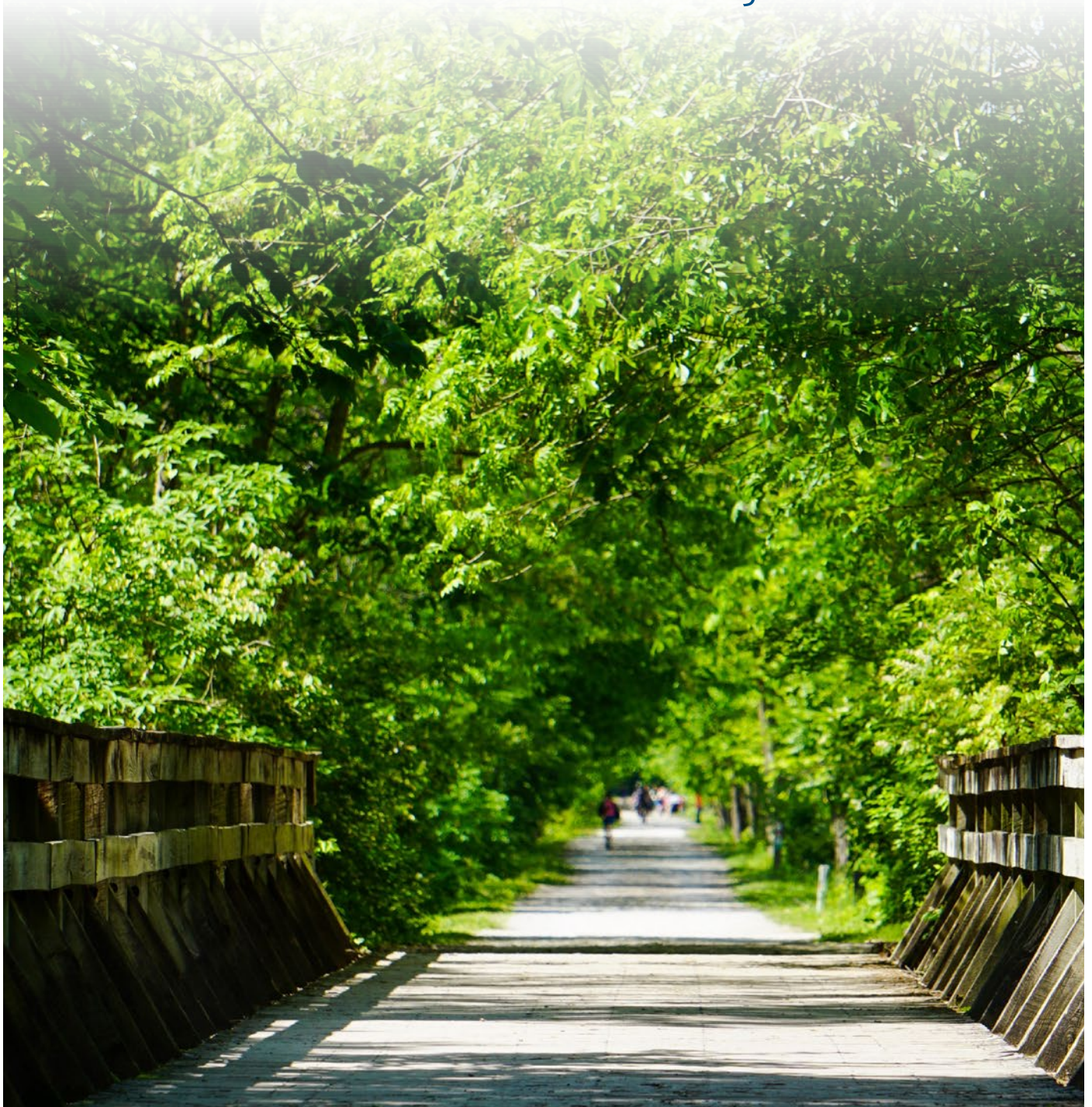




NATURAL RESOURCES INVENTORY

Land Cover Change 2007-22



December 2023

Table of Contents

Section 1:	3
Introduction	
Section 2:	8
Current Context	
Section 3:	18
Land Cover Narratives	
Section 4:	36
Conclusion	

ACKNOWLEDGMENTS

This Inventory is the result of extensive work by staff from across the City of Columbia, spearheaded by Geographic Information Systems and Sustainability. It has also benefited from review by convened experts. The consultant team was Biohabitats and Davey Resource Group.

Section 1: Introduction

STUDY PURPOSE

The purpose of the Natural Resources Inventory (NRI) is to identify areas of local and regional importance including land cover, water and vegetation resources.

Visualizing where natural resources are and how they relate to each other can provide a strong foundation for informed land-use planning and decision-making. NRIs can also serve as the basis for identifying conservation priorities and strategies such as zoning updates or open space protection.

This NRI is important because it helps us:

- See how the landscape has changed since the last NRI, which was from data captured in 2007
- Prioritize natural areas to protect or enhance
- Learn how our land use choices affect our natural resources

BACKGROUND

Columbia faces development pressures coupled with the increasing demand for connectivity and recreational/open space opportunities in our urban environment and wishes to preserve what remains of the regional ecological function.

In order to support these functions and the ecosystem services they provide, Columbia needs a complete and accurate spatial database and associated products that can be managed and updated by city staff, adjusted to future needs, and compared to historic information. The dataset described in this report focuses on some of the changes to Columbia's land cover since the 2007 NRI, which reflect land use trends and the growth of the regional population from 108,500 in 2010 to 126,254 in the 2020 census.

The 2022 NRI data is available on the City of Columbia website at <https://www.como.gov/nri/>.



Forum Nature Area. Photo: D. Fox

NATURAL RESOURCES AND ECOSYSTEM SERVICES

Ecosystem services are the benefits that humans obtain from natural systems such as forests, wetlands, and grasslands. Ecosystem services provide resources such as food and water, regulate climate and pollution, support other ecosystem functions such as nutrient cycling and soil formation, and offer recreational opportunities.

The ecosystem services provided by the trees that make up the urban tree canopy, for example, have both ecological and economic values.

Ecological Benefits of Tree Canopy

- Enhance air quality by absorbing and filtering pollutants such as carbon dioxide, carbon monoxide, ozone, sulfur dioxide, and particulates.
- Improve water quality and protect waterways by reducing sedimentation, absorbing excess nutrients and other pollutants, preventing stream channel erosion, and lowering water temperatures.
- Mitigate stormwater runoff and flooding through interception, evapo-transpiration, and promoting water infiltration.
- Enhance soil quality by adding organic matter and reducing soil erosion.
- Provide habitat for wildlife and preserve native ecosystems.
- Mitigate the urban heat island effect by shading surfaces, cooling the air around them, and reducing greenhouse gases.

Economic Benefits of Tree Canopy

- Decrease energy costs by providing shade in summer, reducing air conditioning expenses, and serving as a windbreak in winter, reducing heating costs.
- Increase property values: the presence of trees and landscaping can increase residential property values by up to 20%. Commercial properties also experience positive effects on rental rates. However, tree maintenance and higher property values can also present an economic burden in under-served neighborhoods.
- Stimulate consumer patronage and spending: shoppers tend to spend more time and money in retail areas shaded by trees. Studies indicate that consumers are willing to pay up to 11% more for products purchased in shops along tree-lined streets compared to shops without surrounding trees.



The four types of ecosystem services.

Graphic: TEEB Europe

Ecosystem Services in Riparian Buffers

Riparian buffers along streams and rivers are areas of vegetation that protect and improve the quality and health of waterways and the surrounding landscape. The buffer width required to provide their ecosystem services depends on the benefit considered:

- Erosion control (10-15 ft): Riparian buffers stabilize streambanks and prevent soil loss by reducing the impact of water flow and flood events. They also prevent undercutting of streambanks and excess sediment that pollutes waterbodies.
- Water quality (25-100 ft): Riparian buffers filter out pollutants, such as sediment, nutrients, pesticides, and bacteria, from runoff and groundwater before they reach the water. They also reduce nutrient pollution by absorbing and transforming excess nitrogen and phosphorus through plant uptake and microbial processes.
- Aquatic habitat (50 to 300 ft): Riparian buffers provide habitat for a variety of aquatic species, such as fish, amphibians, insects, and mollusks. They also moderate water temperature and oxygen levels by shading the water and enhancing groundwater recharge. In additions, they provide food sources and organic matter for aquatic organisms.
- Terrestrial habitat (100-600 ft): Riparian buffers provide habitat for terrestrial species, such as birds, mammals, reptiles, and plants. Alongside enhancing the connectivity of natural areas by serving as corridors or stepping stones for wildlife movement, they provide shelter and nesting sites for terrestrial organisms.



Turtle in Hinkson Creek
Photo: D. Fox

STUDY AREA

The 2022 NRI study area covers about 230 square miles, including the City's 68 square miles and nearby regions. The extent is larger than the 198 square miles included in the 2007 NRI, which included the 180 square mile Metropolitan Planning Area defined by the Columbia Area Transportation Study Organization (CATSO), the federally designated Metropolitan Planning Organization (MPO), and eighteen (18) square miles to the southwest of the MPO boundary (Map 1 Study Area).

The final 2022 NRI project area also reflects the City's interest in understanding resources near the Missouri River and airport as well as some ecologically significant parcels nearer the metro area. The northwestern portion of the 2007 project area was removed from consideration because there has been only modest growth in that direction and according to the interests expressed by relevant city departments.

STUDY DESIGN AND METHODOLOGY

The 2022 NRI is a remotely sensed project that used aerial photography to create an ArcGIS® Geographic Information Systems (GIS) database of the natural resources that exist in Columbia. To provide a detailed and accurate map of current land cover, 2022 leaf-on imagery at a 60 cm resolution from the USDA Department of Agriculture National Agriculture Imagery Program (NAIP) was used to classify land cover. Davey Resource Group completed the land cover assessment, identifying the current extent of seven land classes: tree canopy, shrub, grass/open space, bare ground, impervious surfaces, cropland, and open water. Subclass fields within each feature class store additional classifications of each land use/land cover type, such as canopy height and evergreen vs. deciduous cover for the tree canopy class. Each feature class was compared to the 2007 NRI data, as detailed in the Land Cover Narratives below (pg. 18). City staff are in possession of the complete project GIS dataset for further analysis in the future.

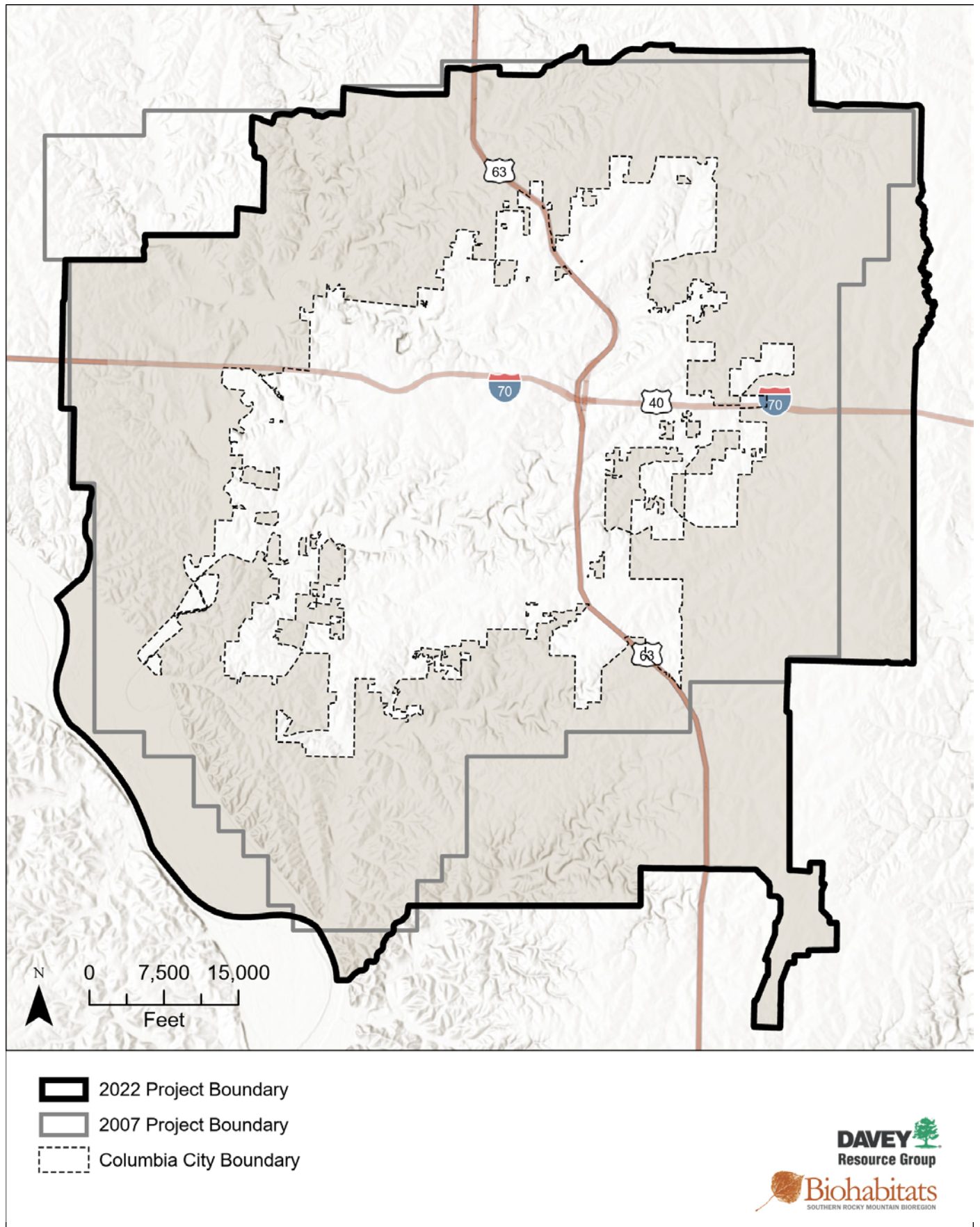
Accuracy Assessment Protocol

Determining the accuracy of spatial data is important in projects that rely on aerial photography and remote sensing. Davey Resource Group manually

edited and conducted thorough quality assessment and quality control checks on all urban tree canopy and land cover layers, which were then reviewed by City staff for accuracy and to resolve errors. The initial land cover layer extractions were edited at a 1:2,000 scale in the urban areas and at a 1:2,500 scale for rural areas utilizing the most current high-resolution aerial imagery to aid in the quality control process.

An additional quality control process was also completed using ArcGIS® to identify, clean, and correct any misclassification or topology errors in the final land cover dataset. To test for accuracy, random plot locations were generated throughout the NRI Study area and verified by comparing each point to current NAIP imagery (reference image) to determine the accuracy of the final land cover layer. Points were classified as either correct or incorrect and recorded in a classification matrix, which allowed the team to obtain an overall accuracy of 92.7%. Tree canopy and grass are the most difficult to classify, whereas open water is generally classified perfectly (100% accuracy). See Appendix 1: Detailed Attribution Methodology for further information, confidence intervals, and specific accuracy metrics.

MAP 1: STUDY AREA



Section 2: Current Context

REGIONAL CONTEXT

Columbia sits at the border of two EPA Level III Ecoregions: Claypan Prairie of the Central Irregular Plains in the east and the River Hills of the Interior River Valleys and Hills to the southwest (Chapman et al 2002). The Claypan Prairie is a diverse mix of land use and has a more varied topography compared to the predominantly crop-based Western Corn Belt Plains further north. The topography in this region is relatively level and gently rolling compared to the western half of the study area and is less densely covered with trees. Prior to urbanization and development for agriculture, this area was mostly covered by tallgrass prairie with few woodlands, which were found mostly near water and in draws.

The River Hills region to the west of the City is characterized by a combination of wide, flat-bottomed, terraced valleys, forested valley slopes, and dissected glacial-till plains, along with some hills covered with loess and areas with karst features (Nelson, 1985). Regionally, this area serves as a transition zone between the loess-covered and till-covered plains to the north and the more dissected interior Ozark Highlands' lighter colored, rocky soils to the south. The River Hills had more forest cover than the Claypan Prairie to the north and less forest cover compared to the Ozarks in the south. The modern landscape is diverse, comprising row crops, improved pasture, woodland, and oak and mixed hardwood forests.

GEOLOGY AND SOILS

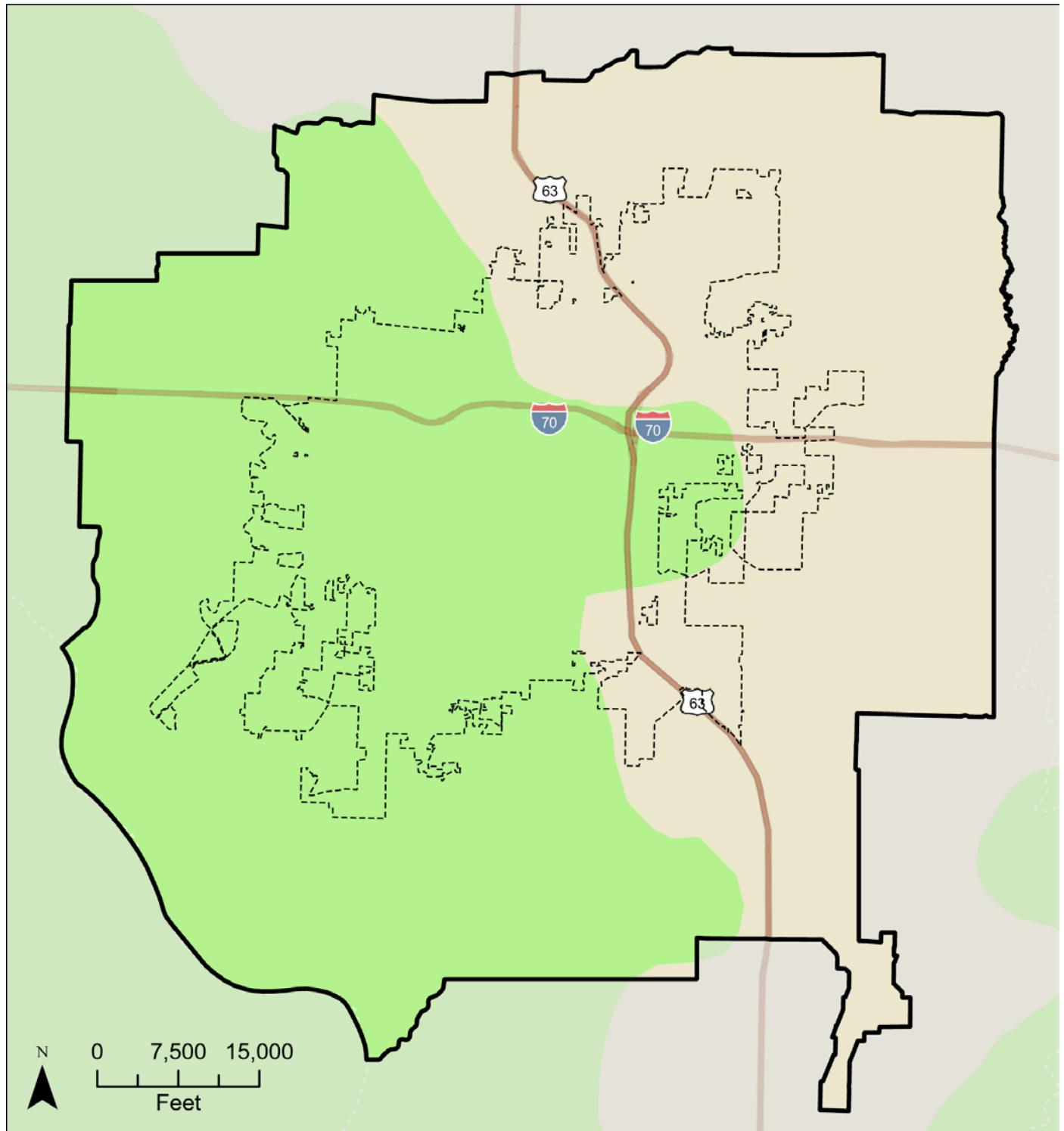
The bedrock that makes up Boone County is of three main types: limestone, shale, and sandstone (Map 3 Geology). These rocks were formed millions of years ago during the Mississippian and Pennsylvanian ages. During the last ice age, as the Wisconsin glacial sheet melted (around 35,500 to 11,500 years ago), large amounts of water flowed down the Missouri River, depositing finely ground rock material on the floodplains, which turned into dry mudflats. Windstorms then carried the rock dust from the dried mudflats, depositing larger particles nearby and finer particles farther away on the uplands. These silty deposits are known as loess, which is the material from which most of the upland soils in the county developed with varied thickness.

In the River Hills ecoregion, the ridges and valleys possess a deep soil layer (Map 4 Soils), while the steep slopes are rocky with frequent rock outcrops. Loess, which can be quite thick in some areas, covers the ridges and uplands. The river valleys are characterized by deep, sandy, and silty alluvium, which is moderately to poorly drained. The Claypan Prairie ecoregion is characterized by well-developed claypan soils found on glacial till.

Columbia faces environmental challenges due to its karst topography, erodible soils, and various steeply sloped areas. Karst is a type of landscape characterized by the presence of springs, sinkholes, losing streams and caves, created as groundwater dissolves soluble rock such as limestone or dolomite. Water often enters the subsurface through cracks, fractures, and holes that have been dissolved into the bedrock, offering a ready pathway for contamination to reach groundwater. Highly erodible soils combined with steep slopes further contribute to regional soil erosion and sediment transport, which negatively affect water quality.

Sinkholes are a common feature in regions with karst geology, and Columbia has several regions where these unique systems are more common. When sinkholes are blocked and form ponds, they support unique wetland communities, which can range from open water to forested ponds that are only wet in late spring, when they become important, fish-free breeding habitat for amphibians.

MAP 2: LEVEL 3 EPA ECOREGIONS



EPA Level 3 Ecoregions

- 8.3.2 Interior River Valleys and Hills
- 9.2.4 Central Irregular Plains

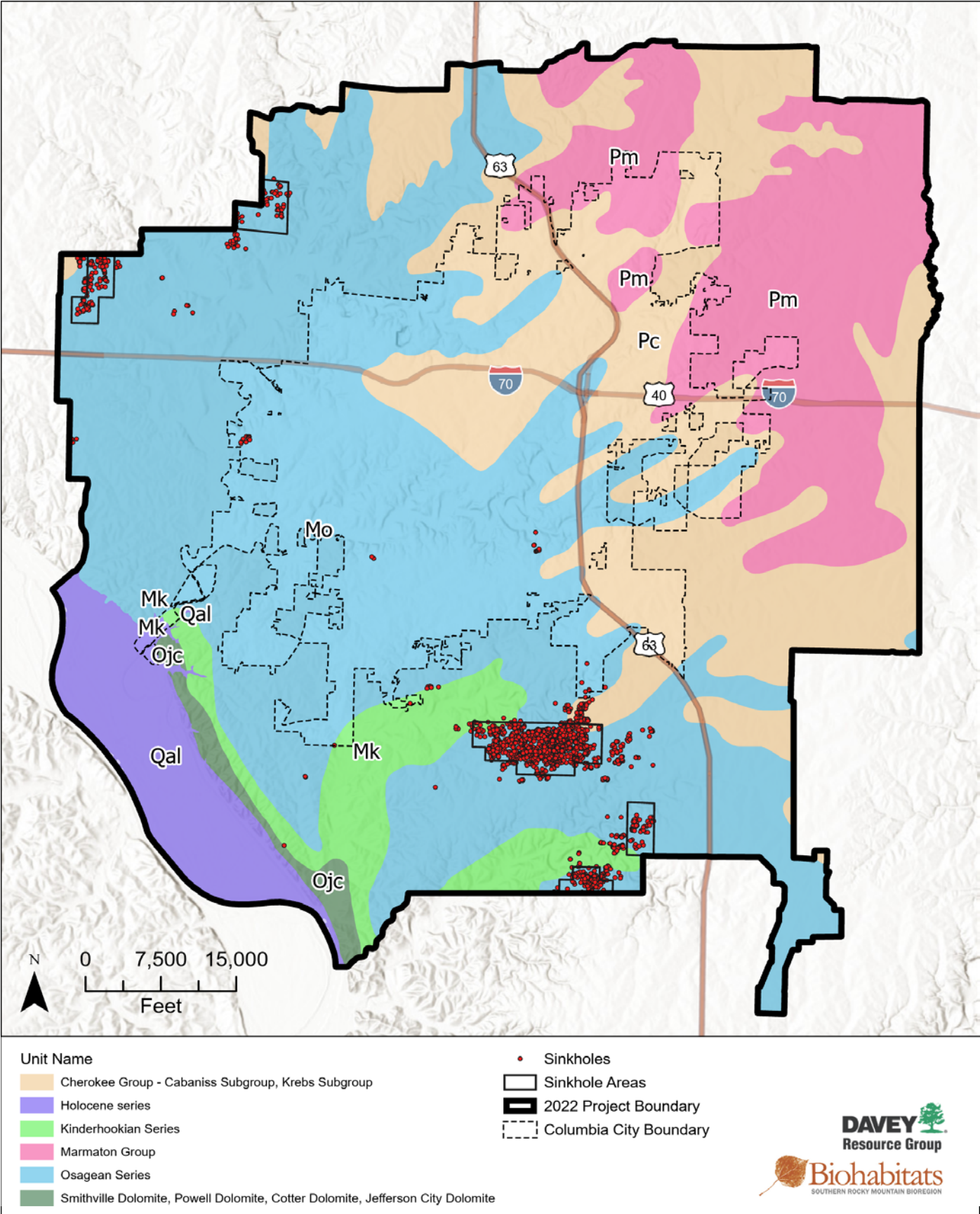
 Columbia City Boundary

 2022 Project Boundary

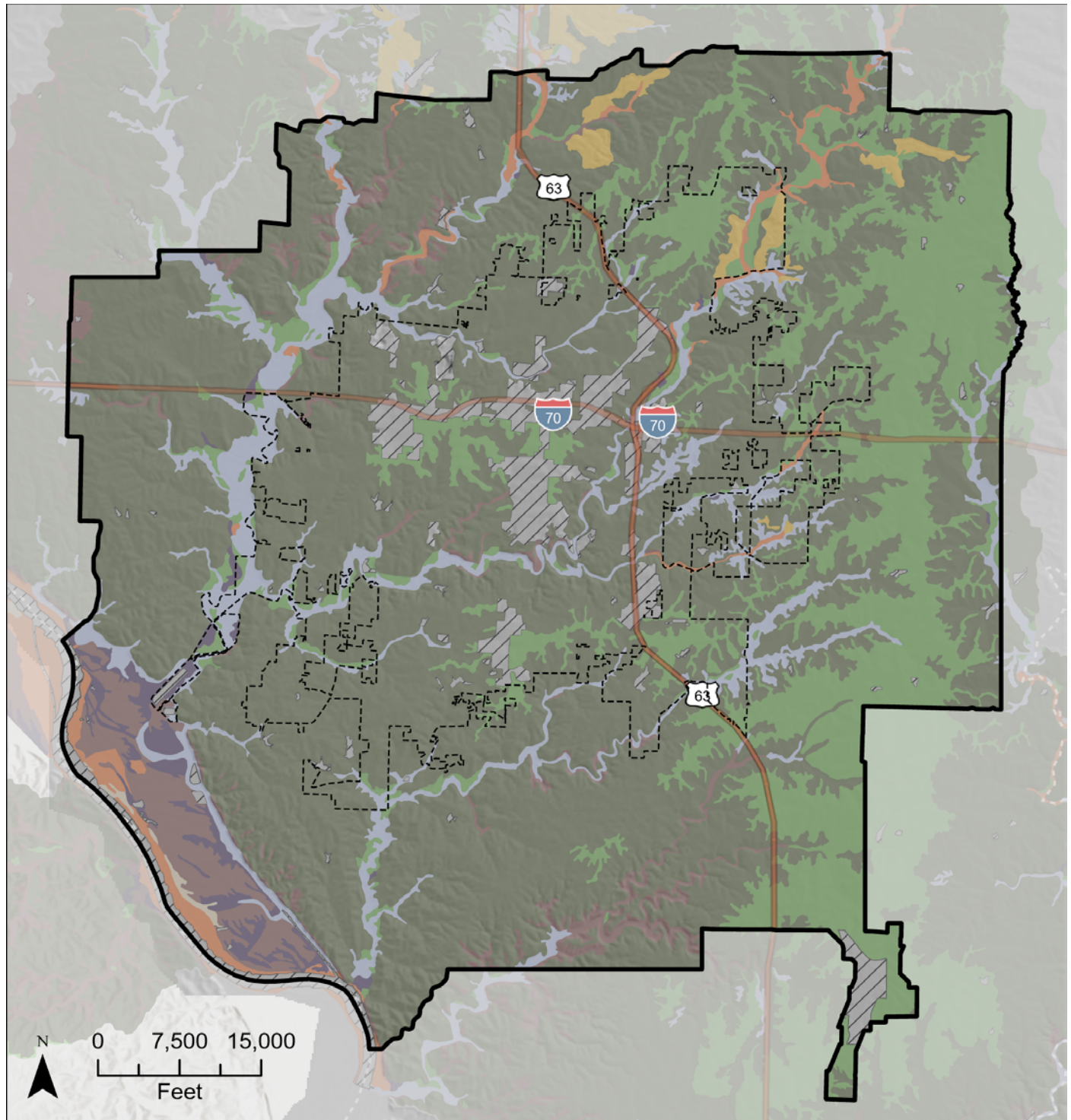
Source: EPA 2021



MAP 3: GEOLOGY



MAP 4: SOILS



- | | | |
|-------------------------|---------------------|---------------------|
| Columbia City Boundary | Alfisols, Udalfs | Inceptisols, Udepts |
| 2022 Project Boundary | Entisols, Arents | Mollisols, Albolls |
| Soils - Order, Suborder | Entisols, Fluvents | Mollisols, Aquolls |
| Not available | Entisols, Psamments | Mollisols, Udolls |
| Alfisols, Aqualfs | | |



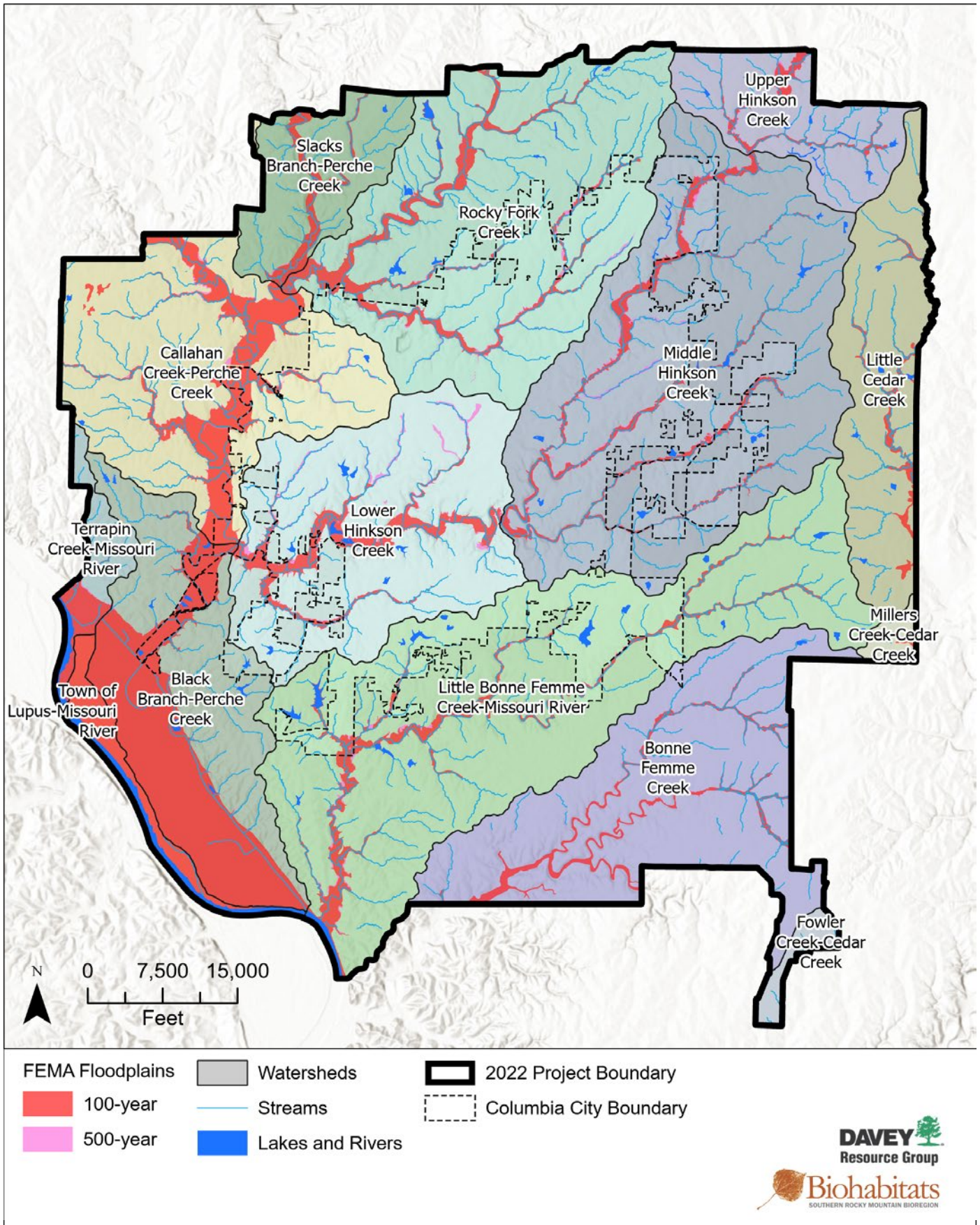
WATERSHEDS

Watersheds determine the flow of surface water, and watershed boundaries are defined by high points and ridges, acting as natural dividers that direct water towards a common destination point. Streams and creeks in the city generally flow from the northeast to the southwest and into the Missouri River. Stream headwaters start mainly from the Claypan Prairie and flow toward the River Hills.

Hinkson Creek begins northeast of Hallsville and is one of the community's most significant, visible, likely to flood, and polluted waterways because it flows southwest across Columbia to Perche Creek. The Perche Creek watershed is very large, draining extensive agricultural land outside the study area. The watershed of Rocky Fork Creek also extends

far beyond the limits of the City of Columbia and into agricultural areas. Little Bonne Femme Creek watershed covers a smaller area of the City but has exceptional value because it is a significant waterway of Rock Bridge Memorial State Park. Little Bonne Femme starts at the confluence of Gans and Clear Creeks and flows through the park, an important habitat and highly recognized area for the residents of Columbia. The watershed of Little Bonne Femme drains a large area of this critical natural area to the far south side of Columbia: an area of rapid suburban development. These watersheds play a significant role in shaping the movement of water and the overall drainage pattern in Columbia, ensuring that surface runoff is effectively channeled towards the Missouri River.

MAP 5: WATERSHEDS AND FLOODPLAINS



URBAN ECOLOGY: TODAY & TOMORROW

Known for its love of nature and green spaces, Columbia boasts a thriving urban ecology and celebrates the outdoors. One of the city's iconic characteristics is its extensive trail network that weaves through parks and green spaces throughout the city. Columbia promotes sustainable transportation options, encouraging residents to embrace eco-friendly commuting and an active lifestyle beneath the urban tree canopy.

Like any city, Columbia faces its share of ecological challenges. One such issue is the proliferation of bush honeysuckle (*Lonicera maackii*), a non-native invasive plant species that outcompetes native plants. Other challenges are more dynamic in nature, and the ability of Columbia's natural resources to adjust to change or recover from disturbance is termed their resilience. Ecological planning to support resilience is important because climate change will result in new patterns in future decades.



Despite consistent honeysuckle control efforts for years at Kiwanis Park, stumps like the one in the foreground of this photo resprout over and over. Photo: JH Norris

Climate Change

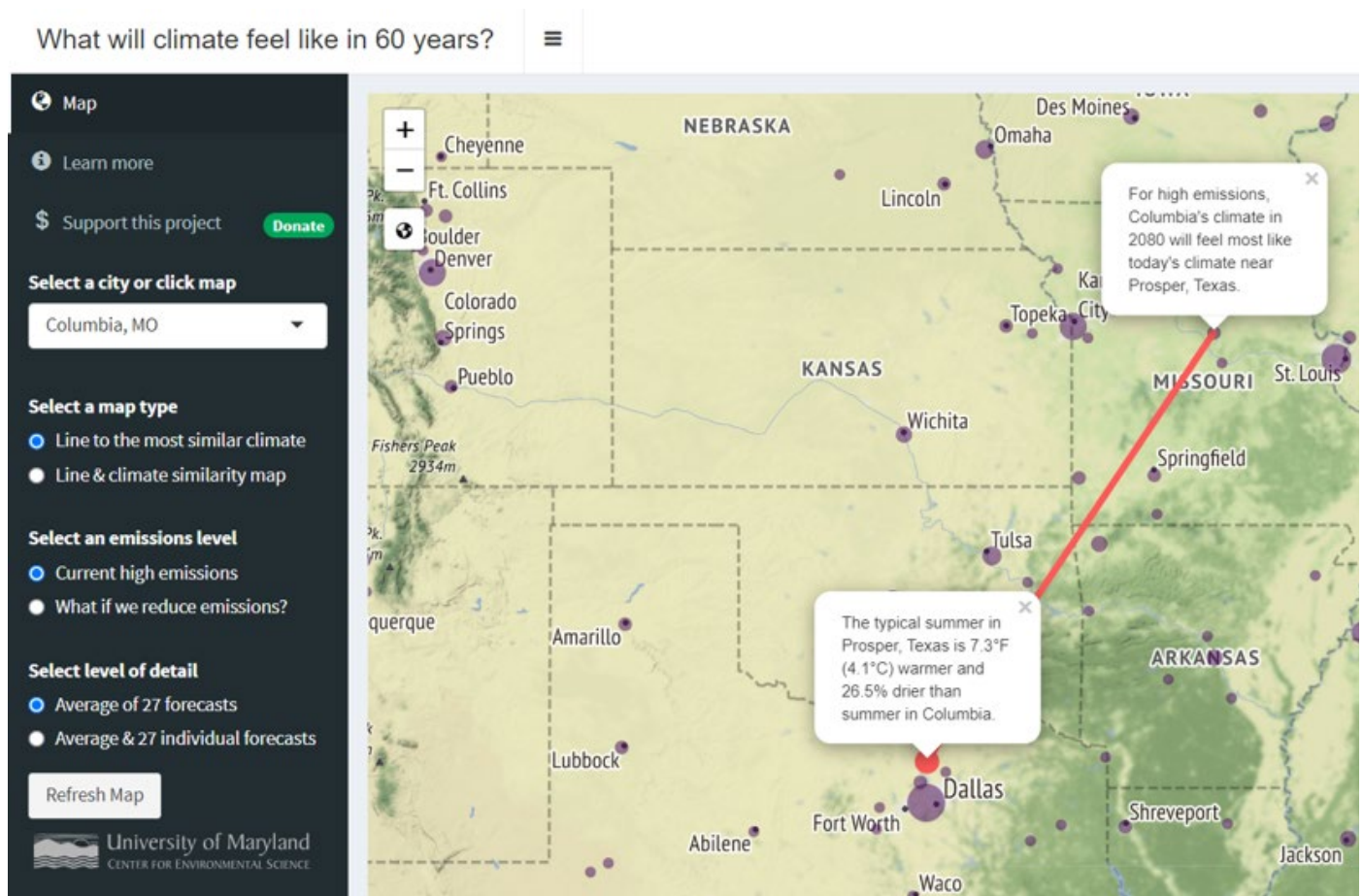
Climate change is caused by human activities that increase the amount of greenhouse gases, such as carbon dioxide and methane, in the atmosphere. These gases trap heat from the sun and increase the Earth's global temperature. In June 2019, the City Council adopted the City's first Climate Action and Adaptation Plan. This plan provides a roadmap to reduce greenhouse gas emissions and prepare for our already changing climate. Some of the effects of climate change in the Midwest are:

- **Flooding:** Climate change increases the frequency and intensity of heavy rainfall, which can cause floods that damage property, infrastructure, and crops.
- **Heat waves:** Climate change raises the average temperature and the number of extremely hot days, which can harm human health, especially for the elderly, children, and people with chronic diseases. Heat waves can also reduce air quality, increase energy demand, and lower crop yields. In 2012, Missouri had its warmest year on record as of 2023, with an average temperature of 58.8°F, which was 4.3°F above normal.
- **Drought:** Climate change reduces summer rainfall and increases evaporation, which can lead to droughts that affect water supply, agriculture, and wildlife. Droughts can also increase the risk of wildfires, as in the recent Town of Woolridge, MO, wildfire, which was exacerbated by drought conditions. For example, in 2012, Missouri suffered from a severe drought that affected 97% of the state and caused \$2.8 billion in agricultural losses.
- **Pests and diseases:** Climate change alters the distribution and behavior of insects, weeds, fungi, bacteria, and viruses that can harm plants, animals, and humans. Climate change may increase the spread of ticks that carry Lyme disease or mosquitoes that carry West Nile virus.

A Climate Analogue for Columbia

Climate analogues are vegetative communities in locations with current conditions that mimic future climatic conditions and help to predict changes in vegetation and habitat as a result of climate change (Fitzpatrick & Dunn, 2019). Although the vegetation and habitat of an area are also influenced by non-climate factors like topography, soil type, and geology, climate analogues can provide a key first step in

predicting vegetative shifts due to climate change. More comprehensive examinations of both climatic and non-climatic conditions in specific areas are needed to fully understand and predict the impact of climate change on ecosystems. Given continued high global carbon emissions, future conditions in Columbia are predicted to be similar to the northern outskirts of Dallas, TX, where the typical winter is 13°F warmer.



Climate analogues are an increasingly popular way to help residents visualize their city's future conditions (Fitzpatrick & Dunn, 2019). Available at <https://fitzlab.shinyapps.io/cityapp/>

EXISTING PLANS AND PROTECTIONS

Columbia's Natural Resources are governed by a suite of federal, state, and local regulations. The important federal regulations have changed little since the 2007 NRI, though the implementation of the Clean Water Act was modified by a May 2023 US Supreme Court decision to restrict the definition of protected wetlands to those that have a continuous surface connection to a stream, river, or lake.

At the state level, the Missouri Department of Natural Resources is responsible for administering most provisions of the federal Clean Water Act through the Missouri Clean Water Law, Chapter 644 RSMo. These laws protect beneficial uses of lakes and streams. The department and the U.S. Environmental Protection Agency have determined that some area streams do not meet water quality standards, which protect the designated beneficial uses of the water body. Such waters are considered "impaired." Impaired waters in the area include Hinkson Creek, Cedar Creek, and Greater Bonne Femme Watersheds, as well as Lake of the Woods and Perry Phillips Lake. In contrast, Gans Creek is designated as a Missouri Outstanding State Resource Water. OSRW's are high quality waters with a significant aesthetic, recreational or scientific value that receive special protections against degradation.

The natural resource protection and management measures under local control are influenced most strongly by the following plans and codes.

Columbia Imagined (2013)

Columbia Imagined is the City of Columbia's comprehensive land use plan, which was adopted in 2013. Its provisions for Natural Resources resulted in the Climate Action & Adaptation Plan and Urban Forest Master plan.

UNIFIED DEVELOPMENT CODE

Many aspects of the Unified Development Code (UDC) have a direct bearing on the preservation and functionality of the City's natural resources. Foremost among these are the tree protection ordinance, the stormwater management regulations, and the protection of sensitive areas and floodplains.

Landscaping, screening, and tree preservation

Section 29-4.4 of the UDC protects trees and vegetation that offer environmental, aesthetic, habitat, sustainability, and economic benefits. Permits for new construction and many renovations require a Landscape and Tree Preservation Plan, which includes denoting the full area of climax forest on the development site. Parcels larger than 1 acre must preserve 25% of the climax forest outside the stream buffer. The tree protection development controls also offer incentives for preserving mature trees and requires preserving 25% of significant trees and replacing the ones that are removed.

Stormwater Management

The City of Columbia adopted Stormwater Management regulations which apply to privately developed sites. See Sec. 12A, Article V, and the City of Columbia Stormwater Management & Water Quality Manual for more information. These regulations include Detention (to control the quantity of stormwater runoff) and Water Quality (to remove pollutants in runoff). The intent is to mimic the natural processes that were present before the site was developed, by constructing on-site facilities (known as Best Management Practices, or "BMPs") to detain and/or treat stormwater. Examples of BMPs include bioretention basins, storm inlet filters, wet or dry detention basins, pervious pavement systems, and various proprietary devices. Credit is also given for preserving or establishing native vegetation on the site. Developers are required to maintain the BMPs on their site after the development has been completed.

To meet Detention requirements, it must be demonstrated that the peak runoff exiting a site after development does not exceed the pre-development peak runoff, for certain design storms.

To meet Water Quality requirements, it must be demonstrated that the site's BMPs provide an acceptable level of water quality improvement (or "level of service"), using tiered requirements determined by the intensity of the proposed development. Facilities are designed to capture and treat the "first flush" after a rain event, which will

contain the most pollutants. There are reduced requirements for re-development projects that expand or replace existing development.

Sensitive Areas & Floodplains

For new subdivisions larger than five acres, the City of Columbia protects sensitive areas from development. Sensitive areas include stream corridors, steep (over 25%) areas, and floodways as designated by the Federal Emergency Management Agency (FEMA).

Outside the floodway, the guidance of the Floodplain Overlay (Sec. 29-2.3) allows construction in the floodplain but requires that residential construction elevate the lowest floor to at least two feet above base flood elevation in the 100-year floodplain.

Urban Forest Master Plan (2018)

This plan provides information on the current urban forest extent and conditions in Columbia, discusses inventory and urban tree canopy data analyses and findings, and makes short- and long-term recommendations to accomplish citywide and urban forest management goals. Those recommendations are grouped into Caring for Existing Trees, Planting New Trees, and Related and Supporting Efforts, and they include specific recommendations that affect the forest as a natural resource. Some of the plan's

recommendations, like the creation of the Tree Board, have already come to fruition.

2013 Parks, Recreation and Open Space Master Plan & 2022 Plan for Trails and Neighborhood Parks

The first strategic priority in Columbia's Parks, Recreation and Open Space Master Plan is to efficiently maintain parks and facilities for public safety, attractiveness and environmental stewardship, including the protection of cultural and natural systems. Park planning in Columbia has grown stronger over recent decades, and is marked by an emphasis on trails, greenways, and greenbelts. Property acquisition priorities, as expressed in the 2013 Master Plan, include trail completions and local access to parks.

Climate Action & Adaptation Plan

In 2017, the City of Columbia launched the development of its first Climate Action & Adaptation Plan (CAAP). The CAAP is the product of over a year-long public and stakeholder engagement process and includes a series of Natural Resource Strategies that provide broad direction for the city. An annual progress report specifies the city's progress toward the goals laid out in the CAAP.



Forum Nature Area. Photo: D. Fox

Section 3: Land Cover Narratives

LAND COVER IN COLUMBIA

Many of the natural resources in the greater Columbia area came into being centuries or millennia ago, so they have changed little since the 2007 Natural Resource Inventory, which offers a deeper review of soils, slopes, geology, historical land use and vegetation patterns. In comparison, the human effects on the landscape, namely land use and land cover, have changed significantly in the 15-year period between the two NRI studies, so this report focuses on a dynamic aspect of our City’s landscape: land cover and land use. A comparison of the two data sets within the 2023 city limits is provided in Table 1 and in greater depth in this section according to each category. Note that there was no shrub category in 2007 NRI.

TABLE 1. Land cover percent change 2007-22.

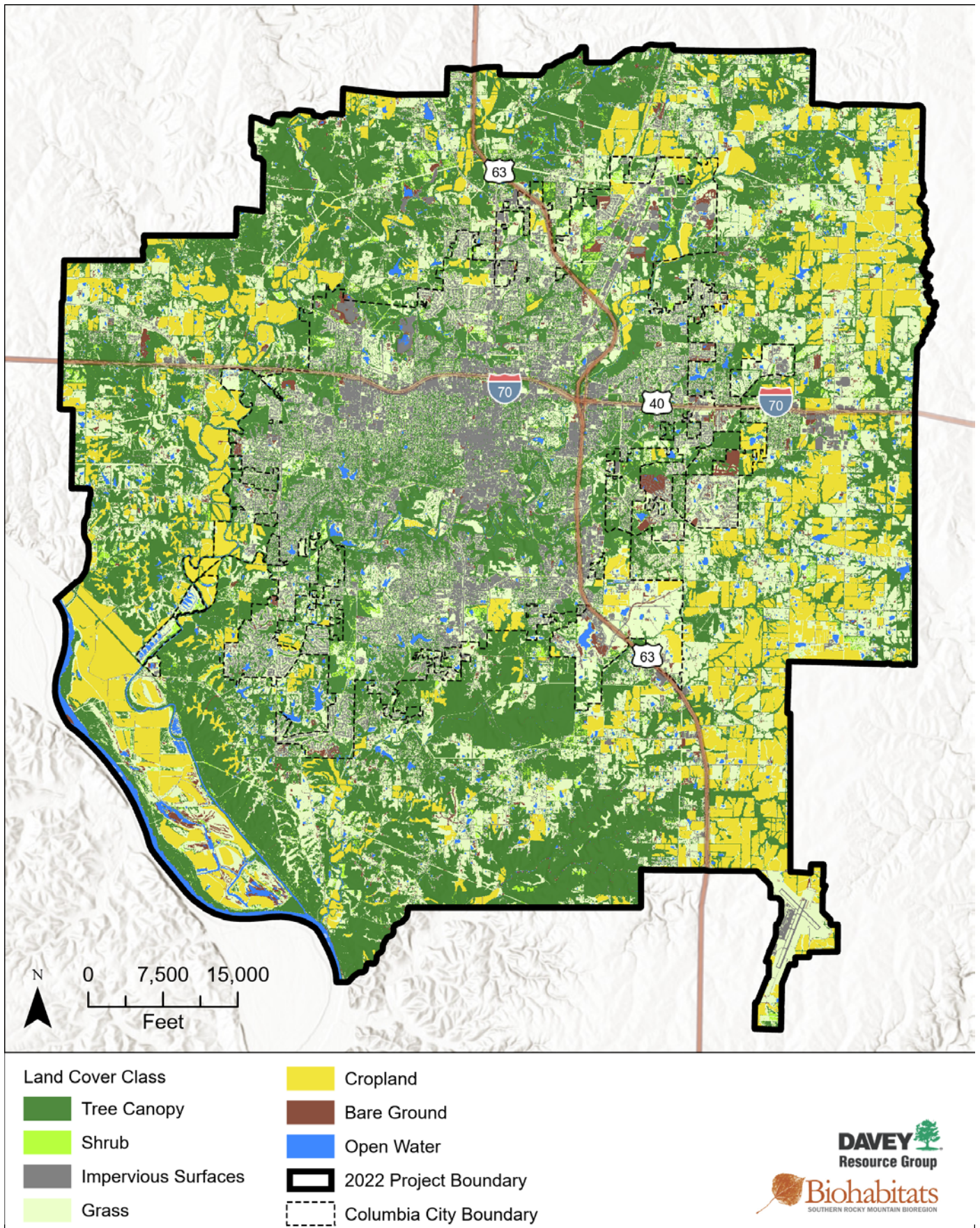
LAND COVER CLASS	% CHANGE SINCE 2007
Tree Canopy (excluding shrub)	-7 %
Shrub	N/A
Impervious	+28 %
Grass	- 12 %
Cropland	+14 %
Bare Ground	- 50 %
Open Water	1 %

TABLE 2. 2022 NRI Land Cover Results

LAND COVER CLASS	ACRES IN NRI STUDY AREA	% OF STUDY AREA	ACRES IN CITY	% COVER OF CITY
Tree Canopy	59,832	41%	14,481	33%
Shrub	3,545	2%	1,275	3%
Impervious	15,209	10%	10,999	25%
Grass	41,307	28%	13,206	30%
Cropland	21,574	15%	1,663	4%
Bare Ground	2,190	1.5%	1,001	2.3%
Open Water	3,790	2.5%	732	1.7%

It is important to note the “impervious surfaces” include data on building footprints and roads from other sources and are not characterized solely by remote imagery. Doing so would result in a serious underestimate of impervious surfaces, since any sidewalk or road or rooftop that was shaded by a tree would be counted as tree canopy and missed in the impervious class. Because these areas have both tree canopy and impervious surfaces, the total acreage of all land classes is slightly larger than the city, and impervious surface can only be compared to itself across years.

MAP 6: LAND COVER CLASSES



FOREST CATEGORIES: OVERVIEW

The 2022 NRI documents 14,481 acres of forest within the city, for about 33% tree canopy cover. Most of that canopy cover (10,693 ac) is on private land. The tree canopy layer was subclassified by type and height, which was used to approximate age. Coniferous forest stands were identified using winter imagery, and height data from 2019/2020 LiDAR data was used to separate trees from shrubs by height (3 - 15 feet) and divide the forest stands into early succession (15 - 40 feet), mid succession (40 - 60 feet), and mature forest (with canopy taller than 60 feet). Very small patches of less than a half acre were eliminated from the analysis because they are not large enough to support forest ecological functions.

The 2007 NRI did not include a Shrub category, which makes interannual comparison more complicated. Looking at the 2007 classifications

of areas that became Shrub in 2022, we note that most of the shrub category (66%) was classed as Grassland in 2007, and about a quarter of it was classified as Tree Canopy. The rest of the 2022 shrub class fell into the other 2007 classifications. Adding a category becomes important for understanding the changes in land cover.

TABLE 3. Forest subcategories

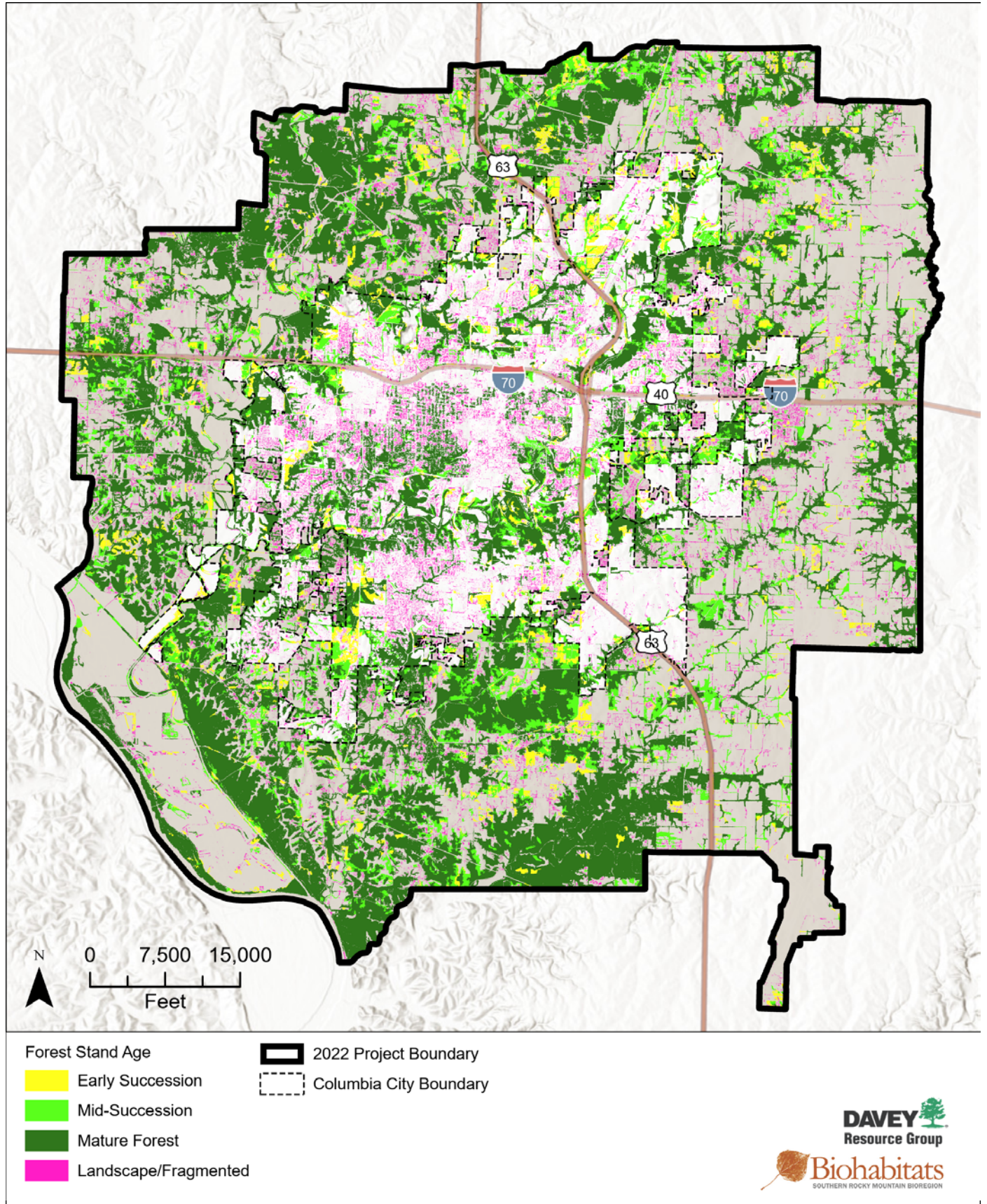
FOREST CATEGORIES	ACRES IN CITY
Broadleaf	14,432
Coniferous	1,326
Mature Forest	8,632
Mid succession	2,798
Early succession	1,550
Shrub	1,275

Special Forest Resources

Before European settlement, Columbia’s vegetation in flat areas was largely prairie, dominated by Indiangrass, big bluestem, little bluestem and sideoats grama, and a wide variety of prairie wildflowers. The largest forest stands were found in the deeply dissected, loess-covered hills and throughout the floodplains and terraces of our waterways. Water-loving trees such as American elm, hackberry, sycamore, eastern cottonwood, and green ash clustered closer to the rivers, with increasing quantities of white oak and hickory on uplands that were not kept in prairie by fires or trampling.

Most of today’s forest in the city is known as old field forest, the result of a natural reclamation of agricultural lands. Columbia hosts over 130 species in our urban forest (Davey 2019), which is a relatively high rate of diversity for urban areas. The primary threat to most local forests is invasive bush honeysuckle, which takes over the understory reducing recruitment of desirable hardwood seedlings, hampering the canopy’s ability to regenerate. Through the Adopt-A-Trail Program, city volunteers have spent many hundreds of hours in parks and along trails removing invasive plants, mostly honeysuckle, and planting back native understory plants. Locally exceptional stands of forest that have mature trees and limited invasive species include the oak forest near Forum theater and Grindstone Nature Area. Pockets of older forest are also protected by the steep slopes south of Hinkson Creek, such as those downstream of Hinkson Valley Nature Preserve.

MAP 7: FOREST CATEGORIES



CHANGES TO THE FOREST CANOPY

Within city limits, the previous NRI documented 15,624 acres of forest in 2007, whereas there are 14,481 acres of forest in the 2022 NRI, alongside 1,275 acres of shrub. This represents a decline from 36% forest canopy to 33% within city limits. About 775 acres of the land now categorized as shrub was categorized as forest in 2007.

Public land in the city had a net gain of 31 acres of canopy, whereas private lands owned by individuals or businesses lost a net 588 acres of canopy.

From 2007 to 2022, 3,497 acres were annexed into the city. According to 2022 NRI classification standards, 34% (1,189 ac) of the annexed acres were forested. By 2022, 8.4% (293 ac) of the annexed forested land was lost.

Across the wider study area, about 119,000 acres of land were classified by land use in both the 2007 and 2022 NRI study areas. Therefore it was possible to examine canopy loss in the portion of the 2022 NRI Study Area that overlapped with the 2007 NRI Study Area. Notable features of that comparable area include:

- Overall, tree canopy covers about 49,806 (41.7%) acres of the comparable study area.
- Most of the current forest experienced no change from 2007 to 2022: 43,686 acres.
- There was both gain and loss of canopy cover, however. The gain from 2007 to 2022 was 6,094 acres, while 7,420 acres of forest was lost, for a net change of -1,326 acres in the comparable NRI area.

NET vs TOTAL Canopy Loss

This section mentions both net loss and total loss. Total loss is all the areas that were canopy in 2007 but are no longer in canopy. For a given region, this change may be offset by areas that added canopy. Net loss takes added canopy into account to state how many acres of tree canopy were lost overall.

MAP 8: TREE CANOPY CHANGE

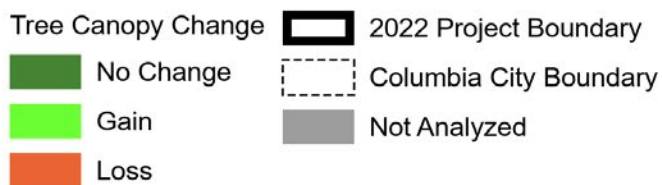
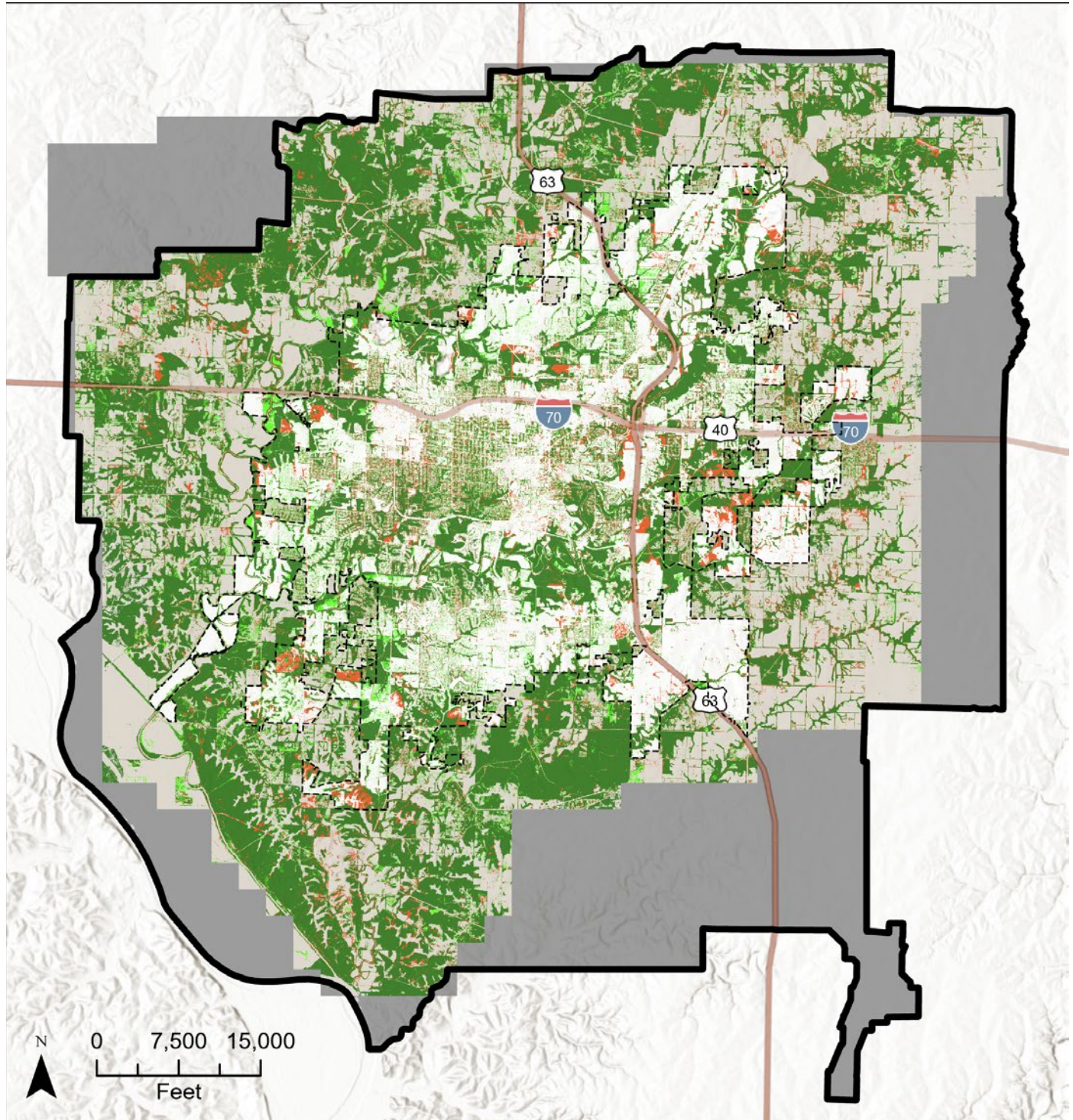


Figure 1. Net Tree Canopy Loss by Ward

Five of Columbia’s six wards lost canopy cover between 2007 & 2022. Most of the losses took place in the 3rd and 6th Wards.

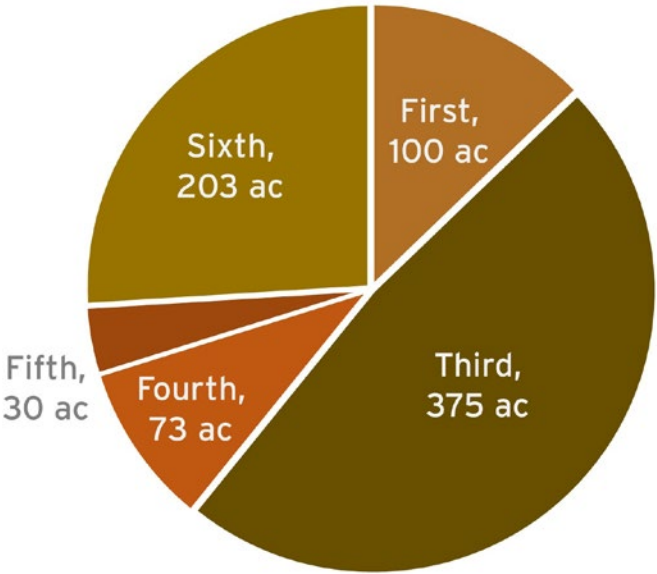


TABLE 4. Canopy change from 2007 to 2022 by city ward.

WARD (SIZE)	CANOPY ACRES IN 2022	% CANOPY COVER	NET ACRES OF GAIN (LOSS)
First (2,560 ac)	503	20%	(100)
Second (7,610 ac)	2,594	34%	33
Third (11,050 ac)	3,503	32%	(375)
Fourth (6,926 ac)	2,820	41%	(73)
Fifth (6,543 ac)	2,449	37%	(30)
Sixth (8,666 ac)	2,600	30%	(203)
CITY TOTAL		33%	(746)



Gans Creek Wildlife Area, Photo: D. Fox

HABITAT VALUE AND TREE CANOPY LOSS

Columbia, thanks to its trails and greenways, already has exceptional connectivity among forested areas. Preserving and improving these connections is an explicit goal of the city’s planning. It is also key to recognize that trails introduce new disturbance, and can be problematic if placed in floodways or along streams.

Landscape connectivity plays a crucial role in supporting wildlife populations and enhancing biodiversity. Connectivity corridors serve as vital pathways between habitat patches, enabling migration, promoting genetic diversity, and facilitating access to essential resources and new habitats. The size, distance, or configuration of habitats are all factors that facilitate or hinder wildlife movement and affect biodiversity in the urban landscape. Landscape connectivity in urban planning can help mitigate the negative impacts of human-induced landscape changes on urban biodiversity (LaPoint et al 2015).

Tree canopy gain/loss has a greater effect on biodiversity outcomes when it occurs in high-quality, connected areas (Diamond, 1975). Therefore, it is important to monitor changes to tree canopy in areas of Columbia that are locally important habitat. This map shows canopy loss in areas of high habitat value as defined by the Southeast Conservation Blueprint. Only 34 acres of the canopy lost in the city since 2007 was in these high priority areas.

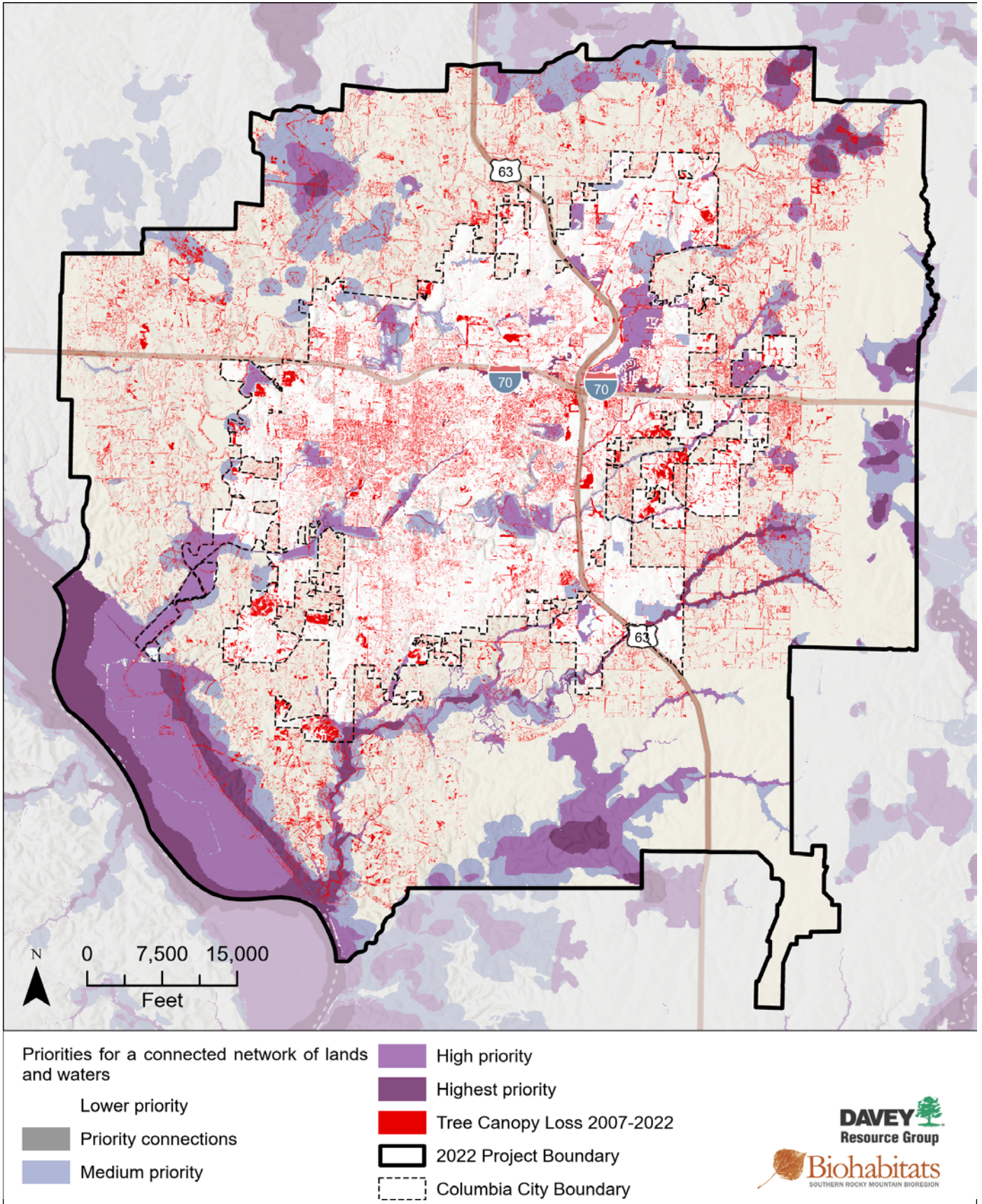
Southeast Conservation Blueprint

The Southeast Conservation Blueprint, spanning 15 states in the Southeastern region, relies on 37 indicators encompassing natural and cultural resources, representing terrestrial, freshwater, and coastal/marine ecosystems. The Blueprint combines information about corridors, bird habitats, water quality, climate resilience, prescribed burning, and reforestation to highlight areas where conservation action can create a connected network of protected lands and waters. These data are intended to be used with local spatial datasets to offer guidance on conservation activities, such as management, economic incentives, and protection. By combining regional perspectives with local data and knowledge, decisions can be better informed about where to focus conservation efforts.

TABLE 5. Canopy loss in priority habitat areas

BLUEPRINT PRIORITY RANK	ACRES IN NRI	TOTAL LOSS IN NRI	ACRES IN CITY	TOTAL LOSS IN CITY
Low	11,4205	6,329	37,877	3,142
Medium	1,2810	542	2,382	153
High	14,225	342	2,720	128
Highest	6,196	203	383	34

MAP 9: TREE CANOPY LOSS IN HIGH-VALUE HABITAT



SOCIAL VULNERABILITY AND TREE CANOPY LOSS

Natural resources such as trees are not evenly distributed throughout the city. For example, higher income areas of Columbia have roughly twice the tree canopy coverage as lower income tracts (Davey, 2019). There are several ways to summarize and track the equity of resource distribution.

Social vulnerability refers to a community’s ability to withstand external pressures, especially those related to community health, such as natural disasters or disease outbreaks. The Social Vulnerability Index (SVI) uses census data to classify census tracts according to their social vulnerabilities, ranking each tract based on 14 social factors, including poverty, lack of vehicle access, and crowded housing, which are then grouped into four interconnected themes. Each census tract receives separate rankings for each theme, along with an overall ranking. This index provides a spatial dataset to analyze the overlap between tree canopy

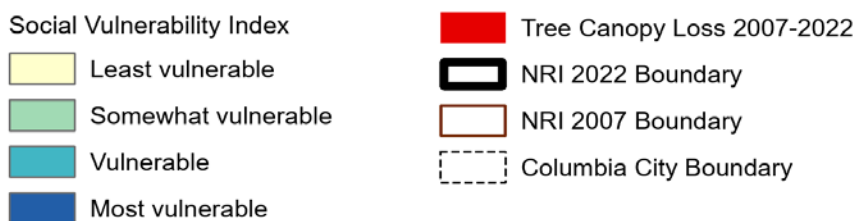
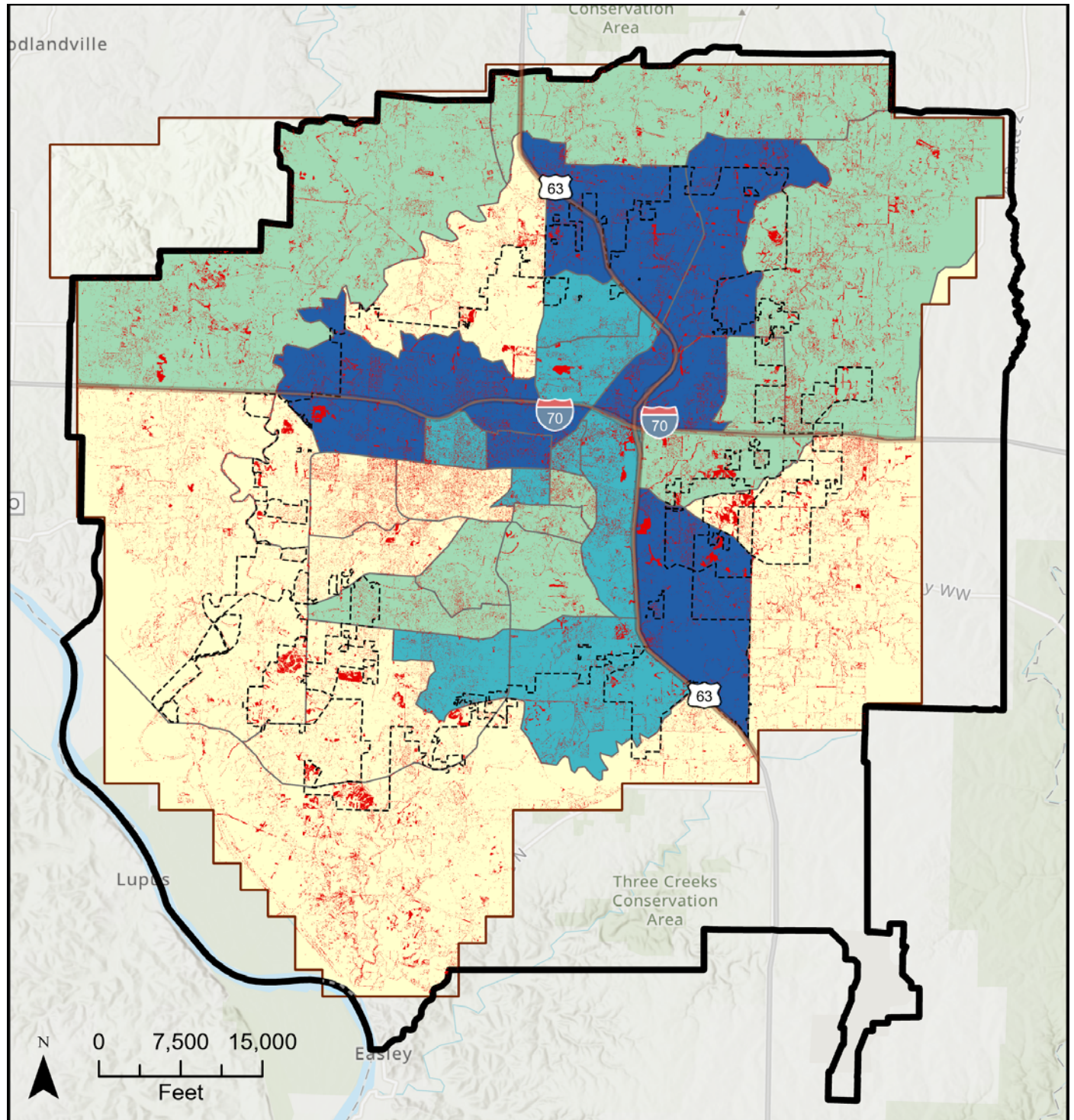
change and social vulnerability. Likely because of development to the northeast of the city, trees were removed from 1,191 acres of “Most Vulnerable” area.

If desired by the people living in unforested vulnerable areas, interventions aimed at improving tree canopy cover can play a role in protecting them from the effects of climate change and enhancing the overall wellbeing of the neighborhood.

TABLE 6. Canopy loss by social vulnerability

SVI CATEGORY	TREE CANOPY LOSS IN NRI
Least Vulnerable	3,180 ac
Somewhat Vulnerable	2,279 ac
Vulnerable	770 ac
Most Vulnerable	1,191 ac

MAP 10: TREE CANOPY LOSS BY SOCIAL VULNERABILITY



WATERWAYS AND WETLANDS

In terms of land use classifications, there has been little change to the extent of open water since 2007, gaining eight acres in the city and losing 221 acres in the wider study area. In contrast, the condition of Columbia's waterways is very dynamic, changing due to more intense rainfall events, urbanization, and stormwater management policy.

Urban Hydrology Process Overview

Hard-working urban streams follow a typical pattern that is useful for understanding Columbia's waterways and flooding issues. With land conversion

and suburban development increasing runoff volumes, and climate change resulting in more intense rainfall events, streams receive more water with higher nutrient loads. The streambeds begin to downcut from the force of the water, becoming entrenched with steep walls. Groundwater levels fall lower because of the downcutting. Added stormwater, which flows quickly off of impervious surfaces, rushes through the deeper channels, widening the bed, eroding the banks, and causing trees to destabilize and tip into the channel (Figure 2, Widening). Lower in the system at a flatter spot, often near a confluence, streams will deposit the sediment eroding from upstream banks in sand bars.

Columbia's streams and unnamed tributaries tend to be somewhere along this stream evolution process, with deeply downcut trenches for channels. Under these conditions streams lose their ecosystem functions and can no longer:

1. Trap sediment and nutrients to filter impurities,
2. Retain water to maintain base flow or store stormwater runoff as groundwater
3. Reduce water volume and velocity downstream

Wetlands

Outside of stream channels and waterways, wetlands and vernal pools are among the most productive ecosystems in the world and provide numerous benefits including flood storage, wildlife habitat, and improved water quality. In agricultural landscapes, they are often drained, and the natural processes that form them near streams are interrupted. Wetlands and vernal pools may also be particularly vulnerable to increasing temperatures and changing precipitation patterns associated with climate change. The NRI area includes constructed and restored wetlands in Perche Creek, Bear Creek, Hinkson Creek, and the Missouri River floodplain.

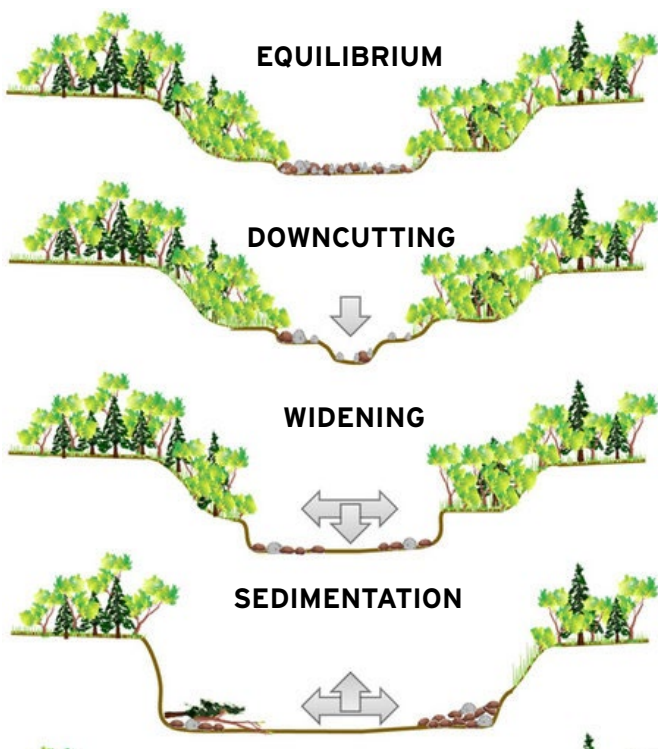
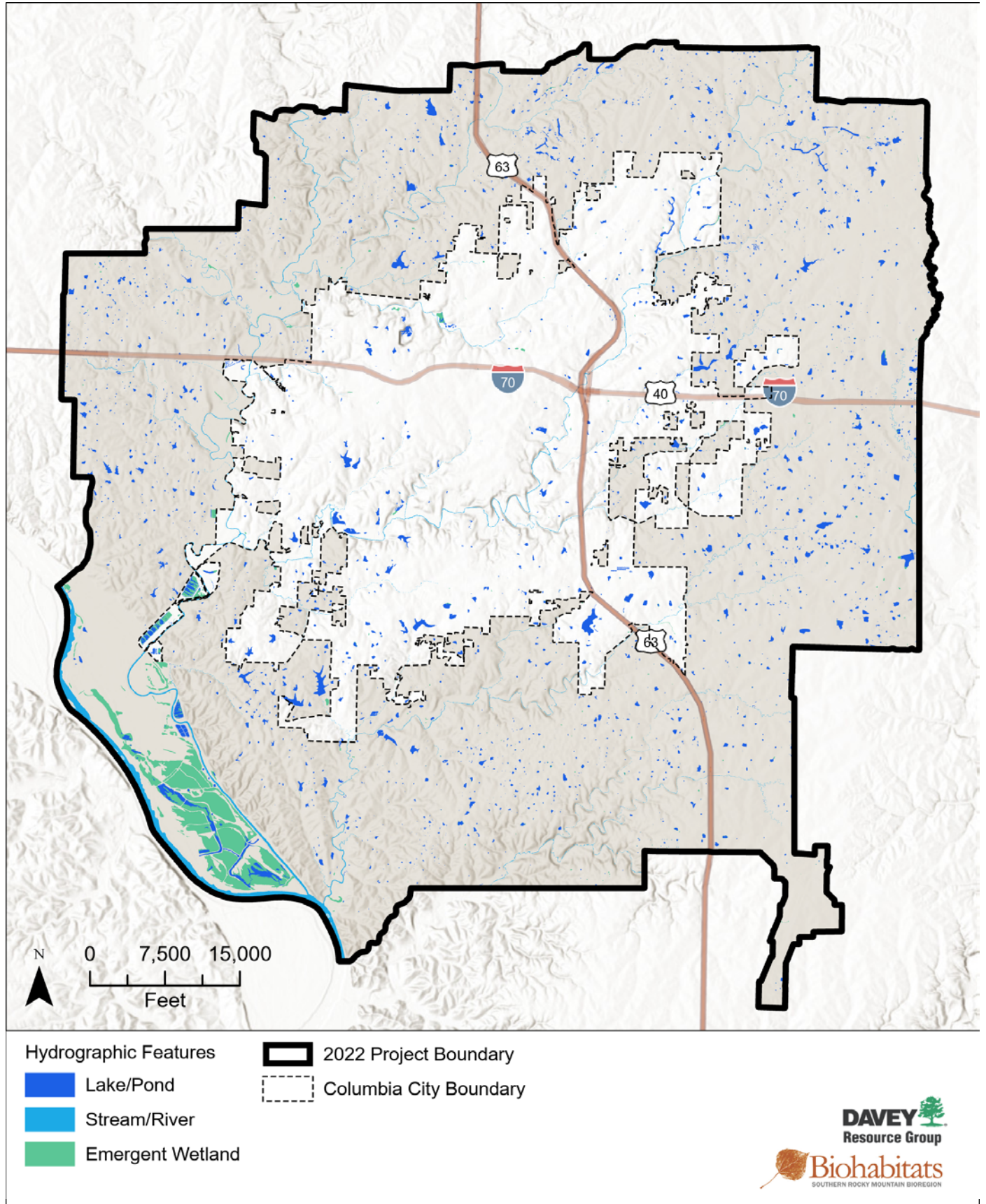


Figure 2. Stream evolution processes from Hawley et al (2020).

MAP 11: WATERWAYS AND WETLANDS



STREAM BUFFERS IN COLUMBIA

As noted above, stream buffers provide important ecosystem services, and the 2022 NRI data allow us to examine how well vegetated they are and how policies have affected their condition.

In 2007, Columbia adopted Stream Buffer regulations that limit land disturbance and development within 30 to 100 feet of a perennial or intermittent watercourse, depending on the classification of the stream. See Sec. 12A, Article X. Native vegetation in stream buffers preserves key ecosystem services such as reducing pollution and flooding. Trees are an important component

of stream buffers. The Urban Forest Master Plan (Davey, 2019) estimates that Columbia avoids 336,306,674 gallons of stormwater runoff because of its current tree cover.

There were 119 acres of tree canopy lost within Type 1 stream buffers since 2007, but only 17 acres were in areas platted since the ordinance passed. This suggests that the stream buffer ordinance has been protecting streams in new developments, but that stream buffers on parcels platted before 2007 are not protected by the new ordinance and may still be experiencing loss.

TABLE 7. Buffer conditions by stream type

TYPE OF STREAM	BUFFER SIZE	ACRES IN THE BUFFER ZONE (CANOPY LOSS)	POST-2007 BUFFER (CANOPY LOSS)
Type 3 EPA III Streams	30 ft	177 (16)	25 (3)
Type 2 Intermittent Streams	50 ft	68 (4)	34 (2)
Type 1 Perennial Streams	100 ft	1335 (119)	200 (17)

LAND COVER ANALYSIS BY WATERSHEDS

The 2022 NRI dataset improves our understanding of land use and land cover variability among Columbia's key watersheds. Percent of impervious cover is the most commonly used measure of watershed condition (Wickham et al 2014), and we know that sensitive streams can be impacted by as little as 5 to 10% impervious surface area, with greater impairments expected when rates exceed 20%.

Increases to impervious surfaces such as pavement or rooftops result in increased stormwater runoff rates and volumes, flooding, stream channel erosion, sediment transport and deposition, and increased quantities of water-borne pollutants. Increasing tree canopy within a watershed, in contrast, is an

indicator of stream health and correlated with higher water quality (Sweeney and Newbold, 2014). These indicators of watershed health are of special importance when coupled with the increasingly intense storm events that Missouri is experiencing.

The 2022 NRI study area comprises some or all of 14 watersheds. Of these, eight are of special importance because of their total area, important aquatic resources, or because they fall almost entirely within the study area (see page 13).

Lower Hinkson Creek is the most developed watershed, with 27% impervious surface. Canopy cover is lowest in the agricultural areas of Little Cedar Creek, which drains directly to the Missouri River.

TABLE 8. Canopy cover, impervious surfaces, and grassland/crops by watershed

WATERSHED	ACRES IN NRI	CANOPY (%)	IMPERVIOUS (%)	GRASSLAND & CROPS (%)
Little Bonne Femme Creek-Missouri River	25,845	11,347 (44%)	1,729 (7%)	11,128 (43%)
Middle Hinkson Creek	24,690	9,003 (37%)	3,725 (15%)	10,240 (41%)
Rocky Fork Creek	19,732	8,282 (42%)	3,188 (16%)	6,849 (35%)
Callahan Creek-Perche Creek	14,529	6,003 (41%)	1,423 (10%)	6,357 (44%)
Bonne Femme Creek	14,375	5,859 (41%)	566 (4%)	7,500 (52%)
Lower Hinkson Creek	14,122	5,570 (39%)	3,762 (27%)	4,105 (29%)
Black Branch-Perche Creek	12,010	4,994 (42%)	287 (2%)	5,619 (47%)
Little Cedar Creek	7,727	2102 (27%)	225 (3%)	5,094 (66%)

IMPERVIOUS SURFACES & BARE GROUND

Increased runoff and stream degradation is largely due to the addition of impervious surfaces at the watershed scale, though the Hinkson Creek Collaborative Adaptive Management Team identified specific factors such as contamination by chloride-based deicers (2023). These chemicals are known to cause problems in Columbia’s waterways and contribute to stream degradation. Impervious surfaces include asphalt, concrete, structures, and artificial playing surfaces.

Columbia added 2,374 acres of impervious surfaces within the city limits since the 2007 NRI. In the lands annexed since 2007, impervious surfaces jumped from 176 to 536 acres, for a 148% change. It is worth noting that bare ground declined by 1,000 acres across the city since 2007, suggesting that much of the added impervious surface was already cleared for development 15 years ago.



Impervious surface that was added since 2007 is pink in the figure above.

GRASSLANDS AND CROPLAND

The agricultural history and feel of open space are important to Columbia residents, and much of the eastern half of the study area was historically a prairie rather than a forested system.

Grasslands and Cropland were the land cover categories that changed the most from 2007 to 2022, with croplands expanding by 4,715 acres and grasslands shrinking by 8,561 acres in the larger NRI study area. This result reflects both land use change and the difficulty in classification and distinguishing between these two land uses. Even after the model sought to classify what it could, technicians had to go back and hand-classify some parcels based on the imagery, e.g. as grassland if hay bales were visible.

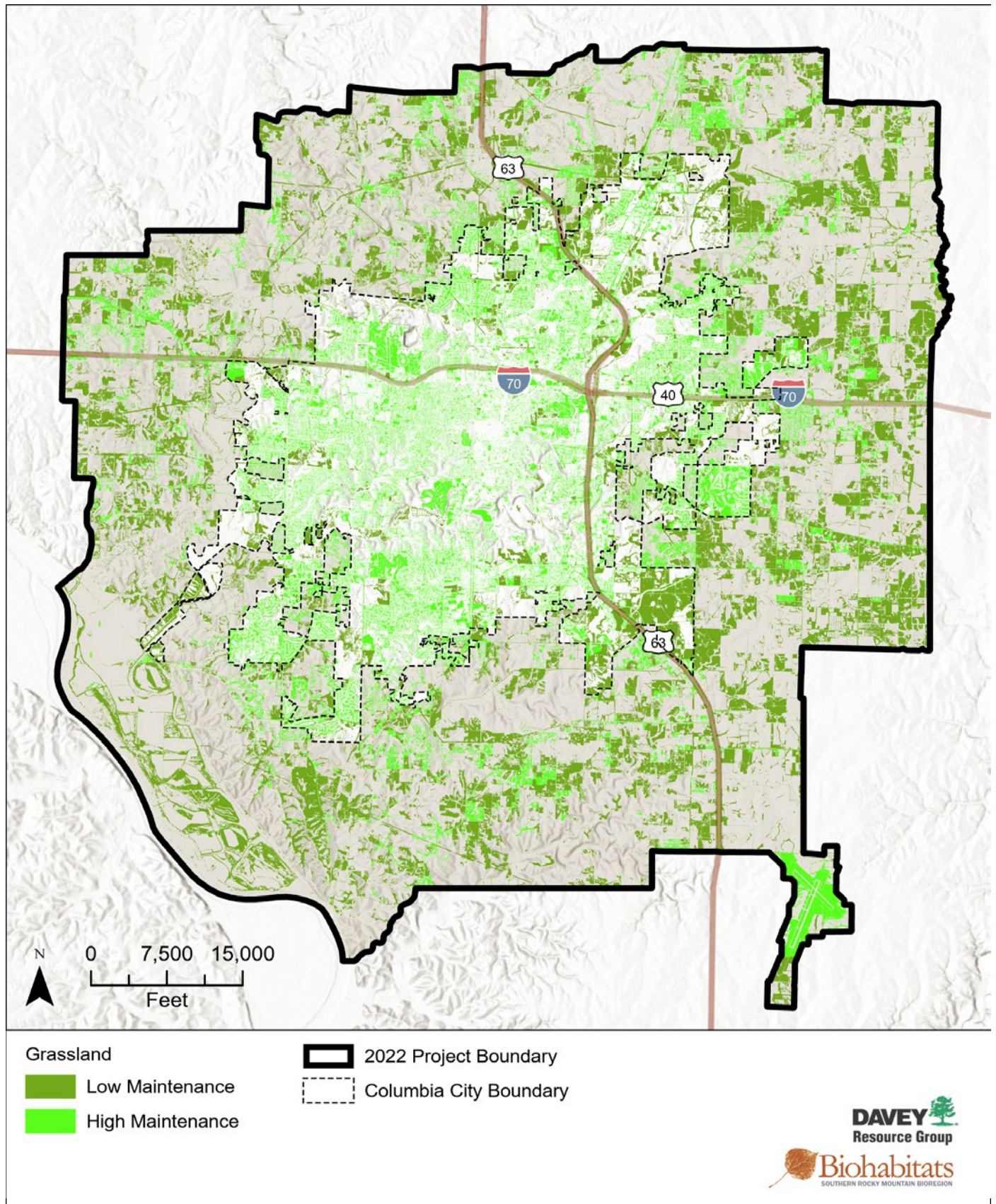
The Grassland data were derived by erasing all Forest, Impervious, Open water, Cropland, and Bare ground from the project boundary. “High” and “low” maintenance categories were then created to show regularly mowed grasses, such as lawns, as high maintenance, while natural grasses, pastures, and infrequently mowed grasses were classified as low maintenance using the 2019 National Land Cover Dataset (NLCD).

If this data set is further validated, however, it could be useful to determine tree planting or prairie restoration opportunities. Sites with non-recreational turf grass, for example, could be candidates for prairie/grassland restoration or for tree planting, depending on the desired land use.

TABLE 9. Grassland and Cropland land use in the NRI study area.

LAND COVER CLASS	ACRES (%) IN NRI AREAS	CHANGE IN NRI AREAS	ACRES (%) IN CITY	CHANGE IN CITY
Grasslands	41,307 (35%)	-8561 ac	13,206 (30%)	-1721
Cropland	21,574 (8%)	+4715 ac	1,663 (4%)	+199

MAP 12: GRASSLANDS



Conclusion: Protecting & Regulating Natural Resources

Natural Resources provide vital ecosystem services that are integral to the health and wellbeing of Columbia's residents, economy, and future. Several City plans focus on protecting natural resources, including the City's Climate Action and Adaptation Plan which highlights the need to conserve these resources to protect future generations from the impacts of climate change. These plans guide the protective and regulatory ordinances and policies set by the City. The 2022 NRI data can be used to further environmental protection and conservation efforts by the City and community. The following are examples of how the NRI data may be used in the future.

EXAMPLE FUTURE USES OF THE 2022 NRI

High resolution datasets such as the one developed for the 2022 NRI can be important to city planners and natural resource managers. The 2022 NRI data can support analysis to answer questions such as:

- Where can land be protected to enhance habitat connectivity?
- Where is land use change most likely to affect important natural resource values?
- Where does existing land use exacerbate flood risk? Where could restoration reduce it?
- How much of the city's stream buffers have natural vegetation?

ECOLOGICAL PRINCIPLES OF NATURAL RESOURCE MANAGEMENT

Managing natural resources and the ecosystem services they provide depends on science-driven principles. Natural resource planning supported by robust data such as this land cover analysis can help communities prioritize and understand how to implement these principles. The following are some of the most common examples.

Protect Biodiversity and Special Features

Regionally rare or important features, such as uncommon native species or south Columbia's karst landscapes and caves are targets for management and protection.

Enhance Habitat Connectivity

Large, continuous extents of habitat provide space for ecological processes such as predator-prey interactions, pollination, and seed dispersal to function properly. Conversely, fragmentation of landscapes and habitat destruction are the greatest threats to biodiversity. Therefore, preserving or enhancing habitat connectivity is a core goal of ecological planning.

Mitigate Threats to Ecological Health

Invasive species and pathogens, pollution, and overpopulation of deer are examples of threats to the long-term well-being of ecological systems. Assessing and managing these threats is key to natural resource management.

Manage and Restore Water Resources

Water resources are especially important because they integrate management problems over large areas and support a disproportionate percentage of regional biodiversity compared to their surface area. Holistic approaches to water management can protect them into the future.

Support Resilience

Natural systems that are resilient can recover from disturbance and adapt to changing conditions. Diversity, redundancy, and adequate space each enhance adaptive capacity and therefore resilience.

PRINCIPLE	EXAMPLES OF IMPLEMENTATION
Protect Biodiversity & Special Features	<ul style="list-style-type: none"> • Towns such as Fort Collins, CO have variable buffer/setback ordinances that recognize special habitat features, e.g. ditches and colonial nesting birds. • Washington State has several kinds of Environmental Protection Districts targeting specific sensitive resources. • Burlington, VT utilizes a Natural Resources Protection Overlay District for the purpose of protecting sensitive features and wildlife connectivity between those areas. • Albemarle County, VA has a stand-alone Biodiversity Action Plan (2018) that is named in their Comprehensive Plan.
Enhance Habitat Connectivity	<ul style="list-style-type: none"> • Atlanta, GA identified “forest connectivity” corridors for tree planting priorities. • Boston’s Emerald Necklace resulted from a park development and land acquisition program that specifically targeted connected lands. • Great Parks of Hamilton County, OH allows no more than 20% of large natural areas to be developed.
Mitigate Threats to Ecological Health	<ul style="list-style-type: none"> • Knox County, IA used local ordinance to ban 64 invasive plant species in the county. • Colorado has experienced successful deployment of Conservation Overlay districts that minimize the footprint of development and protect land in protected area buffers (Mockrin et al 2017).
Manage and Restore Water Resources	<ul style="list-style-type: none"> • Montgomery County, MD requires a standard of Environmental Site Design that requires planning techniques and practices that replicate the stormwater runoff characteristics of “forest in good condition.” • In Lake County, IL, the Stormwater Management Commission created a Wetland Restoration and Preservation Plan as a component of their Comprehensive Stormwater Management Plan. • Atlanta, GA identifies stream buffers with less than 60% canopy cover as restoration priorities. • Watershed Protection Overlays are frequently integrated into municipal zoning, e.g. San Marcos, TX and Cary, NC.
Support Resilience	<ul style="list-style-type: none"> • Many cities, such as Richmond VA, have overarching canopy goals. • Portland, OR adopted an urban forest master plan that addresses tree equity issues. • Alexandria, VA has established a phased requirement to include a percentage of both locally- and regionally-native species in development projects.



LITERATURE CITED

Chapman, S.S., Omernik, J.M., Griffith, G.E., Schroeder, W.A., Nigh, T.A., and Wilton, T.F., 2002, Ecoregions of Iowa and Missouri (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,800,000).

Davey Resource Group. 2019. Urban Forest Master Plan, City of Columbia, Missouri. April 2018. Prepared for City of Columbia.

Diamond, J.M., 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. *Biological conservation*, 7(2), pp.129-146.

Fitzpatrick, M.C. and Dunn, R.R., 2019. Contemporary climatic analogs for 540 North American urban areas in the late 21st century. *Nature communications*, 10(1), pp.1-7.

Hawley, R.J., MacMannis, K.R., Wooten, M.S., Fet, E.V. and Korth, N.L., 2020. Suburban stream erosion rates in northern Kentucky exceed reference channels by an order of magnitude and follow predictable trajectories of channel evolution. *Geomorphology*, 352, p.106998.

Hinkson Creek Collaborative Adaptive Management Team, 2023. Chloride Task Force Report.

LaPoint, S., Balkenhol, N., Hale, J., Sadler, J. and van der Ree, R., 2015. Ecological connectivity research in urban areas. *Functional Ecology*, 29(7), pp.868-878.

Lee, S., Baek, J., Kim, S.W. and Newman, G., 2022. Tree canopy, pediatric asthma, and social vulnerability: An ecological study in Connecticut. *Landscape and urban planning*, 225, p.104451.

Lee, S., Ye, X., Nam, J.W. and Zhang, K., 2022. The association between tree canopy cover over streets and elderly pedestrian falls: a health disparity study in urban areas. *Social Science & Medicine*, 306, p.115169.

Nelson, P.W., 1987. The terrestrial natural communities of Missouri. Missouri Department of Conservation.

Mockrin, M.H., Reed, S.E., Pejchar, L. and Jessica, S., 2017. Balancing housing growth and land conservation: Conservation development preserves private lands near protected areas. *Landscape and Urban Planning*, 157, pp.598-607.

Sweeney, B.W. and Newbold, J.D., 2014. Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review. *JAWRA Journal of the American Water Resources Association*, 50(3), pp.560-584.

Wickham, J.D., Wade, T.G. and Norton, D.J., 2014. Spatial patterns of watershed impervious cover relative to stream location. *Ecological indicators*, 40, pp.109-116.