TECHNICAL DOCUMENTATION

EarthDefine Land Cover: Technical Specification

EarthDefine Land Cover maps seven classes. Standard resolution is 30cm or 60cm. We produce it on demand for any area in the contiguous United States, Hawaii, Puerto Rico and the US Virgin Islands.

Revised 24 November 2026

Current version https://www.earthdefine.com/evaluate/landcover-tech-spec/

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1. What is EarthDefine Land Cover?

EarthDefine Land Cover is a single-band raster. Each mapped pixel has one of the seven class codes below. At 60cm resolution, the raster can show features such as individual driveways, small ponds and tree crowns.

CODE	CLASS	COLOR	IN BRIEF
1	Herbaceous		Grasses, crops, pasture and other non-woody plants
2	Bare		Exposed soil, sand, rock, gravel and snow
3	Impervious		Roads, buildings, parking lots, sidewalks and other constructed surfaces
4	Water		Lakes, rivers, streams, ponds and the ocean
5	Trees		Woody vegetation 10 ft and taller
6	Shrubs		Woody vegetation below 10 ft, including young or stunted trees
7	Trees over Impervious		Tree canopy covering a road, roof or other impervious surface



Figure 1.1. Cape Coral, Florida, shown in 30cm NAIP imagery (left) and EarthDefine Land Cover (right).

2. What areas and resolutions are available?

Projects can cover a single city or span an entire state or the available national coverage area. We can also classify archived NAIP imagery to create a historical baseline for measuring change. When the source NAIP imagery has 1m resolution, we deliver the historical Land Cover raster at 1m.

One 30m pixel in the National Land Cover Database (NLCD) covers the same area as 2,500 EarthDefine pixels at 60cm or 10,000 at 30cm. A 6m by 10m driveway, for example, covers about 170 pixels at 60cm and less than a tenth of a 30m pixel.

Resolution	GROUND AREA PER PIXEL	PIXELS PER SQ MI
30m (NLCD)	900 m²	2,878
60cm (EarthDefine)	0.36 m²	7.19 million
30cm (EarthDefine)	0.09 m²	28.8 million

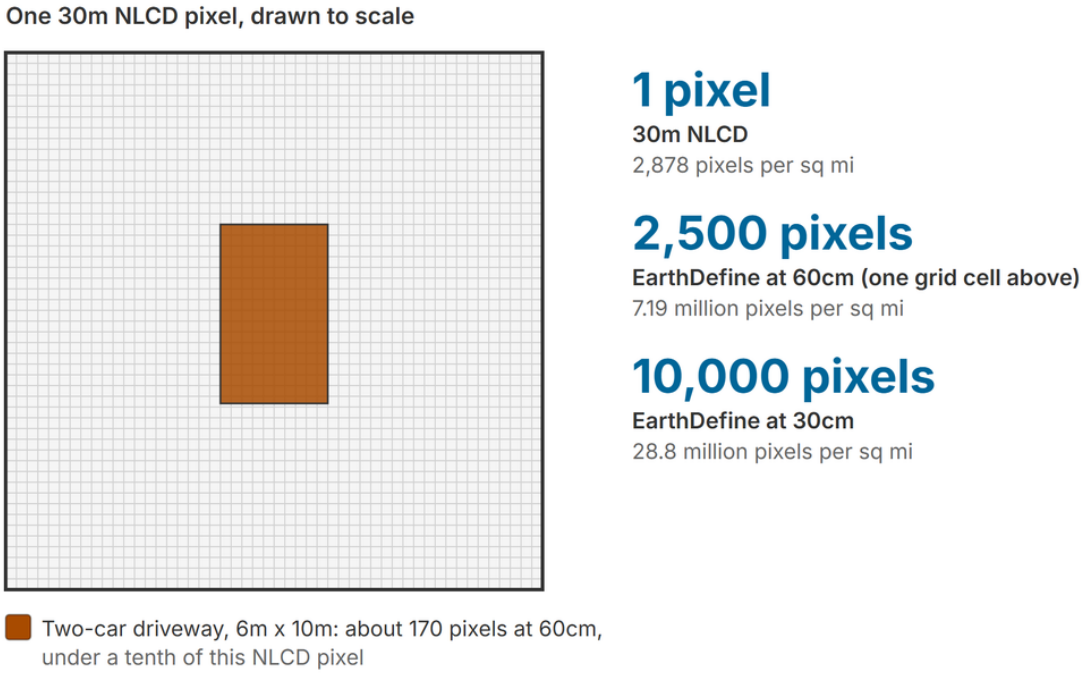


Figure 2.1. One 30m NLCD pixel divided into 60cm EarthDefine pixels, drawn to scale.



30m NLCD | 2025 NAIP imagery | EarthDefine Land Cover

Figure 2.2. Three views of the same area in Cape Coral, Florida. From left to right, the panels show 30m NLCD, 2025 NAIP imagery and EarthDefine Land Cover.

3. How do we produce Land Cover?

We use aerial imagery from the USDA's National Agriculture Imagery Program (NAIP). The imagery has four bands (red, green, blue and near-infrared). Recent imagery is 30cm to 60cm, and some older imagery is 1m. For some classes, we supplement the imagery with LiDAR-derived heights or planimetric layers such as building footprints and road centerlines. Each class model uses four or five input bands.

1. **Inputs.** We prepare the imagery and any supplemental layers for each class.
2. **Training data.** We assemble training labels from manual photointerpretation, automated stratified sampling and our archive of labeled land cover. We balance the labels across the landscapes where each class occurs.

3. **Per-class models.** Six neural network models cover the full project area, one each for Herbaceous, Bare, Impervious, Water, Trees and Shrubs. Each model predicts whether its class is present at each pixel. We select models using intersection over union (IoU) scores from held-out validation and test sets.
4. **Merge.** We combine the six class layers into one raster and label the overlap of Trees and Impervious as Trees over Impervious. We then use morphological filtering to remove isolated pixels.
5. **Gap fill.** A multiclass model assigns a class to pixels left unclassified by the six models.
6. **Review.** We run automated checks on every tile. Analysts then review the tiles against the source imagery and make corrections as needed (Section 6).
7. **Mosaic and reproject.** We mosaic the tiles and reproject the raster to the coordinate system for the project area (Section 7).
8. **Delivery.** We deliver the classified GeoTIFF and can also provide vector layers or summary statistics (Section 8).

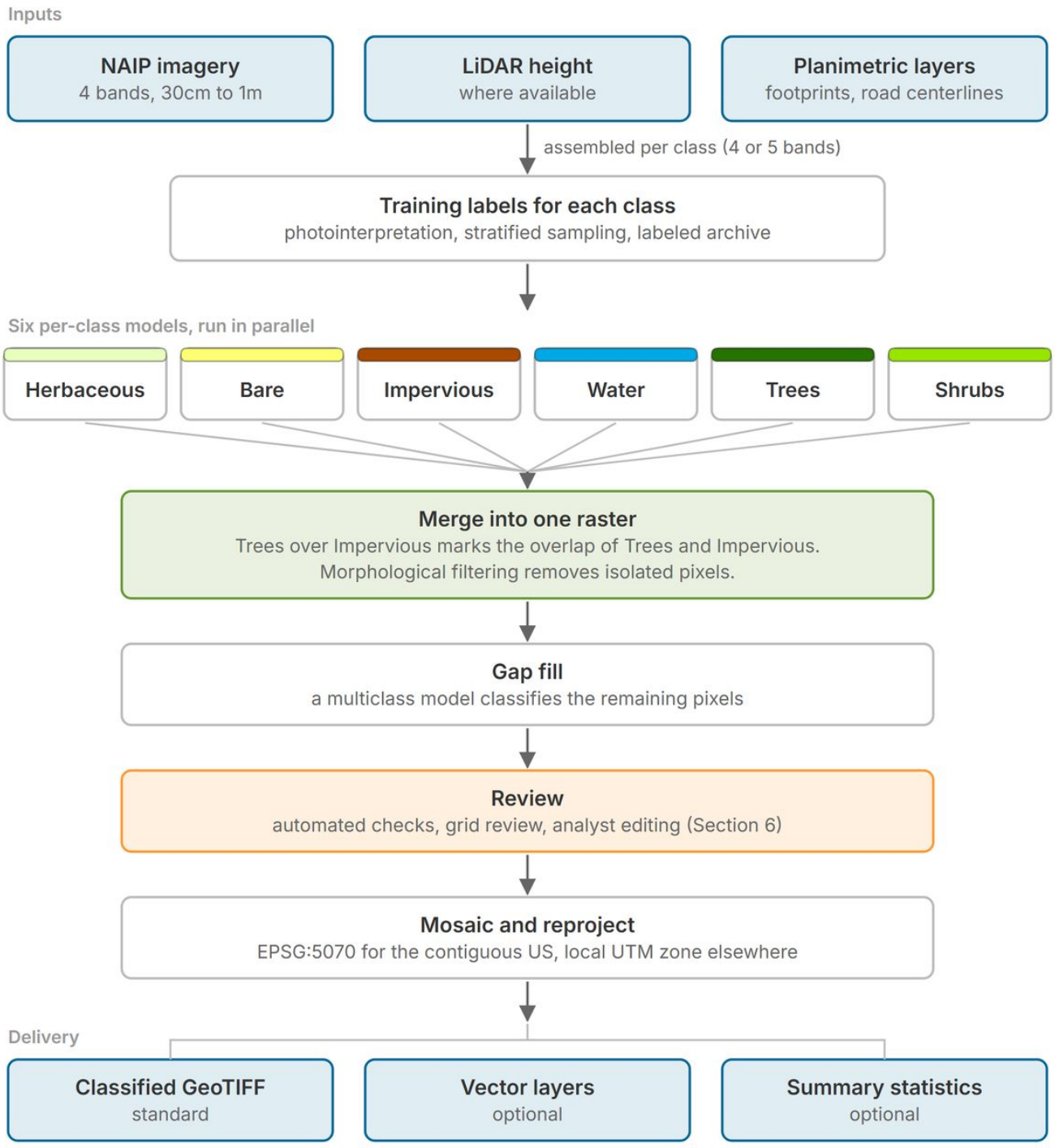


Figure 3.1. The six class models run in parallel. We derive Trees over Impervious when we merge their outputs.

4. How often is it updated?

For current land cover, we use the most recent NAIP imagery available for the project area. NAIP captures new imagery for each state about every two years, covering roughly half the states in a given year. If you

need more frequent updates, we can use satellite imagery to refresh the map every six months or annually at additional cost.

Vancouver, Washington, has Land Cover for 2011, 2019 and 2021. For projects that compare several years, we can reprocess older imagery with the current models so the maps use the same classification method.

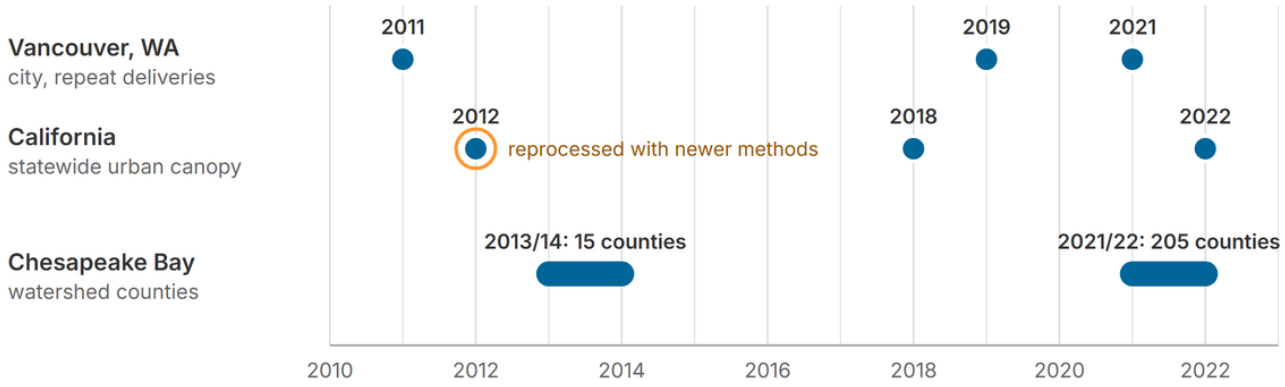


Figure 4.1. Examples of repeat mapping. We reprocessed California's 2012 urban tree canopy to make it comparable with the 2018 and 2022 maps.

5. How do we define each class?

The examples below pair aerial imagery on the left with Land Cover for the same area on the right. Expand the list below each pair to see more examples.

HERBACEOUS	BARE	IMPERVIOUS	WATER	TREES	SHRUBS	TREES OVER IMPERVIOUS

Herbaceous

Grasses, forbs and other non-woody plants, typically under 3 ft.

Includes: lawns and irrigated grass, cropland in rotation, pasture, natural grassland, dry grass and vegetated wetlands.



Imagery



EarthDefine Land Cover

Figure 5.1. Pastures and hayfields are Herbaceous. The hedgerows and woodlots between them are Trees. Fairfax County, Virginia, 2025.

More Herbaceous examples

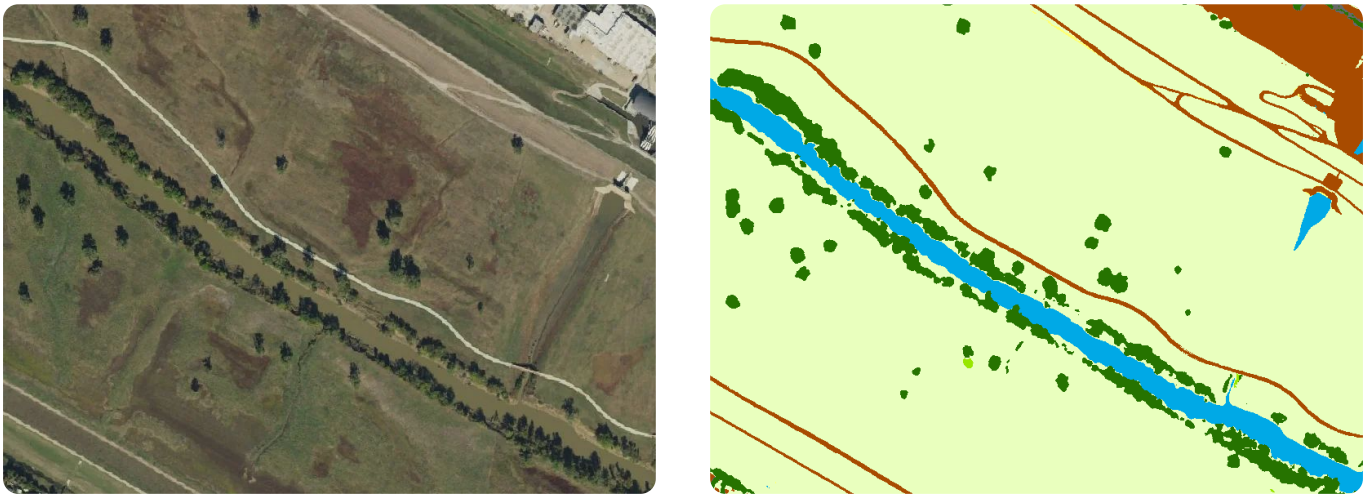


Imagery



EarthDefine Land Cover

Figure 5.2. On this golf course, the grass on fairways and greens is Herbaceous, the sand traps are Bare and the ponds are Water. Norwalk, Connecticut, 2025.



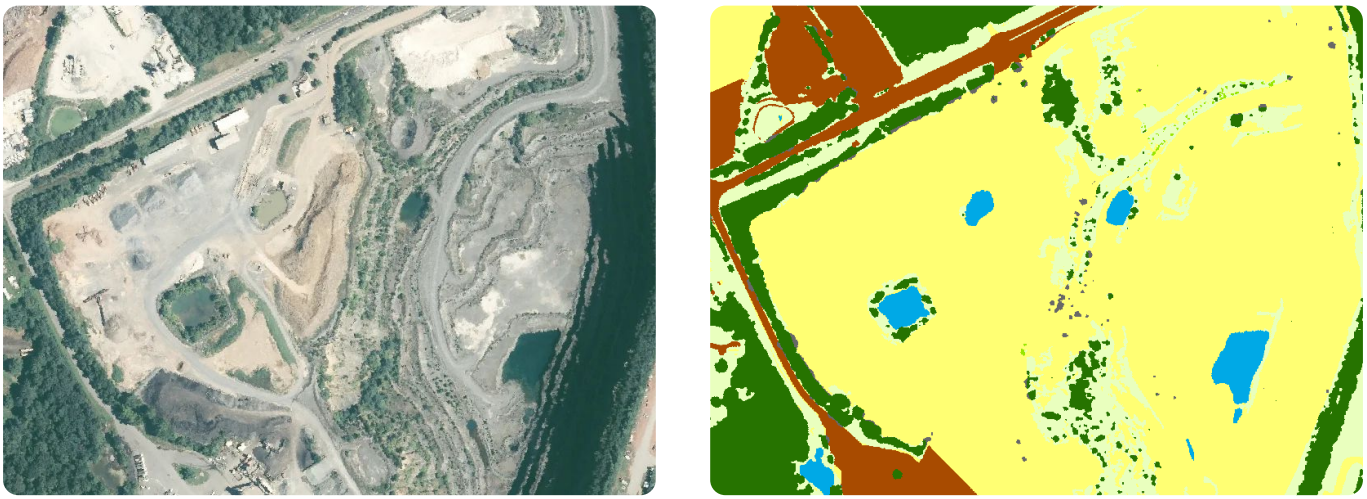
Imagery EarthDefine Land Cover

Figure 5.3. The grass along the channel is Herbaceous, the paved trail is Impervious and the channel is Water. Dallas, Texas, 2024.

Bare

Exposed ground without vegetation or a constructed surface.

Includes: exposed soil, sand, rock, gravel and snow, along with beaches and sand or gravel bars. Examples include fallow cropland, unmaintained or ungraded dirt roads and lots, construction sites, gravel pits, quarries, other excavations, talus, scree, dirt infields and sand traps.



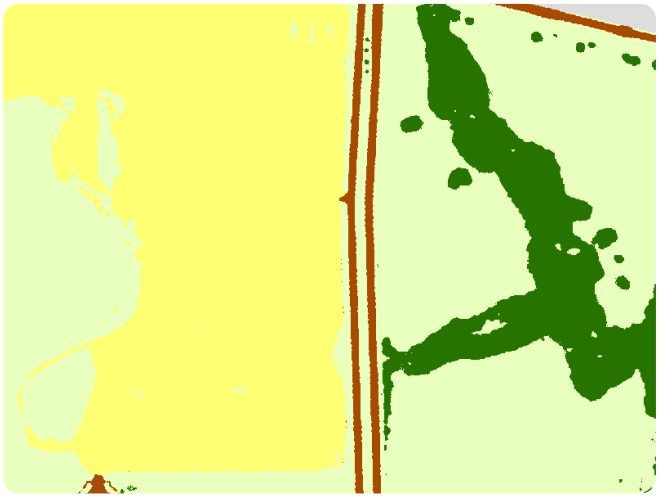
Imagery EarthDefine Land Cover

Figure 5.4. The quarry floor, benches and stockpiles are Bare. The water in the pit is Water, and the paved access roads are Impervious. Fairfax County, Virginia, 2025.

More Bare examples



Imagery



EarthDefine Land Cover

Figure 5.5. A graded construction site is Bare. The pasture beside it is Herbaceous, and the divided highway between them is Impervious. Lexington, Kentucky, 2024.



Imagery



EarthDefine Land Cover

Figure 5.6. The cleared ground, haul roads and spoil piles at this earthworks site are Bare. Dallas, Texas, 2024.

Impervious

Paved surfaces, other constructed hard surfaces and some unpaved roads and lots.

Includes: roads, parking lots, buildings, driveways, sidewalks, railroad tracks and yards, asphalt and concrete surfaces, artificial turf and synthetic running tracks.

We also map unpaved roads and lots as Impervious if they are graded, compacted and show signs of regular vehicle traffic. We classify other exposed or disturbed ground as Bare.

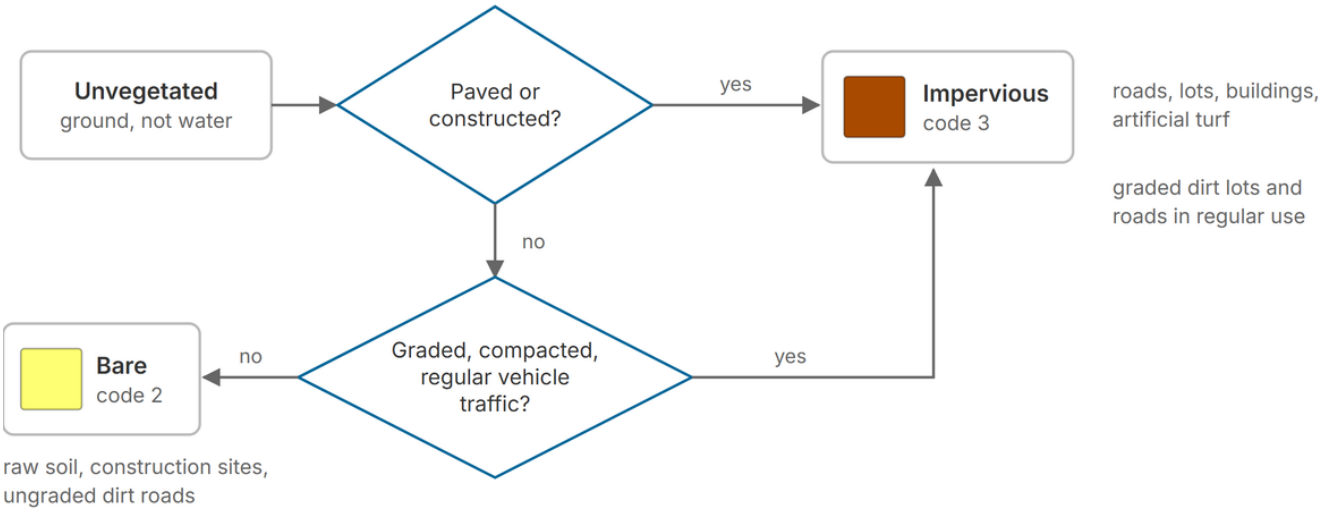
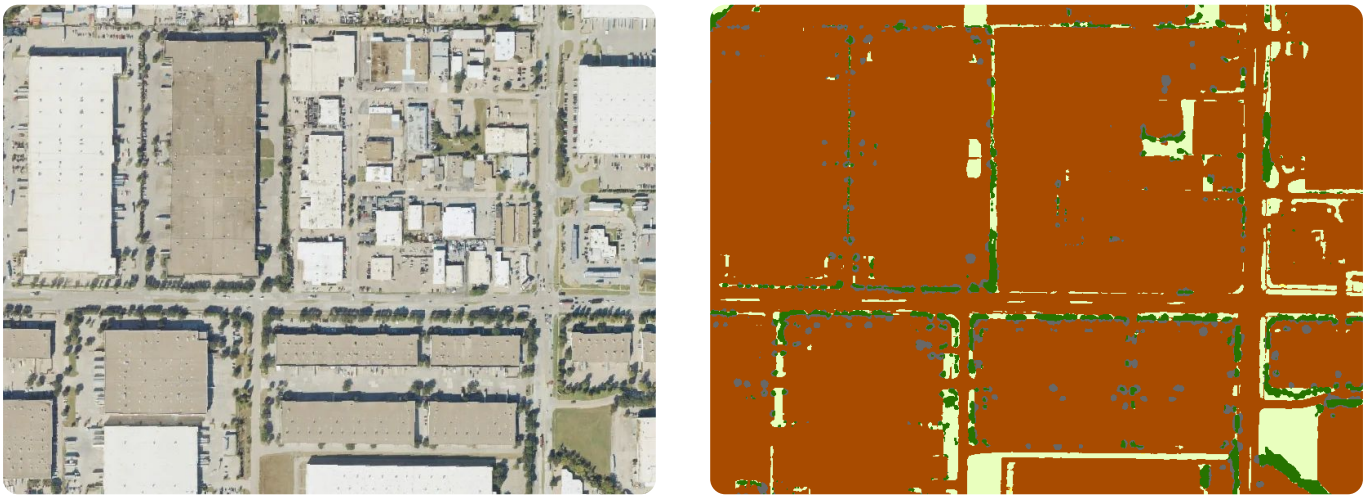


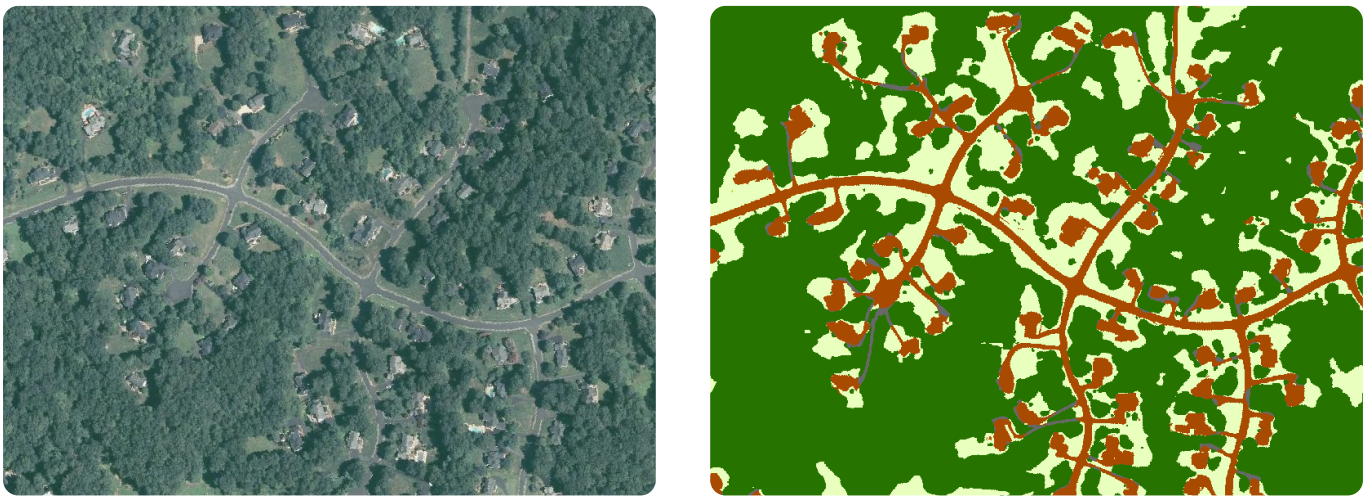
Figure 5.7. The rules we use to classify exposed ground as Impervious or Bare.



Imagery EarthDefine Land Cover

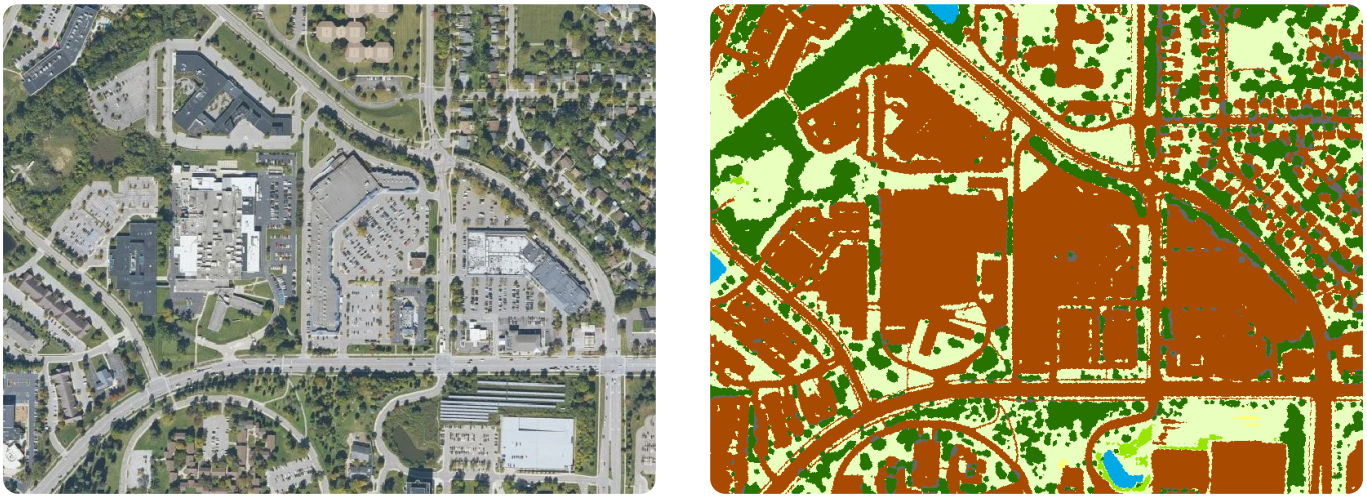
Figure 5.8. Warehouse roofs, loading yards, parking lots and streets are Impervious. Garland, Texas, 2024.

More Impervious examples



Imagery EarthDefine Land Cover

Figure 5.9. Roofs, streets and driveways in this subdivision are Impervious where they are exposed. Where tree crowns cover them, the class is Trees over Impervious. Fairfax County, Virginia, 2025.



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Figure 5.10. Building roofs, parking lots and streets in this commercial area are mapped as Impervious. Where tree crowns overhang pavement, the class is Trees over Impervious. Ann Arbor, Michigan, 2024.

Water

Open water, including surfaces with visible aquatic vegetation.

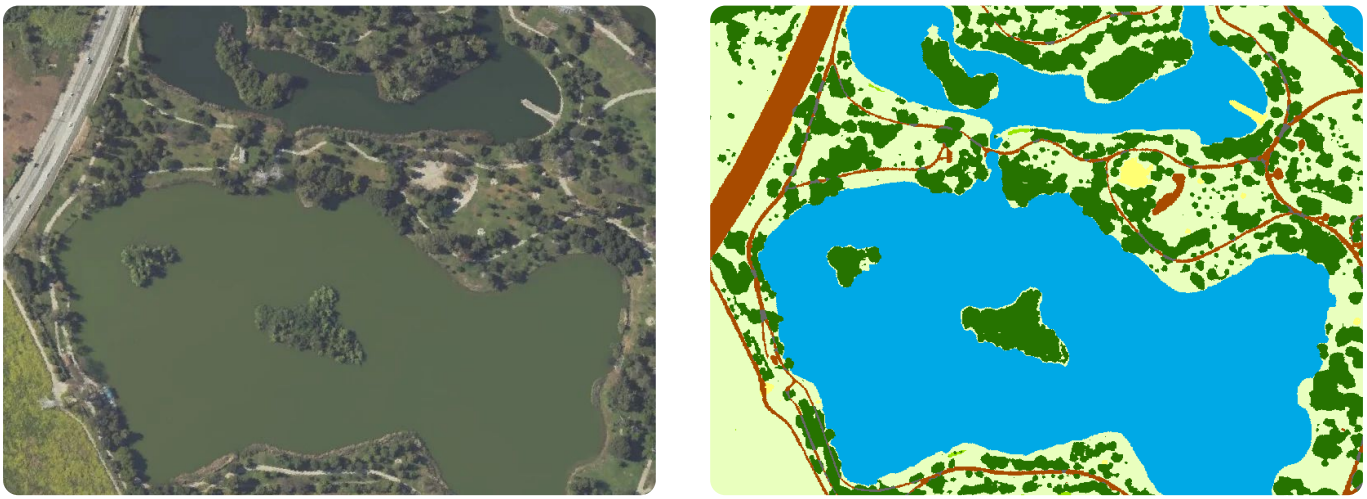
Includes: ponds, lakes, rivers, streams and the ocean. This class also covers water with algae, aquatic grasses, kelp or other floating or partly submerged plants.
Excludes: swimming pools, water tanks and other constructed basins with an impermeable bottom.



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Figure 5.11. The lake basins are Water even where floating plants and algae cover most of the surface. Cape Coral, Florida, 2025.

More Water examples



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Figure 5.12. The lakes are Water, their wooded islands are Trees and the surrounding paths are Impervious. Los Angeles County, California, 2024.



Imagery



EarthDefine Land Cover

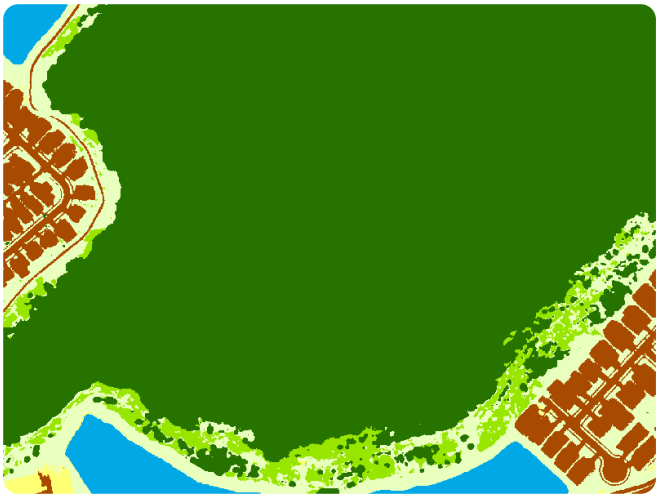
Figure 5.13. The lake is Water up to the shoreline. The exposed sandbar at the creek mouth is Bare. Dallas, Texas, 2024.

Trees

Woody vegetation at least 10 ft tall.



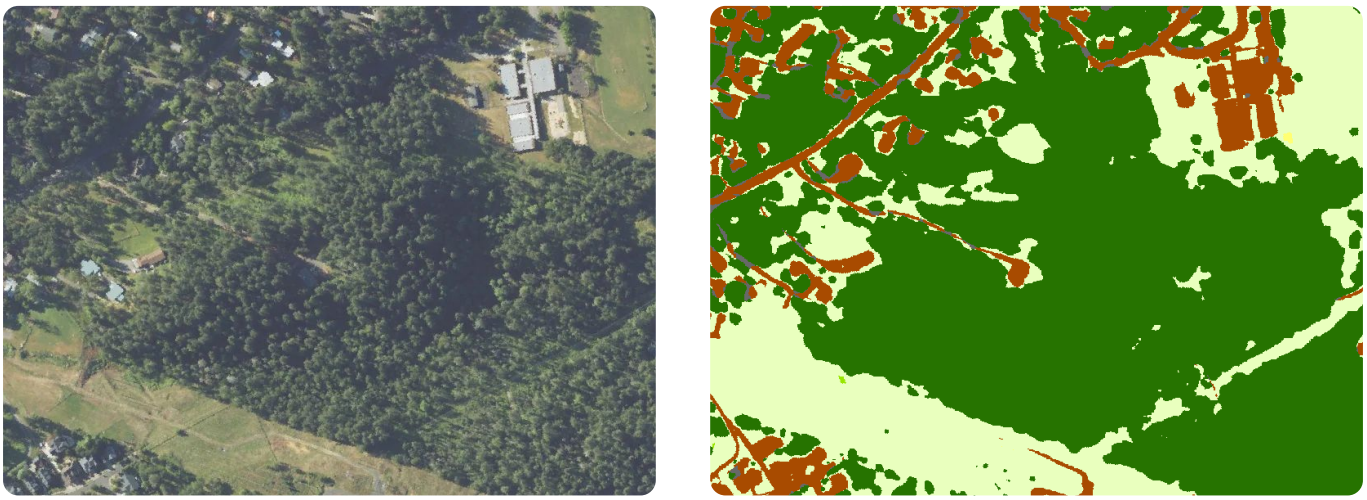
Imagery



EarthDefine Land Cover

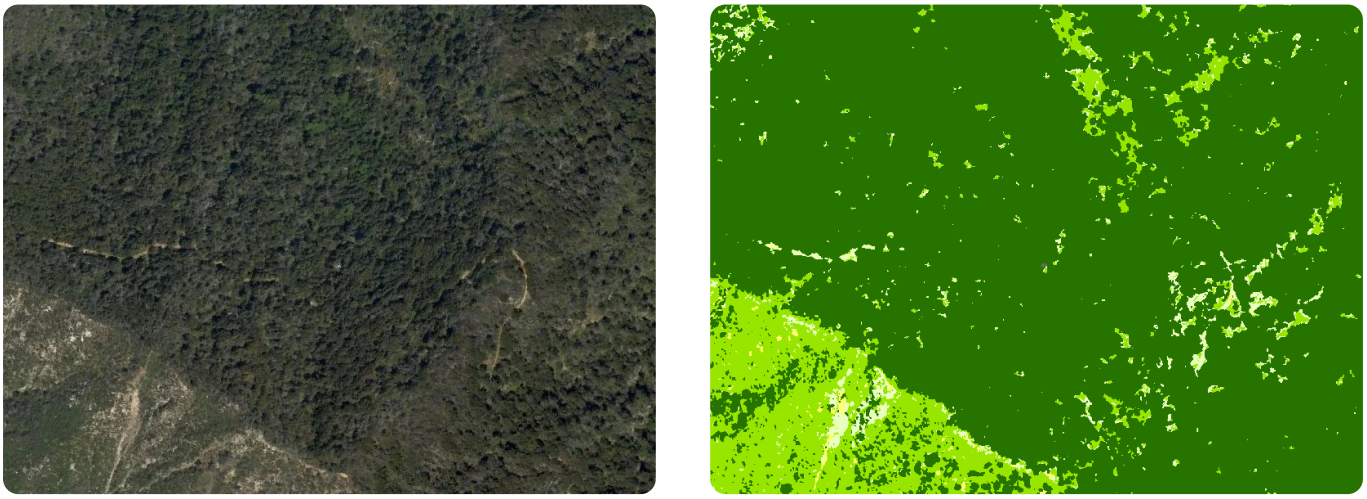
Figure 5.14. The dense forest is Trees, with a band of Shrubs along the retention pond. Orlando, Florida, 2025.

More Trees examples



Imagery EarthDefine Land Cover

Figure 5.15. The hillside forest is Trees, and the dry grass downhill is Herbaceous. Eugene, Oregon, 2024.



Imagery EarthDefine Land Cover

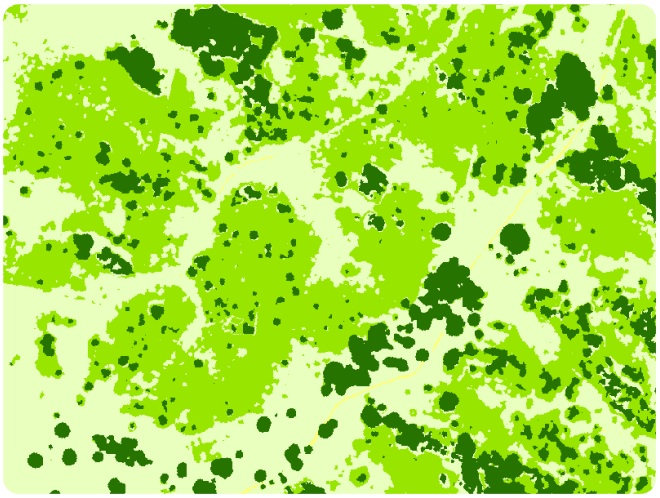
Figure 5.16. The woodland is Trees. The shorter woody growth along its edge is Shrubs. Los Angeles County, California, 2024.

Shrubs

Woody vegetation below 10 ft, including young or stunted trees and woody crops such as berry bushes, grapevines and young orchards.



Imagery



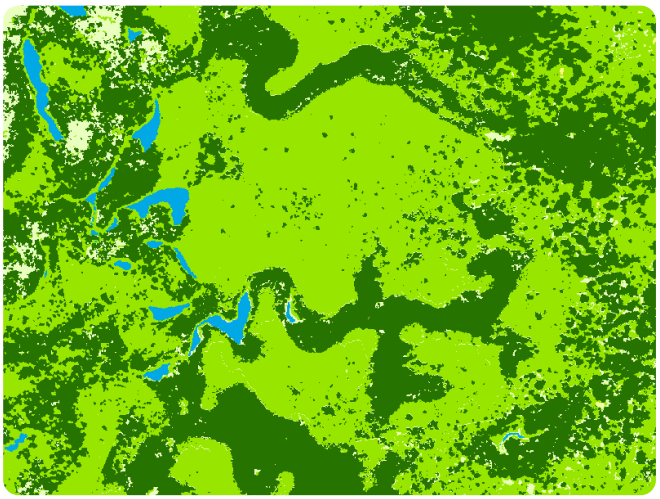
EarthDefine Land Cover

Figure 5.17. Hillside scrub is Shrubs. The taller trees are Trees, and grass between the patches is Herbaceous. Laguna Beach, California, 2024.

More Shrubs examples



Imagery



EarthDefine Land Cover

Figure 5.18. In this wetland, low woody vegetation is Shrubs, taller stands are Trees and open pools are Water. Cape Coral, Florida, 2025.

Trees over Impervious

Tree canopy above roads, buildings, parking lots and other impervious surfaces. We identify these pixels by overlaying the Trees and Impervious layers (Section 3).

Why Trees over Impervious is its own class

Keeping the overlap in its own class accounts for both the canopy and the surface beneath it. To calculate total canopy cover, count pixels with codes 5 and 7. For total impervious cover, count pixels with codes 3 and 7.

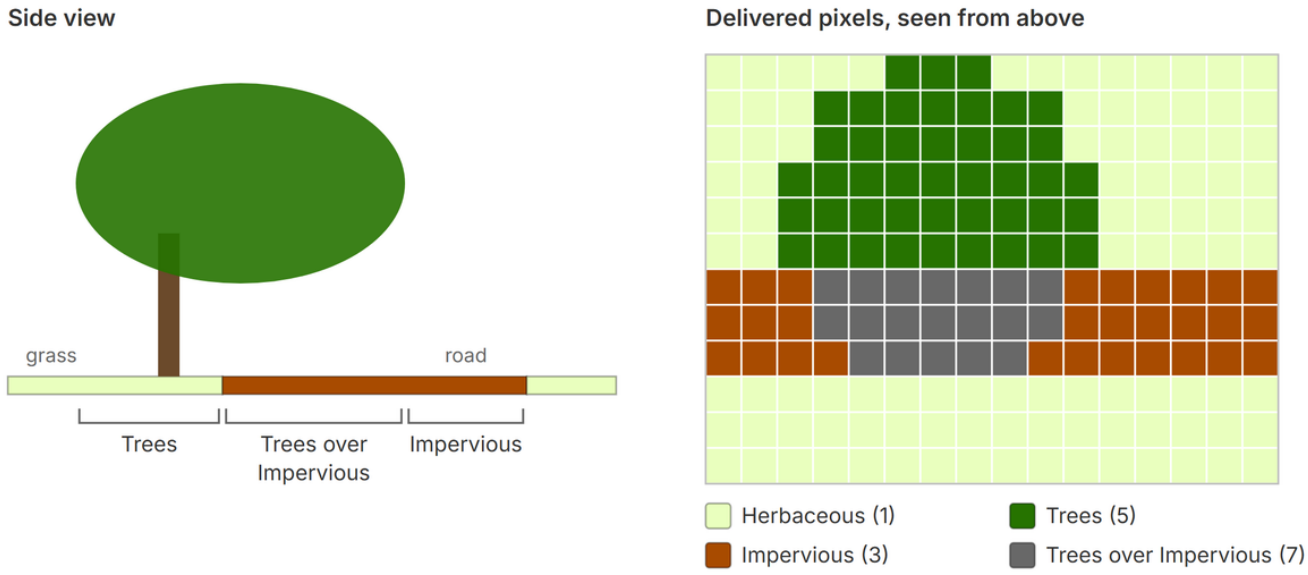


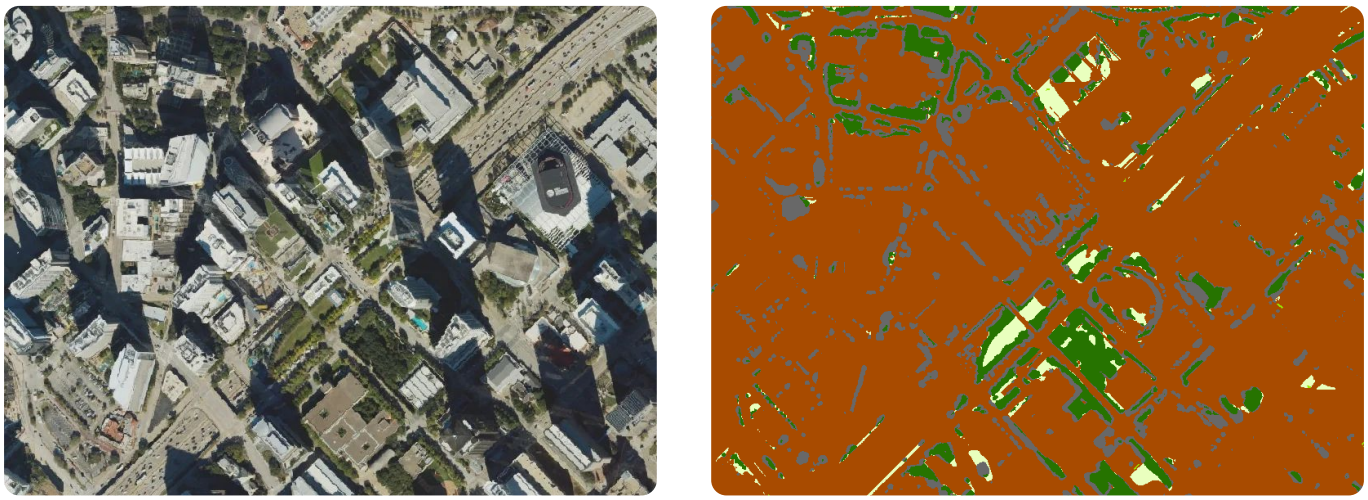
Figure 5.19. The part of the crown over grass is Trees. Where the crown extends over the road, the class is Trees over Impervious. The exposed pavement is Impervious.



Imagery EarthDefine Land Cover

Figure 5.20. Tree crowns cover most of the winding road, which is mapped as Trees over Impervious. Most of the wider highway is exposed and maps as Impervious. Fairfax County, Virginia, 2025.

More Trees over Impervious examples



Imagery EarthDefine Land Cover

Figure 5.21. Canopy from street trees and plaza plantings is mapped as Trees over Impervious where it extends over pavement. Dallas, Texas, 2024.

How do we distinguish Trees from Shrubs?

A tall hedge and a young tree can look similar in aerial imagery. For LiDAR-derived training labels, we classify woody vegetation at least 10 ft tall as Trees and use 3 ft as the typical cutoff between Herbaceous and Shrubs. We adjust the 3 ft cutoff for local vegetation communities. Shrubs are always below 10 ft.

Where LiDAR is unavailable, the models use cues in the NAIP imagery, including canopy texture, shadows and crown shape, to distinguish trees from shrubs. Analysts consult LiDAR, where available, to resolve ambiguous cases.

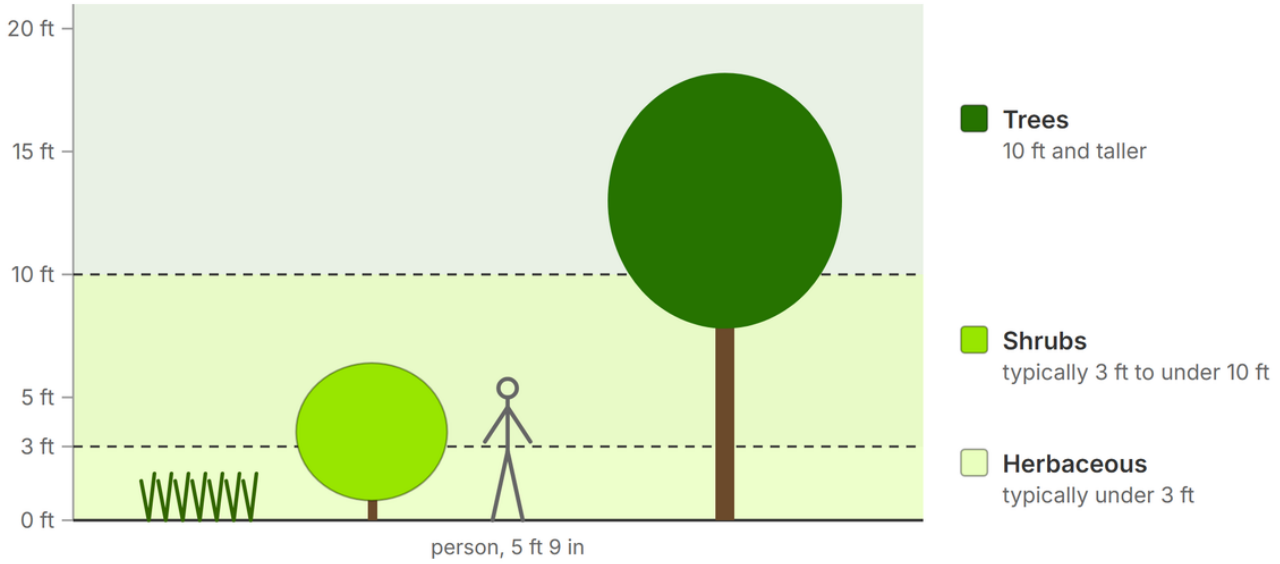


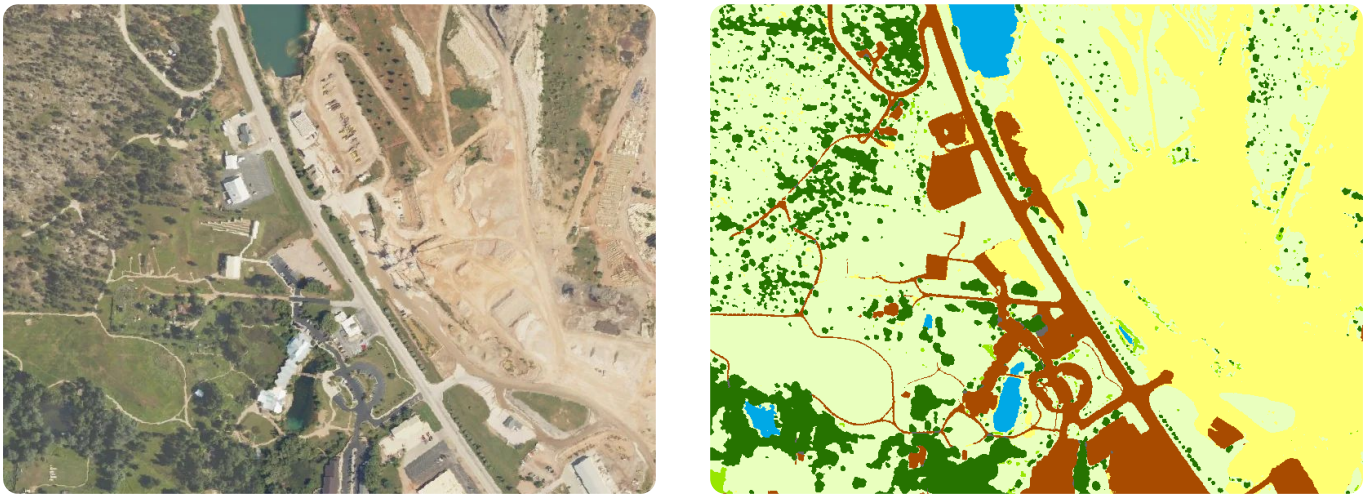
Figure 5.22. Typical height bands for LiDAR-derived training labels. The boundary between Herbaceous and Shrubs varies with local vegetation.

Examples of classification decisions



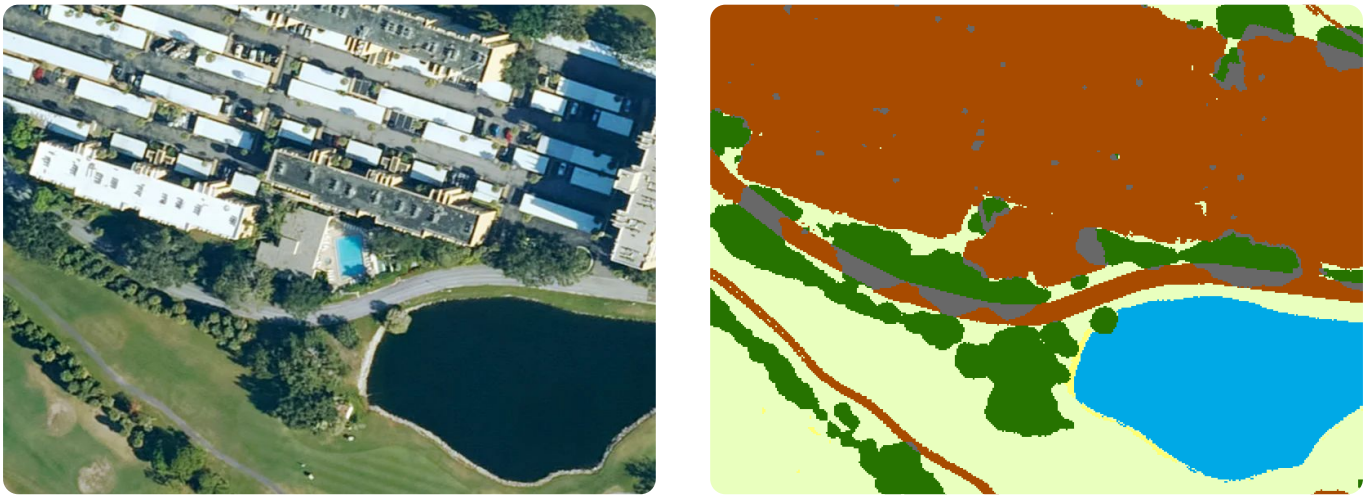
Imagery EarthDefine Land Cover

Figure 5.23. Tree canopy over a road. The canopy above pavement is Trees over Impervious. The rest of the crown is Trees. Florida, 2025 NAIP.



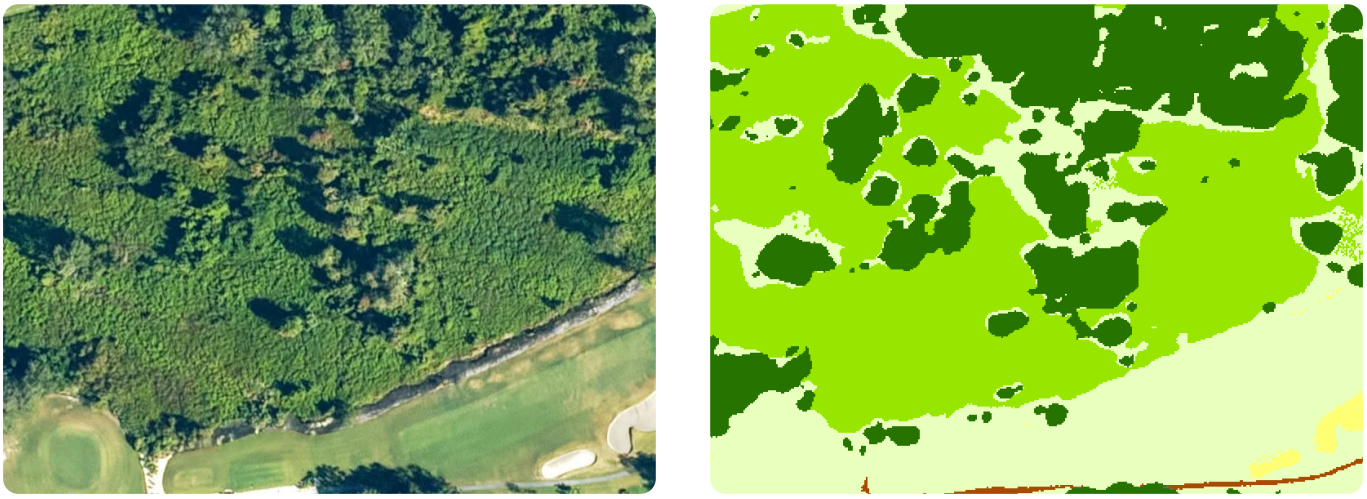
Imagery EarthDefine Land Cover

Figure 5.24. Exposed ground beside a paved road. Exposed soil and rock to the right of the main road are mapped as Bare. The paved road and nearby buildings are mapped as Impervious. Rapid City, South Dakota, 2023.



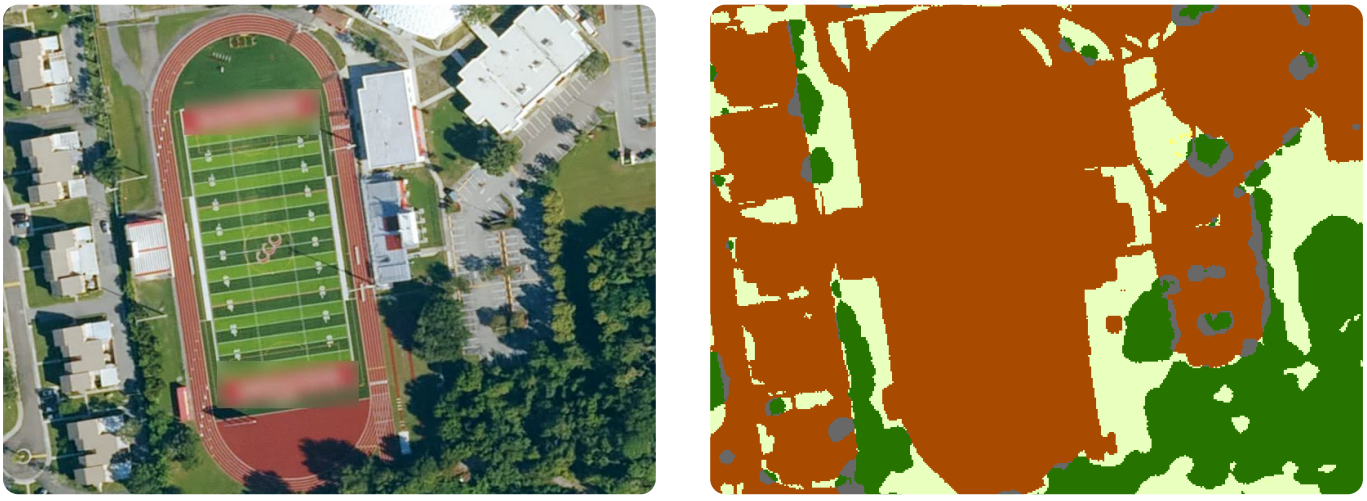
Imagery EarthDefine Land Cover

Figure 5.25. Swimming pool beside a pond. The pool has an impermeable bottom and maps as Impervious. The pond is Water. Florida, 2025 NAIP.



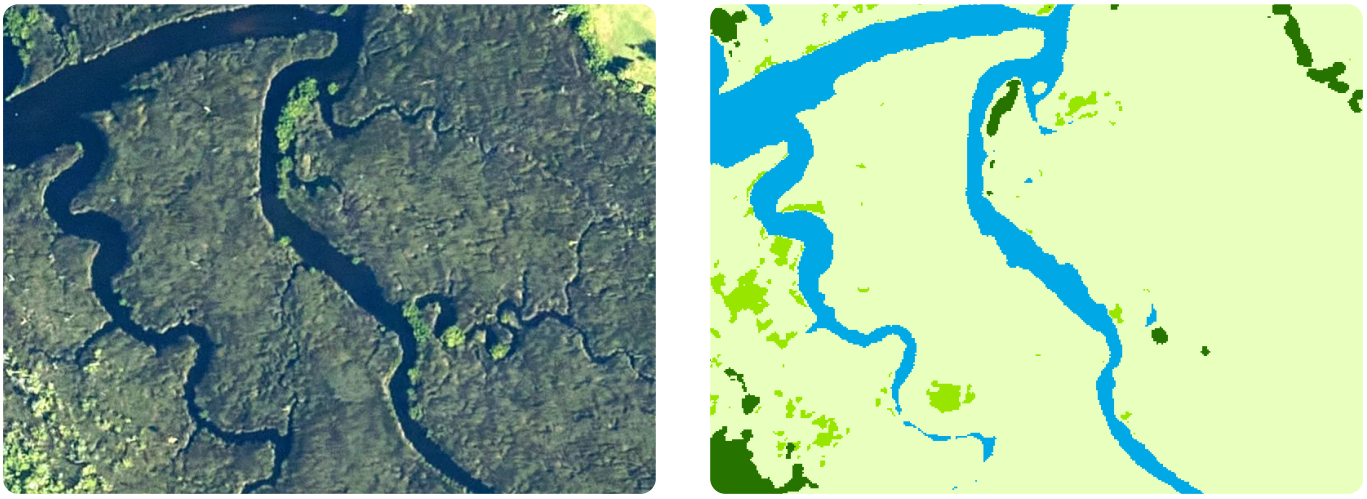
Imagery EarthDefine Land Cover

Figure 5.26. Shrubs next to trees. The low woody vegetation is Shrubs. The vegetation at least 10 ft tall is Trees. Florida, 2025 NAIP.



Imagery EarthDefine Land Cover

Figure 5.27. Artificial turf. Both the synthetic turf field and the running track are Impervious. Florida, 2025 NAIP.



Imagery EarthDefine Land Cover

Figure 5.28. Vegetated wetland. Emergent wetland vegetation is Herbaceous. Open water in the creeks is Water. Florida, 2025 NAIP.



Imagery EarthDefine Land Cover

Figure 5.29. Construction site. The cleared ground at the construction site is Bare. The new road is Impervious. Florida, 2025 NAIP.

6. How is accuracy measured and verified?

Quality assurance

We run automated checks on every tile. Analysts then review each tile on a regular grid against the original NAIP imagery. We correct flagged areas using automated and manual editing tools. Analysts review the edits and repeat the process as needed to meet the project specification.

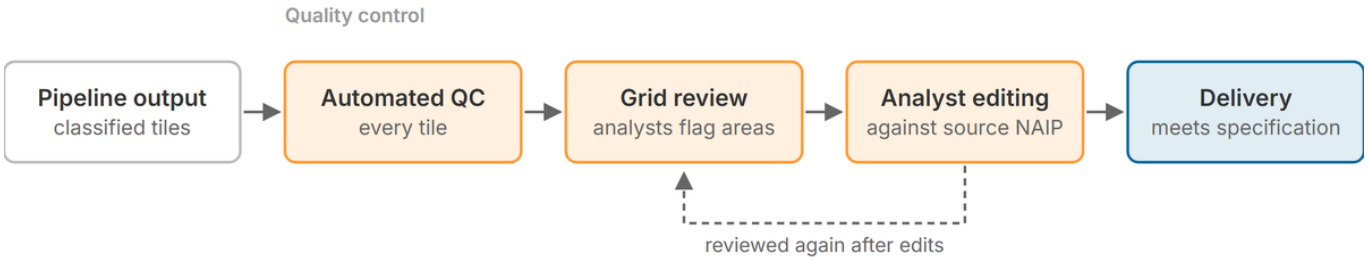


Figure 6.1. We review classified tiles again after making edits.

Accuracy assessment

An optional accuracy assessment is available for any Land Cover delivery.

1. **Sample.** We draw a stratified random sample across the project area, avoiding class boundaries.
2. **Interpret.** An analyst assigns a reference class to each point using the original NAIP imagery and, where available, LiDAR-derived heights.
3. **Adjudicate.** A second analyst independently reviews points where the reference and mapped classes differ.
4. **Exclude.** We exclude points we can't classify confidently because of shadows, clouds, mixed pixels or proximity to a class boundary.
5. **Score.** We use the remaining points to build a confusion matrix and calculate overall accuracy. For each class we report producer's accuracy (1 minus omission error) and user's accuracy (1 minus commission error). We include confidence intervals when the sample size supports them.

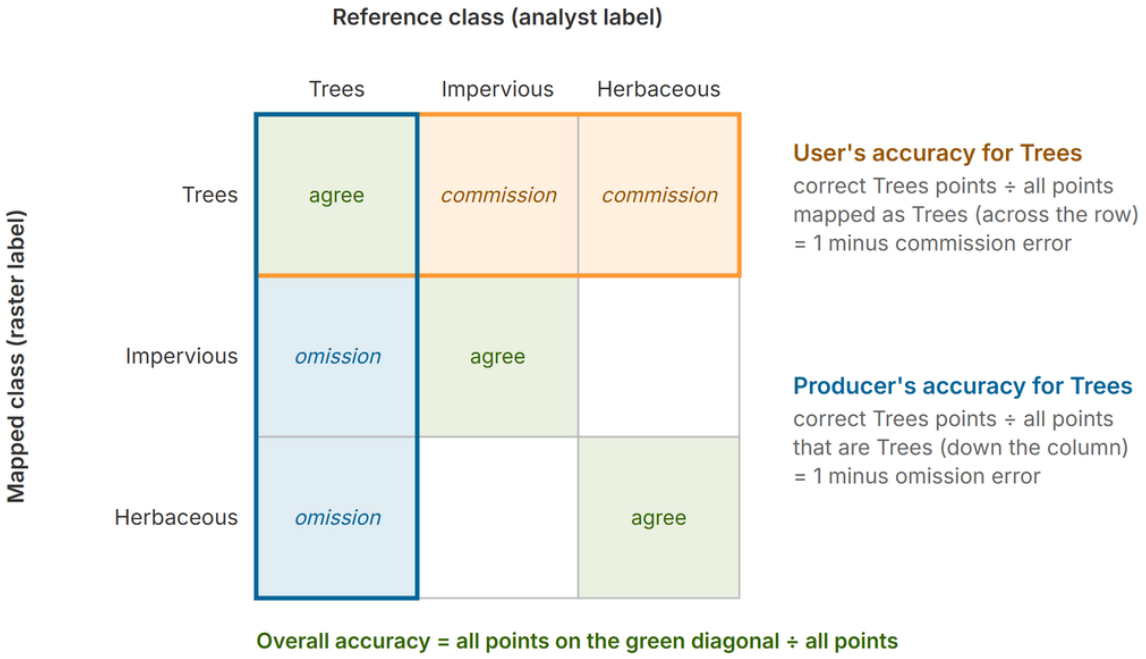


Figure 6.2. A three-class confusion matrix. Rows show mapped classes, and columns show reference classes.

We deliver Land Cover with greater than 95% overall accuracy. Each accuracy assessment reports overall and per-class results for that delivery.

7. What are the raster properties and class codes?

We deliver Land Cover as a single-band, 8-bit raster. Values 1 through 7 identify the land cover classes, and 0 indicates NoData.

Property	VALUE
Format	GeoTIFF, LZW compression
Bands	1
Data type	8-bit unsigned integer
Coordinate system	EPSG:5070 (NAD83 / Conus Albers) for the contiguous United States. The appropriate projected UTM zone for Hawaii, Puerto Rico and the US Virgin Islands.
Pixel size	0.3m x 0.3m or 0.6m x 0.6m. 1m x 1m for historical imagery at 1m.
NoData	0
Symbology	Color table (.clr) included

VALUE	CLASS	COLOR	HEX	RGB
0	NoData		none	none
1	Herbaceous		E9FFBE	233, 255, 190
2	Bare		FFFF73	255, 255, 115
3	Impervious		A84B00	168, 75, 0
4	Water		00A9E6	0, 169, 230
5	Trees		267300	38, 115, 0
6	Shrubs		98E600	152, 230, 0
7	Trees over Impervious		686868	104, 104, 104

Calculate total canopy cover from pixels with codes 5 and 7, and total impervious cover from pixels with codes 3 and 7.

8. What delivery and licensing options are available?

Item	DETAIL
Primary format	Single-band GeoTIFF with LZW compression. See Section 7 for coordinate systems and pixel sizes.

Item	DETAIL
Vector layers (optional)	Selected classes, such as Water, as polygons in GeoPackage or Esri File Geodatabase
Summary statistics (optional)	Percent cover and area by class for each polygon in a boundary layer
Delivery basis	On demand for the project area, including seamless statewide or national coverage
Historical years	Wherever archived NAIP imagery covers the requested year
Accuracy assessment (optional)	Confusion matrix with overall, producer's and user's accuracy (Section 6)

Summary statistics by boundary

We can deliver summary statistics on their own. For each census block, block group, tax parcel or other polygon you specify, we calculate the area and percentage in each class, along with totals such as canopy and impervious cover. We can include these values as attributes in a shapefile, GeoPackage or Esri File Geodatabase, or deliver a separate table linked by the boundary layer's ID field.

Licensing

We price Land Cover by project, with a $1,000 minimum order. Contact us for a quote based on your project area and intended use.

9. Where has Land Cover been used?

We've used this classification approach for projects ranging from individual cities to multistate programs.

- **Coastal change.** For NOAA's Coastal Change Analysis Program (C-CAP), we mapped more than 500,000 sq mi at 1m resolution using seven classes and another 23,000 sq mi using 18 classes. The data support coastal land cover change analysis across multiple states.
- **Chesapeake Bay.** For the Chesapeake Conservancy and the Chesapeake Bay Program, we mapped land use and land cover for 15 counties in 2013/2014 and 205 counties in 2021/2022. The work included measuring tree canopy change from 2013 to 2021 in Wicomico and Baltimore counties, Maryland.
- **Statewide canopy programs.** CAL FIRE and the US Forest Service commissioned three statewide urban tree canopy updates for California, based on NAIP imagery from 2012, 2018 and 2022. Kansas also commissioned a statewide tree canopy layer.
- **Statewide city programs.** We mapped land cover or tree canopy for 63 cities in Texas and 495 cities in Florida through statewide programs.
- **Repeat municipal tracking.** More than 100 cities and counties have ordered Land Cover or tree canopy maps for multiple years to track progress toward urban forestry and planning goals. They include Boulder and Denver in Colorado, Fairfax County in Virginia and Vancouver in Washington.
- **Research.** EarthDefine tree canopy data have supported research at Duke University and in a California program involving MIT and multiple cities.



Figure 9.1. Examples of city, watershed, statewide and multistate projects.

10. Can Land Cover be customized?

We can adapt the classification, resolution or update schedule to your project. For example, we can map deciduous and coniferous trees separately, deliver a single class or time updates to match your imagery collection.

We also offer two products for projects that need only tree canopy or impervious surface data.

- **Tree Map** maps tree canopy at 60cm across the contiguous United States. It is available off the shelf, with about half the states refreshed each year and the full national dataset every two years. Its overall accuracy is 96.6%, rising to 97.3% in census-defined urban areas.
- **Impervious Map** maps impervious surfaces at 60cm, produced to order from the latest available imagery. A national validation set of 48,000 points (1,000 per state) found 94.9% accuracy in census-defined urban areas. Accuracy was higher in rural areas.

Contact us to discuss your project, or download sample data to try it in a familiar area.