**technical memo**

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|---|---|---|---|
| **Project Name** | LSCWP Tree Canopy Assessment Protocol | **Date** | 7/15/22 |
| **To / Contact info** | Craig Mell, Chisago SWCD<br>Mike Isensee, CMSCWD | | |
| **Cc / Contact info** | LSCWP Subcommittee A8 Members | | |
| **From / Contact info** | Paula Kalinosky, EOR<br>Sarah Voje, EOR | | |
| **Regarding** | Tree Canopy Assessment for Street Sweeping Prioritization – Final Report | | |

## Tree Canopy Assessment Protocol for Enhanced Street Sweeping Prioritization

In December 2021, the Lower St. Croix Water Partnership (LSCWP) hired EOR to develop methodology to assessment street corridor tree canopy for use in planning street sweeping practices. The methods described in this memo have been developed to help municipalities identify and prioritize areas within their jurisdiction for enhanced street sweeping practices using GIS data sources that are widely available and analysis methods that do not require advanced software or special training. The method was developed for the LSCWP initiatives plan to improve water quality in the Lower St. Croix region. This plan includes goals for implementation of non-structural BMPs like street sweeping.

## 1 Background and Definitions

In this section we provide a brief summary of the rationale for enhanced street sweeping based along with a discussion of key terms. The information in the section is based on research conducted by the University of Minnesota in 2011-2013 for the Prior Lake, MN Street Sweeping Study (see References and Works Consulted).

*What is Enhanced Street Sweeping?*

Most municipalities sweep streets in the spring to remove accumulated sand and tracked sediment that collects during the winter months. This process is typically repeated in the fall to reduce leaf litter on street surfaces. Enhanced street sweeping is simply additional sweeping protocols that are completed for surface water quality protection and other potential benefits (Table 1).

*What is Street Corridor Tree Canopy?*

As a concept, street corridor tree canopy includes trees located within right-of-way areas and front yards or other areas that are likely to contribute leaf litter and duff to road surfaces. For the purpose of this the assessment outlined in this memo, street corridor tree canopy is defined as canopy cover located within the road right-of-way plus 10 feet. This choice is discussed further in Section 2.1.3

*Why Assess Street Corridor Tree Canopy Cover?*

Solids that collect on road surfaces include organic litter from trees like leaves, pollen, seeds, and other duff. These inputs to street surfaces are obvious during fall leaf drop but can be a significant source of nutrients in accumulated solids at other times during the growing season (Kalinosky, 2015).

*Aren't Trees 'Good' for Water Quality?*

Yes, trees provide multiple benefits including reducing stormwater runoff, reducing pollutants in runoff, and moderating heat island impacts from impervious surfaces like roads in urban areas.

**Table 1. Benefits of street sweeping and factors that influence the effectiveness and cost-effectiveness of street sweeping programs.**

| Benefits of Street Sweeping (Objectives) | Factors that Influence: | |
|---|---|---|
| | **Accumulation of Solids on Road Surfaces** | **Cost-Effectiveness of Street Sweeping** |
| • Aesthetics (clean streets) | • Adjacent land use | • Accumulated Solids: |
| • BMP maintenance benefits (L) | • Construction activity | o Location of sweeping |
| • Driver and pedestrian safety (S) | • Local topography | o Frequency of sweeping |
| • Local flood control (clogged catch basins) | • Roadway traffic volume | o Timing of sweeping |
| • Surface water quality | • **Tree canopy density (This Study)** | • *Objectives for Sweeping* |
| • Pavement management (L) | • Weather | • Sweeper Financing/Ownership |
| | • Winter road practices | • Sweeper Type |

*= Benefits, and implementation factors that are associated to tree canopy*
*(L) = Sparse research available*
*(S) = Seasonal benefit*

## 2 Tree Canopy Assessment Methods

<u>Quantitative Assessment</u>

Tree canopy cover can be assessed quantitatively through geospatial analysis if mapped tree canopy cover data are available for the area of interest. In the method described in Section 2.1, street corridor areas are defined using road centerline data and right-of-way widths. Mapped tree canopy cover is then intersected with defined corridor areas to calculate a percent tree canopy cover over for each street. This assessment method is most efficient for municipalities located within the 7-County Twin Cities Metropolitan Area and other metropolitan areas for which high resolution land cover data are available (e.g., Duluth, Rochester).

Parameters and recommended methods for quantitative assessment of tree canopy cover are discussed in Section 2.1.

<u>Qualitative Assessment</u>

For small municipalities or neighborhood-scale analysis, qualitative assessment of tree canopy cover may be more efficient than geospatial analysis and quantification. Tree canopy cover can be inspected visually using recent aerial photographs or other satellite imagery along with a visual guide to classify canopy cover at a neighborhood or development scale. This method is outlined in Section 2.2.

## 2.1 Quantitative Assessment of Street Corridor Canopy using Geospatial Analysis

### 2.1.1 Municipalities inside the 7-County Metropolitan Area (TCMA)

For municipalities located with the TCMA, mapped tree canopy data are available in raster format through the Minnesota Geospatial Commons. The TCMA 1-Meter (horizontal resolution) Urban Tree Canopy Classification data set distinguishes deciduous and coniferous tree canopy from buildings, bare soil, paved surfaces, and 7 other land cover classifications.

This data set was developed in 2015 by the University of Minnesota Remote Sensing and Geospatial Analysis Laboratory for the purpose of evaluating existing tree canopy cover, particularly where tree canopy overhangs buildings, roads, parking areas and other impervious surfaces.

Because tree canopy cover is not static – trees mature, are removed to develop land or because they are damaged, tree canopy density estimates developed using mapped canopy cover will include some inaccuracies. These are especially accentuated in areas of recent development. In the context of planning street sweeping, these inaccuracies are generally tolerable, though some manual correction may be needed where development has occurred few years before 2015 or after 2015. Examples of 2015 TCMA mapped canopy vs. aerial imagery are shown in Figure 1.

Other land cover data sets typically prioritize impervious surfaces to define roads, buildings, and other paved surfaces (e.g., TCMA High Resolution Land Cover) or to characterize land cover in urban areas using composite values. For example, urban areas are classified using percent impervious rating in the Minnesota Land Cover Classification System (MLCCS). The same areas may be classified as Low-, Medium-, or High-Intensity Developed land cover in the National Landcover Database (NLCD).

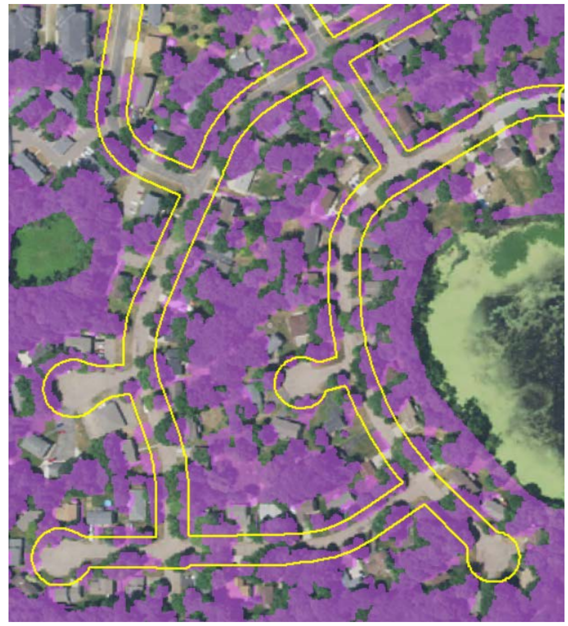
### 2.1.2 Municipalities outside the TCMA

For municipalities outside the 7-County TCMA, mapped tree canopy data are not readily available. Canopy data sets can be developed using false color imagery in combination with LiDAR data that has been processed to reveal bare earth points. This method was used by the University of Minnesota to develop the TCMA 1-meter Urban Tree Canopy data set described in the previous section. While the data required to perform this analysis are available through various government agencies, the methodology requires advanced GIS analytics which are outside the scope of this protocol. Additional information about the methodology is available through the University of Minnesota Digital Conservancy: [https://conservancy.umn.edu/handle/11299/183470mn](https://conservancy.umn.edu/handle/11299/183470mn)

See Section 2.2 for further discussion of tree canopy cover assessment for areas outside the 7-county TCMA.

**2015 TCMA Mapped tree canopy cover data is most accurate in areas with mature trees where development has not occurred in the last decade.**

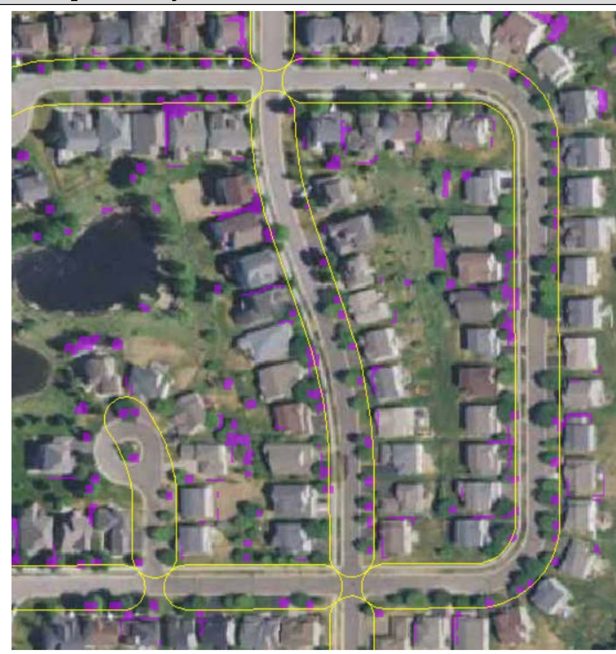
2021 Aerial Imagery (NAIP, Natural Color) in an area of mature tree canopy, Prior Lake, MN



2021 Aerial Imagery with 2015 TCMA mapped tree canopy overlay shown in purple

**Tree canopy data may be out-of-date in areas developed few years before 2015 or after 2015**

2021 Aerial Imagery - In areas developed in 2015 or later, mapped tree canopy cover (purple) may include trees that have since been removed.



2021 Aerial Imagery - In areas developed before 2015, mapped canopy cover (purple) may not be totally representative of current canopy cover.

**Figure 1. Comparison of aerial imagery and 2015 tree cover (TCMA High Resolution Land Cover Data).**

### 2.1.3 Defining boundaries for assessment of street corridor tree canopy

For assessing potential leaf litter and organic inputs to street surface, we recommend quantifying tree canopy at the roadway right-of-way distance plus an additional 10 feet. This recommendation is based on finding from the Prior Lake Street Sweeping Study (Kalinosky, et. al., 2013). When assessed at different buffer distances from the street, correlations between tree canopy cover and recovered pollutant loads tended to increase with increasing distance from the street up to about 20 feet from curb lines (or 10 feet from the right-of-way). Appendix B shows these results numerically and graphically. Figure 2 illustrates that the percentage of tree canopy increases significantly (3% to 26%) when the curb line footprint is expanded by 20 feet. After 20 feet, the percentage of canopy cover increase is relatively small (i.e., 26% at 20 feet and 32% at 50 feet).

Using the boundary width of the right-of-way distance plus an additional 10 feet was considered appropriate for the following reasons:

- Reduced error in estimates compared to smaller assessment corridors – the data sets used in this assessment each contain some amount of error and error accumulates as data sets are clipped and intersected with one another. For raster data, like the tree canopy data used in this assessment, error will increase as feature scale approaches the raster resolution.
- Extending the assessment boundary into front yard areas help account for leaves and organic litter transported to street surfaces by wind and runoff, rather than just what falls onto the street directly.
- Many developed area retain wooded areas in backyard. Including areas like this, which are less likely to contribute organic litter to road surfaces when compared to front yards, may artificially inflate street corridor canopy estimates in some areas, especially newly developed areas.

**Figure 2. Percent tree canopy cover quantified over and within variable distances from the curb line.**

| Tree canopy cover within curb line ~3% | Tree canopy cover within curb line plus 10 feet ~ 16% |
| --- | --- |
|   |  |
| Tree canopy cover within curb line plus 20 feet ~ 26% | Tree canopy cover within curb line plus 50 feet ~32% |
|  |  |

### 2.1.4 Geospatial Analysis for Assessment of Street Corridor Tree Canopy Cover

There are several different methods that can be used to quantify tree canopy cover for defined corridors. A limiting factor for all methods is availability of data sets characterizing the extents of tree canopy. Depending on what tree canopy data is available (if any) for the area of interest, the assessment will be more or less complex. The method summarized below is one that uses public data sets that are readily available and commonly used in water/natural resources planning, analysis, and mapping. This method was chosen for its simplicity and adaptability of the end product for use in different street sweeping prioritization exercises.

#### *2.1.4.1 Recommended workflow for simple quantification of street corridor tree canopy cover.*

The workflow summarized below is shown diagrammatically in Figure 4. These are the Workflow steps:

**Identify and isolate candidate roads**

1) Where available, begin the analysis using road centerline data maintained by the municipality. If county or state-level data are used, the fist step is to refine the data set to eliminate roadways owned by other jurisdictional entities:
    A. Clip road centerline data using the applicable municipal boundary.
    B. Select roads segments by jurisdiction using the MNDOT Route System Code ('ROUTE_SYS' attribute) that is shown in Appendix C. The route system code for municipal streets is number '10'. Other route system codes (e.g., 05 Municipal State Aid Street) may be applicable depending on individual context.
    C. Inspect Road data, remove duplicate linework if coincident segments are present.

**Determine the extents of tree canopy quantification**

Using minimum (local ordinance) or typical right-of-way widths (Table 2), assign centerline buffer distances to define the extents of the tree canopy assessment.

2) For road centerline data that do not include an attribute describing the functional classification OR the ROW width:
    A. Add a text field to classify road segments by functional class. Review data for attributes that can serve as a proxy for functional class (e.g., lane width, speed limit).
    B. If no suitable proxy attributes are included in the data, functional class can be added through visual inspection. It may be easier to identify primary throughfare or high capacity routes visually using satellite/aerial imagery in combination with roadway names. Remaining roads can then be assigned an 'uncategorized' function class (Table 2).
    C. Assign function class based on proxy attribute or manual selection.

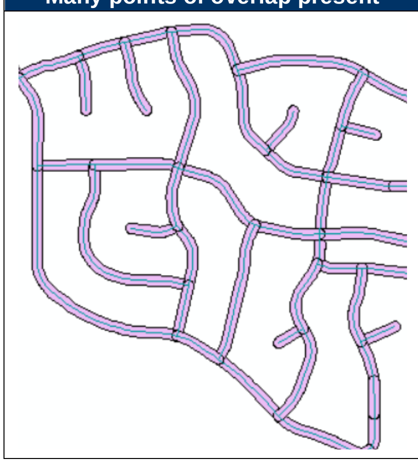
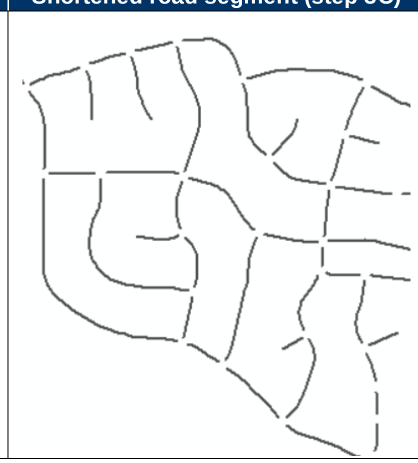
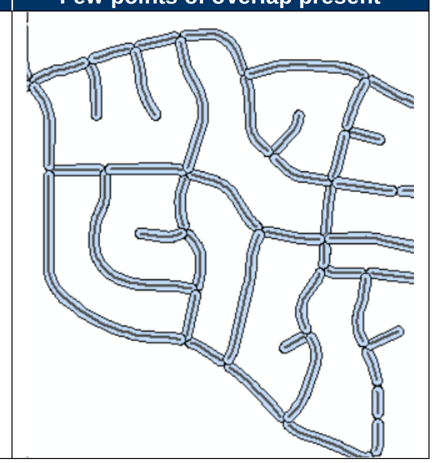
3) If road centerline data do include a functional class, but do not include ROW width data:
    A. Add a new double field, 'ROW,' to the attribute table in the municipal road data set defined in step 1C.
    B. Assign ROW width based on the function classification using minimum ROW widths from local zoning code, engineering standards, or the recommended values in Table 2.

Table 2. Recommended road centerline buffer distance for street corridor canopy assessment.

| Road Type (Functional Class) | Typical ROW Width (feet) | Assessment Boundary | Recommended Centerline Buffer Distance |
|---|---|---|---|
| Major or Minor Arterial | 150 | | 85 feet |
| Collector (neighborhood or other) | 80 - 120 | | 60 feet |
| Commercial or Industrial Service Street | 80 | ROW + 10 feet on either side | 50 feet |
| Local Road | 50 - 60 | | 40 feet |
| Uncategorized (classification or suitable proxy attribute not available) | 50 - 80 | | 50 feet |

4) Calculate centerline buffer distance for canopy assessment
   A. Add a new double field, 'Buffer' to the road centerline data from step 3B.
   B. Select the 'Buffer' attribute field and assign values using the 'Field Calculator' tool. Set the field value to = 0.5 *[ROW] + 10 (one-half the ROW width plus 10 feet).
   C. Geoprocessing – buffer the road segments layer using the 'by field' buffer distance assignment option.

Table 3. Example of intermediate buffer polygons (left) shortened road segments (middle), and refined buffer polygons (right) described in steps 4C, 5A, and 6C.

| Initial buffer polygons (step 2D), Many points of overlap present | Shortened road segment (step 3C) | Refined buffer polygons (step 3D), Few points of overlap present |
|---|---|---|
|  |  |  |

### Refine buffer polygons

5) Buffering line segments, like road centerline, which intersect one another, will produce buffer polygons that overlap at intersections and road segment breaks. Buffer polygons should be 'cleaned' to eliminate double counting tree canopy in the assessment. The following is one simple methods for clean polygon buffers.
   A. Intersect the road segment data from Step 1C with the buffer polygons created in step 4C. This will produce a road centerline data layer with all of the attributes assigned in steps 3 and 4, but with breaks at intersections with buffer polygons as well as centerline intersections.

6) Eliminate road segment within buffer overlap zones:
   A. Calculate the length of the road segments produced in the step 5A.
   B. Select all road segments that have a length less than or equal to the longest specified buffer distance calculated in step 4B. Delete these segments.
   C. Buffer the remaining road segments using the buffer distance attribute. This will produce buffer polygons with no overlap. Gaps on the order of 10 feet may be present at some locations, but for the purpose street sweeping prioritization, these gaps will not introduce significant error in canopy density estimates.

**Process tree canopy data**

7) The 7-County TCMA Urban Tree Canopy data set is quite large. To reduce processing times, clip the data set to the area of interest.
   A. Use ‘Extract by Mask’ to clip the TCMA tree canopy raster to the applicable jurisdictional boundary.
   B. Use the ‘Reclass’ tool to reclassify the ‘Value’ field, replacing the value ‘6’ for coniferous tree canopy with ‘1’ and reclassifying all other values as 0.
   C. (Optional) If available, burn in tree inventory points to the raster
      i. Use ‘Rasterize’ tool to assign all tree points as 1 and remaining points null or 0
      ii. Use ‘Raster Calculator’ to burn in or replace any pixels in the Tree Canopy Raster that have tree inventory points associated with them to 1, indicating tree presence.

**Calculate % canopy cover**

8) Overlay tree canopy data and buffer polygons to determine % canopy cover within each polygon.
   A. Using the buffer polygons created in step 6C and the reclassified tree canopy raster from step 7B (if using tree inventory data, use raster from 7C), run the ‘Zonal Statistics’ tool to calculate the count and sum of tree canopy cover within street corridor areas.
   B. Add a new field, ‘canopy, type = float, to the new layer produced in step 8A.
   C. Calculate the percent canopy per road polygon by taking area occupied by tree cover (sum) divided by the area of the road polygon (count).

### Refine symbology

9) Use symbology to highlight differences in street corridor canopy visually. An example is shown in Figure 3.

| Tree canopy raster produced through raster reclassification (step 7B) overlaid by buffer polygons (step 6C). | Street corridor tree canopy buffer polygons, symbolized to show % tree canopy cover categorically (steps 8 & 9). |
|---|---|

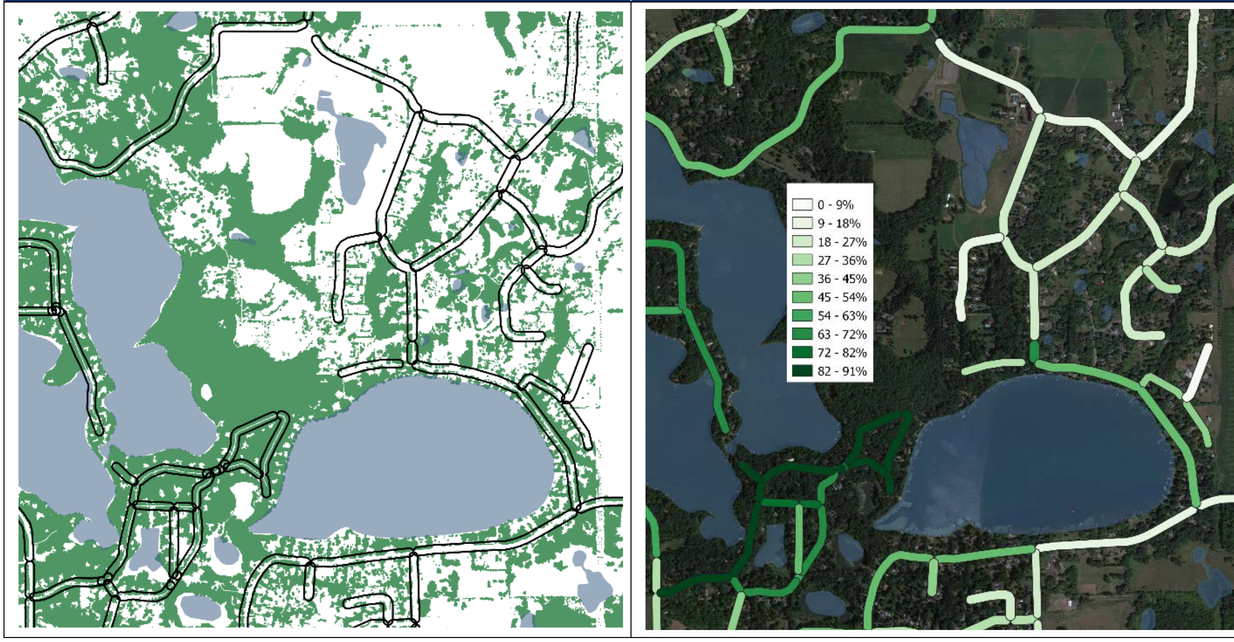



**Figure 3. Tree canopy raster overlaid by buffer polygons (left) and canopy cover buffer polygons with symbology applies to show canopy ratings visually (right).**

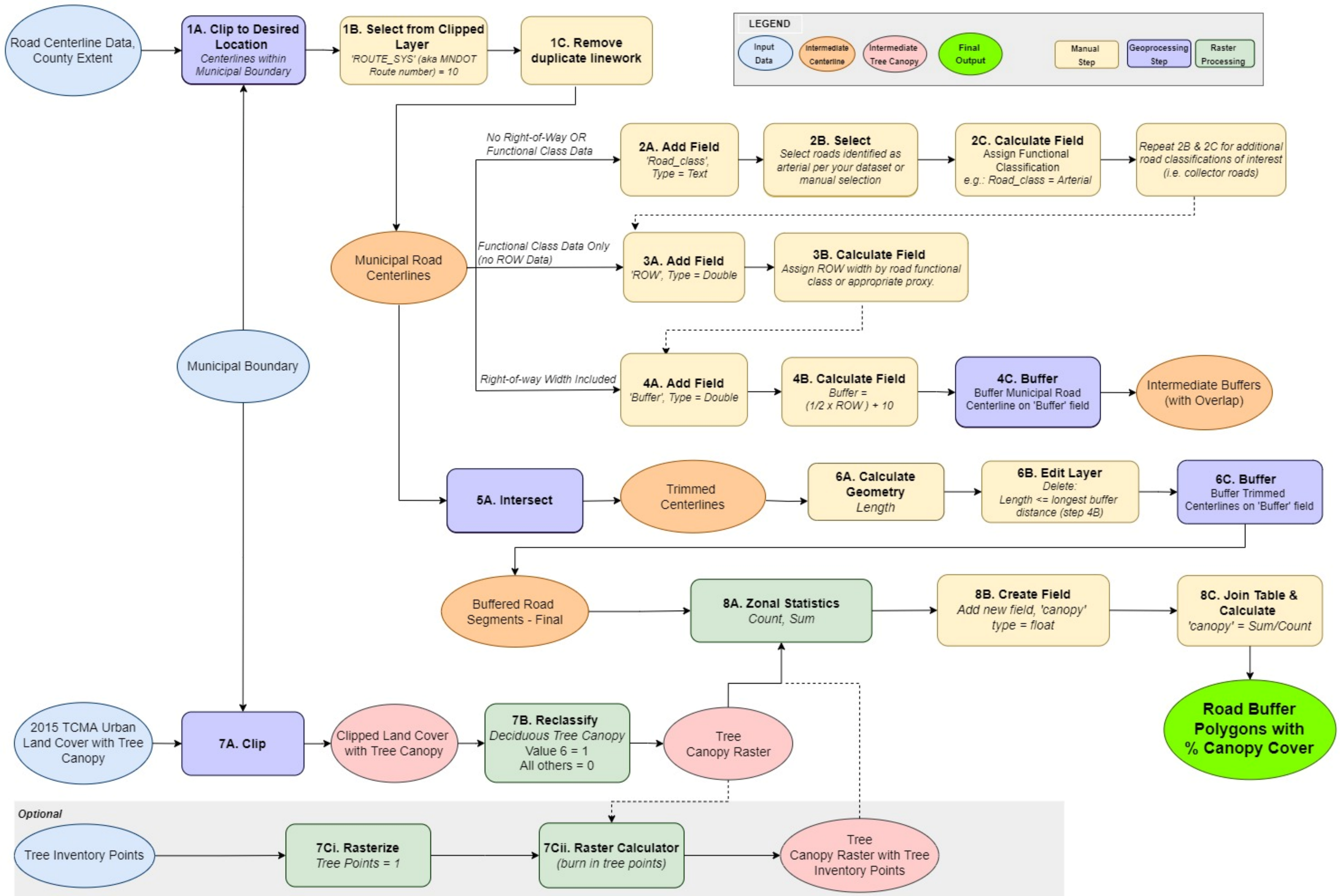



**Figure 4. Workflow diagram for simple quantification of street corridor tree canopy cover using geospatial analysis.**

#### 2.1.4.2 *Recommended Data Sources for Geospatial Analysis of Tree Canopy*

The following data were used in developing the workflow outlined in Section 2.1.4.1. These data sources were chosen because are publicly available, are developed by reliable state and local agencies, and are commonly used in mapping and analysis.

**Table 4. Summary of recommended data sources for geospatial analysis of street corridor tree canopy cover.**

| | |
|---|---|
| **Tree Canopy** | |
| Inside the Twin Cities Metropolitan Area | |
| Data/Source | '2015 Twin Cities Metropolitan Area (TCMA)Urban Tree Canopy Assessment, University of MN'<br>Download available on MN Geospatial Commons |
| Format | Raster, 8-bit GEOTIFF, 1m x 1m pixels |
| Extent | 7-County TCMA |
| Description | 1-Meter high resolution urban land cover classification data set that is optimized for tree canopy mapping. In places where tree canopy overhangs an impervious surface such as a street, the canopy edge mapped rather than the impervious surface. |
| Comments | The data were developed using NAIP imagery from 2011 (fall) and 2015 (summer) and lidar from 2011.<br>• Data accuracy is highest in areas with mature tree canopy.<br>• Where development has occurred few years before 2015, canopy data may be less accurate and should be inspected by comparing to recent aerial photographs.<br>• Data can be supplemented with local tree inventories where available. |
| **Note**: High resolution land cover data for the TCMA is also available in an impervious surface-focused format which prioritizes impervious surface edges over canopy. This version can also be used to assess ROW canopy. Users should be aware that canopy covers values derived through the geoprocessing using the impervious surface-focused version will be somewhat lower than those derived from the TCMA Urban Tree Canopy layer. | |
| Outside the Twin Cities Metropolitan Area | |
| Data/Source | National Agricultural Imagery Program (NAIP) Color Infrared Imagery, raw LiDAR data for the area of interest |
| Format | Raster |
| Extent | County |
| Description | False color high-resolution imagery (1-meter or better) developed from aerial imagery acquired during the growing season. |
| Comments | Special methodology, see University of Minnesota Digital Conservancy:<br>https://conservancy.umn.edu/handle/11299/183470mn |
| **Roadway Centerline Data Sets** | |
| #1 choice | Data maintained by the county of municipality of interest. Key attributes used in this analysis include:<br>• jurisdiction (state, county, local, private)<br>• municipal classification (e.g., arterial, collector, local) or the ROW width. |
| #2 choice | MnDOT Route Centerlines (Statewide). This data set is reliable, but some additional processing may be needed to isolate road of interest when compared to county or local data sets. |
| Format | Vector, typically polylines with breaks at intersections, start/end of curves, changes in jurisdiction or name, and at expansion/contraction in lane number |

| | |
|---|---|
| Extent | Varies depending on jurisdiction |
| Description | Typically shows centerlines of public and some private roads within extents of the data set. It may also include attributes to describe road type, number of lanes, length, name, jurisdiction of roadway, width, etc. |
| Comments | Road centerline data are available statewide and at the county level for most Minnesota counties through the Minnesota Geospatial Commons. Some municipalities maintain geospatial records of local, municipal roads that is available upon request. |
| **Municipal/Jurisdictional Boundary** | |
| Data/Source | 'City, Township, and Unorganized Territory in Minnesota'<br>MN DOT and Minnesota Geospatial Information Office<br>Available through the MN Geospatial Commons |
| Format | Vector |
| Extent | Statewide |
| Description | Dataset represents the boundaries of cities, townships, and unorganized territories (CTUs) in Minnesota |

## 2.2 Visual Assessment of Tree Canopy using Aerial Imagery

For small municipalities, visual assessment of street corridor tree canopy may be more cost effective than geospatial analysis. Tree canopy cover characteristics tends to be fairly homogenous within development boundaries. Also, developments of similar age often concentrated geographically. Likewise, zoning ordinances, which dictate allowable land cover changes by land use, often have the effect of producing large areas within which tree canopy characteristics are similar. These development patterns and the tree canopy characteristics associated with them are discernable on aerial imagery (see Figure 7 in Appendix A).

Visual assessment, streets should be assessed at a development, neighborhood, or zoning scale (or combination thereof) using a categorical tree canopy rating to describe canopy cover. Canopy cover estimates, whether derived quantitatively as described in Section 2.1.4.1 or through Canopy cover estimates - whether derived quantitatively as described in Section 2.1.4.1 or through visual assessment, can be clipped or aggregated to derive average canopy cover for larger or small areas of interest using area-weighting.

Visual examples of quantified street corridor canopy are provided in Appendix A: Guide for Visual Assessment of Street Corridor Tree Canopy. A recommended rating scale (low, moderate, medium, high, or very high) is paired with neighborhood-scale examples that are categorized by average percent tree canopy cover within the area shown.

Canopy cover estimates or rating derived through this method can be added as an attribute to road centerline data sets and used in street sweeping prioritization exercises (Section 3). A sample workflow for integration of visual assessment in street sweeping prioritization is outline below. The workflow is shown diagrammatically in Figure 5

Workflow Summary

**Identify and isolate candidate roads**

1) *See description in Section 2.1.4.1*

**Group roads by land use zoning type** *(Optional)*

*2)* For visual assessment of tree canopy, it may be useful to assign a land use classification to road segment by intersecting municipal roads and municipal zoning boundaries. This field can be used to refine selections in step 3.

**Assign Tree Canopy Rating**

*3)* For visual assessment of tree canopy cover, NAIP true color aerial imagery is preferred to:

A. Add a new text field, 'Canopy' to the road centerline layer.

*B.* Select roads within areas are that have similar tree canopy cover characterizes and assign a canopy rating using the visual comparisons provided in Appendix A.
*Repeat Step 3B as needed until all roads have been assigned a tree canopy rating.*

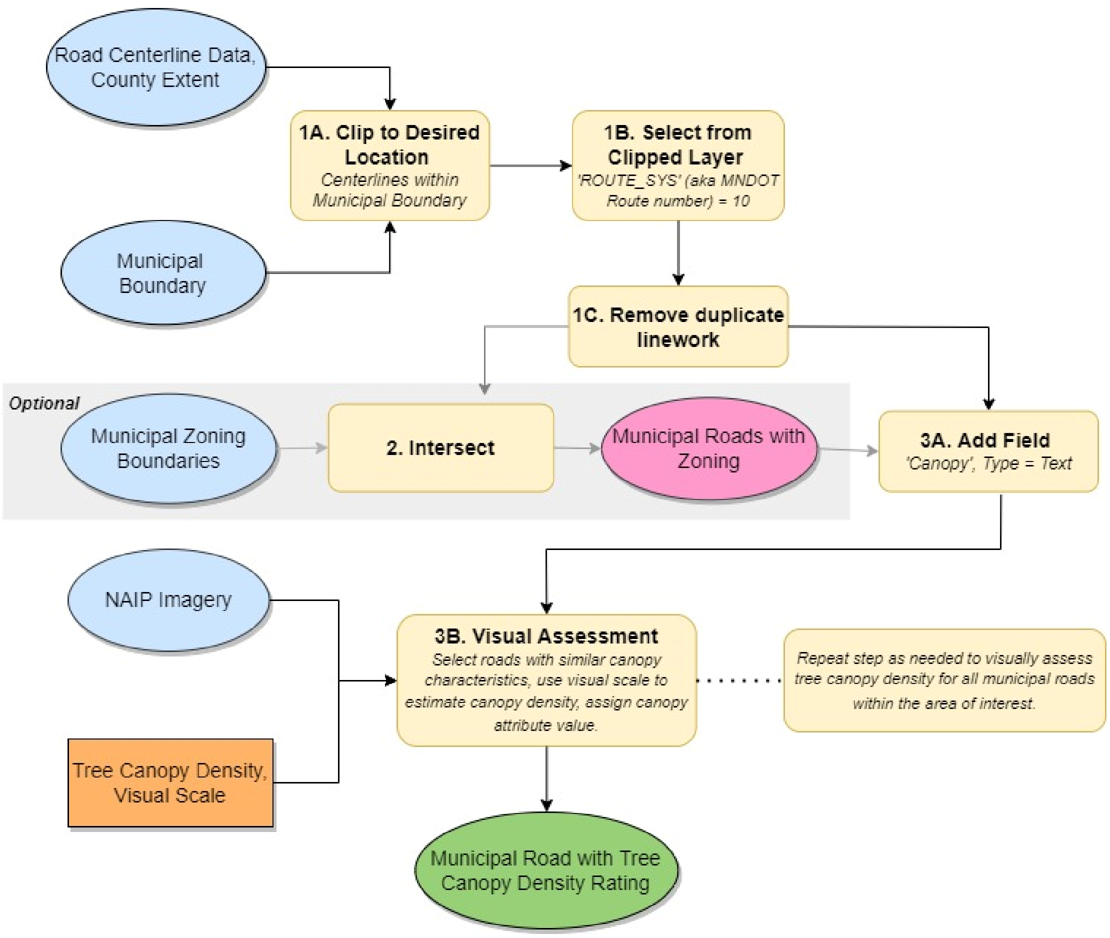



**Figure 5. Workflow diagram for using visual assessment of street corridor tree canopy to associate canopy cover rating with municipal road segments.**

### 2.2.1 Recommended Data Sources for Visual Assessment of Tree Canopy

The following data sources are recommended for visual assessment of tree canopy cover.

**Table 5. Summary of recommended data sources for geospatial analysis of street corridor tree canopy cover.**

| **Aerial Imagery** | |
|---|---|
| Data/Source | National Agricultural Imagery Program (NAIP), True Color Imagery[1] |
| Format | Raster |
| Extent | Statewide by County |
| Description | NAIP Imagery is available through the USDA: https://naip-usdaonline.hub.arcgis.com/ |
| **Boundary Layer (Optional)** | |
| Data/Source | Data layer representing boundaries that characterize land areas within the municipality such as drainage, zoning, or development boundaries may be useful in visual assessment of tree canopy cover.<br>This type of data is typically available through the local agencies (city, county, watershed district, etc.). |
| Description | Typically vector format. |

[1] The same imagery may be available at a statewide extent as 'color FSA' imagery through a WMS server. Note that county-level imagery available through WMS servers tends to favor leaf-off imagery (flown during the spring or fall) any may be difficult to use for the purpose of assessing tree canopy cover. For more information on imager available through WMS servers see Minnesota Geospatial Image Service: https://www.mngeo.state.mn.us/chouse/wms/geo_image_server.html

# 3 Using Tree Canopy Cover Data to Identify Priority Area for Street Sweeping

Outside of additional context, street corridor tree canopy cover data alone would not define priority street sweeping zones. Canopy cover density occurs across a continuum and even where there is stark contrast in canopy cover density, other factors like direct connectivity between streets and surface waters, may provide a context that makes sweeping in lower canopy density areas more beneficial or more cost-effective than sweeping in high canopy density areas.

When used in combination with other data like, storm sewer or BMP catchment boundaries, surface water drainage areas, zoning or neighborhood boundaries, canopy cover provides a means to rank and prioritize areas for street sweeping. This can be done using geospatial analysis by intersecting the feature layer of interest (e.g., drainage boundaries) with street corridor canopy polygons derived through quantitative (Section 2.1.4.1) or qualitative (Section2.2) assessment. Area-weighting can be used to calculate an average street corridor canopy cover at the overlay feature scale. Feature areas can then be prioritized by average tree canopy cover ratings as shown in Figure 6.

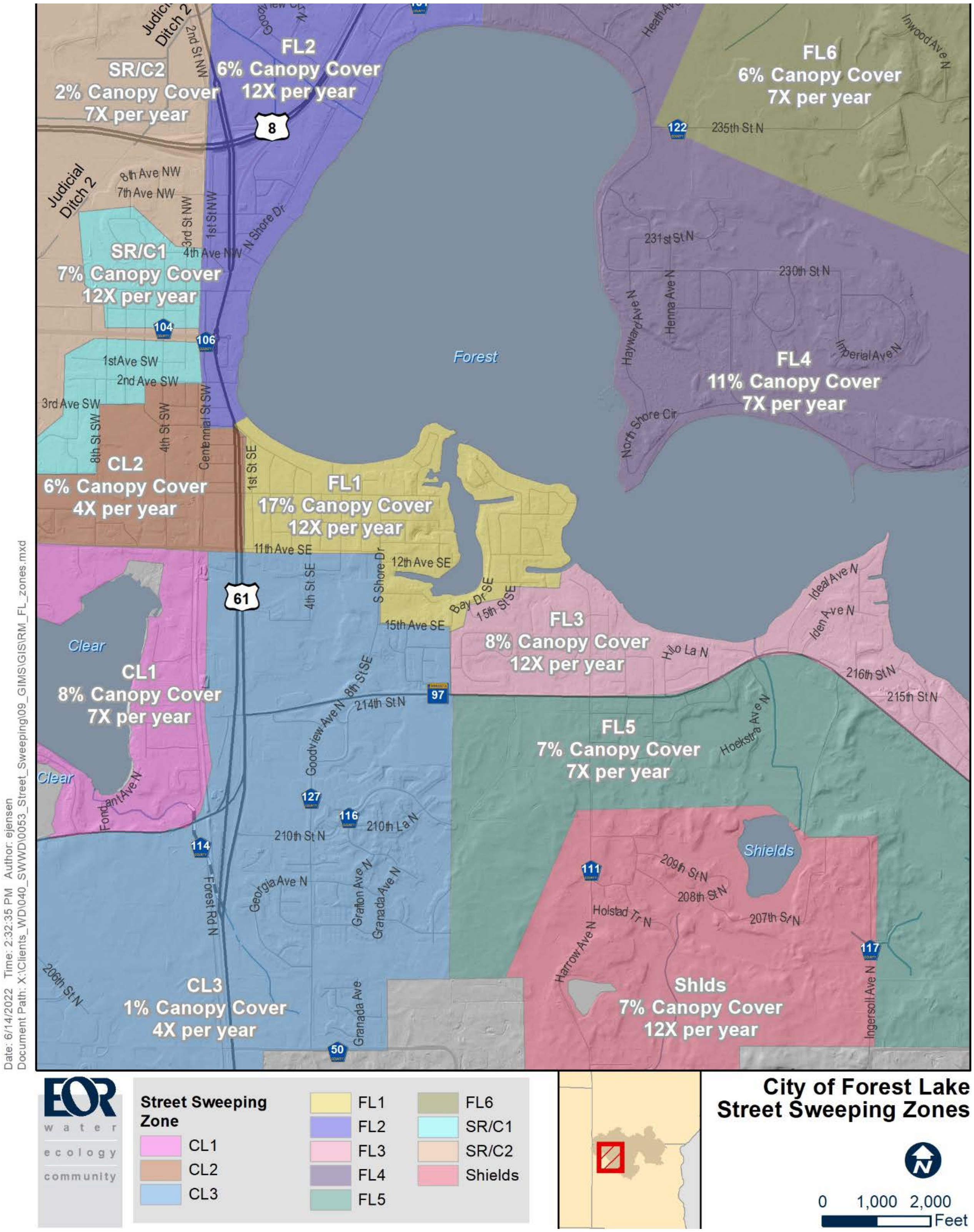



**Figure 6. City of Forest Lake sweeping zones based developed through overlay of lake management areas, storm sewer catchments, and tree canopy cover. Area with high connectivity to surface waters and/or high canopy covers were prioritized for increased sweeping frequency.**

# 4 Summary

I. Mapped tree canopy cover can be used to quantify tree canopy density for areas that are most likely to contribute leaf litter and duff to municipal street surfaces.
   - Where mapped canopy cover data are available (7-County TMCA), this analysis is simple, but additional data and data processing are required to perform the same analysis in other parts of the state.
   - Manual correction of data may be needed in areas of recent development
   - The accuracy of this method is sufficient for use in planning street sweeping; however additional parameters, such as water resource planning priorities or pre-defined routes, are needed to rank or prioritize areas for sweeping.

II. For small study areas, visual assessment of tree canopy cover using aerial imagery may a more efficient way to estimate street corridor tree canopy density for the purpose of planning street sweeping.

III. Tree canopy density ratings can be paired with drainage boundaries or other data sets that inform street sweeping objectives to identify and prioritize area of higher tree canopy cover for high frequency street sweeping.

# 5 References and Works Consulted

EOR, 2018, for the Comfort Lake-Forest Lake Watershed District; City of Forest Lake Street Sweeping Management Plan, http://ci.forest-lake.mn.us/documentcenter.

Kalinosky, P., 2015. Quantifying Solids and Nutrient Recovered Through Street Sweeping in a Suburban Watershed. Master's Thesis, University of Minnesota

Kalinosky, P., Baker, L., Hobbie, S., Bintner, R., Buyarski, C., 2013. User Support Manual: Estimating Nutrient Removal by Enhanced Street Sweeping, University of Minnesota for Minnesota Pollution Control Agency (MPCA).

# Appendix A: Guide for Visual Assessment of Street Corridor Tree Canopy

For some municipalities, zoning boundaries may serve as a proxy for tree canopy assessment. Street corridor tree canopy tends to be most dense in older residential neighborhoods with mature trees in front yards and least dense in commercial industrial areas where trees tend to be less mature and laid out in easily discernable geometries. Areas of new development tend to have the least dense street corridor canopy.

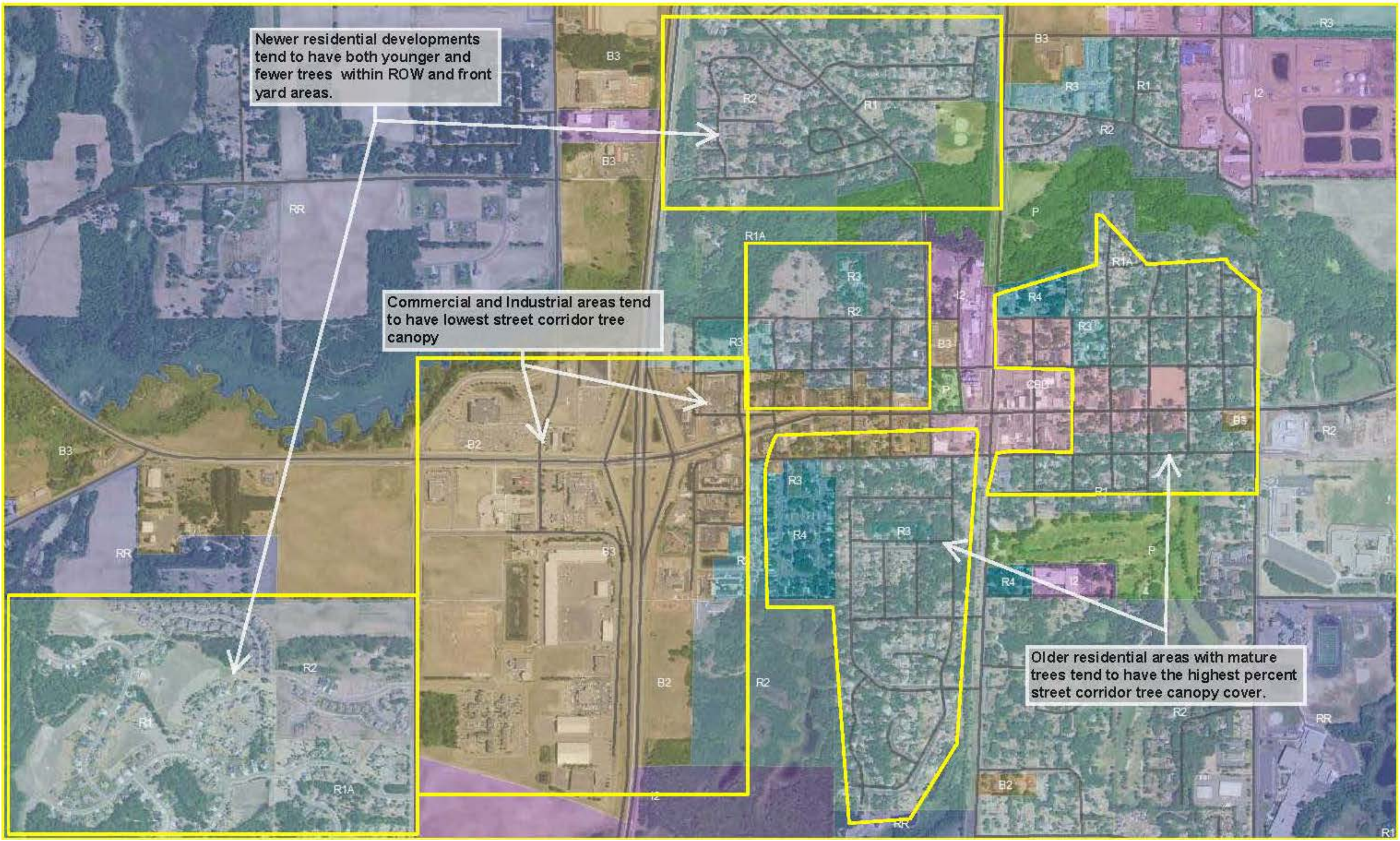



**Figure 7. USDA-NRCS-NCGC Digital Ortho Quad County Mosaic, 1Meter, Typical tree canopy characteristics at the municipal zoning scale.**

**Visual Scale, Street Corridor Tree Canopy Assessment**

<u>Tree Canopy Density</u>: **Low** (<5%) <u>Assessment Boundary</u>: Right-of-Way + 10 feet.

<table>
<tr><td>Area-weighted Average Density ~ 3%</td><td>Area-weighted Average Density = < 1%</td></tr>
<tr><td>
</td><td rowspan="3">
</td></tr>
<tr><td>Area-weighted Average Density ~ 2%</td></tr>
<tr><td></td></tr>
</table>

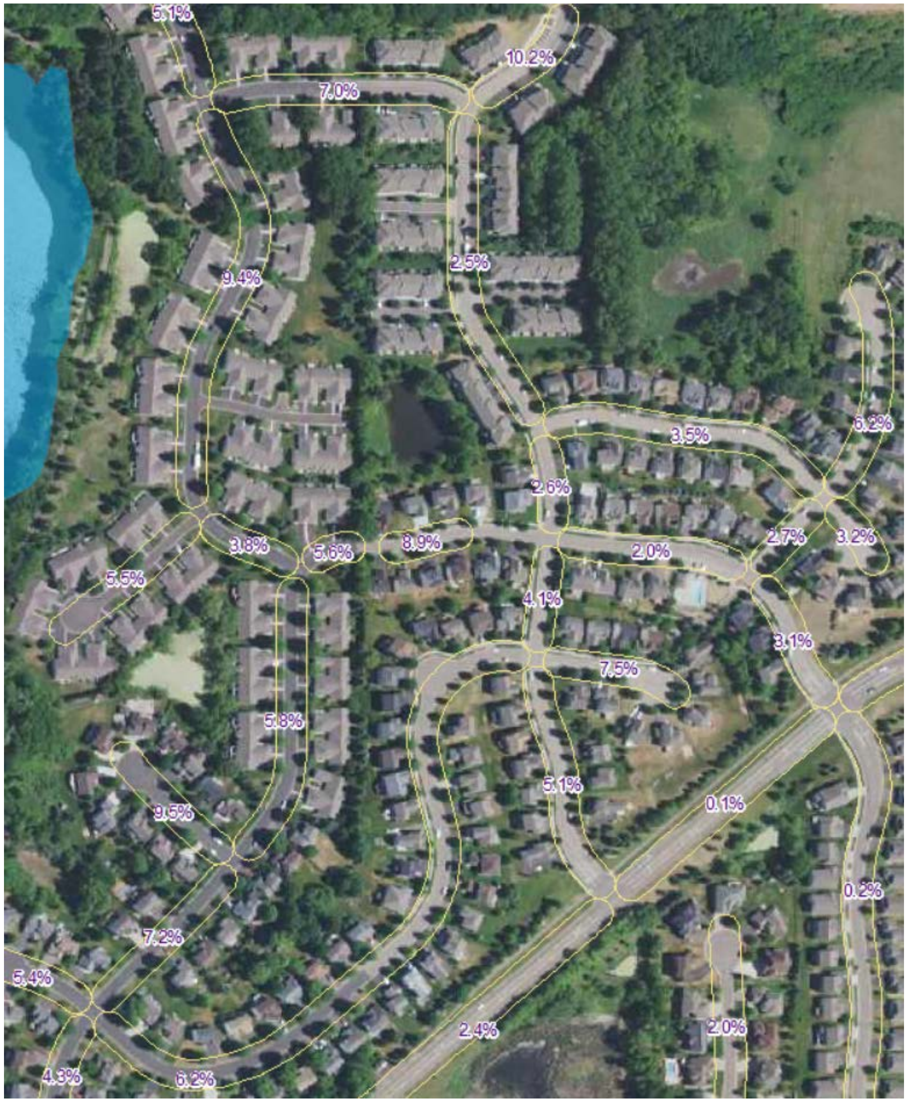
## Visual Scale, Street Corridor Tree Canopy Assessment

Tree Canopy Density: **Moderate** (5%-10% ) Assessment Boundary: Right-of-Way + 10 feet.

Area-weighted Average Density ~ 8%


Area-weighted Average Density ~7%

Area-weighted Average Density ~ 6%



## Visual Scale, Street Corridor Tree Canopy Assessment

<u>Tree Canopy Density</u>: **Medium** (10%-15% ) <u>Assessment Boundary</u>: Right-of-Way + 10 feet.

| Area-weighted Average Density ~ 10% | Area-weighted Average Density ~ 13% | Area-weighted Average Density ~ 11% |
|---|---|---|

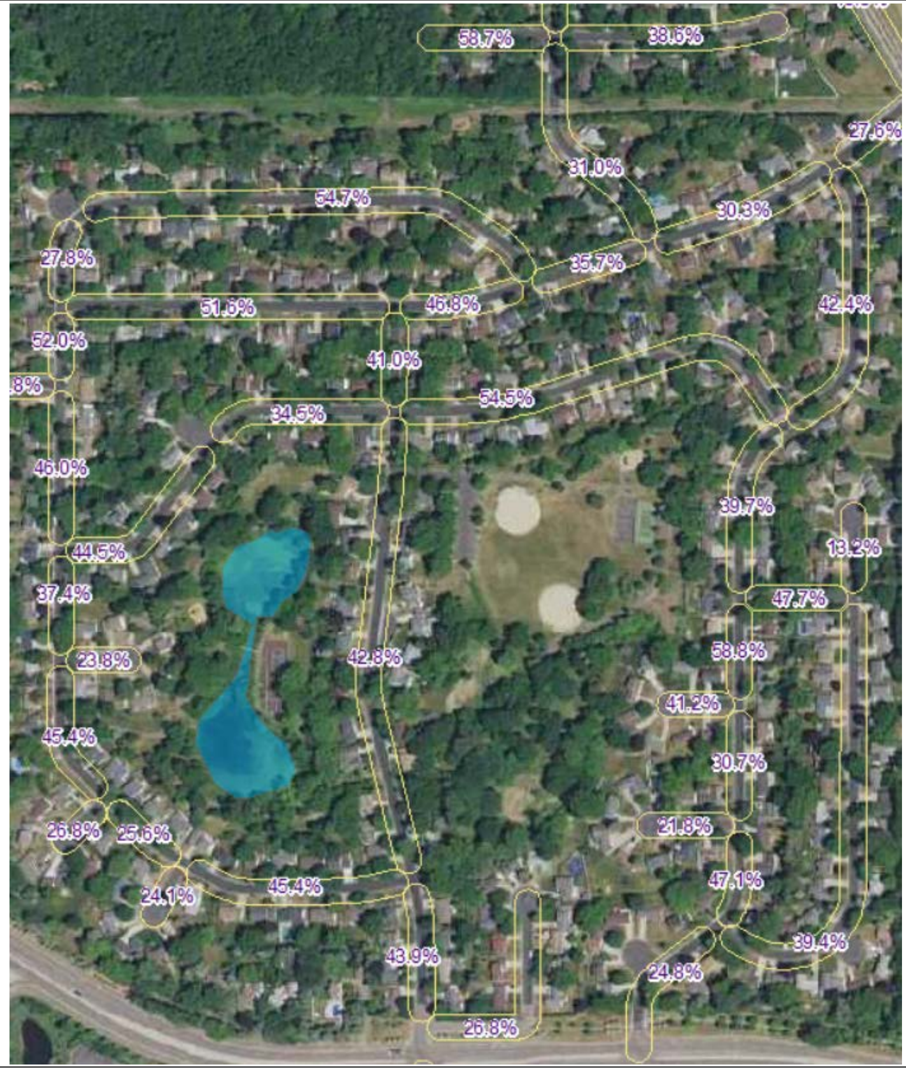


Tree Canopy Density: **High** (15%-25%) Assessment Boundary: Right-of-Way + 10 feet.

Area-weighted Average Density ~ 21%


Area-weighted Average Density ~19%

Tree Canopy Density: **Very High** (≥25% )  Assessment Boundary: Right-of-Way + 10 feet.

| Area-weighted Average Density ~ 42% | Area-weighted Average Density ~ 40% |
| --- | --- |
|  |  |

# APPENDIX B : The Influence of Street Corridor Canopy on Solids Collected from Street Surfaces – Section from the Prior Lake Street Sweeping Study

The mass of recovered solids collected per sweep increased with increasing street corridor tree canopy cover and decreased with increasing sweeping frequency (Table 6). On an annual basis, the mass of recovered solids increased with both increasing street corridor tree canopy and increasing sweeping frequency (Table 7).

**Table 6. Average dry solids collected per sweep by route (lb/lane-mile)**

| Sweeping Interval | | Low Canopy | Medium Canopy | High Canopy |
|---|---|---|---|---|
| Increasing Frequency | 28 days | 0.055 | 0.062§ | 0.121† |
| | 14 days | 0.044 | 0.065 | 0.086 |
| | 7 days | 0.041 | 0.055 | 0.053 |

**Table 7. Average dry solids collected per year by route (lb/lane-mile)**

| Sweeping Interval | | Low Canopy | Medium Canopy | High Canopy |
|---|---|---|---|---|
| Increasing Frequency | 28 days | 195 | 220§ | 429† |
| | 14 days | 156 | 231 | 305 |
| | 7 days | 145 | 195 | 188 |

*§Route originally classified as 'medium' canopy, but quantified canopy cover was closer to 'low' canopy routes.*

*†Route originally classified as 'high' canopy, but quantified canopy cover was closer to 'medium' canopy routes.*

On an annual basis, street corridor tree canopy cover was a significant predictor of recovered total phosphorus (Figure 8).

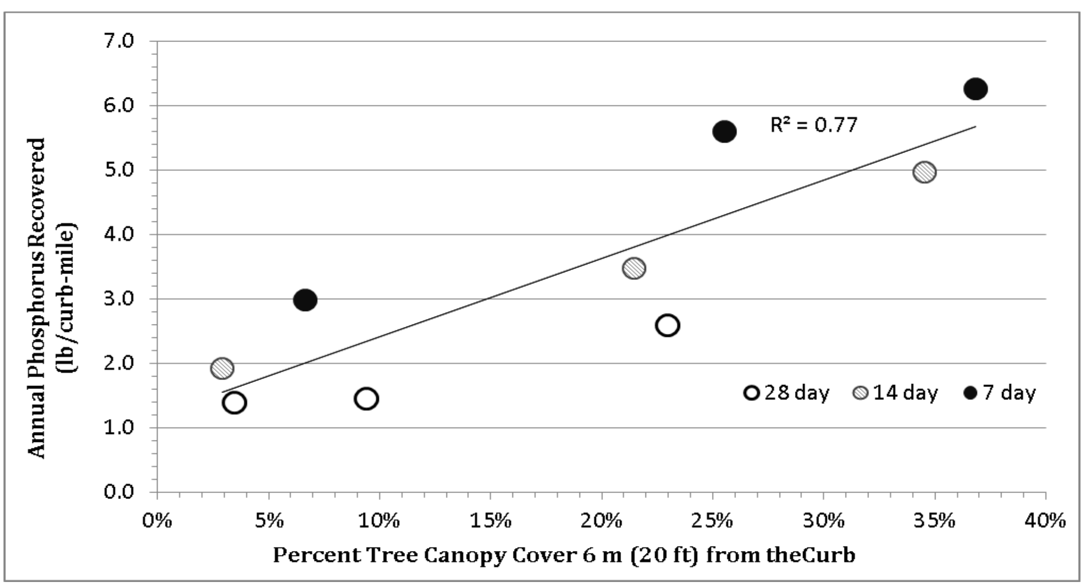



**Figure 8. Average total phosphorus recovered per year vs. percent street corridor tree canopy cover for the nine street sweeping routes in the Prior Lake Street Sweeping Study.**

Street corridor tree canopy cover was a significant predictor of recovered total phosphorus for data points in 6 of the 9 months assessed; and a significant predictor of coarse organic solids and total nitrogen recovered in all months (March – November), (Table 8).

**Table 8. Months for which street corridor tree canopy cover (%) and sweeping frequency were significant predictors of recovered loads, Prior Lake Street Sweeping Study.**

| **Load Type** (lb/curb-mile) | **Months for which each factor was a significant predictor of the total load[1,2]** | |
|---|---|---|
| | **% Street Corridor Canopy Cover** | **Average sweeping interval[3]** |
| Total Dry Solids | Oct, Nov | Apr-Jun, Aug, Sep, Nov |
| Coarse Organic Solids[4] | **Mar-Nov (all)** | Apr, Sep |
| Fine Solids | Oct | Apr-Jun, Aug, Oct, Nov |
| Total P | May, Jun, Aug, Sep, Oct, Nov | Mar-May, Sep, Nov |
| Total N | **Mar-Nov (all)** | Sep |

[1] Data include sweepings in March through November. Data were sparse for the months December though January.
[2] Regression analysis, $\alpha$=0.05 significance level.
[3] Monthly, bi-weekly, or weekly sweeping intervals.
[4] Component of street sweepings = floatable solids with diameter > 2mm. Organic litter with diameter < 2 mm were included in the 'fine solids' component of sweepings along with other soil-like particles.

When assessed at different buffer distances from the street, correlations between tree canopy cover and recovered loads tended to increase with increasing distance from the street. The increase in correlation typically leveled off at about 20 feet from curb lines.

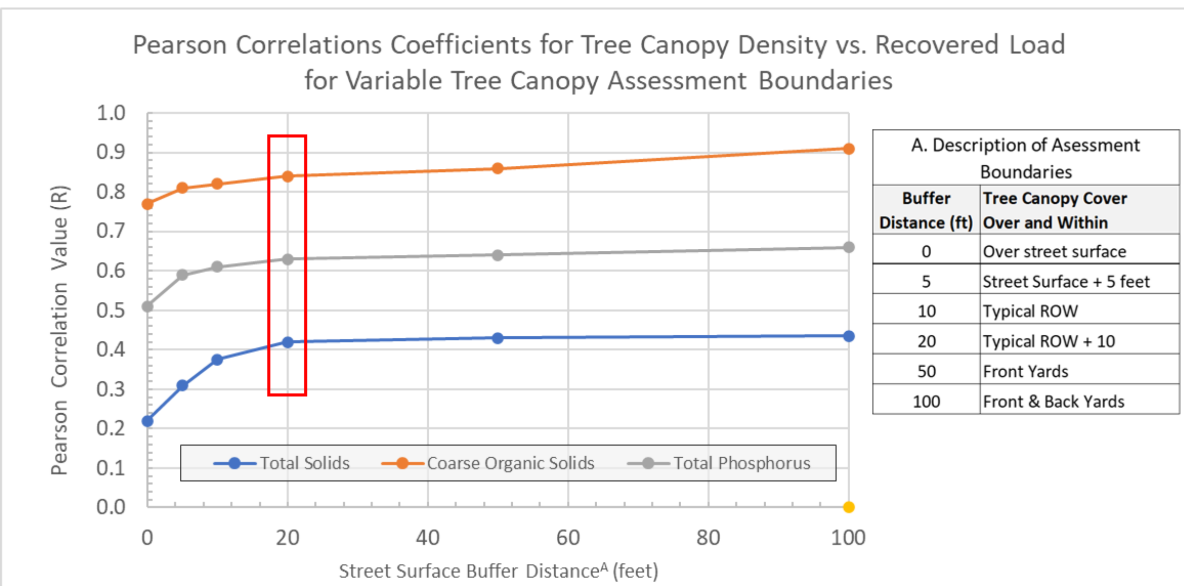



**Figure 9. Pearson correlations for canopy cover vs. recover load (annual) for different canopy cover assessment boundaries and recovered load types.**

# APPENDIX C: Road Classifications and ROW Widths

Road centerline shapefiles developed by the Minnesota Department of Transportation include a route classification attribute, 'ROUTE_SYS,' which contains the route system codes shown below. The full document summarizing MDNOT route system descriptions is available on the MNDOT website.

DEPARTMENT OF TRANSPORTATION

3/9/2020

## Route System Descriptions

| Route System | Abbreviation | Description |
|---|---|---|
| 01 | I | Interstate |
| 41 | IHO | HOV/HOT/Reversible lanes on Interstate |
| 51 | UNI | Non-numbered Interstate |
| 02 | US | US Highway |
| 42 | UHO | HOV/HOT/Reversible lanes on US Hwy |
| 52 | UNU | Non-numbered US Highway |
| 03 | MN | MN Highway |
| 32 | OR | Other Road |
| 43 | MHO | HOV/HOT/Reversible lanes on MN Hwy |
| 53 | UNM | Non-numbered MN Highway |
| 04 | CSAH | County State Aid Highway |
| 05 | MSAS | Municipal State Aid Street |
| 07 | CR | County Road |
| 08 | T | Township Road |
| 09 | UT | Unorganized Territory Road |
| 10 | M | Municipal Street |
| 11 | NPR | National Park Road |
| 12 | NFR | National Forest Road |
| 13 | IND | Indian Tribe Nation Road |
| 14 | SFR | State Forest Road |
| 15 | SPR | State Park Road |
| 16 | MIL | Military Road |
| 17 | OFAR | Other Federal Agency Road |
| 18 | BFWR | Bureau of Fish and Wildlife Road |
| 19 | FRD | Frontage Road |
| 20 | OSAR | Other State Agency Road |
| 21 | PVT | Privately Maintained Public Access Road |
| 22 | CON | Connector |
| 23 | AR | Airport Road |
| 24 | BIA | Bureau of Indian Affairs Road |
| 25 | LOC | Local Park, Forest or Reservation Agency Road |
| 26 | OLR | Other Local Road |
| 27 | RSR | Railroad Service Road |
| 28 | STL | State Toll Road |
| 29 | LTL | Local Toll Road |
| 30 | ALY | Alleyway |
| 31 | BRR | USBR Road |
| 33 | BLM | BLM Road |
| 34 | NTW | Non Trafficway |

**Table 9. Survey of minimum right-of way width by road classification for three TCMA municipalities.**

| Road Type/Functional Class | Minimum ROW Width (feet) | Source |
|---|---|---|
| Arterial | 150 | A |
| Arterial | 100 - 150 | C |
| Collector | 80 - 120 | C |
| Collector | 80 - 100 | A |
| Collector Streets | 150 | B |
| Commercial or Industrial Service Street | 80 | C |
| Street with Medians | 80 | B |
| Residential, High-density | 70 | C |
| Residential, Multi-family | 66 | C |
| Residential, Single family high | 60 | C |
| Local Road | 50 - 60 | A |
| Residential Public Minor Streets | 60 | B |
| Half Street | 30 | A |

*A. City of Inver Grove Heights, MN, Code of Ordinances.*
*B. City of Forest Lake Engineering Design Standards, 2022*
C. *City of Lake Engineering Specifications, 2022.*