Appendix I of Columbia Natural Resource Inventory 2022 Methodology and Accuracy Assessment

Davey Resource Group Classification Methodology

Davey Resource Group utilized the LiDAR-derived height-above-ground raster dataset provided by the Columbia NRI to process and extract tree canopy cover within the project boundary area. The use of LiDAR data provides a highly accurate approach to assessing the community's existing tree canopy coverage. This supports responsible tree management, facilitates community forestry goal setting, and improves urban resource planning for healthier and more sustainable urban environments. Again, the use of LiDAR data helps to reduce the QC time by eliminating all grass and low-lying vegetation and shadows present in the imagery that could otherwise have been extracted as part of the tree canopy due to their spectral similarities with the tree canopy. For instance, setting a threshold of 15 ft above-ground-height helps to eliminate grass and low-vegetation areas from the initial tree canopy extractions.

Shrubs were extracted from a LiDAR-derived raster height-above-ground model. The height model was resampled to a 1-meter resolution and applied 3-cell maximum focal statistics for smoothness and fullness of data. This height model was then reclassified to extract cells valued between 3 and 15 feet above the ground. Normalized Difference Vegetation Index (NDVI), cropland, impervious surfaces, and small tree filters were applied to remove unwanted features. The edges of tree canopy remained, so the filtered raster was shrunk by two cells, expanded back by two cells, and converted to a vector polygon format. This process removed the edges of trees but resulted in lost detail and a blocky appearance. The filtered raster was instead shrunk by 1 cell and expanded by 1 cell, and then converted to polygons. This method preserved more detail but retained excess non-shrub features. To remedy this, only polygons that intersected the 2-cell shrunk and expanded polygons were retained. These polygons were snapped to tree canopy data with the ET GeoWizards Global Snap Polygons function, and small holes were filled. The data was manually edited at a scale of 1:2,000 to remove tall herbaceous vegetation and correct temporal disagreement of the source 2020 LiDAR with the reference 2022 NAIP imagery.

Advanced image analysis methods were used to classify, or separate, impervious land cover layers from the overall imagery. The semi-automated extraction process was completed using Feature Analyst, an extension of ArcGIS®. Feature Analyst uses an object-oriented approach to cluster together objects with similar spectral (i.e., color) and spatial/contextual (e.g., texture, size, shape, pattern, and spatial association) characteristics. During the processing, the Feature analyst software was used to mask out all the areas within the Columbia NRI project area that already had client provided impervious data such as building footprints and roads. The land cover results of the extraction process were post-processed and clipped to each project boundary prior to the manual editing process to create smaller, manageable, and more efficient file sizes. Secondary source data, high-resolution aerial imagery provided by the client, and custom ArcGIS® tools were used to aid in the final manual editing, quality checking, and quality assurance processes (QA/QC). The manual QA/QC process was implemented to identify, define, and correct any misclassifications or omission errors in the final land cover layer.

Again, the semi-automated extraction process was used to classify, or separate coniferous forests from deciduous forests. This was done using a 2022 high resolution leaf off imagery provided by Columbia NRI. The leaf off imagery has a spatial resolution of 0.6 feet. The imagery was resampled to 3.2808 feet (1-meter) to allow for easy processing. Advanced image interpretation methods were used by a GIS Analyst to take training set data samples from areas of the leaf off imagery that were considered as conifers. Conifers are easy to distinguish from leaf off imagery due to their distinct dark green color. Deciduous forests on the other hand have light to deep grey hue. The Feature analyst software was then used to extract the coniferous forests using the tree canopy layer as a mask. Prior to editing the extracted coniferous forests, the conifer layers were clipped to the overall canopy layer (Which includes both conifer and deciduous forests) to stamp out all the areas that are grass. This process is done to speed up editing time and improve accuracy by including smaller individual trees.

Classification Workflow

1) Prepare imagery for feature extraction (resampling, rectification, etc.), if needed.
2) Gather training set data for all desired land cover classes (impervious, bare soil, Coniferous). Water samples are not always needed since hydrologic data are available for most areas. Though the Columbia NRI maintain and provided DRG with a complete building footprint and a comprehensive impervious layer within the Columbia City limit, limited training dataset for impervious features were collected to extract other impervious surfaces in areas within the project boundary that had only building footprints.
3) Extract canopy and shrub layers separately using the height-above-ground LiDAR derived raster dataset; this decreases the amount of shadow removal from large tree canopy shadows and distinguishes between shrubs, grass, and trees. Fill small holes and smooth to remove rigid edges.
4) Edit and finalize canopy layer at 1:2000 scale. A point file is created to digitize-in small individual trees that will be missed during the extraction. These points are buffered to represent the tree canopy. This process is done to speed up editing time and improve accuracy by including smaller individual trees.
5) Edit the impervious layer to reflect actual impervious features, such as roads, buildings, parking lots, etc. to update features.
6) Gather training set data for bare soil. Water samples are not always needed since hydrologic data are available for most areas.
7) Using canopy and actual impervious surfaces as a mask; input the bare soils training data and extract them from the imagery; this ensures that canopy and impervious surfaces are excluded from the bare soil extractions. Quickly edit the layer to remove or add any features. Davey Resource Group tries to delete dry vegetation areas that are associated with lawns, grass/meadows, and agricultural fields.
8) Assemble any hydrological datasets, if provided. Add or remove any water features to create the hydrology class. Perform a feature extraction if no water feature datasets exist.
9) Use geoprocessing tools to clean, repair, and clip all edited land cover layers to remove any self-intersections or topology errors that sometimes occur during editing.

10) Input canopy, impervious, bare soil, and hydrology layers into Davey Resource Group's Five-Class Land Cover Model to complete the classification. This model generates the pervious (grass/low-lying vegetation) class by taking all other areas not previously classified and combining them.

11) Thoroughly inspect final land cover dataset for any classification errors and correct as needed.

12) Perform accuracy assessment. Repeat Step 11, if needed.

Tree Canopy Change

1) The intersection of the 2007 NRI boundary and the 2022 boundary was used to define the area of analysis. The "Union" tool within ArcGIS was used to overlay the 2007 tree canopy with the 2022 tree canopy. Areas with tree canopy recorded for both 2007 and 2022 were classified as "No Change", parts with tree canopy for 2007 but not 2022 were classified as "Loss", and areas without canopy in 2007 with canopy in 2022 were classified as "Gain".
2) Subsequently, the dataset underwent the "Multipart To Singlepart" process to separate contiguous areas of the same change type into individual features. Features measuring less than 20 square feet were eliminated and merged into the polygon with the longest shared boundary. This step aimed to significantly reduce the number of polygons, eliminating those too small to effectively represent meaningful tree canopy changes.
3) However, the perfect identification of tree canopy changes is challenging due to certain factors. Aerial imagery exhibits displacement or a 'lean' of tall objects away from the sensor's direction when the aircraft is not directly overhead. This effect can lead to crescents of loss and gain recorded on opposite sides of a tree that has remained unchanged between 2007 and 2022 if the imagery was captured from significantly different angles each year. In addition to spatial considerations, data inaccuracies also contribute to false recordings of gains and losses. For instance, false losses around trees can occur if the cast shadow of a tree was misclassified as tree canopy in 2007. Despite these nuances, the overall accuracy of tree canopy acreage is maintained at a large scale, as the sum of false gains and losses tends to cancel each other out.
4) The remaining classes were not calculated through a direct change analysis, but are instead compared in total numbers for the analysis (Tables 4 & 5).

Automated Feature Extraction Files

The automated feature extraction (AFE) files allow other users to run the extraction process by replicating the methodology. Since Feature Analyst does not contain all geoprocessing operations that Davey Resource Group utilizes, the AFE only accounts for part of the extraction process. Using Feature Analyst, Davey Resource Group created the training set data, ran the extraction, and then smoothed the features to alleviate the blocky appearance. To complete the actual extraction process, Davey Resource Group uses additional geoprocessing tools within ArcGIS®. From the AFE file results, the following steps are taken to prepare the extracted data for manual editing.

1) Davey Resource Group fills all holes in the canopy that are less than 30 square meters. This eliminates small gaps that were created during the extraction process while still allowing for natural canopy gaps.
2) Davey Resource Group deletes all features that are less than 9 square meters for canopy (50 square meters for impervious surfaces). This process reduces the number of small features that could result in incorrect classifications and also helps computer performance.
3) The Repair Geometry, Dissolve, and Multipart to Singlepart (in that order) geoprocessing tools are run to complete the extraction process.
4) The Multipart to Singlepart shapefile is given to GIS personnel for manual editing to add, remove, or reshape features.

Accuracy Assessment Protocol

Determining the accuracy of spatial data is of high importance to Davey Resource Group and our clients. To achieve the best possible result, Davey Resource Group manually edits and conducts thorough QA/QC checks on all urban tree canopy and land cover layers. A QA/QC process wase completed using ArcGIS® to identify, clean, and correct any misclassification or topology errors in the final land cover dataset. The initial land cover layer extractions were edited at a 1:2000 quality control scale in the urban areas and at a 1:2500 scale for rural areas utilizing the most current high-resolution aerial imagery to aid in the quality control process.

To test accuracy, random plot locations are generated throughout the city area of interest and verified to ensure that the data meets the client standards. Each point will be compared with the most current NAIP imagery (reference image) to determine the accuracy of the final land cover layer. Points will be classified as either correct or incorrect and recorded in a classification matrix. Accuracy will be assessed using four metrics: overall accuracy, kappa, quantity disagreement, and allocation disagreement. These metrics are calculated using a custom Excel® spreadsheet.

Table 1. Land Cover Classification Code Values

Land Cover Classification	Code Value
Tree Canopy	1
Shrub	2
Impervious	3
Grass	4
Cropland	5
Bare Ground	6
Open Water	7

Land Cover Accuracy

The following describes Davey Resource Group's accuracy assessment techniques and outlines procedural steps used to conduct the assessment.

1. *Random Point Generation*—Using ArcGIS, 1,000 random assessment points are generated.

2. *Point Determination*—Each point is carefully assessed by the GIS analyst for likeness with aerial photography. To record findings, two new fields, CODE and TRUTH, are added to the accuracy assessment point shapefile. CODE is a numeric value (1–5) assigned to each land cover class (Table 1) and TRUTH is the actual land cover class as identified according to the reference image. If CODE and TRUTH are the same, then the point is counted as a correct classification. Likewise, if the CODE and TRUTH are not the same, then the point is classified as incorrect. In most cases, distinguishing if a point is correct or incorrect is straightforward. Points will rarely be misclassified by an egregious classification or editing error. Often incorrect points occur where one feature stops and the other begins.

3. *Classification Matrix*—During the accuracy assessment, if a point is considered incorrect, it is given the correct classification in the TRUTH column. Points are first assessed on the NAIP imagery for their correctness using a "blind" assessment—meaning that the analyst does not know the actual classification (the GIS analyst is strictly going off the NAIP high-resolution imagery to determine cover class). Any incorrect classifications found during the "blind" assessment are scrutinized further using sub-meter imagery provided by the client to determine if the point was incorrectly classified due to the fuzziness of the NAIP imagery or an actual misclassification. After all random points are assessed and recorded, a classification (or confusion) matrix is created. The classification matrix for this project is presented in Table 2. The table allows for assessment of user's/producer's accuracy, overall accuracy, omission/commission errors, kappa statistics, allocation/quantity disagreement, and confidence intervals (Tables 2 & 3).

Table 2. Classification Matrix

Reference Data: Classes	Tree Canopy	Shrub	Impervious	Grass	Cropland	Bare Ground	Water	Row Total	Producer's Accuracy	Errors of Omission
Tree Canopy	399	9	2	15	1	0	1	427	93.44%	6.56%
Shrub	0	18	0	3	0	0	0	21	85.71%	14.29%
Impervious	1	0	87	10	1	0	0	99	87.88%	12.12%
Grass	1	1	7	243	2	2	0	256	94.92%	5.08%
Cropland	3	0	0	2	158	0	0	163	96.93%	3.07%
Bare Ground	0	0	1	1	0	13	0	15	86.67%	13.33%
Water	0	0	0	0	0	0	19	19	100.00%	0.00%
Column Total	404	28	97	274	162	15	20	1000		
User's Accuracy	98.76%	64.29%	89.69%	88.69%	97.53%	86.67%	95.00%		Overall Accuracy	93.70%
Errors of Commission	1.24%	35.71%	10.31%	11.31%	2.47%	13.33%	5.00%		Kappa Coefficient	0.9126

4. The following are descriptions of each statistic as well as the results from some of the accuracy assessment tests.

   Overall Accuracy – Percentage of correctly classified pixels; for example, the sum of the diagonals divided by the total points ((399+18+87+243+158+13+19)/1,000 = 93.70%).

   User's Accuracy – Probability that a pixel classified on the map actually represents that category on the ground (correct land cover classifications divided by the column total [399/404 = 98.76%]).

   Producer's Accuracy – Probability of a reference pixel being correctly classified (correct land cover classifications divided by the row total [399/427 = 93.44%]).

   Kappa Coefficient – A statistical metric used to assess the accuracy of classification data. It has been generally accepted as a better determinant of accuracy partly because it accounts for random chance agreement. A value of 0.80 or greater is regarded as "very good" agreement between the land cover classification and reference image.

   Errors of Commission – A pixel reports the presence of a feature (such as trees) that, in reality, is absent (no trees are actually present). This is termed as a false positive. In the matrix above, we can determine that 1.24% of the area classified as canopy is most likely not canopy.

Errors of Omission – A pixel reports the absence of a feature (such as trees) when, in reality, they are actually there. In the matrix below, we can conclude that 6.56% of all canopy classified is actually classified as another land cover class.

Allocation Disagreement – The amount of difference between the reference image and the classified land cover map that is due to less-than-optimal match in the spatial allocation (or position) of the classes.

Quantity Disagreement – The amount of difference between the reference image and the classified land cover map that is due to less than perfect match in the proportions (or area) of the classes.

Confidence Intervals – A confidence interval is a type of interval estimate of a population parameter and is used to indicate the reliability of an estimate. Confidence intervals consist of a range of values (interval) that act as good estimates of the unknown population parameter based on the observed probability of successes and failures. Since all assessments have innate error, defining a lower and upper bound estimate is essential.

Table 3. 95% Confidence Intervals

Landcover Assessment

Class	Acres	Percentage	Lower Bound	Upper Bound
Tree Canopy	59,831.6	40.6%	40.5%	40.7%
Shrub	3,544.6	2.4%	2.4%	2.4%
Impervious	15,208.8	10.3%	10.2%	10.4%
Herbaceous	41,307.1	28.0%	27.9%	28.1%
Cropland	21,573.5	14.6%	14.5%	14.7%
Bare Ground	2,190.1	1.5%	1.5%	1.5%
Water	3,789.9	2.6%	2.5%	2.6%
Total	**147,445.6**	**100.00%**		

Statistical Metrics Summary:

Overall Accuracy =	**93.70%**
Kappa Coefficent =	**0.9126**
Allocation Disagreement =	**4%**
Quantity Disagreement =	**3%**

Accuracy Assessment

Class	User's Accuracy	Lower Bound	Upper Bound	Producer's Accuracy	Lower Bound	Upper Bound
Tree Canopy	98.8%	98.2%	99.3%	93.4%	92.2%	94.6%
Shrub	64.3%	55.2%	73.3%	85.7%	78.1%	93.4%
Impervious	89.7%	86.6%	92.8%	87.9%	84.6%	91.2%
Herbaceous	88.7%	86.8%	90.6%	94.9%	93.5%	96.3%
Cropland	97.5%	96.3%	98.8%	96.9%	95.6%	98.3%
Bare Ground	86.7%	77.9%	95.4%	86.7%	77.9%	95.4%
Water	95.0%	90.1%	99.9%	100.0%	100.0%	100.0%

Table 4. Changes WITHIN CITY LIMITs								
Class	**Unique**	**2007 Acres**	**%**	**2022 Acres**	**%**	**Change**	**%**	**Absolute**
Forest	1	15,623.66	36.03	15,755.82	36.34	132.17	0.85	0.31
Forest w/o shrub	*2*	*15,623.66*	*36.03*	*14,481.24*	*33.40*	*-1,142.42*	*-7.31*	*-2.63*
Impervious	3	8,626.12	19.89	10,999.87	25.37	2,373.75	27.52	5.47
Grass	4	14,927.80	34.43	13,206.88	30.46	-1,720.92	-11.53	-3.97
Cropland	5	1,463.57	3.38	1,662.78	3.83	199.21	13.61	0.46
Bare Ground	6	1,993.37	4.60	1,000.78	2.31	-992.59	-49.79	-2.29
Open Water	7	724.28	1.67	732.16	1.69	7.88	1.09	0.0

Table 5. Changes in SHARED NRI 2007 & 2022 AREA								
Class	**Unique**	**2007 Acres**	**%**	**2022 Acres**	**%**	**Change**	**%**	**Absolute**
Forest	1	51,355.62	43.05	52,907.96	44.35	1,552.34	3.02	1.30
Forest w/o shrub	*2*	*51,355.62*	*43.05*	*49,806.16*	*41.75*	*-1,549.46*	*-3.02*	*-1.30*
Impervious	3	11,211.55	9.40	14,312.78	10.31	3,101.24	27.66	0.92
Grass	4	41,988.18	35.20	33,427.02	28.02	-8,561.16	-20.39	-7.18
Cropland	5	9,697.27	8.13	14,412.53	12.08	4,715.27	48.62	3.95
Bare Ground	6	2,826.81	2.37	1,797.90	1.51	-1,028.91	-36.40	-0.86
Open Water	7	2,212.63	1.85	2,434.07	2.04	221.44	10.01	0.19