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MEMORANDUM

TO: BCWD Board of Managers and Karen Kill, District Administrator

FROM: Aaron DeRusha, Washington Conservation District (WCD)

DATE: 5/20/2026

RE: BCWD Impervious Surfaces GIS Layer Development

Background

Staff at the City of Stillwater have noted increased numbers of variance requests for impervious surface coverage on residential lots in recent years. Through conversations with Administrator Kill, the City is interested in knowing how adjusting zoning regulations to provide better consistency with variance requests would affect the amount of impervious surface allowed on a lot by City ordinance and BCWD's permitting process for stormwater treatment. Administrator Kill noted developers receive approval from BCWD to construct a specific amount of impervious surface and are required to provide stormwater treatment for those areas on site, but the amount of treatment required for a development is often less that the maximum amount of impervious surface allowed by City ordinance when considering each individual lot. As lots develop or re-develop after initial permitting and construction, it is possible for the total impervious surface in a development to exceed the permitted capacity of the stormwater treatment practices and potentially have negative impacts on water quality and flooding. In order to answer these questions around development in the City, and all other areas of BCWD, a better understanding of the permitted impervious surfaces versus the as-built impervious surfaces in developments is needed.

A geographic information systems (GIS) based desktop analysis is well suited to inform these questions. Many available land cover layers, such as the National Land Cover Dataset (NLCD) or Minnesota Land Cover Classification System (MLCCS) are too coarse to make determinations of impervious cover on a lot by lot scale. The University of Minnesota published a 1-meter resolution land cover classification dataset for the Twin Cities Metropolitan Area in 2016 based on 2015 aerial images, but this dataset would be out of date for some newer developments, and no other ready-for-use GIS based products for this scale are known to exist.

BCWD amended its service agreement with the WCD to include development of a new digital impervious surface layer using the most recent 2025 spring leaf-off aerial photos with 1-foot resolution, made available by the Minnesota Geospatial Information Office in early 2026. The scope of service included delivering a digital impervious surface layer, other land cover classes such as tree canopy and turf coverage dependent upon accuracy, a web-based application for easy viewing of the data, and an accuracy assessment.

Methods

After examining feasibility of several image classification methods, it was determined a supervised object-based image analysis (OBIA) conducted using ESRI's ArcGIS Pro would be best suited for development of these layers. In simplest terms, this method groups pixels of the image according to their reflectivity, or color, in various spectral bands, and according to their shape, i.e. rectangularity or circularity, into polygons called objects. This process is called segmentation. The user tells the software what land cover type, or class, a sample of these objects belong to, called training samples. The training samples are used to train algorithms that automatically assign the rest of the objects in the image to a class. Specific classes are then merged together into more general classes to obtain a classified image. This classification can then be further refined with corrections and reclassifications until an adequate end product is achieved, on which an accuracy assessment may be conducted.

For this type of analysis, false-color aerial images are often used because the sensors collecting the images also collect data in near-infrared wavelengths, which we cannot see with our eyes. When viewing these images the near-infrared image band is assigned to the red color, which makes different types of vegetation more visible depending on the vegetation's growth vigor, i.e. the redder the color, the more healthy or active the vegetation is. Other land covers like asphalt or concrete may appear as shades of white, blue, or gray, which also helps algorithms separate pixels into classes. For identifying impervious surfaces it is important to use spring leaf-off aerial photos to minimize the amount of impervious surfaces that would otherwise be obscured by tree canopy.

A general workflow for this analysis is:

1. Obtain false-color leaf-off photos of the study area.
2. Extract spectral bands to display the near-infrared wavelengths.
3. Segment the image into objects.
4. Create land cover classes and collect training samples for each class.
5. Choose and train an image classification algorithm.
6. Classify the image.
7. Merge and reclassify similar classes.
8. Review the classified image and reclassify areas that were misclassified by the algorithm.
9. Generate random points throughout the image and classes.
10. Update the random points with the correct class by reviewing the image, and conduct accuracy assessment.

For this analysis a spring 2025 leaf-off, false-color infrared image with 1-foot resolution was obtained from the Minnesota Geospatial Information Office. An example of the image with true-color and false-color bands displayed can be seen below.

Figure 1. True-color bands displayed on the left side of the image, and false-color bands displayed on the right.

Using ESRI's Image Classification Wizard, the image was then segmented into objects with a Spectral Detail setting of 16 (on a zero to 20 scale) and a Spatial Detail setting of 12 (on a zero to 20 scale). The minimum object size was set to 52 pixels, which equates to roughly 50 square feet.

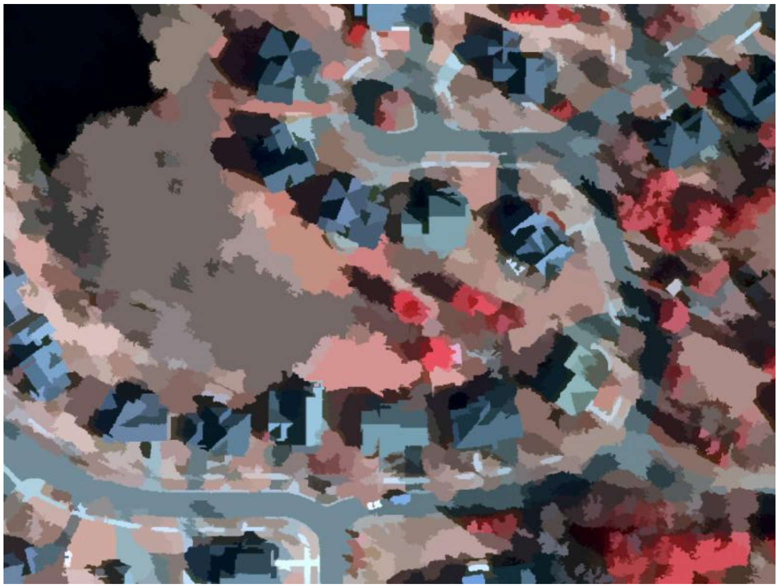
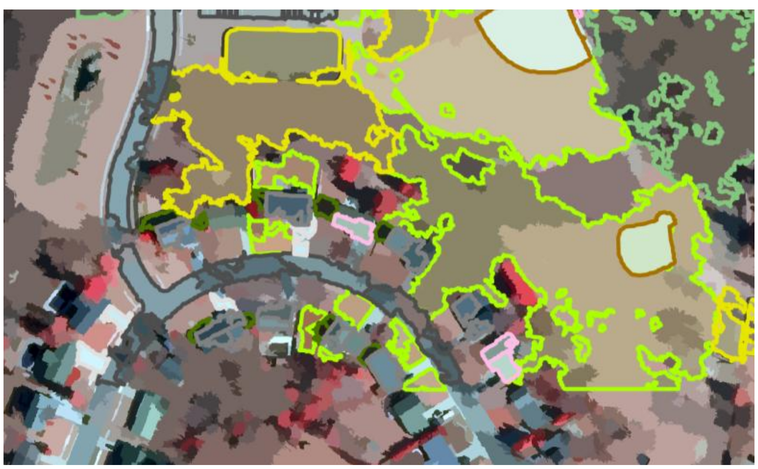


Figure 2. Example of the segmented image at fine scale.

Following segmentation, classes were created and training samples were collected throughout the image. It is important to have highly specific classes at this stage of the analysis to make the algorithm more accurate. Where buildings and trees cast shadows onto other land cover types it is important to create classes for the shadowed areas because they will be darker than their actual land cover class, and may later be misclassified as an impervious surface or water.



Class	# Samples	Pixels (%)
Dead Grass Shadow	9	0.02
Deciduous	78	6.11
Evergreen	111	0.57
Turf	138	15.64
Turf Shadow	122	0.41
Asphalt	90	8.55
Dead Grass	103	17.03
Bright Roof	60	2.60
Concrete	107	1.81
Asphalt Shadow	115	0.91
Other Roof	82	0.91
Bare	38	19.47
Water	156	22.33
Green Roof	88	0.76
Dark Roof	86	2.91

Figure 3. Example of training samples being collected in the image, and initial classes used to train the algorithm.

Once training samples were collected attempts were made to train the Support Vector Machine (SVM) and Random Trees classification algorithms. Due to extremely long processing time for the SVM method, the Random Trees method was used. The model was trained and the classifier was executed. Like classes were then merged, producing the initial classified image below. Note the errors in the image where portions of the streets and rooftops that are partially obscured by tree canopy are misclassified as dead grass or deciduous canopy. There are also portions of roofs and driveways misclassified as water.

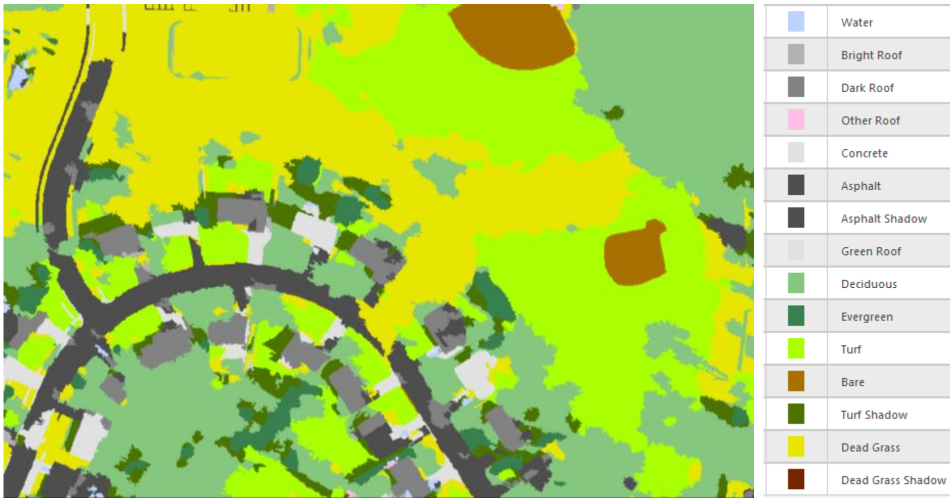


Figure 4. Initial classified image.

Portions of the image where errors were present, such as impervious surfaces being classified as water, or roofs being classified as deciduous canopy, were manually reclassified. The specific classes were also combined into seven generalized classes. Finally, in order to ensure the maximum amount of misclassified portions of impervious surfaces were corrected, road centerline and building footprint data layers were used to reclassify these areas. The County developed a building footprint layer derived from LIDAR elevation data in 2024, and a road centerline layer is continuously updated. The building footprints and a 10-foot buffer from the centerline of the roads were used to overwrite these areas of the classified image to increase the accuracy of the impervious surfaces. These areas can be seen in the image below.

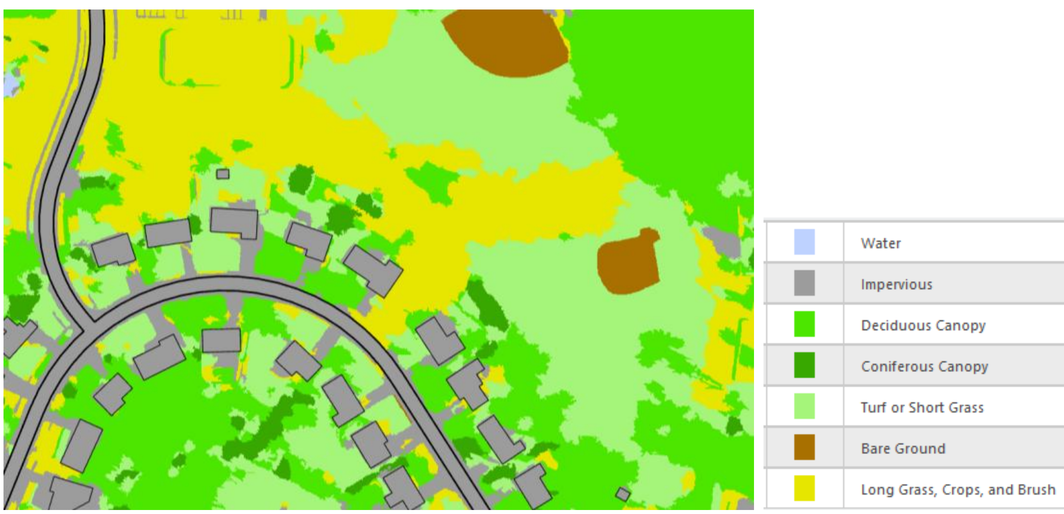


Figure 5. Example of final classified image with building footprint and street buffers overlaid.

In order to provide information on the amount of impervious surface in terms of square footage and percent cover on each parcel, the classified image was summarized using the County's parcel data, and joined back to the parcel data. This allows the end user to view the area and percent cover for each parcel, or summarize the amount of impervious surface for an entire development. Note the methods described in this memo are a simplified workflow, and documentation on specific processes may be provided upon request.

Accuracy Assessment

Assessing the accuracy of classified imagery is an important step to ensure the model represents real world conditions as accurately as possible. Errors will exist in every image classification due to spectral and spatial similarities between land covers, but a high degree of accuracy can be expected. It should be noted the data developed through this process is intended to provide general information on development status at the parcel scale, but real world conditions should be verified through finer review of aerial images or in-field surveys.

In order to assess the accuracy of the classified image 505 randomly stratified points were generated throughout the image. This distributes the amount of random points by class depending on the total area covered by each class. The random points were then manually updated with the actual land cover class and used to compute a confusion matrix and overall accuracy score. In the confusion matrix below, the cells along the green diagonal line represent random points that were accurately classified by the model. Cells off the diagonal represent random points that were misclassified, i.e. the model classified the pixel as impervious, but it was actually water. These provide details on errors of commission (false positives) and errors of omission (false negatives), where classes may include pixels that aren't actually in that class (commission) or classes do not include pixels that should be in that class (omission). The confusion matrix also provides an accuracy score for each class, and a kappa statistic that represents the overall accuracy of the classification. This statistic ranges from zero to one, with one representing perfect accuracy. The most accurate classes are water, impervious surfaces, and coniferous canopy. The least accurate classes are bare ground and deciduous canopy. Bare ground was most commonly misclassified as long grass, crops, and brush, and deciduous canopy errors were most commonly misclassified as turf or short grass, or long grass, crops, and brush. The overall accuracy score of the image is 0.856, which is considered excellent agreement between the model and real world conditions.

Table 1. Confusion matrix for randomly distributed points on the final classified image.

Class	Water	Impervious	Deciduous Canopy	Coniferous Canopy	Turf or Short Grass	Bare Ground	Long Grass, Crops, and Brush	Total	User Accuracy	Kappa
Water	33	1	0	0	0	0	0	34	0.971	0
Impervious	0	42	0	0	0	0	0	42	1.000	0
Deciduous Canopy	0	0	113	2	4	0	9	128	0.883	0
Coniferous Canopy	0	0	0	36	0	0	0	36	1.000	0
Turf or Short Grass	2	1	5	2	47	0	6	63	0.746	0
Bare Ground	0	0	0	0	0	3	2	5	0.600	0
Long Grass, Crops, and Brush	0	2	13	0	3	3	176	197	0.893	0
Total	35	46	131	40	54	6	193	505	0.000	0
Producer Accuracy	0.943	0.913	0.863	0.900	0.870	0.500	0.912	0.000	0.891	0
Kappa	0	0	0	0	0	0	0	0	0	0.856

Deliverables

In order to make use of this classification as convenient as possible a web application was developed using ArcGIS Online Experience Builder to host the data. This application can be used to view the amount of impervious surface on each parcel in the watershed, as well as export selections of parcels to other formats for further analysis. The application can be accessed by clicking the following link or by typing in the URL: BCWD Impervious Surface and Land Cover Viewer or tinyurl.com/4c9fx8ym. The raw underlying data can also be provided directly in various formats by contacting Aaron DeRusha at aderusha@mnwcd.org.