consideration in policy development.

Because both the LiDAR data and the color infrared data are available statewide through the Ohio Statewide Imaging Program (OSIP), this process of analysis will be transferable to other areas in Ohio. To that end, the methodology developed during the analysis and cross-checking process is summarized in this report, and more information about the transferability of the data and OKI's willingness to provide technical assistance is provided in the final section of the report, entitled *Sharing OKI's Methodology with Others*.

Methodology

<u>*Definition of Terms*</u>

In using the term methodology, OKI relies on *The American Heritage Dictionary* definition: "A body of practices, procedures and rules used in a discipline." This better describes our product than the Webster's New World Dictionary definition: "A system of methods, as in any particular science." It would be overstatement to call the methodology for *Relative Densities of Tree Canopy* pure science. In the course of developing a field-tested, digital methodology for analyzing and mapping remotely sensed forest areas, OKI staff relied on best professional judgment, GIS ground rules and sound planning practices. Some of the finer points of our work gave us a greater appreciation for the expression that a technique can be as much art as it is science. We conducted the work from two general approaches: (1) geographic information system (GIS) study methods, and (2) environmental field study methods. Both are described further in sections that follow.

<u>*Geographic Information System Study Methods*</u>

GIS study proceeded along three lines of inquiry: LiDAR data, color infrared data and forest density analysis. They are described below – first in layman's terms, then in technical GIS terms.

With a state-generated dataset on Light Detection and Ranging (LiDAR), the GIS Division at OKI discerned areas where trees are concentrated because LiDAR beams reflect back from trees to the flyover airplane sooner than LiDAR beams reflect back from ground level turf, pavement or even low-lying buildings. This was only a start, however, because the LiDAR dataset typically does not distinguish cell phone towers, light poles, large antennas and other tall artificial objects from trees.

With another state-generated dataset on infrared imagery, the GIS Division at OKI discerned areas with vegetation because the light absorbing chlorophyll of green plants has a different infrared heat signature than artificial materials, such as concrete sidewalks or asphalt shingles. The remotely sensed infrared imagery is not reliably accurate to the focal point of a single tree but is a fairly good indicator of plant aggregations in three classes: grass turf, shrubland and forest area. Though it is more discriminating than LiDAR, infrared imagery can miss some woody vegetation or can misclassify some shrubs as trees.

Armed with the LiDAR and infrared datasets, the GIS Division at OKI then applied GIS analysis to the information at hand. In combination with a digital elevation model and a digital surface model, the GIS Division classified the LiDAR data to a 20- to 130-foot range. Anything measuring 20 feet or less in height was not classified as a tree and anything measuring 130 feet or more was also not classified as a tree. This eliminated shrubs, houses and the like on the short end of the height scale while also eliminating tall antennas, high office buildings and other towering structures on the tall end of the height scale. Then color infrared imagery went into the creation of a tool that assigned all areas in Butler, Clermont, Hamilton and Warren counties in two land cover classes: forested and non-forested. After filtering, smoothing and generalizing sparsely spaced trees out of the forested land cover class, the GIS Division achieved a digital mask to eliminate false tree indicators from the LiDAR dataset. This masked dataset was then processed with a focal tool that estimates forest area density from the number of masked LiDAR tree counts in neighboring statistical sampling areas of various shapes and sizes.

For a more technical understanding of how the GIS Division at OKI achieved a reliable raster layer of forested areas in Butler, Clermont, Hamilton and Warren counties, refer to OKI's tree canopy geo-processing notes below.

Light Detection and Ranging (LiDAR) processing

The goal of the LiDAR processing was to create a layer of tree canopy heights across the study area of Butler, Clermont, Hamilton and Warren Counties, which constitute the Ohio part of OKI's planning area. For basic information on Light Detection and Ranging, visit the website at: http://resources.arcgis.com/en/help/main/10.1/index.html#//015w00000041000000

OKI downloaded LiDAR data in tiles from the Ohio Statewide Imagery Program at: http://gis3.oit.ohio.gov/geodatadownload/osip.aspx. Data was combined into one LAS dataset. (LAS is not an acronym, but the name of a file extension, such as docx or jpeg.)

Using the LAS dataset to Raster (i.e., pixel) tool, OKI created a Digital Elevation Model (DEM). LiDAR data was filtered to use only ground returns. Ground returns are the LiDAR points that are reflected back from the Earth's surface. OKI used these points to create a digital model of the earth's bare surface without any trees or man-made structures. Pixel elevation values were averaged from all bare ground LiDAR point returns. ArcGIS recommends averaging at this website: http://resources.arcgis.com/en/help/main/10.2/index.html#/Creating_raster_DEMs_and_DSMs_from_large_lidar_point_collections/015w0000004q000000/

Again using the LAS dataset to Raster tool, OKI also created a Digital Surface Model (DSM) that analyzes tree canopy elevation. LiDAR data was filtered to use only first return data for this step. Pixel elevation values represent the maximum or highest point return that occurred in the cell. This helps bias the DSM upwards to reduce any error that could be associated with the LiDAR beam missing the very top of the tree. (See link above.)

Outputs for the Digital Elevation Model and Digital Surface Model rasters were integer type, meaning whole rather than decimal numbers. The cell size was set at 30 feet squared.

To create the tree canopy height raster, OKI subtracted the DEM from the DSM using the raster calculator tool. Values less than or equal to 20 feet or greater than or equal to 130 feet were thought to be non-forest or small random errors and were removed from the tree canopy height raster.

Infrared Image Classification

The goal of this work was to distinguish forested areas from non-forested areas via image classification and to eliminate non-forested cells from the tree canopy height raster. The GIS Division at OKI took these steps:

- Color infrared (CIR) images for Butler, Clermont, Hamilton and Warren counties were combined into one raster via the Mosaic to create a new raster tool.

- Polygons were digitized representing two land cover classes (forest and non-forest) across the four counties using the image classification toolbar.
- Classes were examined with histogram and scatter plot tools in the training sample manager window, which was accessed through the image classification toolbar.
- A signature file was created from the training sites. This file is used as an input to train the classifier tool about each land cover class.
- A maximum likelihood classification was performed using the signature file. This created a raster that identifies each cell from the CIR layer as forest or non-forest.
- Three post-classification steps were then performed to remove noise from the classified image. As recommended by ESRI (Environmental Systems Research Institute) at http://resources.arcgis.com/en/help/main/10.2/index.html#/Processing_classified_output/00nv00000015000000/, OKI performed these three steps:
    - Filtering the classified image by running the majority filter tool to reclassify isolated pixels.
    - Smoothing the classes by using the boundary clean tool. As recommended by ArcGIS Online, parameters were set to sort by ascending, and to sort twice by un-checking a box.
    - Generalizing by reclassifying small isolated pixel regions with this workflow: http://resources.arcgis.com/en/help/main/10.2/index.html#/Generalizing_classified_output_by_removing_small_isolated_regions/00nv00000010000000/
- Output was resampled to the LiDAR tree height raster resolution and snapped to the LiDAR raster, using majority method.
- Non-forested cells were reclassified to NoData. This raster was used to mask the LiDAR tree height raster to eliminate non-forested cells from the LiDAR tree height raster.
- The name of LiDAR Masked was given to the final LiDAR tree canopy height raster with non-forested pixels removed.

Forest Density Analysis

The GIS Division at OKI reclassified the LiDAR Masked raster where values 1 = forest and 0 = not forest. This raster was used as the input to the Focal Statistics tool, which calculated percent forest density using various neighborhood shapes and sizes, such as a 90-foot-by-90-foot square or a 90-foot-radius circle. OKI assigned the name *LiDAR ForestDensity* to these rasters. A value of 1 was assigned to areas where all (100 percent) of the cells in a neighborhood were found to be forested.

The cover of this report and Figure 1 on the next page have examples of the GIS imagery of forest density resulting from OKI's geoprocessing of LiDAR and infrared datasets.

Figure 1: Forest Density Image Based on OKI's Geoprocessing of LiDAR and Infrared Datasets

Environmental Field Study Methods

As described in its scope of work, OKI's Water Quality Program staff identified forested stream segments that may be affected by future development, but are not necessarily affected by current development. Here's how it was done.

First, the regional stream layer on OKI's geographic information system network was applied to two GIS maps (ArcMap Documents), 2012 Zoning.mxd and 2012 Existing Land Use.mxd. Then, the 2012 Zoning map with a stream layer overlay was printed to highlight areas still used for agriculture, but zoned for potential development. Then, the ArcMap files were methodically compared side by side. OKI staff noted stream segments that flow through areas that have agricultural land use but are zoned for residential, commercial, industrial, or public use. These stream segments were circled in pen on the printout of the 2012 Zoning map, assigned numbers, then listed on a number-key Microsoft Word document.

Having identified the general areas where stream segments, agricultural land use and development zoning overlap, OKI staff then examined real world conditions. Much of this work relied on aerial orthophotos, which are digitized on OKI's geographic information system network. Staff studied the aerial photo layer at a scale of 1:5,000 or less to locate areas with riparian tree canopy in relation to areas with development. Their proximity to each other served as the primary factor for identifying where future development may affect the forested stream segments. OKI used the ArcMap identification tool to provide the stream or tributary name, 12-digit Hydrologic Unit Code (HUC-12) watershed, political jurisdiction (city, village, or township), public or private land, acreage (using calculate geometry tool in the attribute table), and (if possible) potential wetland overlap of the identified areas. Land was assumed to be private unless located on or directly adjacent to current public park and preservation lands.

Next, OKI created a polygon shapefile layer to highlight specific areas where development is drawing nearer to fully functional riparian forests as indicated by aerial orthophotos. Polygon boundaries were established by consistent standards. For instance, wooded streambanks were excluded from further study if they exhibited fragmentation or low density. Additionally, if a large amount of tree cover existed beside a stream, not all of it was included within the polygon boundary if the tree canopy extended beyond what appeared to be the riparian corridor.

A shapefile of selected areas was then added to a map that included layers for tree canopy, stream network, watershed boundaries, county lines, inventoried wetlands, street centerlines, aerial orthophotos, and OKI's base map. An alternative map without the streets layer was also created to offer a better view of more natural features. This multi-layered map covered Butler, Clermont, Hamilton and Warren counties.

The final step for identifying areas of concern was to winnow the set of polygons based on more interpretive criteria, such as: relative proximity to roadways, thickness or width of riparian forest area, riparian forest loss to the clearing of an adjacent field, relative distance to parks or public areas, and other potential developmental disturbances. Roadways can facilitate development, especially where nearby fields have been cleared. Areas that were relatively low in tree canopy cover were less preferable. Polygon size was not a factor in considering which areas to select or eliminate. Most if not all selected areas provide more than adequate distance along a riparian corridor to conduct environmental field studies. Canopy density was a factor. The polygon construction phase eliminated most of the sparsely wooded riparian corridors.

Overall, OKI's site selection process for environmental field studies generated 52 riparian corridor candidate sites, which were winnowed down to 15 priority sites, from which OKI chose four sites for field check procedures. In alphabetical order, the four sites visited by OKI were:

- Dry Fork Whitewater River, in Hamilton County's Crosby Township. It is a Whitewater River tributary in the Howard Creek-Dry Fork Whitewater River subwatershed (HUC-12# 050800030808), which is part of the Whitewater River watershed (HUC-10# 0508000308).

- Jamison Run, in Warren County's Turtle Creek Township. It is a Turtle Creek tributary in the Turtle Creek subwatershed (HUC-12# 050902020803), which is part of the Turtle Creek-Little Miami River watershed (HUC-10# 0509020208).

- Mill Creek, in Butler County, in the City of Fairfield. The site is along the Mill Creek main stem in the East Fork Mill Creek-Mill Creek subwatershed (HUC-12# 050902030101), which is a part of Mill Creek watershed (HUC-12# 0509020301).

- Paddy's Run, in Hamilton County's Crosby Township. It is a tributary to the Great Miami River in the Paddy's Run subwatershed (HUC-12# 050800020903), which is part of the Taylor Creek-Great Miami River watershed (HUC-10# 0508000209).

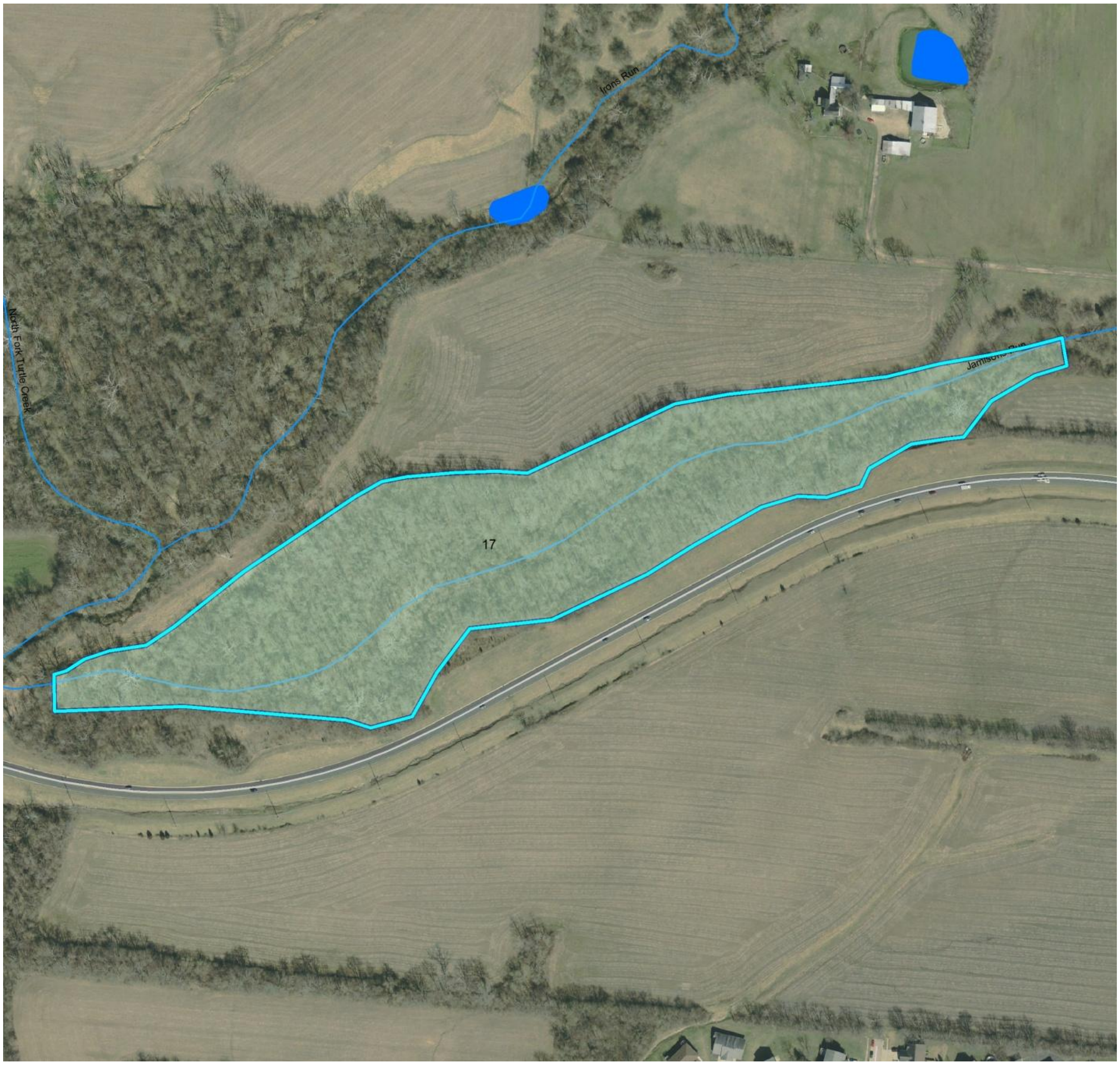
Figure 2 below shows the field check site along the Dry Fork Whitewater River, a western Hamilton County stream that may eventually lose parts of its broadly distributed riparian tree canopy to subdivisions. The stream reaches in the aerial orthophotograph below flow through private property. Other significant reaches of the Dry Fork Whitewater River flow through Miami Whitewater Forest, so they are under the protection of Great Parks of Hamilton County.

Figure 2: Dry Fork Whitewater River and Tributaries in Western Hamilton County

In Figure 2 above, Dry Fork Whitewater River is designated by the blue line that meanders from northwest to south. The odd-shaped polygon with a bright blue border represents the area where future development in Hamilton County's Crosby Township could further narrow the stream's corridor of riparian tree canopy. The bright blue, odd-shaped ovals are wetlands, as indicated by the National Wetland Inventory.

Figure 3 below shows the field check site along Jamison Run, a central Warren County stream that eventually may lose parts of its relative broad riparian tree canopy to continuing development in the Little Miami River drainage basin.

Figure 3: Jamison Run in the Little Miami River Basin in Central Warren County



In Figure 3 above, Jamison Creek is designated by the blue line that roughly runs parallel to the curving roadway. The odd-shaped polygon with a bright blue border represents the area where continuing development in Warren County's Turtle Creek Township may narrow the stream's relatively wide corridor of riparian tree canopy. The bright blue, odd-shaped ovals are wetlands, as indicated by the National Wetland Inventory.

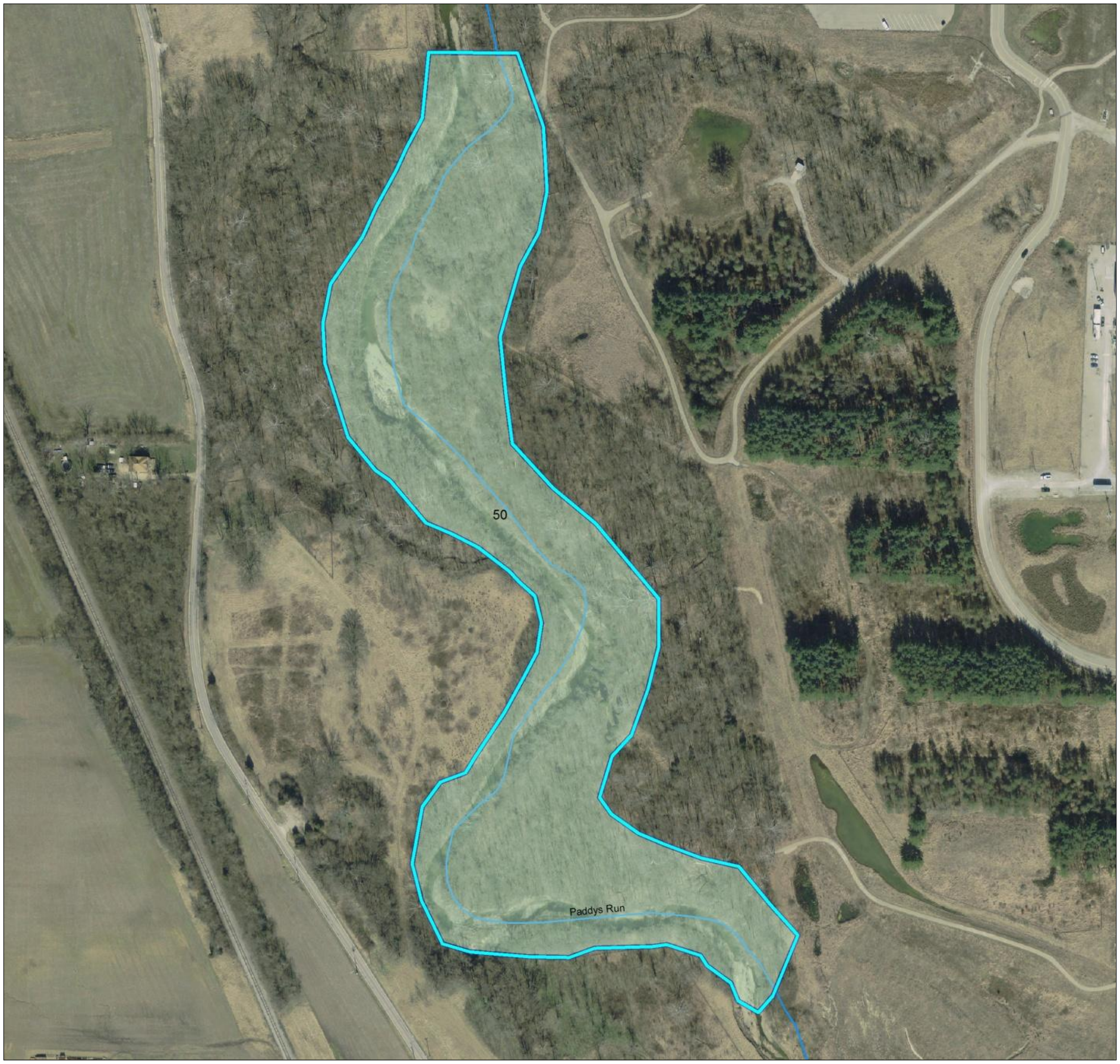
Figure 4 below is a zoomed image of the field check site along the Mill Creek. It was selected for further field study because the area shows a potential for future development that would encroach upon the stream's relatively narrow but enduring riparian corridor forest.

Figure 4: Mill Creek's Narrow Band of Riparian Forest in Butler County

In Figure 4 above, blue lines designate the Mill Creek (at an angle through the center) and an un-named tributary (curving channel to the southwest). The oblong polygon with a bright blue border represents the area where continuing Butler County development may one day further weaken or eliminate part of the upper Mill Creek's narrow band of riparian tree canopy.

Figure 5 below shows the field check site along Paddy's Run, a northwestern Hamilton County stream that flows into the Great Miami River. The stream may eventually lose parts of its broad riparian tree canopy to development in Crosby Township.

Figure 5: Paddy's Run in Northwestern Hamilton County's Crosby Township



Paddy's Run overlies a porous stream valley of sand and gravel. During warm weather dry spells, parts of the stream are reduced to a slow trickle or even a subterranean flow.

Field checks at the four sites depicted in Figures 2 through 5 allowed OKI staff to study reliability of the LiDAR dataset. The equipment necessary for such cross-checking consisted of: (1) two Haglöf Electronic Clinometers, (2) Trimble Geo XM global positioning system (GPS), (3) a 100-foot tape measure, and (4) a clipboard for taking notes, carrying maps, and serving as a bright white tree base marker that is visible through sparse vegetation from 100 feet away. With this equipment, OKI used the following procedure to build field study dataset for comparison to the LiDAR dataset:

1. Select a tree with a sizable drip line (i.e., foliage circumference) that has grown to the greatest or nearly the greatest height in its vicinity. This will make it easier to confirm proper identification of the same tree later on an aerial orthophoto.

2. Determine the tree's exact geographical coordinates (decimalized longitude and latitude) with Trimble Geo XM global positioning system (GPS). If the GPS operator must move away from the tree trunk to establish connection with the minimum of five GPS satellites, the direction and distance of the GPS offset should be noted to confirm proper identification of the tree's geographical coordinates later on an aerial orthophoto.

3. Walk 100 feet away from the tree to a spot where the tree's base is still within reasonable view. If this is not possible, try for a nearer spot that is no closer than 50 feet. A greater distance up to 100 feet affords more accuracy for the next step.

4. Upon finding a good measuring spot that is ideally 100 feet distant from the tree, use a clinometer to estimate the tree's height. Ensure that the clinometer is set for whatever distance the operator is standing from the tree, then take a reading.

5. To eliminate errors and increase accuracy, take three clinometer readings of each tree, then average the heights for a single figure that is recorded on the GPS unit. Another safeguard is to alternate between the two clinometers for each reading, provided that each clinometer is set to the proper distance away from the tree. To ensure that the clinometer operator is properly angling the clinometer toward the tree base with one eye while monitoring the clinometer readout with the other eye, it is useful to have a second person wave the white-clipboard at tree base level for easy sighting, especially in areas where honeysuckle bushes or other vegetation partially block a clear view of the tree base.

6. Find another tall tree and repeat steps 1 through 5 above. In moving from tree to tree, it is best to choose specimens that are at least 100 feet apart. This prevents confusion later when examining aerial photos of trees. Though geographical coordinates, related offsets, and tree height averages are recorded on the GPS unit, handwritten notes on all clinometer readings can prove to be useful later for data backup purposes.

7. Download and process the GPS data. This should set up a comparison of the LiDAR tree height reading to the clinometer tree height reading for each tree that was geo-referenced and measured in the field. An accurately projected geographic information system and recent aerial orthophotographs are needed for this analysis.

To achieve sampling data that is reasonably representative of the sampling site, OKI tried measuring 10 trees at each field check site. This was not always possible, especially in areas where obstructed views, natural barriers, poor satellite reception, a paucity of tall trees, chain link fences, or concerns about trespassing on private property existed.

Findings

Utility of the GIS Study Methodology

The utility of the GIS study methodology lies in good combinations. Through experimentation and analysis, the GIS Division at OKI has found that a LiDAR dataset can be combined with an infrared image dataset to create a useful tree canopy shapefile that provides:

- Tree canopy locations, shapes and sizes
- Tree canopy height ranges, which in turn indicate forested area age and maturity
- Relative tree canopy densities, which in turn indicate local ecotone, meaning the transition zone between forests and fields (*Wikipedia*). As illustrated above in Figure 1, the tree canopy shapefile shows where the ecotone is a gradual blending of forested and unforested areas, or where it may manifest itself in a narrower conversion area.

Much of the GIS methodology involves the geo-processing needed to achieve a productive combination of LiDAR and infrared imagery datasets. And much of the geo-processing relies on GIS tools that must be downloaded from or at least explained by online references. If Ohio EPA and other state agencies need technical guidance on how to apply ArcGIS and online geo-processing tools for tree canopy analysis, OKI has the capability to provide such guidance.

Longevity of the GIS study methodology is partly limited because GIS software is always in a state of frequent upgrades. The building blocks of this methodology, however, are more enduring. LiDAR and infrared imagery datasets may undergo further refinements, but their remote sensing fundamentals will persist. It is the geo-processing tools and procedures that keep evolving most often. When Ohio EPA and other state agencies learn of new GIS tools and techniques to better digitize different aspects of tree canopy, OKI would welcome advisories on such advances.

Utility of the Environmental Field Study Methodology

The utility of the environmental field study methodology is based on adaptability. During this project, OKI's Water Quality Program staff learned how to better characterize areas where riparian tree canopy is at risk from future development if it is not designed and managed properly. The factors for such a characterization are:

- zoning classification
- existing land use
- areas where the zoning classification allows for more intensive land use than the current land use
- the overlap of forested stream corridors with lightly developed areas that have zoning classifications to allow more intensive land use
- continuity versus fragmentation of the riparian forest
- width of the riparian forest
- apparent density of the riparian forest
- proximity of roads that can attract or at least facilitate further development, especially new roads
- location amidst two or more nearby roads
- proximity of excavations and fields that already have been cleared of riparian forest
- proximity and acreage of private land, which is expected to be more likely to develop
- proximity of residential subdivision development, especially more recent subdivisions

While conducting environmental field studies of the GIS study methodology, OKI staff learned techniques for characterizing riparian tree stock. The techniques for characterizing riparian tree stock can be applied to:

- prioritizing issues for watershed studies
- proposing project sites for watershed action plans
- preparing better grant applications for stream restoration projects
- implementing projects that use or supplement tree stock

Integrating Both Methodologies

When they are well integrated with each other, the GIS and environmental field study methodologies show potential for improving water quality management planning at various scales – from a site specific restoration project on up to a regional plan. For the employees of OKI's Water Quality Program and GIS Division, the overriding goal was to find ways of blending diverse knowledge bases into a useful product. In so doing, they learned a few lessons.

Lessons Learned

Clinometer Confidence

Despite the manufacturer's detailed instructions, OKI staff learned that use of the Haglöf Electronic Clinometer can be challenging for a novice operator. Several practice rounds in the field gradually trained staff how to: (1) properly interpret the messages on the clinometer's encased display screen, (2) initiate the next clinometer function with a firm press of a button or a long pause, (3) hold the clinometer steady at the correct position at certain moments while measuring angle and then height, (4) lock in the clinometer's reading once the proper position is reached, (4) adjust the clinometer's distance setting in cases where it was not possible to stand 100 feet away from the tree, and (5) read the clinometer's encased display screen with near vision in one eye while using far vision in the other eye to aim the clinometer at the tree base and then the tree crown. OKI gained confidence in its operation of the Haglöf Electronic Clinometer after a training session with a field representative of the Ohio Department of Natural Resources, Division of Forestry. The state forester taught OKI staff how to lock in readings and explained the rationale of several intermediate steps. Most importantly, the state forester compared his mechanical clinometer readings to OKI's electronic clinometer readings and confirmed that both devices were computing virtually the same tree heights.

LiDAR Tree Heights Versus Clinometer Tree Heights

LiDAR tree height readings were shorter than clinometer tree height readings for all but one of 30 trees that OKI measured with field checks on April 16, 2014. OKI staff ultimately attributed this consistent difference to three major factors:

1. Remote LiDAR sensing occurred during a season when the deciduous trees did not have leaves. The LiDAR readings, accordingly, were not of the tree's topmost peak but of a somewhat lower level where the tree's branches or trunk had enough critical mass to trigger a LiDAR point reading. The clinometer tree height readings, on the other hand, top out at tree crowns, as interpreted by the human eye.
2. The LiDAR readings were remotely sensed from an airplane in 2007. The clinometer readings were measured from the ground in 2014. It was natural for the clinometer readings to consistently exceed the LiDAR readings, because the clinometer readings were based on seven more years of growth in tree height.

3. Because the LiDAR readings were remotely sensed from an angle, they did not always signify the height of the tallest tree within the 30-foot-by-30-foot cell later applied by the GIS Division at OKI. Clinometer readings, on the other hand, were derived from on-the-ground searches for tall trees within a 100-foot radius. Despite the field verification of tree locations with a Trimble Geo XM global positioning system, it appears that the clinometer operator measured a different tree than LiDAR did seven years ago in a few cells where the LiDAR-based tree height diverged widely from the clinometer-based tree height.

For the reasons above GIS staff at OKI did not take issue with the difference in LiDAR and clinometer tree height readings. They saw more significance in the fact that clinometer readings consistently accounted for seven years of tree growth with greater tree heights. The GIS staff also noted that the GIS study methodology and the environmental field study methodology located tree canopies in the same areas with only minor differences.

Operating the GPS in the Field

While operating the Trimble Geo XM global positioning system (GPS) in the field, OKI staff occasionally had trouble establishing simultaneous reception with five GPS satellites, which was lowest number of satellites for assigning geographical coordinates to a tree being measured. At five of the 30 trees assigned to geographical coordinates, OKI staff found it necessary to hold the GPS unit several feet away from the tree trunk to establish reception with at least five GPS satellites. Staff noted the distance and general direction of the offset, then later advised the GIS Division at OKI that offset metrics gave the distance and direction of the GPS from the tree, not vice versa. In dealing with offsets, OKI staff learned that a simple compass would have been handy in the field for more accurately detecting offset direction.

Avoiding Rough Terrain

Narrow stream corridors between steeply sloped, tall ridges proved most troublesome to OKI's efforts to establish simultaneous reception with five or more GPS satellites. Preliminary practice runs with the Trimble Geo XM global positioning system taught OKI staff the lesson that better reception can be achieved in gentler terrain. This influenced OKI to select field check sites with lower or more distant ridges and broader stream valleys. At one of the field check sites, OKI also learned that GPS readings should not be attempted near power lines, substations and other sources of electrical interference.

<u>*Other Tree Canopy Studies*</u>

While implementing this project, OKI became aware of two other recent tree canopy studies in the Tri-State area. In January 2011, Cincinnati Parks and other project partners completed *Cincinnati & Hamilton County, Ohio, Urban Tree Canopy (UTC) Assessment*. In December 2013, the Northern Kentucky Urban and Community Forestry Council won a grant from the U.S. Forest Service to develop land classifications and forest canopy data for Kenton, Campbell, and Boone counties. The major difference between the OKI study and the other two studies is land use analysis. *Relative Densities of Tree Canopy in Butler, Clermont, Hamilton and Warren Counties, Ohio* operates from a simple binary logic: *Is an area forested or non-forested?* The other two studies delve deeper into the question by distinguishing multiple classes of land use and land cover. It should also be pointed out that the OKI study should not be regarded as a tree canopy inventory, meaning it does not specify tree species.

Recommendations

Renewed Datasets

OKI recommends that Ohio renew its LiDAR and infrared image datasets. Non-native insects have decimated a lot of tree canopy since the state last assembled these datasets in 2007. Emerald ash borers were first spotted in Warren County in 2006 and Southwest Ohio lost a significant amount of its ash trees during the eight years that followed. The problem with insect infestations continues. Conservationists found the Asian long-horned beetle in Clermont County in June 2011 and discovered the walnut twig beetle in Butler County in late 2012. While the emerald ash borer and the Asian long-horned beetle kill trees with trunk boring, the walnut twig beetle infects trees with a fungus that causes the deadly, incurable thousand cankers disease. Insect pests and fungal tree disease may be turning the 2007 datasets into historical files rather than indicators of current conditions.

Economic development is another reason for renewing the LiDAR and infrared datasets. Now that the nation and the OKI region are rebounding from the Great Recession, development is reviving. Some of the development has probably occurred or will occur in areas that registered as forest in the LiDAR and infrared image datasets of 2007.

Additional Equipment

OKI recommends that future studies should consider the use of a laser range finder, especially one that is pre-programmed to measure tree heights. Such a device can accelerate tree height readings or at least confirm clinometer readings. The cost of a laser range finder, however, can be prohibitive in comparison to the minor expense of a clinometer and tape measure. Another possible drawback to the laser range finder is that it may not always accurately measure the distance to a tree crown that is leafless and sparsely branched. The laser range finder seems more appropriate for the seasons when deciduous trees are in leaf.

If a future study seeks more detailed information on tree canopy density over a relatively small area, it may need a periscope-like device known as the Cajanus tube. This ground-truthing device provides vertical views of overhead leaf and branch cover for a statistical analysis of tree canopy percentages. The drawback to this piece of equipment is that field measurements with a Cajanus tube are time consuming and expensive.

Sharing OKI's Methodology with Others

Essential components of *Relative Densities of Tree Canopy in Butler, Clermont, Hamilton and Warren Counties, Ohio* are not contained in this document but digitized in GIS files. Because such files are too large and complex to share by email attachment, OKI recommends that users of the GIS files make arrangements with OKI to get the data in one of three ways: (1) from OKI's ftp (file transfer protocol) site, (2) through an online ftp service, such as www.dropbox.com, or (3) from a CD mailed by OKI in the user's self-addressed and stamped envelope. As stated in Findings, if the Ohio EPA or other state agencies need technical guidance on how to apply OKI's tree canopy methodology, OKI has the capability to provide such guidance.