Scenarios for Pollinator Habitat at Denver International Airport

by
Tiantong Gu (Landscape Architecture)
Xuan Jin (Landscape Architecture)
Jiayang Li (Landscape Architecture)
Annemarie McDonald (Conservation Ecology)
Chang Ni (Conservation Ecology)

Client: Sasaki
Adviser: Professor Joan Nassauer

Submitted in partial fulfillment
of the requirements for the degrees of
Master of Landscape Architecture and
Master of Natural Resources and Environment
at the University of Michigan
School for Environment and Sustainability

April 17th 2018

SEAS SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY UNIVERSITY OF MICHIGAN

Acknowledgments

We would like to thank our adviser, Joan Nassauer, for her patience and thoughtful advice throughout the course of this project. We would also like to thank Tao Zhang, our client liaison, for his critiques and suggestions.

We are grateful to the staff at the Rocky Mountain Arsenal National Wildlife Refuge, especially Tom Wall, and the Applewood Seed Company for their assistance in the planting designs in this project.

Funding for our project was provided by University of Michigan School for Environment and Sustainability.

Finally, we would like to thank all of our families for their support and encouragement during this process.

Table of Contents

Abstract

Denver International Airport (DEN) is the 6th busiest airport in the United States, serving 58 million passengers in 2016. This rapid growth has made the airport an economic engine of the region. In order to capitalize on this economic resource, Michael Hancock, the mayor of Denver, envisions creating an Airport City of mixed use, retail, office, and industrial development on the airport's property along Peña Boulevard, which connects the airport to downtown Denver. However, this corridor is also strategically located to provide a habitat connection between the Rocky Mountain Arsenal National Wildlife Refuge and the prairie on the airport's property.
In order to understand the tradeoffs between these two landuses, we created four scenarios of future development on the property. Two of the scenarios prioritize the Airport City (AC), while the other two prioritize the Habitat Corridor (HC). For each of these priorities, we created one scenario that maintains the airport property's current boundaries and one that imagines an expanded boundary. Based on these four scenarios, we developed four alternative landscape futures, and modeled the pollinator abundance in each. Our results suggest that pollinator abundance is higher in landscapes that have more restored prairie. Expanding the property boundary increased pollinator abundances as well, particularly when the expansion region was prairie. Based on these findings, we recommend that any future development plans include the restoration of shortgrass prairie with native plant species to enhance pollinator habitat.

Introduction

Pollination is a mutualistic relationship between flowering plants and animal pollinators. The pollinator facilitates plant reproduction through the transfer of pollen from anthers to stigma, a process which allows plants to make seeds and reproduce. In exchange, the pollinator receives floral resources (i.e., nectar and pollen). Over 80% of angiosperms require an animal pollinator, and this relationship is important to plant reproduction in both natural ecosystems and agroecosystems. Animal pollinators, including insects, birds, and bats, are associated with 35% of the world's agricultural production (Reddy et al., 2013). In order for pollination to occur, pollinators must co-occur with their potential plant partners, both spatially and temporally. Anthropogenic changes to natural ecosystems have threatened both spatial co-occurrence, though habitat loss and fragmentation, and temporal co-occurrence, through changes in phenology due to climate change (Reddy et al., 2013). In order to preserve species richness and abundance of pollinators in developed areas, it is important to create and enhance habitat to meet the needs of pollinators.

Several groups in Colorado have noted pollinator decline as a significant issue, and have some initiatives in place in order to improve conditions for these important species. For example, Environment Colorado has started the Bee Friendly Food Alliance to bring together chefs and others in the restaurant business to work on issues related to declining bee populations. This year, 235 of those chefs and restaurateurs sent a letter to the EPA, calling on the government to ban pesticides that are harmful to pollinators (Environment Colorado, n.d.). The Front Range chapter of Wild Ones promotes increasing pollinator habitat through planting pollinator gardens, using information from the Xerces Society (Front Range Wild Ones, n.d.). The Rocky Mountain Arsenal Wildlife Refuge has a pollinator garden on site, and holds programs for families to learn how to plant pollinator gardens in their yards, or incorporate pollinator-friendly plants into vegetable gardens (Wall, T., personal communication). In light of the problems that bees face, Sasaki, our client, has decided to consider strategies for optimizing pollinator habitat in the

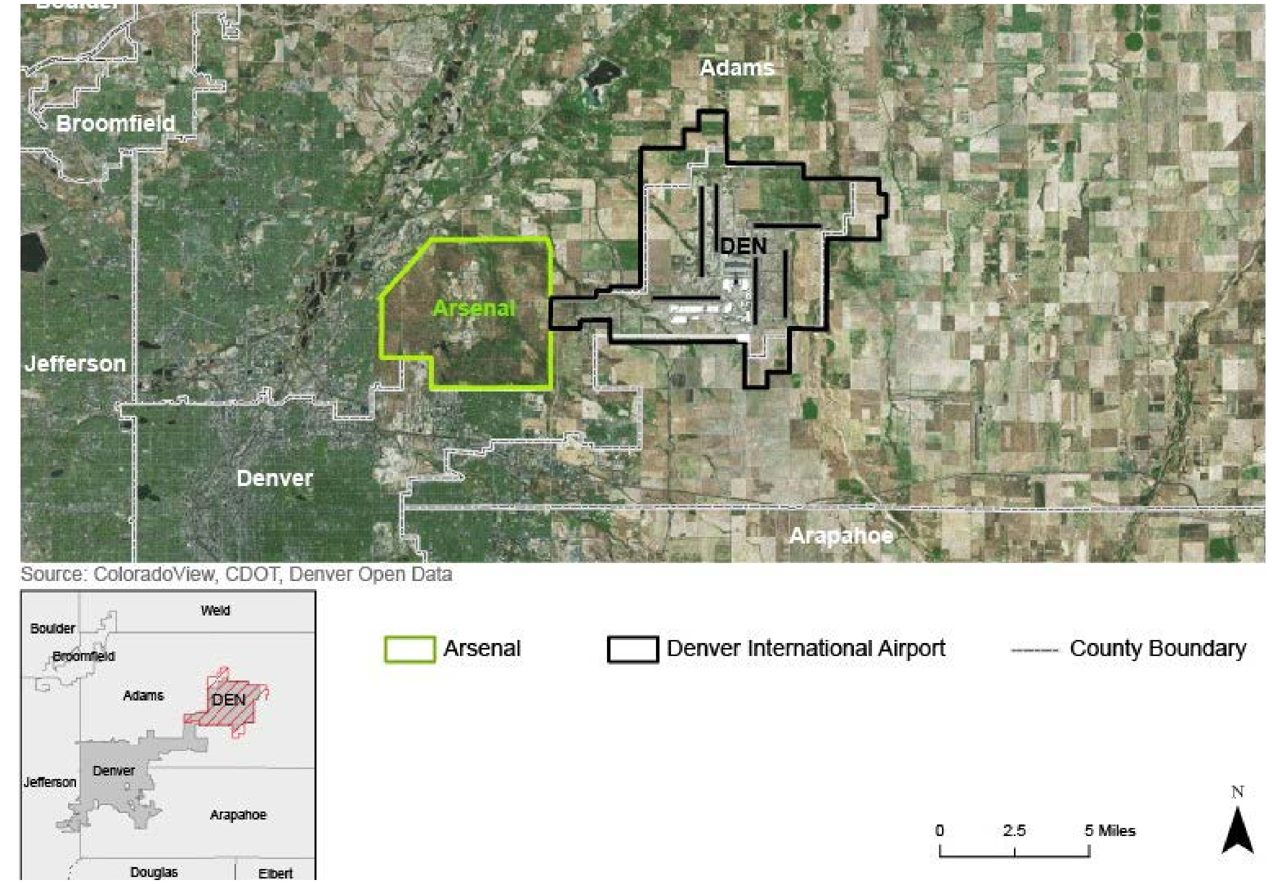


Figure 1: Denver International Airport (DEN) is located to the northeast of downtown Denver. The direct adjacency to the Rocky Mountain Arsenal Wildlife National Wildlife Refuge makes a unique spatial characteristics that offers great pollinator habitat opportunities, while the juxtaposition of County and City of Denver and Adam County poses potential land management challenges (data source: Colorado View, CDO, Denver Open Data).

master plan for the DEN site.
Denver International Airport (DEN) is situated about 25 miles southeast of downtown Denver in the Metro Denver area, Colorado. With 33,000 acres (51.56 square kilometers) of land, 8, 754 acres (35.43 square kilometers) of which is developable, it is the biggest airport property in U.S. and the second-biggest one in the world (Fig.1). DEN is ranked the 6th busiest airport in the United States and 18th busiest the world in 2016 by passenger traffic, with over 58 million passengers for the year of 2016 (DEN, n.d.).

The area has rapid population growth and huge potential for economic development, and at the same time, emerging environmental challenges. Because land use change often results in the reduction of natural areas, the expansion of the Denver International Airport (DEN) may have significant impacts on the quality and quantity of pollinator habitat. Therefore, DEN may provide an example of how to meet the challenge of providing enough development area for future needs while establishing well-connected habitats in the special setting of a relatively open and undeveloped urban area. The current plan for the expansion of the airport comes in the form of a Corridor of Opportunity and Airport City, envisioned by Denver's mayor, Michael Hancock. As a first step to realize this vision, a new 519-room hotel and a rail station that links DEN to Denver Union Station via the Corridor of Opportunity has already been built. Future plans for the area will also include transit-oriented development with housing, a Fortune 500 headquarters, and abundant open space (City and County of Denver, n.d.). SASAKI, an interdisciplinary design firm, has used this existing train line as the basis for a strategic development plan that provides a comprehensive development strategy and vision for future streets, blocks, and public open space.

Land uses including mixed-use, office, retail, industrial use, educational use and public transit centers are proposed, based on which we will build our study. This plan also seeks to create a unique landscape experience that truly represents DEN and Colorado, and establishing pollinator habitats is viewed as a significant interest for landscape design.

In order to better inform the decision-making process and present broader future possibilities for the airport, we not only envision a future of comprehensive development, but also seek to reimagine how an airport can provide pollinator habitat as one aspect of sustainability. DEN is well-positioned to create habitat for native species because the property possesses vast undeveloped lands that are adjacent to the Rocky Mountain Arsenal National Wildlife Refuge. We investigated these opportunities through scenarios, which represent plausible futures. By prioritizing different drivers and comparing results, the scenarios in this study can indicate trade-offs between development potential and pollinator support on a landscape scale (Fig. 2).

Figure 2: Four plausible futures are represented through detailed landcover patterns.

The first set of scenarios (AC: Airport City and EAC: Expanded Airport City) prioritizes Airport City development, the key idea of which is to view airports as broadly based land uses that can generate additional non-aeronautical revenues for a long-term financial sustainability; while the second set (HC: Habitat Corridor and EHC: Expanded Habitat Corridor) prioritizes the expansion and enhancement of potential pollinator habitat (table 1). Within both of these sets of scenarios, one uses the existing boundaries of the airport property while the other envisions a future in which the boundaries are expanded (Fig. 3). This expansion can be fulfilled when more lands between the airport property and Arsenal are purchased by DEN to secure more space for future development flexibility and to achieve more collaborative management with adjacent properties for better pollinator habitats. We envision such plausible futures to study the corresponding outcomes and to understand the potential opportunities. All four scenarios are based on a timeframe of 2030. We chose this timeline in response to the twenty-year long term forecast that three more runways will be constructed by 2030 and the availability of data for the estimated volume of passengers and cargo in 2030 (City and County of Denver, 2011).

	Airport City Priority	Habitat Improvement Priority
Existing Boundaries	Airport City (AC)	Habitat Corridor (HC)
Expanded Boundaries	Expanded Airport City (EAC)	Expanded Habitat Corridor (EHC)

Table 1: Two major research questions studied through two sets of scenarios. How does prioritizing Airport City Development and prioritizing pollinator habitat compare against each other? How does keeping existing property boundary and expanding the current boundary for more flexible development or better habitats compare against each other?

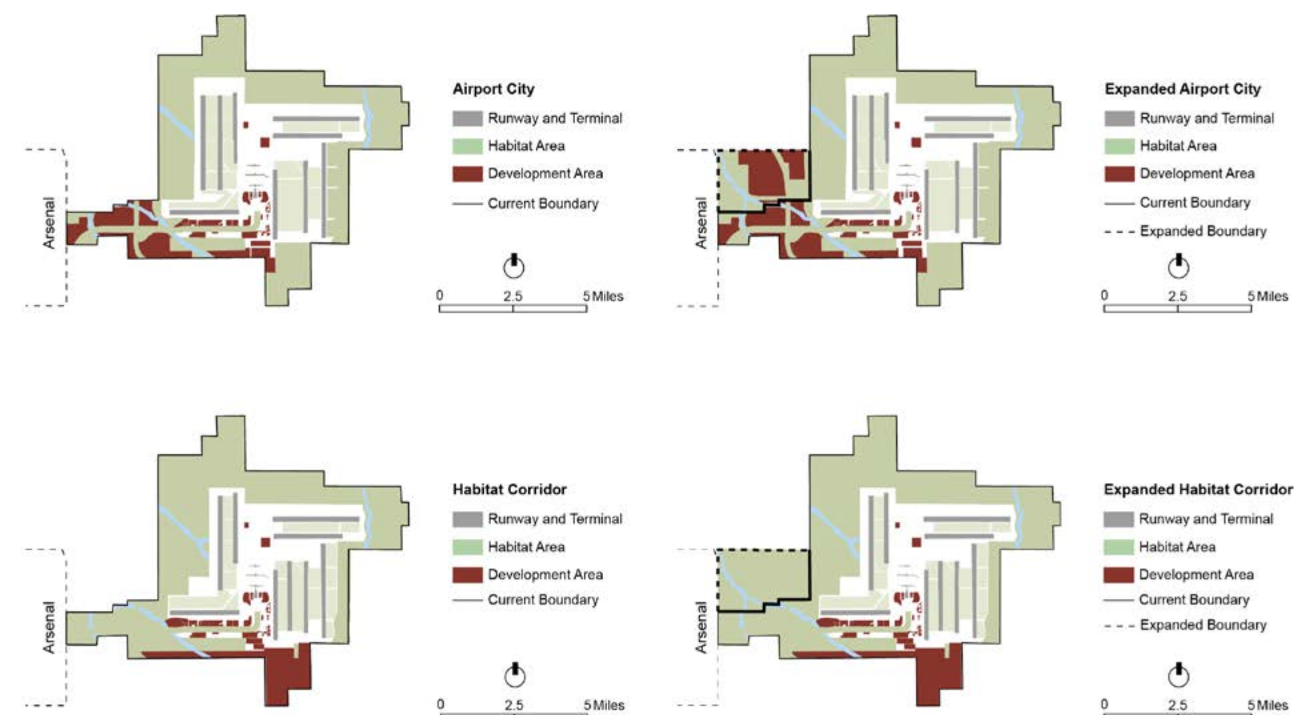


Figure 3: Diagrammatic visualization of the location of the expanded boundary, and the distribution of habitats and developed area in four scenarios.

We used the InVEST Crop Pollination model (Lonsdorf et al., 2009) to simulate the effects of our four different scenarios on the abundance of four different guilds of bees in the DEN property. The landscape futures for each scenario determined the nesting sites and floral resources available, and the abundance indices produced by the model indicate the relative pollinator habitat quality and allow us to compare and evaluate the four landcover patterns.

Reserach Goals

The overall goal of the study is to investigate how pollinator habitat may fit into an extensively human-dominated landscape, using the specific site of Denver International Airport (DEN) as an example. We aim to compare the influences different landscape patterns may have on pollinator abundance, represented patches of habitat in a highly developed matrix and lands restored for pollinator habitat, as well as the influences from the size of the landscape unit. Both sets of scenarios include same proposed development land use types and landscape element types targeted for pollinator habitat. The first set of scenarios prioritizes airport city development along the major connection corridor, while the second set of scenarios prioritizes using the same corridor as wildlife habitat to strengthen the connection with the Rocky Mountain Arsenal National Wildlife Refuge. Through the following processes, we seek to make such comparisons and understand the potential for incorporating pollinator habitats in human-dominated landscapes.

- Identify key potential pollinator species in the site and within a larger geographic context; identify the nesting and forage needs of those pollinators
- Determine native plant species relevant to natural communities on the site as well as non-native ornamental plant species that might provide floral resources for pollinators in developed areas
- Propose and assess scenarios of landscape patterns in terms of their potential to support pollinators, operationalized by size, shape and adjacent distance
- Develop and contrast the landscape patterns and species selection under each scenario
- Determine the abundance of key pollinator guilds under each scenario
- Communicate research findings and results to provide a useful reference for future decision-making about the site

Literature Review

The Shortgrass Prairie Ecosystem

The undeveloped areas of the airport site are largely shortgrass prairie, which covered the entire airport site as well as the city of Denver prior to development. At present, this ecosystem covers 90,700 square miles of North America (or 22% of the total area of grassland), and is dominated by shortgrass, mixed grass, and sand sage prairie (Venner, 2014). Different grassland types are influenced by north-south and east-west gradients. Temperatures and daylight hours increase from north to south, and precipitation decreases from east to west (Drecker, 2007). Throughout North America, land covered by shortgrass prairie is largely privately owned and much of it has been converted to agriculture (Venner, 2014). Grasslands are one of the most imperiled ecosystem types in North America and a priority for conservation.

This system is dominated by Bouteloua species. Associated graminoids frequently include Buchloe dactyloides, Hesperostipa comata, Koeleria macrantha, Pascopyrum smithii, Aristida purpurea, and Sporobolus cryptandrus (Western Great Plains Shortgrass Prairie, 2005). Important disturbance regimes include fire, grazing, and drought (Drecker, 2007). There is only a slight influence of livestock grazing on vegetation composition, which likely relates to the fact that the North American shortgrass prairie coevolved with grazing mammals (Moir and Trlica, 1976). Grasses are tolerant to both drought and grazing.

Loss of prairie lands is often caused by habitat conversion to urban and agricultural land, due to population growth. The rate of population growth in Colorado is twice the national average, and that trend is likely to continue in the future (Venner, 2014). This increases development pressure and decreases habitat for many endangered species in the region. Much of the land around the airport site, which was originally short or mixed grass prairie, was converted to agriculture or grazing after European settlement. The U.S. Fish and Wildlife Service has worked to restore land to its “native condition” at the Arsenal Wildlife Refuge (US Fish and Wildlife Service, n.d.). This restoration is a lengthy process that can include burning and herbicides to remove non-native vegetation, tilling, planting sorghum to increase soil organic matter, and finally introducing a native prairie seed mix (R, n.d.). In order to provide habitat for native wildlife species, it is important to have a diverse mixture of native prairie species.

Airport Impacts on Ecosystems

Airports can cause a loss or degradation of habitats for native wildlife, as well as impact wildlife through toxins in wastewater and light and noise pollution (Aviation Environment Federation, n.d.). Habitat loss occurs when previously natural areas are converted to an urban, industrial, or agricultural land use. Airports can also increase habitat fragmentation, which occurs when a large patch of a natural area is divided into smaller patches, separated by development. This can have many effects on wildlife, including making it more difficult for native species to move between patches for foraging, breeding, or migration (Aviation Environment Federation Planning Guide, n.d.).

For pollinators, habitat fragmentation can have multiple impacts. As described by Xiao et al. (2016), the impacts of fragmentation vary by pollinator and can be difficult to test. Studies often examine the quantity of resources available to pollinators, primarily native plant species that provide nectar and pollen. Plant diversity and population size have both been shown to generally decrease with fragmentation, as habitat size and connectivity are reduced (Xiao et al., 2016). However, if small patches have high floral diversity, they can support a high level of pollinator diversity. A study of bee communities in Iowa demonstrated that bees were as abundant and diverse in small prairie preserves as they were in larger prairie preserves, and that bee diversity was significantly correlated with floral diversity (Hendrix et al., 2010).

The isolation of patches and edge-to-area ratio can also affect the abundance and density of flowering plants (Xiao et al., 2016). Fragmentation tends to increase the edge-to-area ratio of a patch, and edges can have significantly different microclimates than the center of the patch. This can lead to changes in species composition as well as the phenology of those species. A prairie study has shown that plants at the center of a patch have longer flowering periods than conspecifics at the edge of the patch (Ison et al., 2014). In this case, plants at the center provide resources to pollinators for a much longer period of the growing season. Changes in phenology can also reduce synchrony between plants and their pollinators, weakening the interaction between the two. This may result disruptions of the food supply for some pollinator species and reductions in pollination for plant species.

Fragmentation can result in changes in the behavior of pollinators. A study conducted in Switzerland demonstrated that bumblebee behavior was altered by fragmentation (Goverde et al., 2002). Bumblebees visited fragmented patches at a much lower rate, and while there, tended to stay longer and visit more inflorescences from the same patch rather than flying a long distance to reach the next patch (Goverde et al., 2002). The reduced visitation may result in lower reproductive fitness (seed set) for plants in fragmented patches, and the tendency to spend longer in the same patch may decrease genetic diversity.

The level of disruption that fragmentation poses to pollinators may depend on their level of specialization, as well as the level of specialization of the flowers that they visit. Specialist pollinators visit only a few taxa of plants (e.g., monolectic or oligolectic bees), while generalists visit many. Specialist plants are only pollinated by a few taxa of pollinators, while generalists can be pollinated by many. Habitat fragmentation often affects specialist species more severely than generalists, and can increase the ratio of generalists to specialists in an ecosystem (Xiao et al. 2016). This occurs because specialists species cannot easily compensate for the loss of a partner by switching to another partner, while generalists can. However, this effect can be complicated by the existence of asymmetric interactions, in which a specialist pollinator visits a generalist plant, or vice versa.

Airports have several other important impacts on wildlife. Airport runoff is considered a major source of pollution as it can contain toxic chemicals, often from aircraft and airfield de-icing and anti-icing, fuel spills, firefighting foam, and detergents (Voskaki, 2015). Light pollution can have a variety of impacts on wildlife. It can cause migrating animals to change course because they are attracted to the light. It can also attract insects; higher insect populations can attract predators like birds and bats (Aviation Environment Federation, n.d.).

Strategies for minimizing the impact of airports on biodiversity of native species include minimizing intrusion of development on existing habitat, restoring and creating habitats, rescuing important species, and replacing ponds (Aviation Environment Federation, n.d.). However, large flocking birds (e.g., geese) are seen as a threat to airports and aircrafts (Aviation Environment Federation, n.d.). It is frequently recommended that populations of these types of birds are minimized in close proximity to airports, and this should be taken into account when restoring and creating habitat.
In order to inform the development of our scenarios, we investigated airport precedents with an emphasis on economic development or biodiversity support, especially for pollinators.

Airport Case Study: Airport City and Habitat Commitment

In order to inform the development of our scenarios, we investigated airport precedents with an emphasis on airport city and environmental commitment, especially for pollinators. Several cases are closely examined and summarized below (table 2).

DEN	Denver, Colorado, USA	53 square miles	25 miles	
Airport	**Location**	**Size**	**Distance to downtown**	**Study focus**
Tullamarine	Melbourne, Australia	8.3 square miles	14 miles	Airport city concept
Amsterdam Airport Schiphol	Amsterdam, Netherland	10.8 square miles	5.6 miles	General landscape design and management
O’Hare International Airport	Chicago, Illinois, USA	11.25 square miles	17 miles	Innovative environmental projects
Zurich Airport	Zurich, Switzerland	3.4 square miles	8 miles	Conservation zones

Table 2: A summary of airport case studies highlighting design and planning ideas on Airport City, landscape design, environmental and conservation projects. The comparisons of size and location with DEN are also included.

Airport City

As mentioned in the previous section, not only has DEN's current non-airline revenues kept increasing from 2014 to 2016, to increase non-airline revenues is also a main goal in DEN'S strategic plan (Denver Airport Layout Plan Narrative Report, 2011). One way to realize this goal is through the concept of Airport City, which is being incorporated into airport planning of different scales and in varied ways universally (Baker & Freestone, 2010). The key idea of the Airport City is to view airports as broadly based land uses rather than pure transportation nodes, taking advantage of the usage mix to to generate additional non-aeronautical revenues for a long-term financial sustainability (Baker & Freestone, 2010; Kasarda, 2010). The spatial and functional core of the Airport City is the passenger terminal, which acts like an urban central square that is surrounded by offices, hotels, exhibition complexes etc., creating a city-center-like environment around the airport; and aviation-linked functions are located outward, primarily along connecting transportation corridors (Kasarda, 2010).

The Melbourne Airport (8.3 square miles, 14 miles from downtown Melbourne), often referred to as Tullamarine, in Melbourne, Australia, was one of the first comprehensive examples of a planned, purpose-built Airport City using airport land for non-aviation purposes at a greenfield site (Chandu, 2017). The principal planner, Bill Bradfield, conceived the airport more than just a transport facility, but also an attraction of its own, a breathing open space to the city, and a center of public attraction (Bradfield, 1945). Based on these perceptions, the terminal, landside facilities, and buffer zones were all utilized to set up a comprehensive suite of facilities to maximize income from non-aviation sources. Such non-aviation amenities included fine dining, retail shops, food and drink outlets, observation decks, a substantial industrial park, a hotel, a service station, an 18-hole golf course and country club, and the Astrojet Centre with its exhibition spaces, dentist, chemist, bottle-shop, galleries, and cinema (Chandu, 2017).

Environmental Commitment to Pollinator Habitats

Environmental management plans and eco-friendly policies and strategies are being adopted increasingly by airports around the world (Baxter et al. 2014; Giustozzi et al. 2012). Many projects turn out to not only support wildlife and biodiversity while ensuring aviation safety, but also bring other social, environmental, and economic benefits with a multifunctional performance.

A growing number of airports are playing host to beehives (Baskas, 2017). In 2011, O'Hare International Airport in Chicago introduced many eco-projects, including an apiary in a vacant lot of undeveloped grassy area on the east side of the airport (Fig.4). This project was an attempt to replenish bee population as well as engage community. With the support of a wide collaboration, the Chicago Department of Aviation (CDA) also helped to provide job experience to returning citizens and other disadvantaged persons in the North Lawndale community (CDA, n.d.). Now, products ranging from natural honey to various honey-based skin care cosmetics are being sold at both the terminal 3 and local stores, bringing a strong identity to the airport. Seattle Tacoma International Airport, St. Louis Lambert International Airport, Austin Bergstrom International Airport and Minneapolis St. Paul International Airport also hold apiaries within the airport property. In addition to making honey, as a sensitive insect, bees can also be used as a"biomonitor" to the air quality of the airport, which have been adopted by some German airports as early as 1999 (CDA, n.d.). By supporting the growth of dense vegetation on a former golf course in Seattle Tacoma International Airport, the bees also help the airport keep large birds away from airplanes (Baskas, 2017). Starting in 2013, the Chicago Department of Aviation (CDA) introduced a herd of goats, sheep, llamas and burros to clear dense scrub vegetation on O'Hare


Figure 4: Apiary in a vacant lot of undeveloped grassy area in O'Hare International Airport in Chicago as an effort to replenish bee population and engage community (City and County of Denver, n.d.)

Figure 5: Goats, sheep and other animals graze remote sections of O'Hare Airport in Chicago to clear dense scrub vegetation on challenging landforms to reduce maintenance costs (Kersey, 2014).

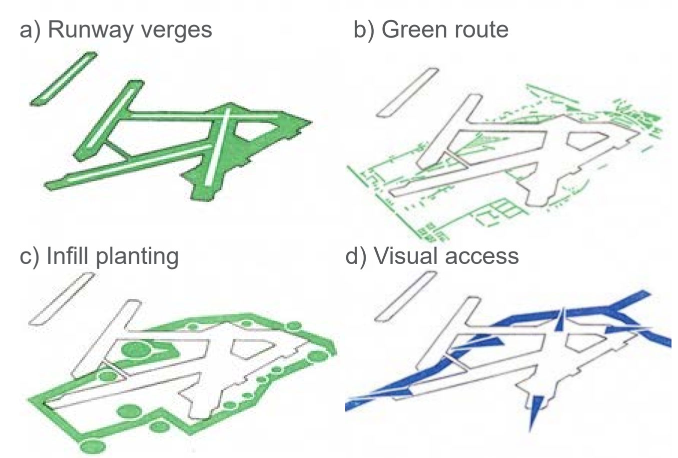


Figure 6: Four simple layers proposed by West 8 for the landscape design and planning of Schiphol Airport: a) Runway verges- well-maintained grassy area assuring the clean and tidy image; b) Green route- a uniform landscape treatment along the circulation system; c) Infill planting- tree planting within all kinds of vacant land and open space to unify the complicated appearances; d) Visual access- obscuring the infrastructural complexity of the airport (Geuze & Buijs, 2014).


Figure 7: Hardy, adaptable and bird-repelling European White Birch with the extensive and quickly-established clover in the understorey bringing in nutrients and effectively improving the poor-quality roadside soils (West 8, n.d.).


Figure 8: Mown lawn along road side as a clean landscape edge and the installation of apiary (Geuze & Buijs, 2014).


Figure 9. The 183-acre natural conservation area in Zurich Airport, a third of which is low moorland. These areas are preserved as meadow zones instead of being developed into functions directly for aviation purposes (Flughafen Zürich AG, 2010; Google Maps, February, 2013; Graphic compiled by Lydia Kalinke).

property where traditional maintenance is challenged by the landform (Fig.5). Their grazing helps to eliminate habitat for wildlife that can pose safety hazards, decrease maintenance cost, reduce erosion and herbicides, achieving many economic, operational and environmental benefits (CDA, n.d.).

Besides eco-friendly projects, larger visions of the entire airfield complex and its connections to the metropolitan region are also being emphasized. As a vital issue in decades to come, the sustainability of air travel will not only depend upon designing more fuel-efficient aircraft and reducing CO2 emissions, but also depend upon the airport's location, the current situation, available opportunities, and architecture/urban design of the airport (Lyster, 2013). Also, it is indicated that implementations such as pedestrian/cycling infrastructure, art and culture expressions of identity, green space and nature trails can help to enhance airports' cultural sustainability by promoting wellbeing of employees and passengers and preserving local identity, culture and heritage (National Academies of Sciences, Engineering, and Medicine, 2008). The Amsterdam Airport Schiphol (10.8 square miles, 5.6 miles from downtown Amsterdam) in Netherlands, is a famous case known for its landscape design aimed to create high visual quality and highlight the airport's environmental responsibilities (Gueze and Buijs, 2014). The landscape firm West 8 introduced four simple layers (Fig.6) as an integrated, low-cost strategy on the site to obscure the infrastructural complexity of the airport -- Runway verges, the well-maintained grassy area assures the clean and tidy image of Holland; Green route, a uniform landscape treatments along the circulation system links different areas; Infill planting, tree planting within all kinds of vacant land and open space unifies the complicated appearances; Visual access, clear visual corridors offer people authentic landing and take-off experiences. The planting strategy was also an important part of the design. Based on the specific concerns of the airport including complicated soil conditions, unacceptance to attract large birds, harsh wind conditions, limits of budget and maintenance, a hardy and adaptable natural pioneer tree species European White Birch (Betula pubescens) was chosen (Fig.7). Learning from a common agricultural practice, the idea of promoting natural soil mitigation through the extensive seeding of clover was also introduced. The clover quickly colonized under the birch trees and brought into nutrients, effectively improving the poor-quality roadside soils. A clean landscape edge was easily kept while the inner area remained more natural by mowing just the road edges (Fig. 8). For about ten years, the planting strategy became extraordinarily successful and was proving to be self-sustaining, even without West 8's attention (Gueze and Buijs, 2014). The landscape of Schiphol, described as the "green counterpart" to the buildings and infrastructure, underscores the value of providing a strong spatial identity to the airport, of enhancing rather than degrading the macro-environment, and of creating productive and multidimensional complexes that move beyond the utilitarian programs of the conventional airport (Lyster, 2013).

Another good example is the Zurich Airport (3.4 square miles, 8 miles from downtown Zurich) in Zurich, Switzerland. According to the sustainability report from the airport, over half of its property is not developed nor used directly for aviation purposes, but is preserved as green zones of various meadows (Flughafen Zürich AG, 2008). A unique feature is the 183-acre natural conservation area known as "Klotener Riet", a third of which is low moorland (Fig.9). During its expansion in 2001, a new-5 acre biotope was established in an area north of the airport and conservation areas were also set up along the river Glatt. It has been indicated by the airport that this nature-oriented approach helps to lower bird strike by increasing the difficulty for birds of prey to hunt and to promote the development of a cohesive meadow landscape (Flughafen Zürich AG, 2010).

Pollinator Conservation Strategies

Pollination is an ecologically important relationship between animal pollinators and flowering plants. Pollination ensures that plants are able to reproduce, and a major factor in the decline of native plant reproduction is the loss of pollinators (Williams and Winfree, 2013). This mutualism also provides pollinators with food in the form of nectar and pollen. Declines in pollinator populations in North America and around the world have prompted considerable research in pollinator conservation. Many studies investigate the relationship between the broader landscape and local habitat patches, like parks, pollinator gardens, and green roofs. The relationship between agriculture, domesticated bees, and native pollinators is also a key component of conservation planning.

Habitat loss and fragmentation is likely the most important cause of declining pollinator populations. The primary driver of habitat loss for pollinators is the expansion of urban, suburban, and agricultural zones (Williams and Winfree, 2013). Urbanization and conversion to agriculture not only convert natural areas, but also fragments and isolates patches of native habitat that remain. These landscape-scale changes can isolate pollinators from natural habitat and reduce their abundance, diversity, and provision of ecosystem services (Winfree et al., 2009). Increases in agricultural production often result in the replacement of native species with monocultures. Wheat and corn, which cover up to 20% of some midwestern states, do not provide nectar or pollen for bees or other pollinators (Cane and Tepedino, 2001). A study in the UK found that Bombus terrestris (bumblebee) nests grew more quickly and gained a larger size in suburban areas than in agricultural areas, even in farms that had undertaken conservation efforts (Goulson et al., 2002). The suburban bees also gathered a higher diversity of pollen. The authors suggest that the extent over which the bumble bee forages is large enough that conservation efforts must be made on a larger scale (Goulson et al., 2002). A bumblebee study in Colorado found a high number of bumble bee species present in Boulder County, likely due to the diverse plant communities at different elevations (Kearns et al., 2017). However, the authors note that pesticide, herbicide, and fungicide use, all associated with agricultural production, have been linked to declines in bumble bee populations.

However, local habitat quality can mitigate the effect of larger landscape changes and may have more of an impact on pollinator populations. Remnant habitats are not sufficient to conserve pollinator biodiversity, so managed habitats within urban areas are vital (Rosenzweig, 2003). Non-industrial urban areas often have diverse flower resources, including gardens, parks, and semi-natural habitats, which all support bee populations (Osborne et al., 2002; McFrederick and LeBuhn, 2006). Bee abundance in parks and other urban settings has been found to increase with increasing nesting sites (McFrederick and LeBuhn, 2006). Roadsides can also provide nesting sites for bees and wasps because they provide partially compacted soils (Cane and Tepedino, 2001). For small bees with short flight ranges (tens to a few hundred meters), local habitat quality has a stronger impact on pollinator populations than landscape-level changes (Williams and Winfree, 2013).

Urban gardens in Europe and North America support higher densities of bumblebees and solitary bees than agricultural areas, due to higher floral density and diversity as well as high percentage of suitable nesting sites (Osborne et al., 2008). However, many urban and residential gardens and planted with an eye toward the aesthetics of the site, rather than the native vegetation of the area. It is important to understand how the use of native and non-native flower species are used by pollinators. Salisbury et al. (2015) found that flowering garden plant assemblages can provide foraging resources for pollinators even when the plants are not native in origin; when a greater quantity of flowers is available, more pollinators will visit. They experimented with native, near-native, and exotic flowers in gardens and found that native and near-native garden plants saw the greatest abundance of pollinators. However, they also found that exotic plants extended the flowering season and provided additional resources to pollinators, and that some groups of bees favored exotic plants (Salisbury, 2015).

Furthermore, anthropogenic changes to a landscape may cause declines in some species and increases in others. A study in Chicago found that native bees were present on green roofs but there were fewer species and total individuals than in prairies or parks (Tonietto et al., 2011). The green roofs had fewer species of flowering plants in bloom;at the site scale, bee diversity increased as the diversity of blooming plants increased (Tonietto et al., 2011). Native bee species prefer native plant species over introduced ornamental species (Frankie et al., 2005). Oligolectic, or specialist, bees are rarely found in urban environments because there are not enough host plants to support them (Tonietto et al., 2011).

In order to protect native pollinator populations, is important to begin conservation programs before declines occur (Cane and Tepedino, 2001). It is difficult to measure and analyze declines in populations of native pollinators, especially compared to domesticated bees (i.e., honey bees). Keasar (2001) suggests designing honey bee conservation plans that also provide forage and nesting sites for native pollinator species.

Pollinators of the Denver Region

Bees

The four major bee families found in the Denver area are: Andrenidae, Apidae, Halictidae, and Megachilidae. The following sections outline the life histories, social habits, forage, and nesting needs of each family. This information informs the team's planning for the needs of various pollinators, in order to increase pollinator richness and abundance at the site. This information also informs our predictions about how each scenario will impact different taxa of pollinators.

Andrenidae
Andrenidae is the largest of bee family, with over 4500 species that can be found on all continents besides Australia (Wilson & Carril, 2015). In North America, they are mainly distributed in temperate and xeric areas (Michener, 2000). As their common names (digger bee and mining bee) indicate, all species of Andrenidae nest in earth. They prefer dry soil without dense vegetation (Chance, n.d.). The female digs burrow and cells, stores collected pollen and nectar, and lays an egg in each cell. Most species (except some Panurginae species) also line their cells with a waterproof secretion to protect the offspring and its food from moisture and bacteria (Michener, 2000; Wilson & Carril, 2015). The larvae emerges from the egg and feeds on the stored provision before pupating. It then emerges as adult in spring or autumn. In the genus Andrena, autumnal species overwinter as prepupae while most other species hibernate as adults during winter before emerging in spring. So far none of the species are known to spin cocoons (Williamson, 2013; Michener, 2000).

This family contains both solitary and communal species. Many in the subfamily Andrenidae are solitary and make their own nests, although their nests may occur in large aggregation. On the other hand, a lot of species in subfamily Panurginae are communal, sharing a nest (but not the cells) between multiple females (Michener, 2000).

There are both polylectic and oligolectic members in the family. Each of the oligolectic species collect pollen from one single plant taxon (usually genus), and may play important roles in pollinating native plants. Polylectic bees, on the other hand, collect pollen and nectar from many plant taxa. Examples include Perdita albipennis specializing in Helianthus, Andrena violae on Viola, and multiple others (Scott, Ascher, Griswold, & Nufio, 2011). These bees are also more active than honey bees in colder environments, and are therefore better pollinators for plants blooming in early spring (Joey Williamson, 2013).

Generally speaking, Andrenidae species are not aggressive and rarely sting, only using it as a last resort. However, they are considered pests by some as their nests can appear unsightly in a garden lawn (Williamson, 2013).

Apidae
The family Apidae contains more than 5700 species in over 200 genera distributed worldwide (Wilson & Carril, 2015). It includes a diverse range of well-known bees: carpenter bee, bumble bee, honey bee and more. Many play important roles in ecosystem as well as agriculture. However, the scale and diversity of the family also makes it very difficult to introduce the family as a whole. Therefore, the following paragraphs will be organized by life history and include only taxa present in Denver area.

Cuckoo Bees
Scientific reference to cuckoo bees is "kleptoparasite". Klepto means "thief" in Greece (Wilson & Carril, 2015), indicating their lifestyle of stealing the host's provision for its own offspring. It is worth noting that since the adult cuckoo bees do not need to provision their nests, they do not collect pollen and have lost their pollen-carrying structures (Moissett & Buchanan, 2010).

Cuckoo bees in Apidae family comes from tribe Melectini in subfamily Apinae, and subfamily Nomadinae. There is only one Melectini species in Denver, Xeromelecta californica. They parasitize Anthophora. The female digs her way into the closed cells of the host and lays her egg. Its egg hatches no later than the host's, and the larvae feeds on the host's egg and provision before becoming pupae and finally emerging as adult (Michener, 2000; Torchio & Trostle, 1986).

The entire subfamily Nomadinae are kleptoparasites. The female enters the host's cell when the host female is out, inserts an egg into the cell's wall or the lining on the wall and departs. The egg hatches after the host has finished provisioning and closed the cell. The larvae kill the host's egg or larvae and feed on the stored nectar and pollen. The larvae will then become pupae and finally adult, before starting the life cycle again (Michener 2000; Rozen, 1991; Wilson & Carril, 2015).

Solitary Bees
Solitary bees build and provision their nests by themselves. In Denver, solitary bees include species from tribe Emphorini, tribe Eucerini and tribe Anthophorini. Their life histories are similar. The adult female digs burrows on banks or flat ground, sometimes in aggregation for some species. Each has their preferred soil types. In tribe Emphorini, Melitomas carry water to soften clay, while Diadasia use nectar on hard soil. In fact, their soil preferences has led to an increase in their habitat, since they are drawn to trails and road cuts, and in Melitoma's case, adobe brick walls (Wilson & Carril, 2015). Anthophorini regurgitate water or nectar for a similar purpose (Michener, 2000). In tribe Eucerini, some Melissodes prefer sand or sandy loam soil, while Svastra burrow in clay (Clement, 1973; Rozen,1964).

After the cells are finished and provisioned with pollen and nectar, she lays her eggs and seals the nest off. The egg hatches into larvae. The larvae feeds on the stored food, then undergo metamorphosis and become pupae, and finally emerge as adults (Michener, 2000). Different species emerge and fly at different times of the year. Most species emerge in spring or early summer and remain active through summer, while there are exceptions. The extreme case is Melissodes, with some species in Midwest flying as late as October and November (Wilson & Carril, 2015).

Many of those bees are oligolectic, and serves as pollinators for wild plants and crop species. In Emphorini, many Diadasia specialize on cactus (Cactaceae) and mallow (Malvaceae). Melitoma specialize on morning glories (Ipomoea) almost exlusively and even nest close to the flowers. Some oligolectic Anthophora pollinate creosote and evening primroses, while one of the generalists, Anthophora urbana, increases the production of tomatoes. In Eucerini, some Svastra pollinate sunflower crops. Peponapis and Xenoglossa's specialization on squash plants (Cucurbita) earned them the common name "squash bees". They are important pollinators for both wild and cultivated squash plants, including pumpkin, zucchini and butternut squash. Unfortunately, their reliance on the squash plants, which also includes nesting close to them in farmlands, makes their nests vulnerable to destruction by tillage. (Wilson & Carril, 2015).

Eusocial bees

Eusocial means "truly social". Eusocial bees in family Apidae belong to tribe Bombini and tribe Apini. Species in the former are commonly known as bumblebees. The only species present in America in tribe Apini is Apis mellifera, also known as European honey bees. Eusocial bumble bees form annual colonies. In temperate areas (as is the case of Denver), the cycle starts in spring. The queen emerges from hibernation and searches for suitable nest sites, which includes abandoned rodent nests, bird nests, and cavities under vegetation, rocks, or other manmade structures. Then she starts building a nest cavity with fine materials such as dead grass, hair or moss and stock pollen and nectar. Next, she lays her eggs, which will develop into the first workers of the colonies to take over the work of foraging, taking care of larva, and nest maintenance and defense. The only role for the queen afterwards is reproduction. The colony grows during the summer. At the end of the season, the queen produces male offspring and new queens, who leaves the nest to mate. The males die after mating, so do the old queen and workers later in the year. The new queen finds somewhere suitable to hibernate until next spring (Hatfield, Jepsen, Lee-Mäder, Black, & Shepherd, 2012; Michener, 2000; Wilson & Carril, 2015).

Bumblebees are generalists and visits a wide range of flowers, thus playing an important role in the ecosystem. On the other hand, they also contribute considerably to agriculture. Greenhouse tomatoes rely completely on their buzz pollination, and this alone generates €120 billion worldwide (Velthuis, & Van Doorn, 2006). They are also pollinators of peppers, blueberries, cranberries, clover, apple, and a series of other crops (Koch, Strange, & Williams, 2012).

There are a couple of reasons behind their outstanding performance. Compared to honey bees, bumble bees work faster, and remain active for longer periods of time both in a day and the year since they tolerate lower temperatures. They can also buzz pollinate, a skill honey bees don't have. For some plants in Solanaceae family such as tomatoes, potatoes and eggplants, pollen can only be released by tipping the anthers upside down and shaking them. Bumble bees are some of the bees that can buzz their flight muscles to shake the pollens loose, allowing them to pollinate plants honey bees cannot (Wilson & Carril, 2015).

However, the population of many bumble bee species are experiencing severe decline. In America, Franklin's bumble bee (Bombus franklini) and the rusty-patched bumble bee (B. affinis)

are listed as "Critically Endangered" in IUCN Red List. For those in Denver area, southern plains bumble bee (B. fraternus) is listed as "Endangered"; yellow bumble bee (B. fervidus), Morrison bumble bee (B. morrisoni), western bumble bee (B. occidentalis) and American bumble bee (B. pensylvanicus) are listed as "Vulnerable" (IUCN, 2017).

The decline results from a combination of factors. Land-disturbing activities may destroy nesting sites and foraging grounds. Pesticide use has been known to cause massive die-off of bumble bees. In a parking lot in Oregon, at least 50,000 bumble bees perished after pesticide has been applied to trees in the area (Xerces Society, 2013). Another threat to wild population is pathogens introduced by bumble bees reared for commercial use. Other risk factors include uncontrolled grazing, competition from honey bees, climate change, and so on (Hatfield et al., 2012).

European honey bees, as their name suggests, are not native to North America. They were brought to North America by European settlers in 1600s (Wilson & Carril, 2015). Unlike bumble bees, honey bees have permanent colonies. They build their hives with wax in hollow trees or rock cavities. A hive is made up of two layers of sub-horizontal cells opening in opposite directions and sharing a vertical wax sheet as the base. A colony is made up of a queen, a large number of drones and even more female workers. The queen is the reproducer in the colony. After mating, she stores the sperm in her body and can choose whether to lay an unfertilized egg, which will develop into a male, or a fertilized egg to have a future worker or queen. The drones are fertile male bees, and their only role is to mate with a queen. The workers are sterile and perform all other duties, including foraging, attending to the larva, drones and queen, building new cells and defending the hive, and so on. Sometimes a colony undergo fission, where the old queen and a group of workers leave to find a new site (Michener, 2000).

Honey bees are generalists and may collect nectar and pollen from any available source. This, combined with their large and highly portable colonies, made them ideal pollinators for agriculture use. They take up 80% of the crop pollination work in U.S. It is estimated that in 2010, honey bees pollinated $12.4 billion worth of directly dependent crops and $6.8 billion indirectly dependent crops for American farms (Ramanujan, 2012).

A major threat for honey bees is Colony Collapse Disorder (CCD). The main sign is the sudden disappearance of workers with few dead bees left behind. The queen and brood will remain in the hive, but without the workers the colony will eventually die off. During the winter of 2006-2007, some bee keeper lost 30% to 90% of their colonies, with nearly 50% of the loss resulting from CCD. The cause is yet to be discovered. Some studies claim the cause is a combination of different factors, including parasites, virus, pesticides, stress caused by transportation and more (Ratnieks & Carreck, 2010). Good news is that the mysterious ailment seems to be easing off. In recent years, loss attributed to CCD has dropped from nearly 60% in 2008 to 31.3% in 2013. In 2014 and 2015, no case has been reported (US EPA, n.d.).

Halictidae

Halictid bees are also known as sweat bees, and are more abundant than most other species of bees outside of honey bees (UF IFA, n.d.) (figure 10). Halictid bees can be solitary, communal, semi-social, or eusocial (Michener 2007). Some exhibit different forms of sociality at different times of year and different locations. Social halictid bees are particularly interesting to biologists because they evolved to live in social colonies relatively recently in evolutionary history--this means that these bees might be used to study the development of social behavior (Newton, 2005). Most are dull or metallic black, while others are metallic green, blue, or purple.

In the spring or summer, females emerge, mate, and begin digging nests. They provision their nests with pollen and nectar, and lay a single egg in each cell (UF IFA, n.d.). When the larva emerges from the egg, it consumes the pollen and nectar stored in the cell. It can remain in this prepupal form for the rest of the year, possibly as a fallback for years of drought or other poor conditions (UF IFA, n.d.). Some pupate immediately and emerge as adults; others overwinter in the cell and emerge the following spring or summer. Most halictid bees nest underground, but some build nests in rotting wood. In order to nest in the ground, these bees require bare soil in a sunny location. Minimizing tillage of the soil and reducing use of insecticide use will help promote sweat bee populations (UF IFA, n.d.).

Most halictid species are generalists, meaning that they gather nectar and pollen from multiple plant species (Tepidino [USFS], n.d.). However, the University of Florida notes that some species feed from a single plant family (UF IFA, n.d.). Sweat bees are important pollinators for many native plant species and crops, including stone fruits, pomme fruits, alfalfa, and sunflowers (UF IFA, n.d.). Increasing the quantity of native flora will benefit halictid bee populations, as these bees are able to forage from many different native flower species (Tepidino [USFS], n.d.).

Megachilidae
The family Megachilidae is the second largest family of bees and contains more than 4,000 species on all continents except Antarctica (Gonzalez et al., 2012). In North America, Megachilid bees are primarily leafcutter bees and mason bees. These bees are solitary; each female constructs her own nest and provisions it with a supply of pollen and honey before laying a single egg in each cell (Hurd and Michener, 1955). Once an egg hatches (generally in the summer), the larva eats through the pollen until it reaches maturity. It then spins a silk cocoon, where it spends the rest of the summer, fall, and winter before emerging in the spring (Hurd and Michener, 1955).

The common names of Megachilid bees reflect their method of nest construction: leaf cutter bees use leaves and mason bees use soil (Fig.11). Other bees in the Megachilid family use pebbles, resin, and fibers to form their nests (GAPP, n.d.). Bees in this family generally construct nests in natural cavities, but in a few species the female creates a burrow in which to nest (Hurd and Michener, 1955). This means that in terms of suitable habitat, bees in this family require rotting wood or other naturally-forming cavities. Man-made nesting sites made of pre-drilled wood can also be provided, especially for commercial agricultural use (Cranshaw, n.d.). Leafcutting bees are sometimes considered a pest due to the characteristic damage they cause to leaves in the process of building their nests (GAPP, n.d.).

Many Megachilid bees are mesolectic, or restricted to certain types of flowers in gathering pollen, which means they have strong relationships with native flora (Scott et al., 2001; Hurd and Michener, 1955). Some species are used as commercial pollinators for crops, including alfalfa and blueberries (UF IFAS, n.d.). The orchard mason bee is particularly important as an agricultural pollinator. It is also unlikely to sting, and for this reason it is often a preferred pollinator for urban settings (GAPP, n.d.). A distinguishing feature of the Megachilid bees is that they carry pollen on the underside of their abdomens, rather than on their legs as other bees do. This can be helpful in identifying members of this family.

Butterflies

Hesperiidae (Skippers)
These small to medium butterflies are not true butterflies and are known as skippers because their pattern of flight is rapd and erratic, with the appearance of skipping (Idaho Museum of Natural History Digital Atlas, n.d.). Skippers usually have the following characteristics: a large, hair body, a large head (relative to the thorax); fully developed and functioning forelegs; small, pointed wings; a unique pattern of vennation on the forewing; and curved or hooked antennae tips (Idaho Museum of Natural History Digital Atlas, n.d.). There are 4,100 species of Skippers around the world and at least 250 in North America (Heppner, 2008). They are usually orange, brown, black, white, or gray, and may have iridescent colors. Adult skippers are diurnal have long proboscises, which they used to feed on floral nectar. Larvae are leafrollers or borers, and host plants are primarily grasses and other monocots (Heppner, 2008).

Papilionidae (Parnassians and Swallowtails)
Worldwide, there are 589 Papilionidae species, which include swallowtails, birdwings, parnassians, and kits (Heppner, 2008). 30 of these species are present in North America (Idaho Museum of Natural History Digital Atlas, n.d.). Members of this family generally display the following characteristics: medium to large size, unique pattern of wing vennation on the fore- and hindwing, and fully developed and functioning forelegs (Idaho Museum of Natural History Digital Atlas, n.d.). Adults are usually slow and gliding fliers, and feed on nectar. Larvae feed on leaves and their host plants come from many groups, including Crassulaceae, Lauraceae, Leguminosae, Rutaceae, and Saxifragaceae (Heppner, 2008). These butterflies have brilliant colors, which makes them charismatic and more likely be be recognized by people. Some are distasteful to birds, which discourages predation (Idaho Museum of Natural History Digital Atlas, n.d.).

Pieridae (Whites and Sulphurs)
There are 1,275 species total in the Pieridae family, including jezebels, orangetips, sulphurs, whites, and alfalfa and cabbage butterflies (Heppner, 2008). Adults are generally characterized by: medium size, forked claws (tips of the legs), full-sized and functional forelegs, wings that reflect and absorb ultraviolet light in specific patterns, and sexual dimorphism (Idaho Museum of Natural History Digital Atlas, n.d.). Colors can include white, yellow, and orange, with some black or red; however, as the common name implies, the most prominent colors are white and yellow (Idaho Museum of Natural History Digital Atlas, n.d.). Adults are diurnal and feed on nectar. Larvae feed on leaves; host plant families include Capparidaceae, Leguminose, Loranthaceae, Santalaceae, and most notably, Cruciferae (Heppner, 2008). Temperate species overwinter in the pupal or larval stage, and many species are seasonally variable, such that individuals emerging earlier in the season are distinct in appearance from those emerging later (Idaho Museum of Natural History Digital Atlas, n.d.).

Lycaenidae (Gossamer-wing Butterflies)
There are at 5,955 species of Lycaenids worldwide, including 100 in North America (Heppner, 2008; Idaho Museum of Natural History Digital Atlas, n.d.). These butterflies generally have the following characteristics: small size, reduced forelegs in males and full-sized forelegs in females, and a slightly different pattern of wing veins (Idaho Museum of Natural History Digital Atlas, n.d.). Their coloring is varied, but often includes blues, greens, and other bright colors, as well as iridescence (Heppner, 2008). Adults are diurnal and feed on nectar. These butterflies overwinter as eggs, caterpillars, or pupae (Idaho Museum of Natural History Digital Atlas, n.d.). The caterpillars of many species of Blues and Hairstreaks can produce a sugary solution that ants feed on; in turn, those ants protect the caterpillars from predators (Idaho Museum of Natural History Digital Atlas, n.d.). Most larvae are leaf feeders (host plants include Fagaceae and Leguminosae); some are myrmecophilous or carnivorous on ant larvae or hemipterans (Heppner, 2008).

Nymphalidae (Brush-footed Butterflies)
This family is called the Brush-footed butterflies because the forelegs of the adults are small

and hairy; they are not used for walking (Idaho Museum of Natural History Digital Atlas, n.d.). The Nymphalid family includes approximately 6,000 to 7,000 species, and at least 150 are found in North America (Heppner, 2008). The butterflies in the Nymphalidae family are varied in appearance, but are generally characterized by the following attributes: medium to large size, bright or unique markings, unique patterning of veins in the forewing, and antennae tipped with clubs (Idaho Museum of Natural History Digital Atlas, n.d.). Some members of this family migrate long distances or display territoriality (Idaho Museum of Natural History Digital Atlas, n.d.). Adults from different species feed on nectar, sap, rotting fruit, dung, and animal carcasses. Caterpillars are often hairy or spiny, although the Nymphalid immature stages are morphologically diverse (Heppner, 2008). Nymphalid butterflies typically overwinter as caterpillars, but some species can overwinter as adults as well (Idaho Museum of Natural History Digital Atlas, n.d.). Monarchs and Painted Ladies are both members of this family. Because the family is diverse and many species are easy to identify, they are considered charismatic and often used as a flagship taxa for conservation (Heppner, 2008).

Painted Lady Butterflies

Because these butterflies are considered particularly charismatic and Denver experienced a mass migration in 2017, we are including more information on the painted lady species. This butterfly is likely recognizable to more people in Denver, likely leading to a higher degree of investment in its conservation.

Painted lady butterflies (Vanessa cardui) are medium-sized butterflies with different patterns and colors on the sides of their wings (Fig.12). The tops are orange and black/brown in a bold pattern, while the undersides are brown and tan with a slim section of orange (Brenner, 2011). They are frequently found in urban and disturbed habitats. Their preferred nectar plants are composite flowers between three and six feet tall (Brenner, 2011).

Painted ladies have migratory populations on every continent except Australia and Antarctica (Helzer, 2017). They use larval host plants from many different host families; according to the US Fish and Wildlife Service, there are more than 100 North American plants that can host painted lady caterpillars (US Fish and Wildlife Service, 2017). Females can lay up to 500 eggs. Once they hatch, the larvae make a silken tent on the leaf, eventually leaving to find a suitable pupation site (Stefanescu et al., 2013).

North American populations of painted lady butterflies are centered on the southwestern United States and northern Mexico (Helzer, 2017). Generally painted ladies migrated north in the spring

Moths

and south in the in the fall, but migrations can be erratic and irregular (US Fish and Wildlife Service, 2017). Migrations to the north and west occur frequently and are stronger in years with more rainfall in the southwest (Helzer, 2017). These migrations occur because the rainfall leads to increased plant growth (forage for the butterflies) in the southwest. As the butterfly population grows, it outstrips the food availability, and this creates the impetus for migration (Helzer, 2017).

Saturniidae (Wild Silk Moths)

Moths of the family Saturniidae are also called Emperor moths due to their large size, with wingspans of up to 30 cm (Heppner, 2008).. The family includes 1,435 species worldwide (Heppner, 2008). Their colors vary, but most are shades of brown with eyespots and terminal border bands, or white with spots (Heppner, 2008). Adults are mostly crepuscular or nocturnal, but some are diurnal. Caterpillars feed on leaves from a variety of host families, including many broadleaf forest tree families (Heppner, 2008).

Sphingidae (Sphinx Moths, Hawkmoths)

There are 1,235 species of Sphingid moths worldwide (Heppner, 2008). Mosts adults are medium to large and colored with shades of brown and gray, and usually have few markings (Heppner, 2008). Most are nocturnal or crepuscular, but some are diurnal (Heppner, 2008). Larvae feed on leaves from many different hosts families, and can be destructive to some agricultural crops and ornamental plants (Heppner, 2008).

Notodontidae (Prominents)

The Notodontidae family has 3,562 species worldwide (Heppner, 2008). Adults can be very small to very large and are usually drab brown and gray; however, some are white or more colorful. Adults are mostly nocturnal and feed on nectar (Heppner, 2008). Larvae feed on leaves from a variety of host plant families, especially broadleaf forest tree species (Heppner, 2008).

Noctuidae (Owlet Moths, Miller Moths)

The Noctuidae family is the second largest in Lepidoptera, with 11,772 species (Heppner, 2008). Species in this large family have a great deal of variation in their appearance and behavior. Most are gray-brown in color and have lines or spots on their wings, but some are brightly colored (Heppner, 2008). Most are nocturnal, but some are active during the daytime.Their larvae feed on plant foliage, dead leaves, lichens, and fungi. Some are considered serious forest pests.

Elachistidae (Grass Miner Moths)

Although there is some controversy over which species should be included in this family, it is generally accepted that its members are tiny-small in size as adults. They have narrow, lance-like wings and are usually white, gray, or black with white markings (Heppner, 2008). Their larvae feed on leaves of grasses and sedges.

Figure 10. Halictid bee (Newton, 2003). Most halictid species are generalists that gather nectar and pollen from multiple plant species. They are important for many native plant species and crops.

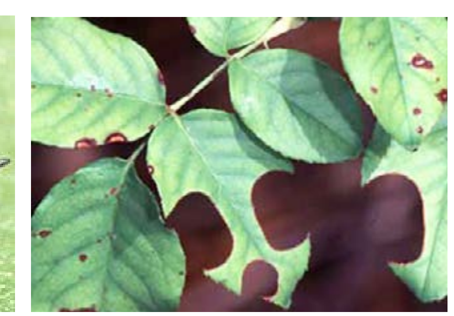


Figure 11. Characteristic leaf damage caused by leafcutting Megachilid bees (UF IFAS)

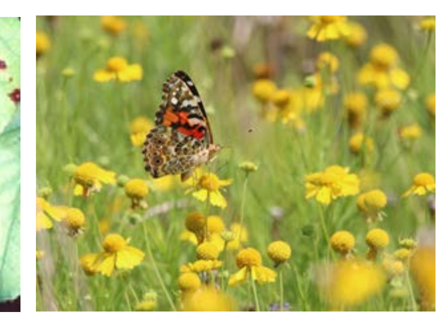


Figure 12. Painted lady butterflies, frequently found in urban and disturbed habitats. Their preferred nectar plants are composite flowers between three and six feet tall (photo by Debbie Koenigs/USFWS).

Climate Change Resilience

For the shortgrass prairie ecosystem located in North America Great Plain, climate change is likely to cause increase in average temperature and heat waves, heavy precipitation, and both the frequency and severity of drought (Finch, Smith, LeDee, Cartron & Rumble, 2012). Some impacts relevant to pollinator populations may include, but not limited to, the following (Finch et.al, 2012):

- Changes in vegetation composition caused by increased temperature and drought. This include the northward range shift of multiple species, as well as increase in drought-tolerant species. However, the increased drought severity and frequency may cause an overall decrease in vegetation.
- Heat stress may lead to behavioral changes in pollinator species. In case of bees, bigger bees stop flying when it becomes too hot, while smaller bees take more frequent, short flies (Chappell, 1982; Corbet & Huang, 2016).
- Increased water scarcity has negative impact on species reliant on wetland or have high demand on water resources, such as the ground-nesting bees using water to soften the hard soil at nesting site.
- The increase in temperature may lead to disrupt the temporal synchronization between plant and pollinators. The pollinators may either arrive too early or too late for the blooming time of their host.
- The environmental cue prompting earlier bloom (plant) or emergence (pollinator) may expose both to hostile conditions such as cold snaps.

The resilience of an ecosystem refers to its ability to respond to changing conditions and maintain its function. Contributing factors cover multiple ones on species, community, and landscape level. (Oliver et al., 2015) In our study, factors of major concern and may guide the design of scenarios are habitat area and landscape connectivity.

Large habitat areas provide more resources in terms of both amount and kinds, therefore are capable of supporting bigger populations as well as more species. This will in turn increase the chance that there will be species functioning well under changing conditions and those have the potential to adapt to the changes, which, in other words, maintain the present and future function of the ecosystem, and increase the resilience of the ecosystem. In the case of pollinators, habitat areas may refer to both foraging habitat with floral resources and nesting habitat containing cavity, bare ground or other nesting sites.

The connectivity of landscape serves as a mean for individuals to move between habitat patches. This allows a species to find refuge elsewhere and recolonize the landscape quickly under changing conditions, so the species can persist and maintain their function even when local populations go extinct. More specifically, pollinators need to have all the needed resources within flight distance, preferably as close as possible, since flight may be cost a lot of energy that can otherwise be spent elsewhere. Species utilizing more than one type of habitats, such as ground-nesting bees foraging among flowers while nesting in bare ground, will be especially sensitive to this factor as they must be able to move freely in the landscape to survive.

Research Methods

Using a Normative Scenario Approach

Scenarios are developed from assumptions about possible and plausible futures (Mahmoud, 2009). In landscape planning, the landcover pattern and functional consequences is referred as a "future" (Steinitz et al., 2003). Through the descriptions of how present situation and alternative futures can be connected and the comparison between different futures, decision-makers can anticipate the implications of potential decisions on particular landscapes (Swetnam et al, 1998; Countryman & Murrow, 2000; Nassauer & Corry, 2004; Shearer, 2005).

Scenarios can be categorized into two types, projective scenarios and prospective scenarios. While projective scenarios describe what the future is likely to be, prospective scenarios describe how the future could be (Schoonenboom, 1995; Beck, 2002; Nassauer & Corry, 2004). Among all prospective scenarios describing unpredictable futures, the specific type of normative scenario aims to generate desirable futures that are plausible (Nassauer & Corry, 2004). Since for normative scenarios, it is desirable future states that subsequently employ process models for assessment rather than the opposite, developers must hypothesize what landscape patterns can lead to desired outcomes and test against these hypothesis (Nassauer & Corry, 2004).

Nassauer and Corry (2004) describe a method to develop normative scenarios. The development method can be characterized by four parts, which each includes questions that must be answered:

1. Existing Data includes past and present landscape data-- "What is relevant about the present landscape and its past?"
2. Formulate Hypotheses-- "How should landscape change?"
    - Make assumptions from future landscape policy goals-- "What are plausible goals for future landscape policy?" However, these goals should be imaginative, speculative that show how landscape changed under qualitative changes including social values, economic support, etc., since the the purpose of normative scenario is also to help public and policy-makers to inspire the future.
    - Generalize hypothesis of desirable landscape pattern-- "What characteristics of the landscape could help to achieve those goals?" The explicit of landscape characteristics (location, configuration, composition, and management) will be needed to hypothesize the desirable future with regards to ecology, society, and culture.
    - Make land allocation models-- "What characteristics of existing landcover and other coverages indicate the location of future landcover?" The ideas from experts will be translated to landscape pattern changes.
3. New Data represents alternative futures-- "what is relevant about how the landscape could be?" The development process will be iterative, involving portraying and comparing new landscape patterns.
4. Test Hypotheses, which evaluates the new landscape patterns-- "How does their performance compare?" The evaluation could happen in various criteria, for example, generality, accuracy, precision, data availability, scale of application, etc.

Normative scenarios are more useful than descriptive scenarios or other types of prospective scenarios in situations where neither trends based on past changes nor understandings and anticipations about surprising futures is the focus (Science Advisory Board ,1995; Beck et al., 2002; Varis, 2002; Peterson et al., 2003; Nassauer & Corry, 2004). Since we are trying to take advantage of the vast open space in Denver International Airport to reimagine future landcover patterns to support pollinators, which we see as an overlooked opportunity rather than a trend built on the past, developing normative scenarios is a particularly suitable approach for the purpose of this study.

Normative Scenario Framework of the Study

Based on the method framework proposed by Nassauer and Corry (2004), we established a normative scenario framework specific to our study (Fig.13).

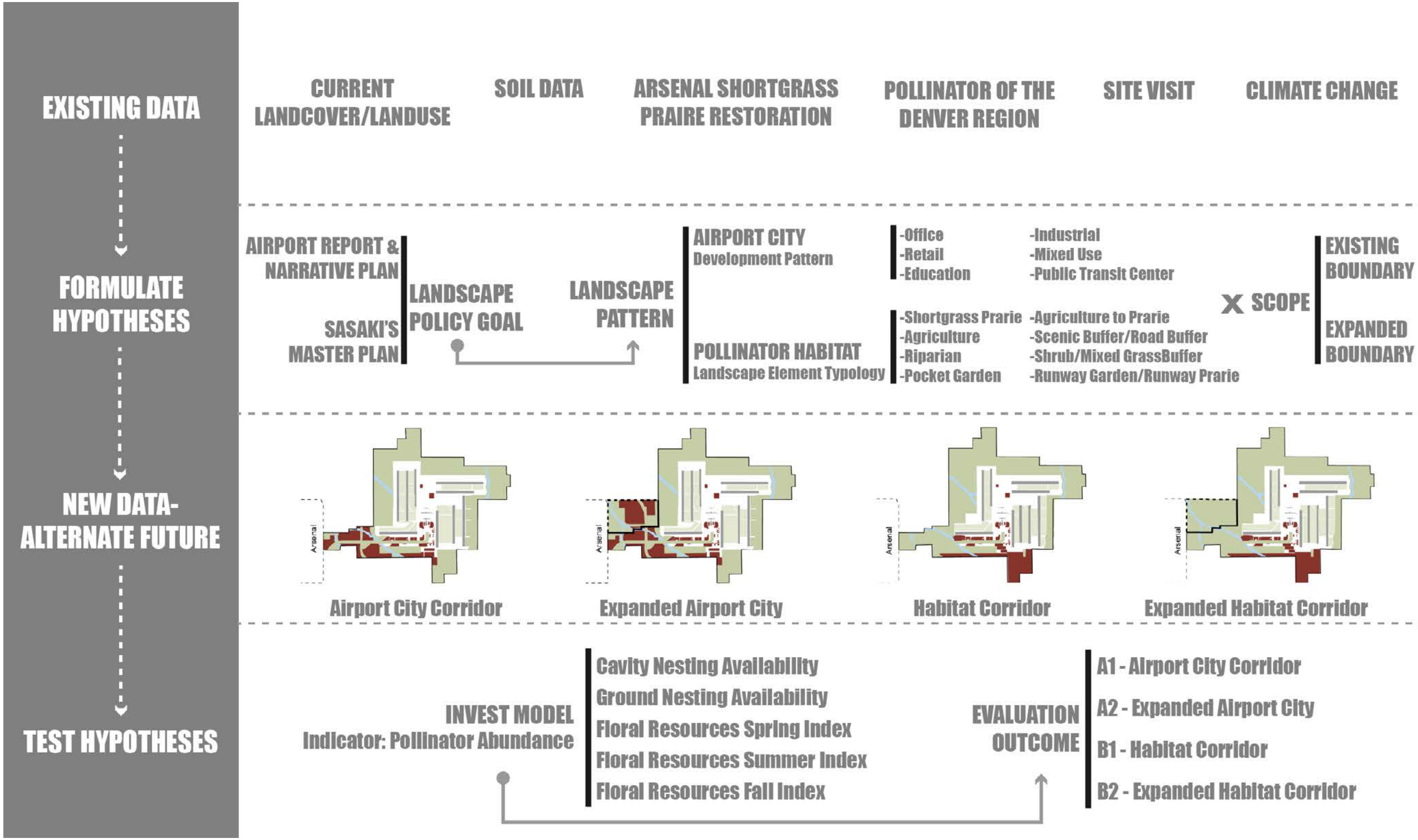


Figure 13. The normative scenario framework specific to our study, based on the one developed by Nassauer and Corry (2004).

As for the past and present landscape of DEN, we looked into the general spatial data and ecological factors. The spatial data included context, the functional components of the airport, connectivity, landuse and landcover and transportation. Particularly, the current landcover was the basis for the land allocation models that delineate plausible landscape futures under each scenario. As for the ecological factors, we looked into soil, pollinators in the Denver area and the prairie restoration projects going on in Arsenal National Wildlife Reserve.

As for formulating hypotheses, the Smart Jobs Development (City and County of Denver, n.d.), Denver Airport Layout Plan Narrative Report developed by the Department of Aviation (City and County of Denver, 2011), and the Strategic Development Plan developed by SASAKI were used as the major reference to make overall assumptions to develop airport city to address transportation and economic demands, and to establish pollinator habitats as a major focus in sustainability. Moreover, we made another assumption about expanding the airport's current boundary to include the land between the airport and Arsenal. Given that the area still sees population growth and development expansion in the future, it is plausible that lands may be purchased by DEN to become part of the airport's property to secure more space for future flexibility and to achieve more collaborative management with adjacent properties for better pollinator habitats.

To formulate hypotheses of desirable landscape patterns, we referred to SASAKI's strategic plan to include mixed-use, office, retail, industrial use, educational use and public transit centers as development types and to identify new roads. The detailed block size for each land use were set by the team for the purpose of modeling based on current land use and transportation conditions of the airport, and precedents in Denver and other airports. In the aim of accomodating pollinators, we proposed nine landscape element typologies for potential pollinator habitats focusing on location, distribution and species composition. The locations of different typologies responded to features including urban area, major roads, runways, stream corridors, Arsenal National Wildlife Refuge, remaining vegetated area, and agricultural practice; and correspondingly, the plant species compositions target to maximize the capability to support pollinators in each type of habitat, with design considerations also given to public perception, climate change resilience and stormwater management.

Then we developed four scenarios Airport City (AC), Expanded Airport City (EAC), Habitat Corridor (HC) and Expanded Habitat Corridor (EHC), informed by current landcover and the above hypotheses of desirable landscape patterns (fig. 2). The four scenarios are compared and summarized briefly here (table 3), the detailed descriptions are in the following section of Alternative Landscape Futures.

Finally, the four scenarios are assessed and compared through the InVEST pollination model (Lonsdorf et al., 2009; Natural Capital Project, 2017). The outcome will be represented by the modelled abundance of pollinators. The four scenarios themselves are also an important outcome of the study that can provide specific landcover patterns for decision makers to consider.

	Airport City (AC)	*Expanded Airport City (EAC)*	*Habitat Corridor (HC)*	*Expanded Habitat (EHC)*
Priority	Airport City	Airport City	Pollinator habitat	Pollinator habitat
Study Boundary	Current boundary	Expanded boundary	Current boundary	Expanded boundary
Development Landuse	Mixed-use, office, retail, industrial and educational	Mixed-use, office, retail, industrial and educational	Mixed-use, office, retail, industrial use and public transit centers	Mixed-use, office, retail, industrial use and public transit centers
Habitat Typology	Pocket gardens, Scenic Buffer, Runway Gardens, Riparian, Shortgrass Prarie, Shrub/Mixed Grass, Agriculture Converted to Prairie	Pocket gardens, Scenic Buffer, Runway Gardens, Riparian, Shortgrass Prarie, Shrub/Mixed Grass, Agriculture Converted to Prairie	Pocket gardens, Road Buffer, Runway Prairie, Riparian, Shortgrass Prarie, Shrub/Mixed Grass, Agriculture	Pocket gardens, Road Buffer, Runway Prairie, Riparian, Shortgrass Prarie, Shrub/Mixed Grass, Agriculture
Testable Hypothese	Pollinator abundance	Pollinator abundance	Pollinator abundance	Pollinator abundance
Other Likely Outcomes	- development focusing on connection to downtown - Aesthetics of "welcoming airport city"	- high flexibility and potential for future expansion - connection to both downtown and adjacent urban area - Aesthetics of "welcoming airport city"	- More consolidated development - Agricultural lands as new non-airline revenue source - Aesthetics of "being away in nature"	Same as B1

Table 3: The summary and comparison of four scenarios.

Past and Present Landscape

Functional Components

Spatially, DEN's property can be categorized into airport operational components, transportation components, and the surrounding open space that creates buffers and ensures future expansion flexibility. The current essential structure of DEN consists of 4 main elements: airfield, terminal complex, landside facilities, and support facilities (Fig. 14). There are six runways on the airfield, four north-south oriented and two east-west oriented; and the Jeppesen Terminal, Terminals A, B, and C, together form the terminal complex Denver Airport Layout Plan Narrative Report, 2011). Landside facilities are mainly located along Pena Boulevard. Public parking is currently provided in seven garages and four surface parking lots, adding up to approximate 41,000 parking spaces in total. The rental car facilities are also along Pena Blvd, covering 96 acres. The majority of support facilities, including cargo facilities, fuel farm, etc. are located at north of the terminal and south and east of Pena Boulevard.

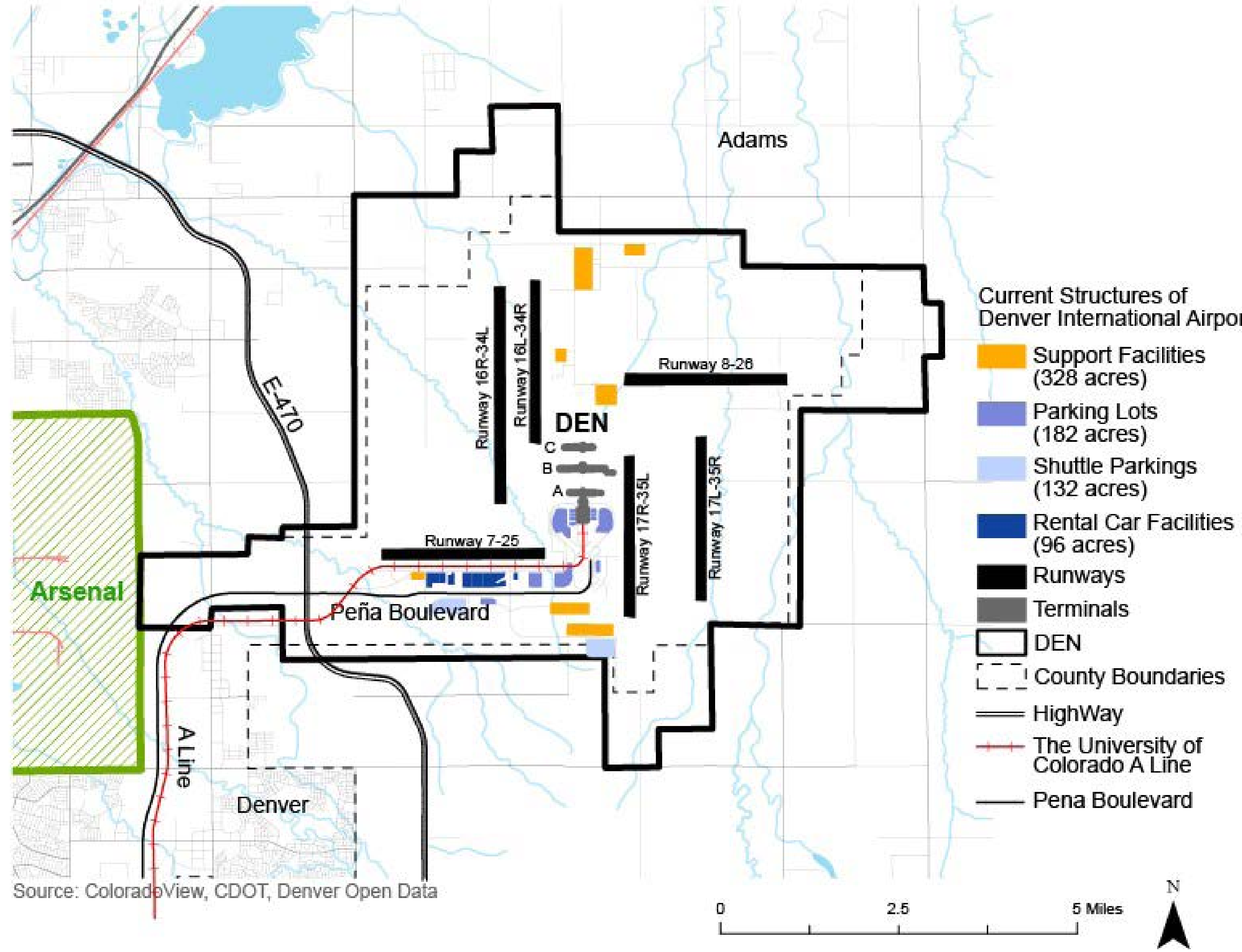


Figure 14: Four essential functional components of DEN: a) the airfield with six runways; b) four terminal complexes; c) landside facilities including parking and rental car facilities; and d) support facilities including cargo facilities, fuel farm, etc. (Data source: Colorado View, CDOT and Denver Open Data).

Connectivity

While the I-70, the E-470 toll road, and several arterial roadways provide secondary access to the airport, the main transportation corridor to DEN is Peña Boulevard (Fig.15). As projected, an increase in both passengers and total operations will result in more demand for development along Peña Blvd such as hotels, retails, global distribution, public transportation system and consolidated rental car and parking space (City and County of Denver, 2011). However, it is not only a desirable location for future development, but also the potential to build up habitat connectivity based on its adjacency to the Arsenal National Wildlife Reserve (Fig.15). Located just to the west of Peña Blvd and DEN, the Rocky Mountain Arsenal National Wildlife Refuge covers 15,000-acres with an expanse of prairie, wetlands and woodlands. It is one of the finest conservation success stories in history, through its transition from farmland to war-time manufacturing site, and ultimately to wildlife sanctuary (U.S. Fish & Wildlife Service, 2017).

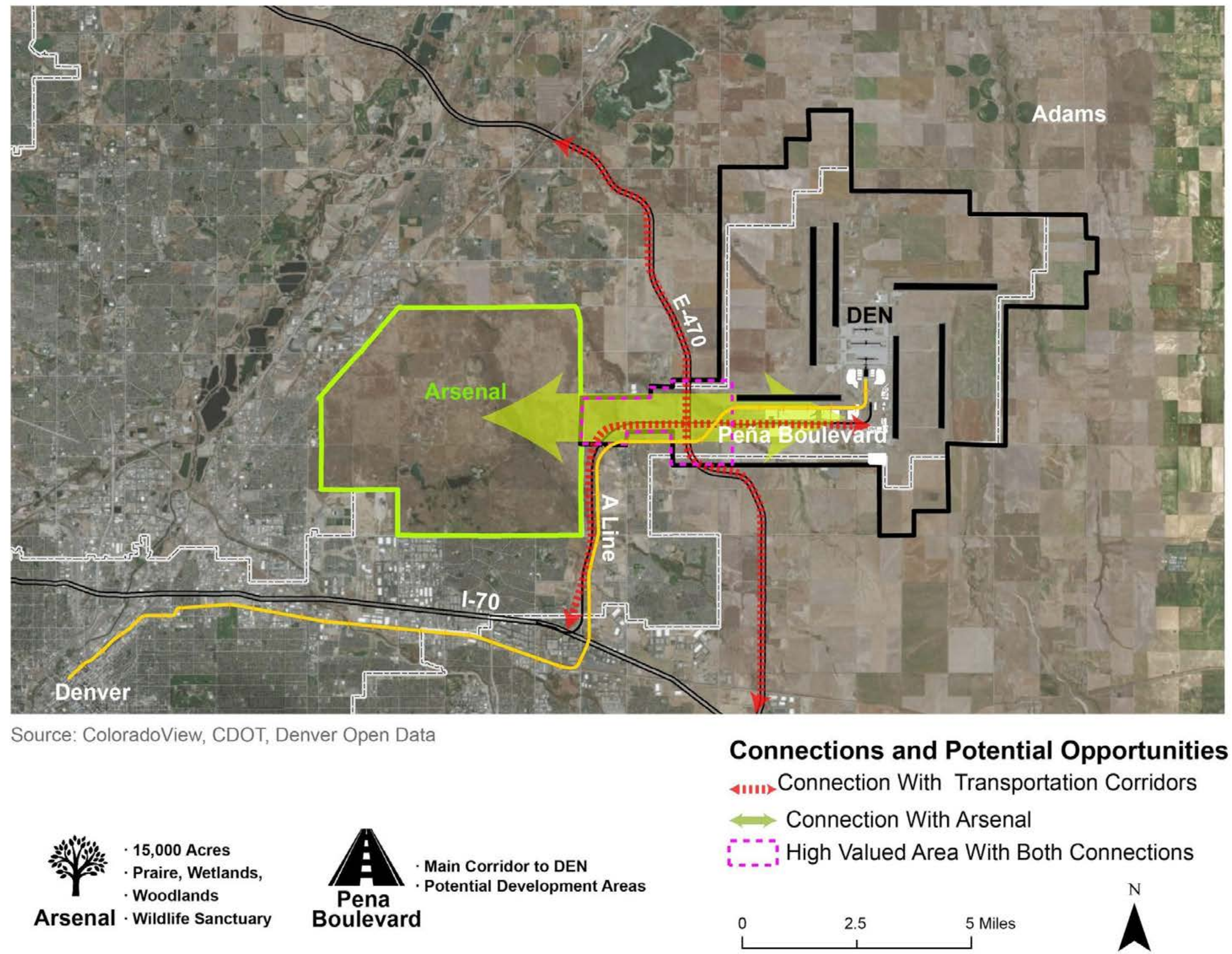
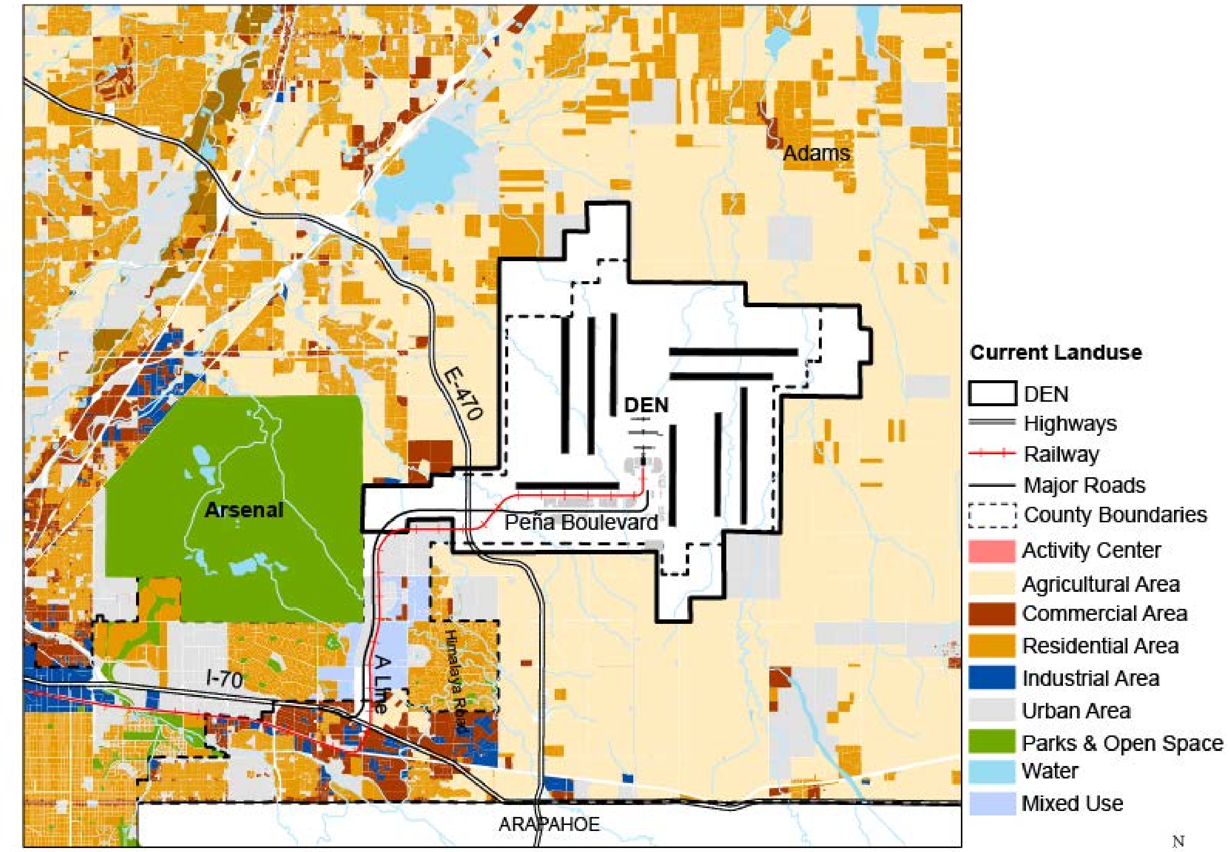


Figure 15: While I-70 and E-470 provides main access to DEN regionally, Peña Blvd is the direct major transportation corridor to DEN. At the same time, it also represents the great opportunity to spatially connect DEN and Arsenal National Wildlife Reserve for a cooperative management of the vast open space (Data source: Colorado View, CDOT, Denver Open Data and Adam County Open Data).

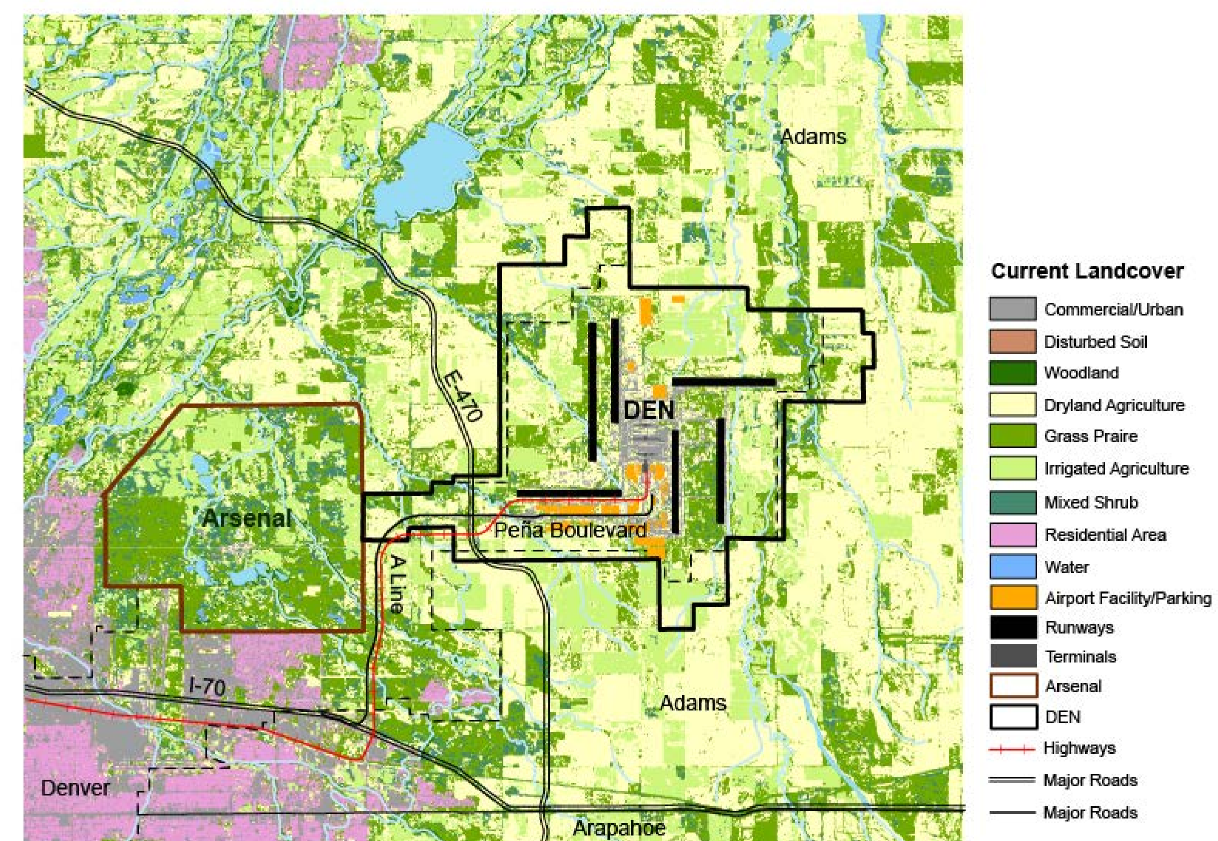
Land use and Landcover

DEN is zoned as a special district as Denver International Airport zone district (DIA). Within this zone, all applicable building form standards, design and development standards including landscaping and parking, are determined by the Denver Department of Aviation (Denver Zoning Code, 2017). The special zoning regulations applicable to the airport provide great freedom and flexibility for the future that is unlikely to happen in other zoning districts.

Currently, DEN is mainly surrounded by agricultural lands. But residential development is growing towards the airport especially to its northwest (Fig.16). Based on the data from Colorado Vegetation Classification Project, the landcover types present in and within a proximity of DEN include commercial, dryland agriculture, irrigated agriculture, grass dominated, grass/forb mix, shrub/grass/forb mix, sagebrush/grass mix, herbaceous riparian and cottonwood (figure 17). Though the airport property is as big as 53 square miles, the built surfaces only take up about 10%, leaving great opportunity to reimagine the landcover types and distributions for the future.



Source: ColoradoView, CDOT, Denver Open Data, Colorado Vegetation



Source: ColoradoView, CDOT, Denver Open Data, Colorado Vegetation

Figure 16 (top). DEN is mainly surrounded by agricultural lands. About 90% of DEN's property is currently undeveloped, offering great potential for pollinator habitat establishment. The urban growth and expansion tendency indicates that future development may take place on the west side of the property rather than the east side (Data source: Colorado View, CDOT, Denver Open Data and Adam County Open Data).

Figure 17 (bottom). About 90% of DEN's property has not been developed yet, covered by dryland agriculture, irrigated agriculture, grass dominated, grass/forb mix, shrub/grass/forb mix, sagebrush/grass mix, herbaceous riparian and cottonwood (Data source: Colorado View, CDOT, Denver Open Data and Colorado Vegetation Classification Project).

Ecological Considerations

According to land managers at the Rocky Mountain Arsenal National Wildlife Refuge, the refuge lands adjacent to the airport property are old agricultural fields and the airport property has a similar history (Wall, T., personal communication). Therefore, any lands on the property classified as grass-dominated or grass-forb mix likely require restoration in order to achieve a plant species diversity similar to a remnant shortgrass prairie site. In restoring shortgrass prairie throughout the refuge, managers have used the Applewood Seed Company High Plains Pollinator Seed Mix in order to increase the diversity of native plant species with a focus on plants that provide nectar and pollen (Wall, T., personal communication). Other successful pollinator habitat enhancements pioneered by the refuge include planting pollinator gardens in schools and residential areas (Wall, T., personal communication).

Hypotheses of Desirable Landscape Patterns

Airport City

Based on the visions to make DEN the transportation hub and economic engine of the Denver Metro Area mentioned in Smart Jobs Development (City and County of Denver, n.d.) and Denver Airport Layout Plan Narrative Report (City and County of Denver, 2011), we make the assumption to develop airport city for DEN and hypothesize development patterns that will achieve these goals. The key idea of the Airport City is to view airports as broadly based land uses rather than pure transportation nodes, taking advantage of the usage mix to generate additional non-aeronautical revenues for a long-term financial sustainability (Baker & Freestone, 2010; Kasarda, 2010). The general pattern will be include the passenger terminal as the functional core. This will be surrounded by offices, hotels, retail stores, industry, an education campus, and mixed-use development to create a city-center-like environment around the airport. Aviation-related functions are located outward along connecting transportation corridors (Kasarda, 2010).

The detailed assumptions about future landuses are based on the SASAKI's proposal for the strategic development plan, including mixed-use, office, retail, industrial, educational and transit centers. The sizing of individual use is based on block sizes of the same uses in the Denver area and other airports, as measured in Google Maps.

As for the functional core, no new terminal will be built by 2030, but Terminal A, B and C will be expanded. Three new runways will be constructed by 2030 and six in total will be built ultimately. Six locations are designated in Denver Airport Layout Plan Narrative Report (City and County of Denver, 2011), and the three shown in dark green solid line represents the construction by 2030 (Fig.18). However, for the purpose of this study, we view all six designated locations as potential

construction locations by 2030. In the A set of scenarios prioritizing Airport City development, new runways will be 16R-34L, 8L-26R and 18-36, leaving more room for airline operations in the northeastern area; while in the B set of scenarios prioritizing pollinator habitat, new runways will be 17C-35C, 18L-26R and 18-36, consolidating operational functions to the northeast and leaving more space for habitats in the west.
As for other aviation-related functions, based on the increase of passengers and cargo operations, we hypothesized the basic facilities need in 2030 as follows (table 3).

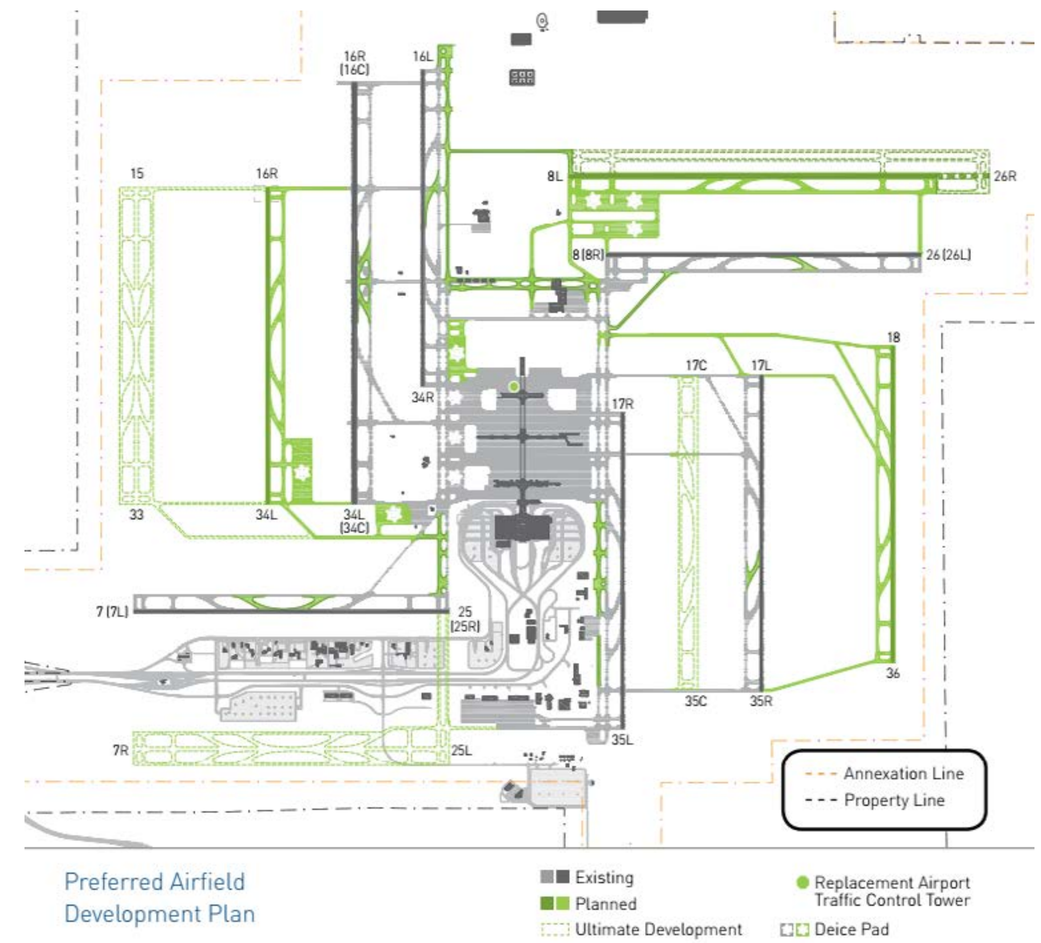


Figure 18. Three new runways will be built by 2030 and six in total will be built ultimately. All six designated locations are viewed as potential construction locations by 2030 for the study purpose. In scenario A1.Airport City Corridor and A2. Expanded Airport City, new runways will be 16R-34L, 8L-26R and 18-36. In scenario B1. Habitat Corridor and B2. Expanded Habitat, new runways will be 17C-35C, 18L-26R and 18-36 (City and County of Denver Department of Aviation, 2012)

	Parking spots	Rental car facilities	Terminal complexes	Road expansion
2030 forecast	47,921 to 93,531	96 acres to 150 acres	- more concentrat-ed, - a new 500-room business hotel	- Picadilly: expanded to six lanes - 74th Ave: expanded to six lanes - Harvest Rd: supporting off-airport development

Table 4: Forecast for other aviation-related functions in 2030 (City and County of Denver, 2011).

Pollinator Habitat

Because habitat fragmentation is such a significant cause of declines in pollinator populations, large and well-connected patches will provide higher quality habitat than smaller, more distant patches. Since we are most concerned about native pollinator species, the highest quality patches will be planted with native species of flowering plants. Native plant species are also drought tolerant and thus more resistant to the impacts of climate change. This means that restored shortgrass prairie and shrub/mixed-grass prairie will provide the optimal habitat for pollinators in less developed areas, as these habitat types provide both floral resources and abundant ground nesting sites.

In more developed areas, pocket gardens can provide small patches of nectar resources for pollinators. These sites often have diverse and abundant floral resources within a small space. Although native plant species are preferred, non-natives species can also provide resources to pollinators as well. Because these gardens are also intended for an aesthetic purpose, a mix of native and non-native plant species can be used to maximize both public perception and pollinator resources. Furthermore, man-made cavity nesting sites in pollinator gardens can enhance the habitat so that it provides nesting sites as well as nectar and pollen resources.

All pollinator habitat on the site should provide a variety of floral resources throughout the active season for all insect pollinators. This means that prairies and pocket gardens must be designed such that species bloom continuously through spring, summer, and fall. The existence of a period in which no species are blooming indicates an interruption in food resources for pollinators.

Assumptions Across All Scenarios

Category	All Scenarios	Airport City Scenarios	Habitat Corridor Scenarios
Pollinator Habitat	• The shortgrass prairie area west of the airport requires restoration in order to provide high quality pollinator habitat • Insect pollinators are the primary focus of habitat enhancement • All development types except Industrial will contain pollinator habitat patches	• The agricultural fields in the northern portion of the property can be restored to shortgrass prairie • Native and non-native species can be used on runway gardens, scenic buffers, etc. to maximize public perception of the airport city	• Agricultural fields can be maintained as long as a buffer is provided to protect new habitat from pesticide drift • Native species should be used on runways and roadside buffers to maximize suitability of habitat
Airport Needs	• Current runways will remain in place and operational • Rental car property must expand from 96 acres to 150 acres • Airport parking will increase from 47,921 spots to 93,431 spots	• By 2030, 3 new runways will be located at 16R-34L, 8L-26R, and 18-26 (Fig. 6)	• By 2030, 3 new runways will be located at 17C-35C, 8L-26R, and 18-26 (Fig. 6)
Development	• There is a market for mixed-use, retail, office, and industrial development on the airport site • New roads on the site will be Harvest Road and Picadilly Road • All current transit stations and stops will remain in place and operational	• There is a market for residential development on the airport property • An education campus (Arsenal Research Center) will provide research and educational opportunities for scholars and students	• An additional new transit center can be built in accordance with the location of new development

Table 5. Assumptions made across all four scenarios and different assumptions made specifically for the Airport City set and the Habitat Corridor set.

Alternative Landscape Futures

In both groups of scenarios we introduce development patterns including mixed-use, retail, industrial, office, educational, and transit centers, while at the same time, introduce different types of habitats to support pollinators. In the Airport City scenarios, Peña Blvd serves as an ideal location around which to build the airport city, and along this corridor mixed-use, retail, industrial, office, and educational will be introduced. In the Habitat Corridor scenarios, the development will be concentrated in the south part of the DEN property, while the area around Peña Blvd will be the main habitat corridor to support pollinators. This corridor of habitat will help connect the airport property to the Rocky Mountain Arsenal National Wildlife Refuge.

Airport City Scenarios

The Airport City scenarios, Airport City (AC) and Expanded Airport City (EAC) use development precedents to envision the creation of an airport city on the DEN site. The airport city includes an education district, with a campus that has access to the Rocky Mountain Arsenal National Wildlife Refuge, an industrial/manufacturing district, a mixed use district, and a retail district. While Airport City (AC) uses the current boundaries of the DEN site, Expanded Airport City (EAC) envisions an expanded boundary to connect the airport open space directly to the Arsenal National Wildlife Refuge, targeting to demonstrate a future that is plausible if more lands are purchased to be included in the airport's property and to study the corresponding outcomes to understand the potential opportunities.

Scenario Performance Hypotheses

In scenario Airport City (AC) (fig.19 & fig.20), the airport city will be established along Peña Boulevard. Work opportunities will increase with the introduction of land uses such as office, retail and industrial, and the desire to live closer to workplace will increase. This drives the need for mixed-use development that provides living space and basic infrastructure for future residents. This scenario promotes circulation that supports connections to airport and to the downtown, and facilitate the road networks proposed in the Sasaki DEN plan. All the new development will contribute to non-airline revenue. Shortgrass prairie will be the primary pollinator habitat, and will be primarily located on the rural edge to provide nesting and feeding sites for the pollinators. Connectivity of habitats throughout the urban matrix will be achieved by pocket gardens in the development area, which act as feeding sites. In terms of travel experience, the brightly colored planting mass between runways will create a sense of welcome to the new DEN airport city. The scenic buffer along Peña Boulevard will carry the characteristics of the planting from airport into the development area.

In scenario Expanded Airport City (EAC) (fig.21 & fig.22), the boundary will be expanded to catalyze growth of the new airport city. The development will be expanded into the new property, while the area within current property stays the same as scenario Airport City (AC). Additional industrial district will be introduced and built on an existing landfill area in the expanded property. As the population increases and the property expands, the demand of more housing and public space will be meet by introducing more mixed use, new residential district and parks into the new property. This scenario promotes circulation that supports connections to the surrounding future planning and from airport to the downtown, building upon the road networks proposed in the Sasaki DEN plan. Non-airline revenue will be increased in this scenario as well. The habitat connectivity will be enhanced through the establishment of continuous shortgrass prairie habitat between key Arsenal patch and new habitat patch on the west edge, which functions as nesting and feeding site for the pollinators. Eventually support more pollinator abundance than Airport City (AC). The connectivity throughout urban matrix will be achieved by the pocket gardens in the development area and through residential backyard, which act as feeding site. Travel experience will be the same to Airport City (AC).

Figure 19. The detailed landcover pattern of scenario Airport City (AC), addressing the location and distribution of both development area and potential habitat area.

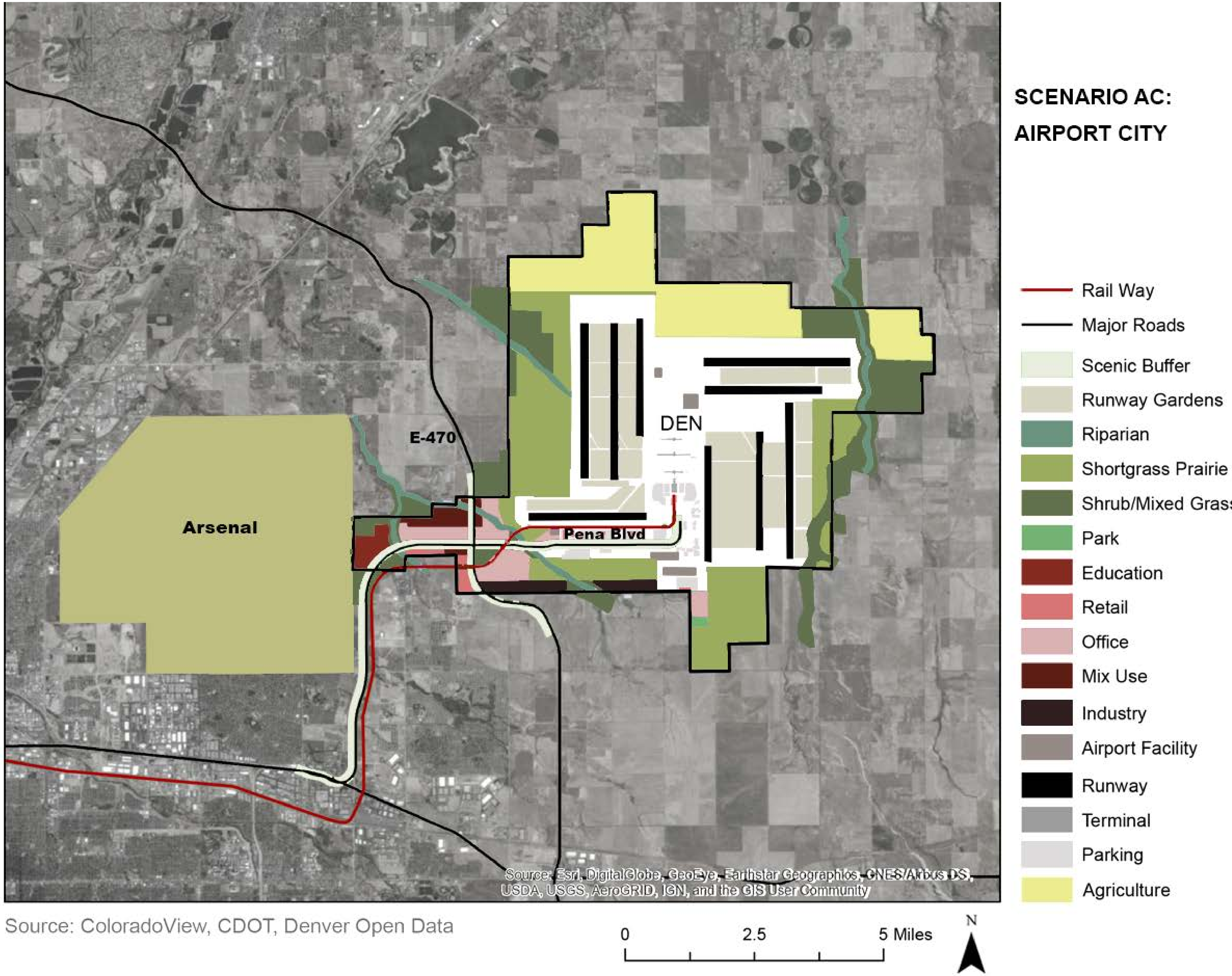
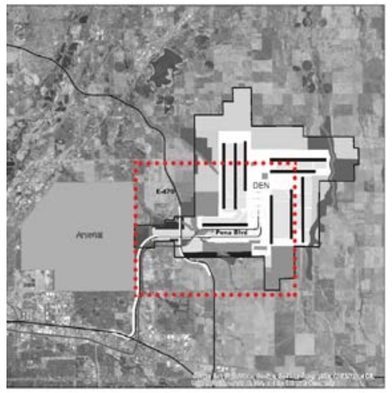


Figure 20. Detailed landcover pattern along Peña Boulevard in Airport City (AC).



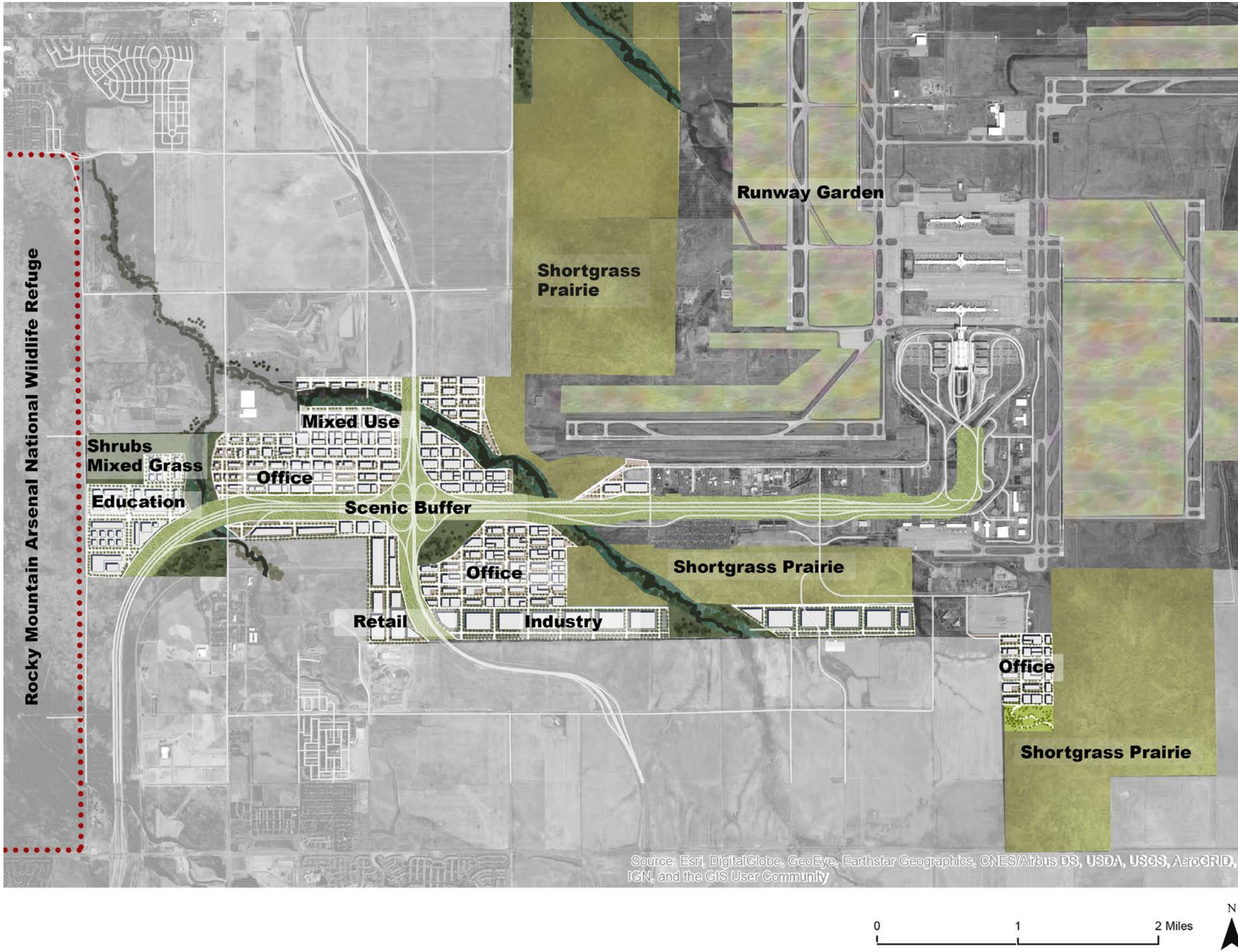
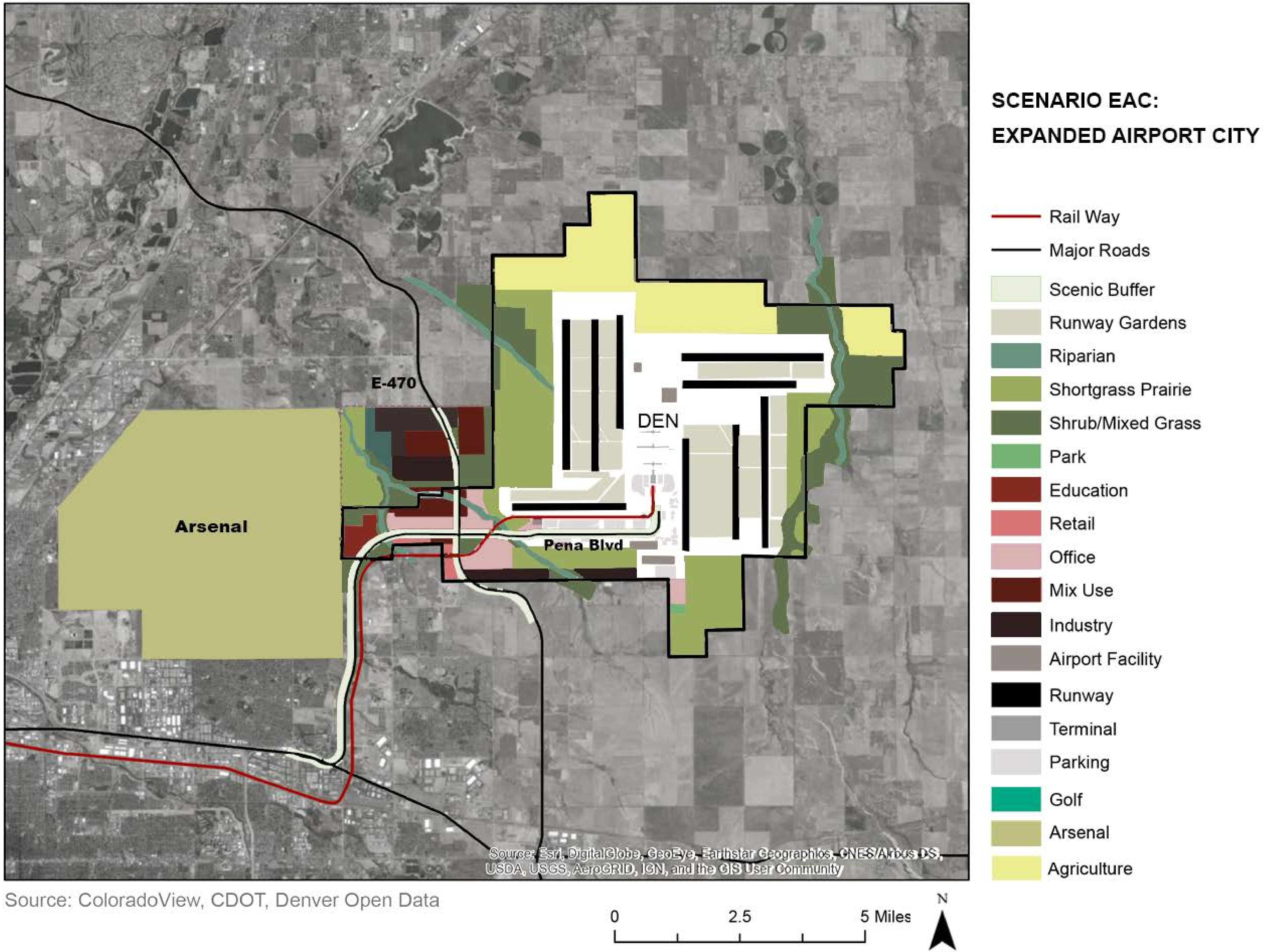
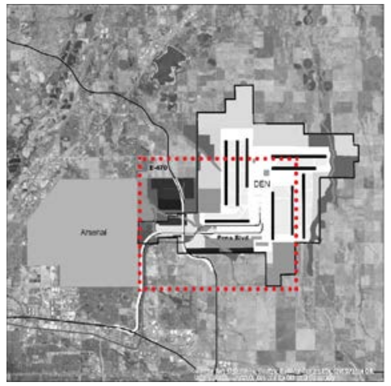


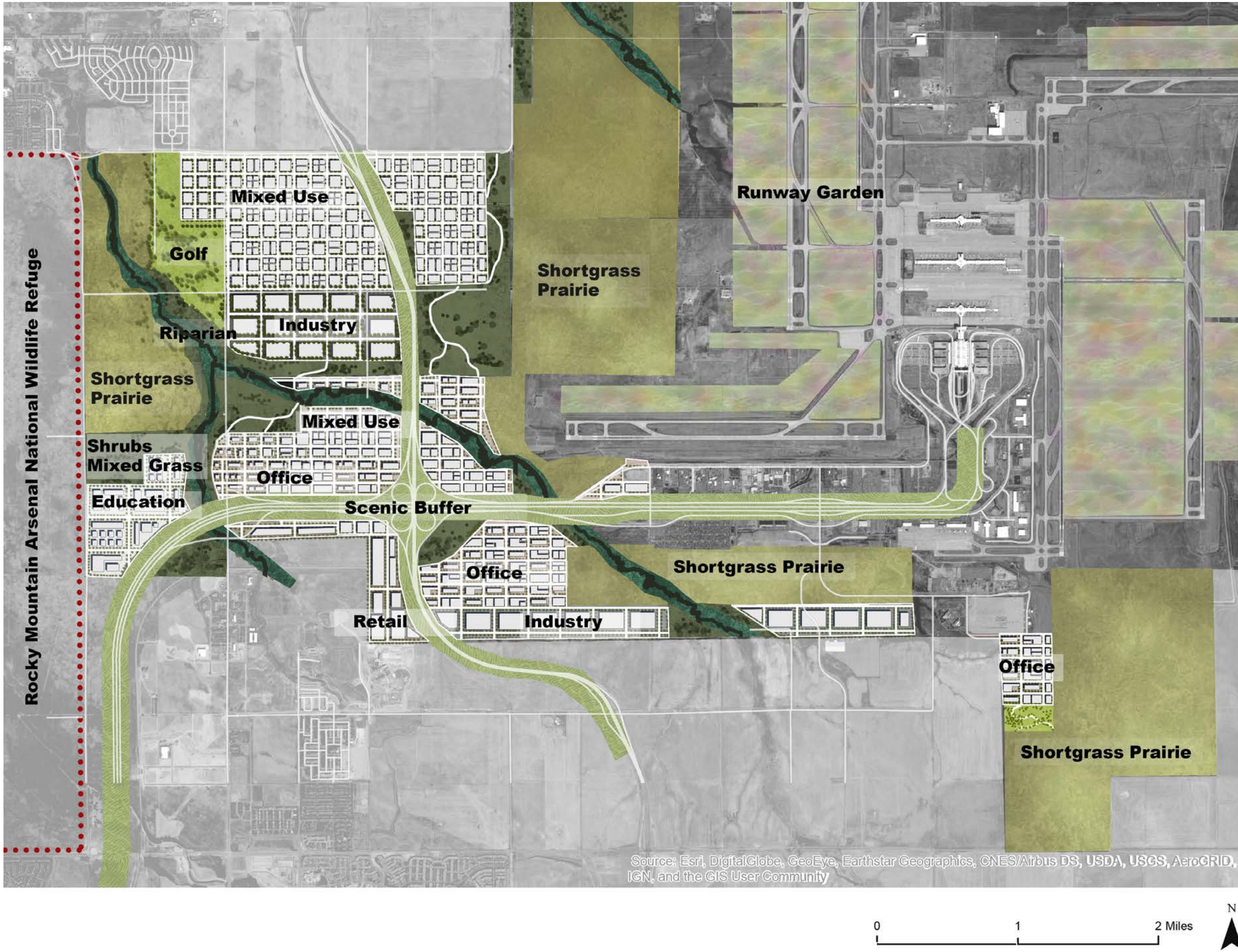
Figure 21. The detailed landcover pattern of scenario Expanded Airport City (EAC), addressing the location and distribution of both development area and potential habitat area.



Source: ColoradoView, CDOT, Denver Open Data

Figure 22. Detailed landcover pattern along Peña Boulevard in Expanded Airport City (EAC). The landcover pattern with the current scope remains the same as Airport City (AC), while in the expanded area the same pattern repeats to cover a broader area.





Development Pattern

In the Airport City scenarios, land along the Peña Boulevard corridor has been allocated to different development patterns, or districts. Each district is described below, and their locations and block sizes are detailed in Figure 23.

- Mixed-use
  This district will contain both retail and residential development along Peña Boulevard, a key transportation corridor connecting the airport to downtown Denver. The block sizes in this district are based on previous airport city case studies; the Schipol Airport Mixed use Block size is 580' x 580'.

- Office
  Denver hopes to house more headquarters for Fortune 500 companies; the retail district envisioned on the airport property will provide opportunities for these headquarters as well as for local businesses. Referred to the Schiphol Airport Block size, which is 800' x 410'.

- Retail
  The retail district is both a shopping center and a primary location for public education in the Airport City scenarios. Because retail centers draw large crowds, it is likely that the highest degree of interaction between the public and the pollinator habitat will occur here. Brightly-colored, showy floral species that provide nectar and pollen to butterflies and bees were chosen for their aesthetic appeal as well as their forage value to pollinators. Visitors will be able to view the pollination process in action on a relatively small scale, while also appreciating the gardens as an aesthetic addition to the shopping center.

- Industrial
  The industrial district is necessary to provide support and storage for the shipping industry, including FedEx. This sector is based on the Schipol Airport. Block sizes are 370' x 900',1280' x 900', and 1560' x 760'. The location of the district supports access to the airport through its location. In scenario Expanded Airport City (EAC), a new industrial district will be built on the existing landfill site.

- Education
  An education campus will provide opportunities for environmental science research and education using the habitat spaces on the airport property as well as the Rocky Mountain Arsenal National Wildlife Refuge. The education district is based on Chiswick Park (UK), designed by West 8 (citation). The block size of the main campus area is 1200' x 1500', which resembles the size of the Diag, the central quad at the University of Michigan in Ann Arbor.

In all of the development districts above (except the industrial district), pollinator habitat will be established in the form of pocket gardens, which will provide pollinator food resources as well as man-made cavity nesting sites for bees. The pollinator gardens will be located every 700 meters, and the size will be around 450 square feet, based on the size of the pocket garden at the University of Michigan.

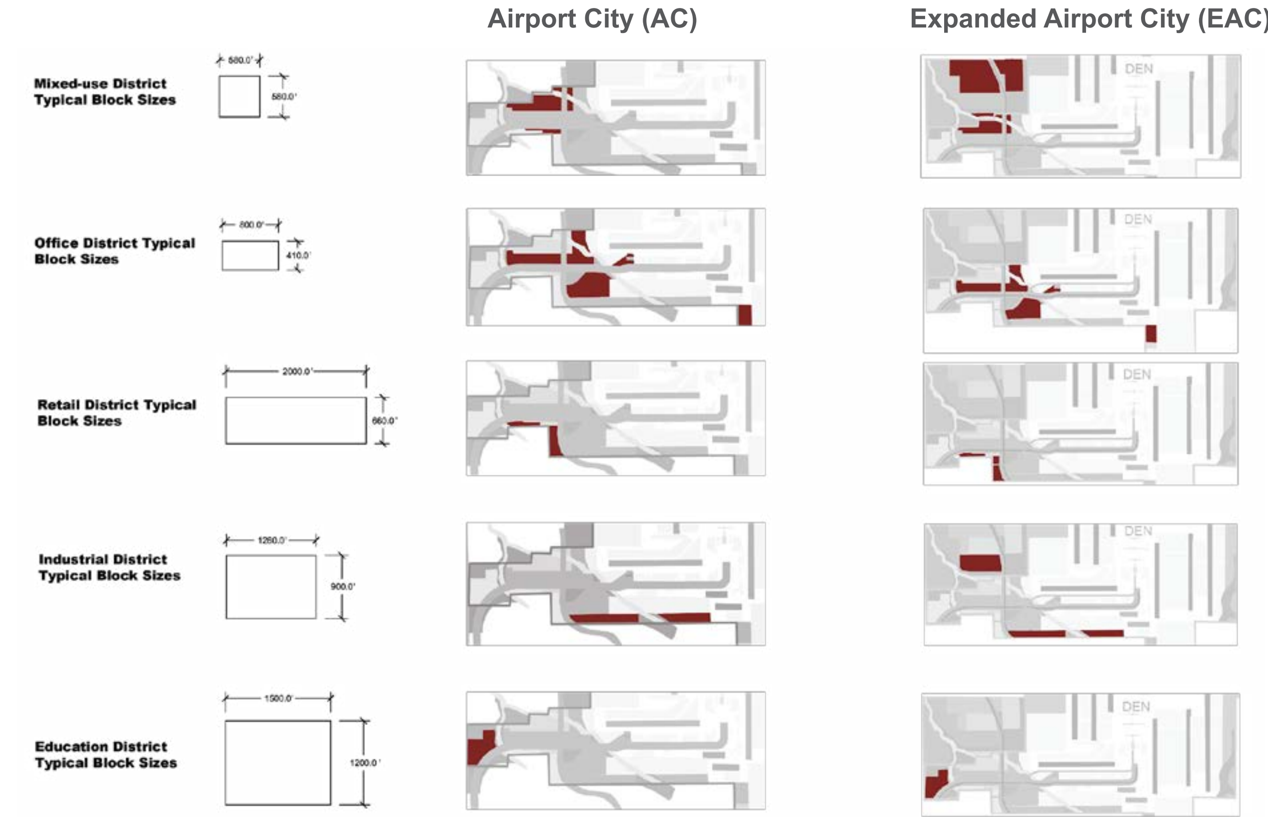
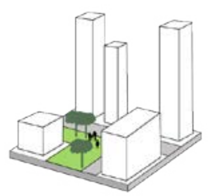


Figure 23. Diagrams showing typical block sizes for different land uses in Airport City scenarios (units in feet), based on precedents of the same type.

Figure 24. Precendents of different development patterns in Airport City scenarios.

Landscape Element Typologies

These typologies describe what plant species will be present in areas with different land allocations under each scenario. Because our evaluation of the scenarios is based on the floral resources available to pollinators in each alternative future, these typologies are an important component of the evaluation. They determine the floral resources available during each season in the various land types of each alternative future. Some typologies are used in all scenarios while others, denoted with a AC or HC, are used only in Airport City scenarios or Habitat Corridor scenarios.



I: Pocket Gardens

The pocket gardens located every 700 meters throughout the newly developed area, and the size will be around 450 square feet, based on the size of the pocket garden at the University of Michigan. It will be planted with a mixture of species based on the Bee Feed and Butterfly Feed seed mixes from the Applewood Seed Company, which is located in Denver. These mixes were chosen because they provide nectar and pollen to pollinators while also using showy species that are aesthetically appealing in a developed area. Pocket gardens will also include cavity nesting sites.

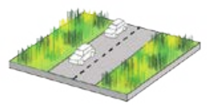
Common Name	**Scientific Name**	**Bloom Color**	**Bloom Period**
Baby Blue Eyes	*Nemophila menziesii*	Blue	Spring
Bergamot	*Monarda fistulosa*	Pink, Purple	Summer
Blue Flax	*Linum lewisii*	Blue, Purple	Spring-Fall
California Poppy	*Eschscholzia californica*	Orange, Yellow	Spring-Fall
China Aster	*Callistephus chinensis*	Pink, Purple, Red	Summer-Fall
Chinese Forget-Me-Not	*Cynoglossum amabile*	Blue	Spring-Summer
Corn Poppy	*Papaver rhoeas*	Red	Summer
Fleabane Daisy	*Erigeron strigosus*	White, Pink	Spring
Globe Gilia	*Gilia capitata*	Blue	Summer
Indian Blanket	*Gaillardia pulchella*	Red, Yellow	Summer
Lance-Leaved Coreopsis	*Coreopsis lanceolata*	Yellow	Spring
Lavender Hyssop	*Agastache foeniculum*	Blue, Purple	Summer
New England Aster	*Symphyotrichum no-vae-angliae*	Pink, Purple	Fall
Plains Coreopsis	*Coreopsis tinctoria*	Red, Yellow	Spring
Purple Coneflower	*Echinacea purpurea*	Pink, Purple	Spring-Summer
Siberian Wallflower	*Cheiranthus allionii*	Orange	Spring-Fall
Sweet Alyssum	*Lobularia maritima*	White, Pink	Spring-Fall
Tidy Tips	*Layia platyglossa*	Yellow	Summer

Table 6: Bee Feed seed mixture with flower colors and bloom period

Common Name	**Scientific Name**	**Bloom Color**	**Bloom Period**
Black-Eyed Susan	*Rudbeckia hirta*	Yellow	Summer-Fall
Butterfly Milkweed	*Asclepias tuberosa*	Orange, Yellow	Spring-Summer
Candytuft	*Noccacea montana*	White	Summer
Dwarf Cosmos	*Cosmos bipinnatus*	Pink, White, Red	Summer-Fall
Dwarf Godetia	*Clarkia amoena*	Pink	Summer
Gayfeather	*Liatris spicata*	Purple	Summer
Illinois Bundleflower	*Desmanthus illinoensis*	White	Spring-Summer
Indian Blanket	*Gaillardia pulchella*	Red, Yellow	Summer
Lance-Leaved Coreopsis	*Coreopsis lanceolata*	Yellow	Spring
New England Aster	*Symphyotrichum no-vae-angliae*	Purple	Fall
Pincushion Flower	*Scabiosa atropurpurea*	Mixed	Summer-Fall
Purple Coneflower	*Echinacea purpurea*	Pink, Purple	Spring-Summer
Purple Prairie Clover	*Dalea purpurea*	Purple, Yellow	Summer
Roundheaded Bush Clover	*Lespedeza capitata*	White	Summer
Shasta Daisy	*Leucanthemum x super-bum*	White	Summer
Siberian Wallflower	*Cheiranthus allionii*	Orange	Spring-Fall
Sweet Alyssum	*Lobularia maritima*	White, Pink	Spring-Fall
Sweet William Pinks	*Dianthus barbatus*	Pink	Summer
Zinnia	*Zinnia spp.*	Mixed	Summer-Fall

Table 7: Butterfly Feed seed mixture with flower colors and bloom period

Figure25. Seasonal interest chart of landscape element typology *I.Pocket Gardens.*



IIAC: Scenic Buffer

The scenic buffer along Peña Boulevard was designed as a way for visitors and residents to experience the native ecosystem of the Denver region as they travel between the airport and downtown Denver. Many of these plants are recommended on the basis of their hardiness and ability to withstand roadside conditions. Slender Wheatgrass and Prairie Junegrass are both recommended by the Colorado Department of Transportation for the revegetation of roadsides. Other species were chosen based on their ability to tolerate low-water conditions.

Common Name	Scientific Name	Bloom Color	Bloom Period
Prairie Junegrass	*Koeleria macrantha*	Graminoids	
Slender Wheatgrass	*Elymus trachycaulus*		
Blue Grama	*Bouteloua gracilis*		
Sideoats Grama	*Bouteloua curtipendula*		
Copper Globemallow	*Sphaeralcea angustifolia*	Orange	Spring-Fall
Galleta	*Hilaria jamesii*	Yellow	Spring
Scarlet Beeblossom	*Oenothera suffrutescens*	Red, White	Summer
Maximilian's Sunflower	*Helianthus maximus*	Yellow	Summer
Purple Prairie Clover	*Dalea purpurea*	Purple	Summer
Showy Milkweed	*Asclepias speciosa*	Pink	Summer
Plains Wallflower	*Erysimum diffusum*	Yellow	Spring
Prairie Coneflower	*Ratibida columnifera*	Yellow	Summer-Fall
Bergamot	*Monarda fistulosa*	Purple	Summer
Narrow-Leaved Penste-mon	*Penstemon angustifolius*	Pink, Purple	Spring-Summer

Table 8: Species chosen to enhance the travel experience on Pena Blvd.

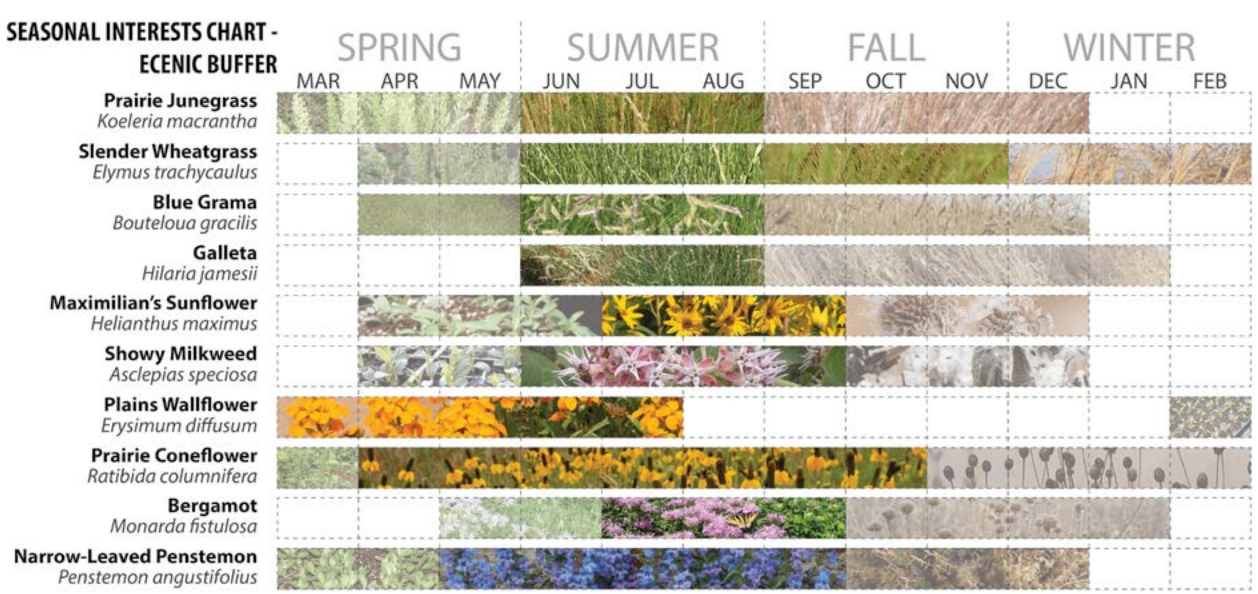
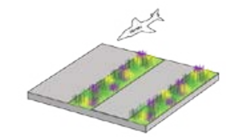


Figure 26. Seasonal interest chart of landscape element typology *IIAC: Scenic Buffer.*



IIIAC: Runway Gardens

In this design, the spaces between the runways will be planted in blocks of showy species that will flower together. This will provide a brightly colored and aesthetically appealing introduction to the city as planes land. These flowers will also provide pollen and nectar to pollinators when they are in bloom.

Common Name	Scientific Name	Bloom Color	Bloom Period
Black-eyed Susan	*Rudbeckia hirta*	Yellow	Summer-Fall
Dotted Gayfeather	*Liatris punctata*	Purple	Summer
Globe Gilia	*Gilia capitata*	Blue	Summer
New England Aster	*Symphyotrichum no-vae-angliae*	Pink, Purple	Fall
Prairie Coneflower	*Ratibida columnifera*	Yellow	Spring-Fall
Purple Coneflower	*Echinacea purpurea*	Pink, Purple	Spring-Summer

Table 9: Showy plants species that have at least three seasons interests for runway gardens

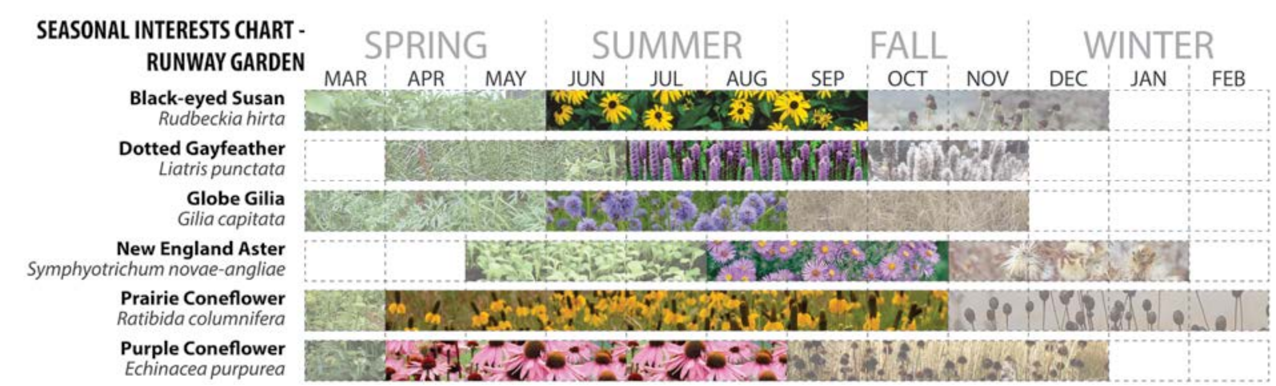


Figure 27. Seasonal interest chart of landscape element typology *IIIAC: Runway Gardens.*

IV: Riparian

The riparian Habitat will be established along the Second Creek, Third Creek and Box Elder Creek. It will be a special landscape feature showing the waterways. This design will be mainly surrounding by other habitats. However, human access will be provided, through a trail system, where the riparian habitat interacting with new development. The riparian habitat will be planted using species chosen from the native plant revegetation guide list for riparian communities of eastern plains and foothill regions of Colorado. The list was composed by Colorado Department of Natural Resources, Colorado State Parks and Colorado Natural Areas Program. The plant list below includes all the grass and forb species (except for two without bloom information), but only the dominant shrub/ tree species of the original list, as there is no dominant species in the former category and we have to assume that all the species might be more or less equally competitive in the riparian community.

Common Name	Scientific Name	Bloom Color	Bloom Period
Inland Saltgrass	*Distichlis spicata*	Yellow	Spring- Mid Fall
American Mannagrass	*Glyceria grandis*	Purple	Spring-Summer
Fowl Mannagrass	*Glyceria striata*	Green	Summer
Foxtail Barley	*Hordeum jubatum*	White, green, purple	Spring-Summer
Arctic Rush	*Juncus arcticus*	Brown, green	Summer
Switchgrass	*Panicum virgatum*	Brown, green	Summer-Fall
Western Wheatgrass	*Pascopyron smithii*	Yellow	Spring
Fowl Bluegrass	*Poa palustris*	Yellow	Spring
Prairie Cordgrass	*Spartina pectinata*	Yellow	Spring
Alkali Sacaton	*Sporobolus airoides*	Yellow	Summer-Fall
Green Needlegrass	*Stipa viridula*	Yellow	Spring
Indian Hemp	*Apocynum cannabinum*	White, green, brown	Spring-Summer
Swamp Milkweed	*Asclepias incarnata*	Pink,purple	Summer-Mid Fall
Western White Clematis	*Clematis ligusticifolia*	White	Spring-Summer
Marsh-elder	*Cyclachaena xanthifolia*	greenish white to yellow	Summer-Mid Fall
Fireweed	*Epilobium angustifolium*	Pink	Summer
Wild Licorice	*Glycyrrhiza lepidota*	White	Summer
Cow-parsnip	*Heracleum sphondylium*	White	Spring-Summer
Fendler's Waterleaf	*Hydrophyllum fendleri*	white, lavander	Spring-Summer
St. Johnswort	*Hypericum formosum*	Yellow	Summer
Rocky Mountain Iris	*Iris missouriensis*	Purple	Spring
Starry False Solomon's Seal	*Maianthemum stellatum*	White	Spring
Wild Mint	*Mentha arvensis*	White, purple	Summer
Mountain Bluebells	*Mertensia ciliata*	Blue	Summer
Wild Bergamot	*Monarda fistulosa*	White, pink, purple	Spring-Summer
Virginia Creeper	*Parthenocissus inserta*	White, green	Spring
Brook Cinquefoil	*Potentilla rivalis*	Pale yellow	Summer
Canada Goldenrod	*Solidago canadensis*	Yellow	Fall
American Vetch	*Vicia americana*	Purple	Spring-Summer
Box-elder	*Acer negundo*	Yellow, green, brown	Spring
Thinleaf Alder	*Alnus incana*	Purplish-red	Spring
River Hawthorn	*Crataegus rivularis*	White	Spring
Oneseed Juniper	*Juniperus monosperma*	Orange	Spring
Rocky Mountain Juniper	*Juniperus scopulorum*	Yellow	Spring
Narrowleaf Cottonwood	*Populus angustifolia*	white	Spring
Plains Cottonwood	*Populus deltoides*	Yellow	Spring
American Plum	*Prunus americana*	White	Spring
Black Chokecherry	*Prunus virginiana*	White	Spring-Summer
Wax Currant	*Ribes cereum*	Pink	Spring-Summer
Woods' Rose	*Rosa woodsii*	Pink	Spring-Summer
Peachleaf Willow	*Salix amygdaloides*	Yellow, green	Spring
Bebb Willow	*Salix bebbiana*	White, green, brown	Spring
Sandbar Willow	*Salix exigua*	White, yellow	Spring

Table 10: Species list for the riparian typology.

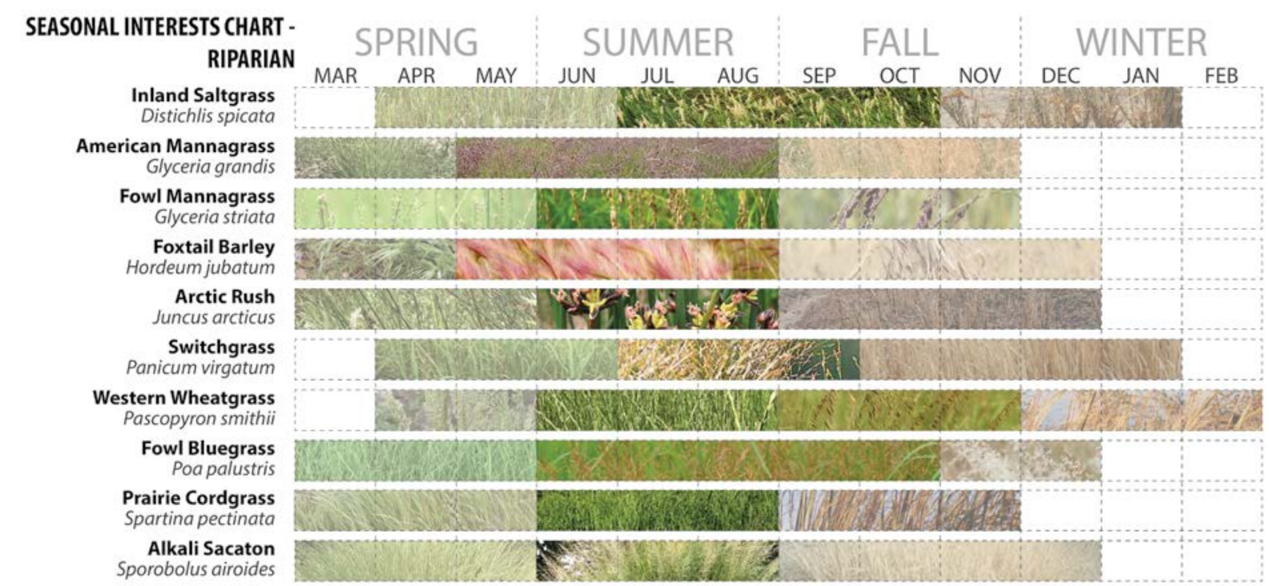
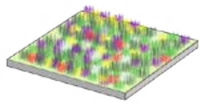


Figure 28. Seasonal interest chart of landscape element typology *IV: Riparian.*



V: Shortgrass Prairie

The shortgrass prairie will be planted using the High Plains Pollinator Mix from Applewood Seed Company. This mix is used for prairie restoration and pollinator habitat enhancement at the Rocky Mountain Arsenal National Wildlife Refuge (Wall, T., personal communication). Using this mix will enhance the connectivity between the refuge and the airport property. Furthermore, the species in this mix are more tolerant of low water conditions and therefore more resistant to the effects of climate change.

Common Name	**Scientific Name**	**Bloom Color**	**Bloom Period**
Dotted Gayfeather	*Liatris punctata*	Purple	Summer
Golden Crownbeard	*Verbesina encelioides*	Yellow	Spring-Fall
Greenthread	*Thelesperma filifolium*	Yellow	Spring-Summer
Narrow Leaf Purple Cone-flower	*Echinacea angustifolia*	Purple	Spring-Summer
Narrow-Leaved Beard-tongue	*Penstemon angustifolia*	Blue, Purple	Spring-Summer
Plains Coreopsis	*Coreopsis tinctoria*	Yellow	Spring-Summer
Prairie Aster	*Aster tanacetifolius*	Purple	Summer-Fall
Prairie Coneflower	*Ratibida columnifera*	Yellow	Spring-Fall
Prairie Sunflower	*Helianthus petiolaris*	Yellow	Summer
Prairie Spiderwort	*Tradescantia occidentalis*	Purple	Summer
Purple Prairie Clover	*Dalea purpurea*	Purple, Yellow	Summer
Rocky Mountain Beeplant	*Cleome serrulata*	Pink, Purple	Summer
Scarlet Globemallow	*Sphaeralcea coccinea*	Red	Spring-Summer
Blue Grama	*Bouteloua gracilis*	Graminoids	
Prairie Junegrass	*Koeleria macrantha*		
Sideoats Grama	*Bouteloua curtipendula*		

Table 11: High Plains Pollinator seed mixture with flower colors and bloom period

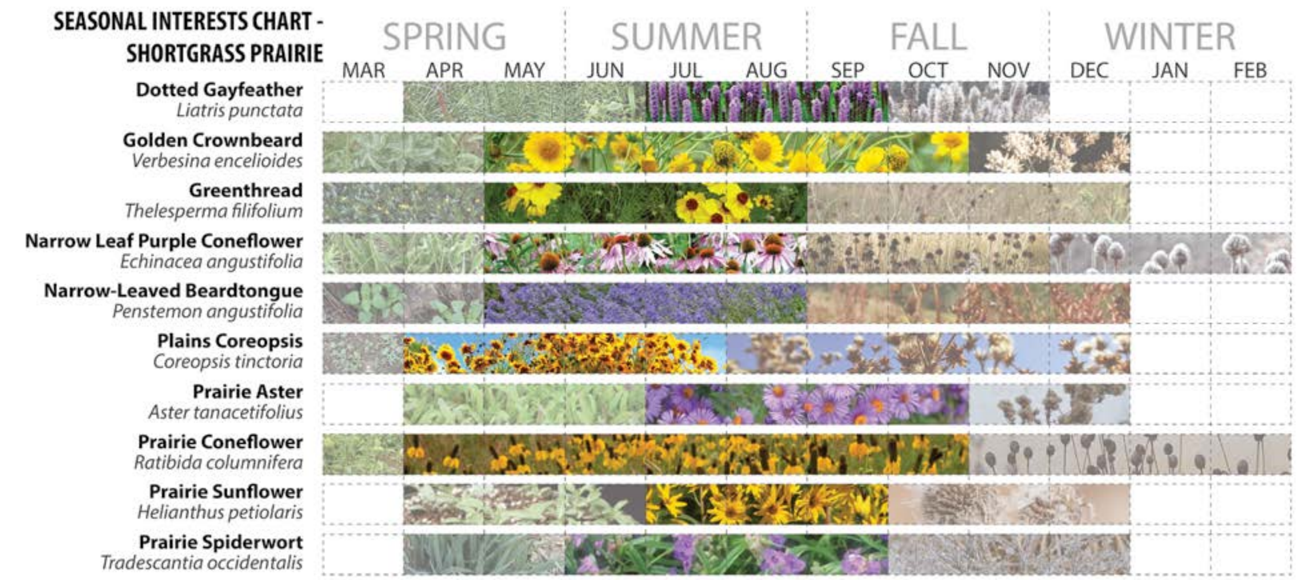


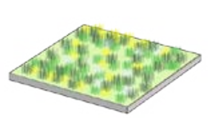
Figure 29. Seasonal interest chart of landscape element typology *V: Shortgrass Prairie*.

VI: Shrub/Mixed Grass

The shrub/ mixed grass habitat will be planted with species chosen from the native plant revegetation guide list for upland grassland communities of eastern plains and foothill regions of Colorado. In the document, the grassland community is divided into shortgrass prairie, mid-grass prairie, tallgrass prairie and foothill grassland. The list is made up of species from the other three ecosystems excluding tallgrass prairie. For practicality and simplicity, only dominant species and non-dominant species present in all three ecosystems are included.

Common Name	Scientific name	Color	Bloom time
Sideoats Grama	*Bouteloua curtipendula*	Red, orange, yellow	Summer-Fall
Blue Grama	*Bouteloua gracilis*	Yellow	Summer-Fall
Buffalograss	*Buchloe dactyloides*	Yellow	Spring-Fall
Galleta	*Hilaria jamesii*	Yellow, probably very small	Mid-summer
Junegrass	*Koeleria macrantha*	Yellow	Spring
Mountain Muhly	*Muhlenbergia montana*	No info	No info
Western Wheatgrass	*Pascopyrum smithii*	Yellow	Spring
Little Bluestem	*Schizachyrium scoparium*	White, green, brown	Summer-Fall
Needleandthread	*Stipa comata*	NA (small to the point of invisible)	Summer
Fringed Sagewort	*Artemisia frigida*	Yellow	Summer
Porter Aster	*Aster porteri*	White	Summer
White Prairie Clover	*Dalea candida*	White	Spring-Summer
Purple Prairie Clover	*Dalea purpurea*	Purple	Summer
Spreading Buckwheat	*Eriogonum effusum*	Yellow	Summer
Scarlet Beeblossom	*Gaura coccinea*	White, red	Summer
Dotted Gayfeather	*Liatris punctata*	Pink, purple	Summer-Fall
Slimflower scurfpea	*Psoralidium tenuiflorum*	Purple	No information
Upright Prairie Clover	*Ratibida columnifera*	Orange, yellow, brown	Spring-Fall
Scarlet Globemallow	*Sphaeralcea coccinea*	Red, orange	Spring-Summer
True Mountain Mahogany	*Cercocarpus montanus*	White	Spring
Parry's Rabbitbrush	*Chrysothamnus parryi*	Yellow	No Info
Winterfat	*Krascheninnikovia lanata*	White	Spring
Mojave Pricklypear	*Opuntia phaeacantha*	Red, orange, yellow	Spring-Summer
Skunkbush Sumac	*Rhus trilobata*	White, yellow	Spring
Wax Currant	*Ribes cereum*	Pink	Spring-Summer
Small Soapweed	*Yucca glauca*	White	Summer

Table 12: Species list for the shrub/mixed grass typology



VII: Agriculture

The agricultural land in northern part of property will be preserved in all scenarios. A new buffer will be created between shortgrass prairie and agriculture land in the form of areas in which no pesticides are used in order to limit pesticide drift and reduce the pesticide effects on surrounding pollinator habitats.

Figure 30. Seasonal interest chart of landscape element typology *VI: Shrub/Mixed Grass.*

Habitat Corridor Scenarios

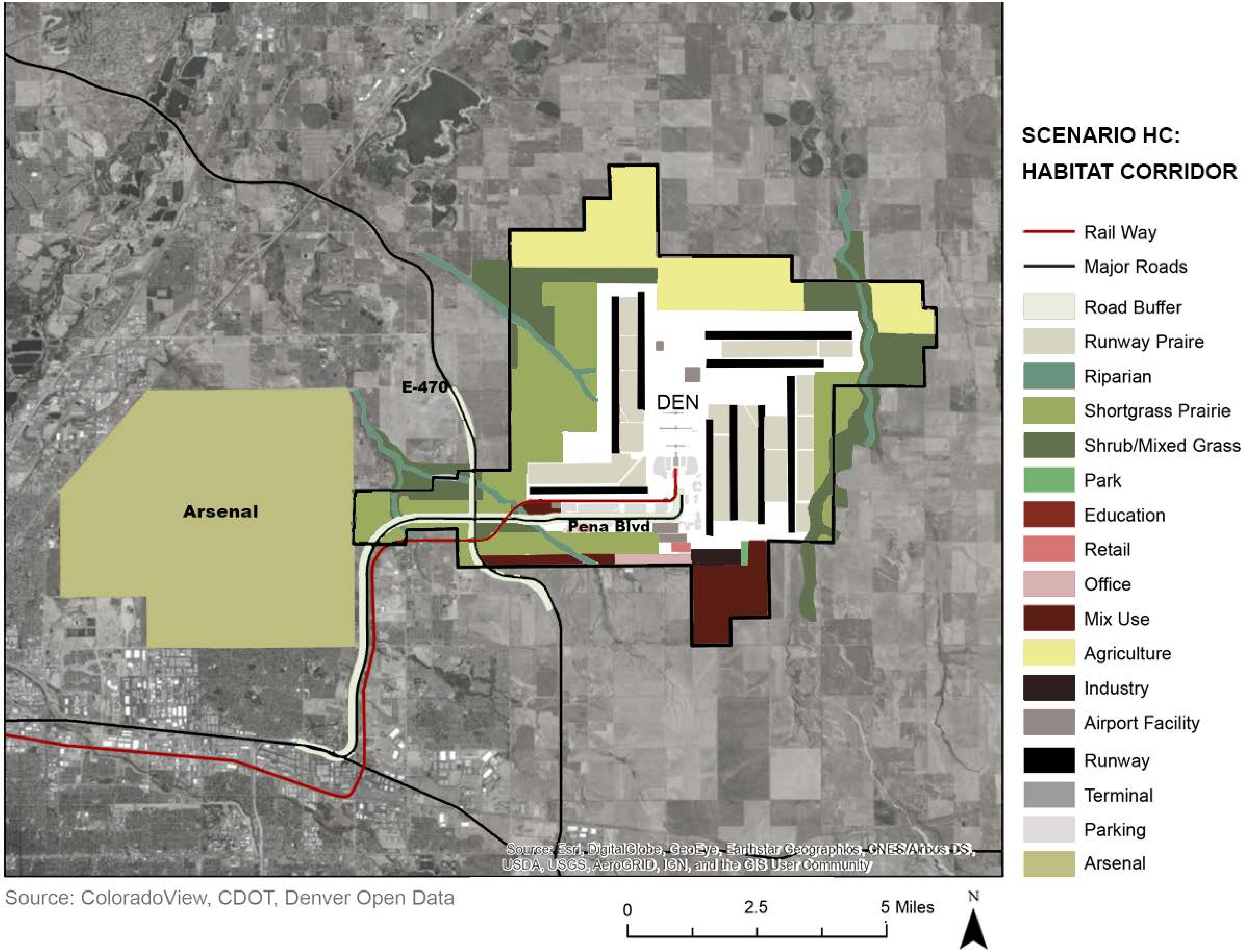
The Habitat Corridor scenarios, Habitat Corridor (HC) and Expanded Habitat Corridor (EHC), prioritize the expansion of high quality pollinator habitat. The development will therefore be more centralized on the south part of the DEN property in order to facilitate future development in surrounding areas within Adams county. The agriculture on the north edge of DEN property will be preserved. While Habitat Corridor (HC) uses the current boundaries of the DEN site, Expanded Habitat Corridor (EHC) envisions an expanded boundary to connect the airport open space directly to the Arsenal National Wildlife Refuge, targeting to demonstrate a future that is plausible if more lands are purchased to be included in the airport's property and to study the corresponding outcomes to understand the potential opportunities.

Scenario Performance Hypothesis

In Habitat Corridor (HC) (Fig.31 & Fig.32), designing to prioritize habitat opportunities is leading another plausible vision of the site. Pena blvd will be converted into shortgrass prairie and served as an ecological corridor between existing Arsenal and new habitat on west edge of DEN property. To mitigate the pressing development pressures, the associated development will be concentrated into the south part of the DEN property. Compared to Airport City scenarios, the development will be more consolidated and located closer to the airport with public transit system provided. The new circulation will be created in new developed areas. The preserved agriculture land on the north part of the property will become a new non-airline revenue source. The organic farm between agriculture and shortgrass prairie will become a pesticide-free buffer. The ecological character of the site will become a more natural prairie system serving as nesting site and overall eventually support more pollinator abundance. The cavity nesting site will be created inside the development in the form of pocket garden. While, all the planting combination in different typologies will maximize the floral abundance for each season. Runway prairie creates a sense of being-away into a nature prairie when landing and taking off, and then visual connection will carry out through the planting on Road Buffer.

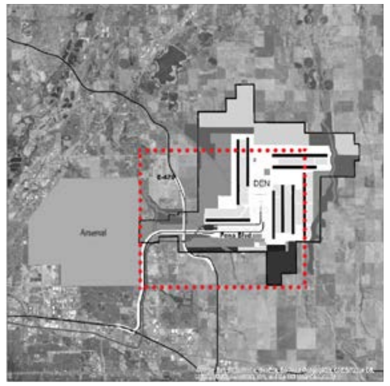
In Expanded Habitat Corridor (EHC) (Fig.33 & Fig.34), prioritizing habitat is still a leading factor, the expansion of the boundary will maximize the opportunities for pollinators. This scenario will support most pollinator abundance with larger and connected shortgrass prairie patches. No more development will be added into this scenario and the development pattern will be same to Habitat Corridor (HC) The agriculture land on the north part of the property will also be persevered and could become a new non-airline revenue source. The organic farm between agriculture and shortgrass prairie will also act as pesticide-free buffer. Travel experience will be same to Habitat Corridor (HC).

Figure 31. The detailed landcover pattern of scenario Habitat Corridor (HC), addressing the location and distribution of both development area and potential habitat area.



Source: ColoradoView, CDOT, Denver Open Data

Figure 32. Detailed landcover pattern along Peña Boulevard in Habitat Corridor (HC).



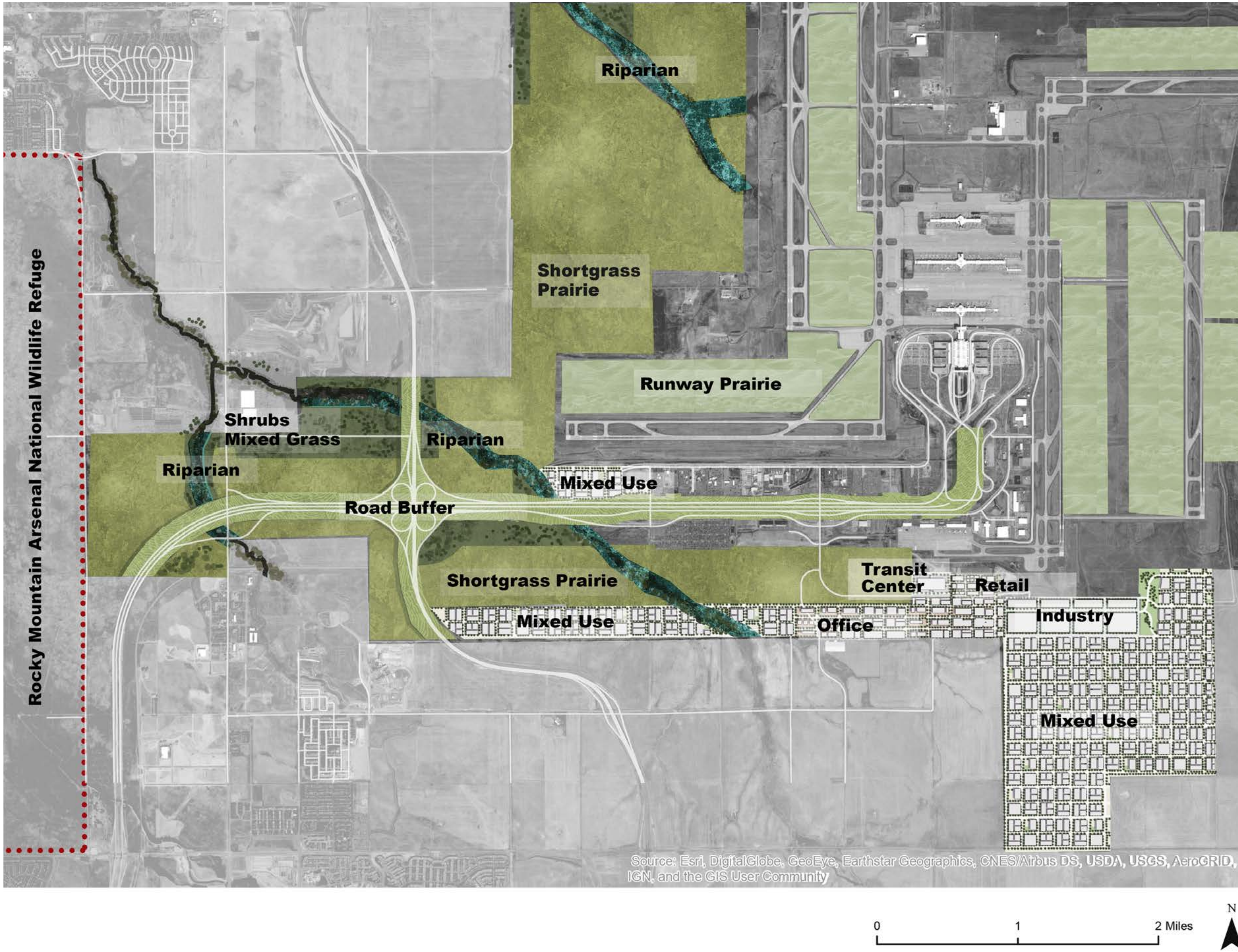
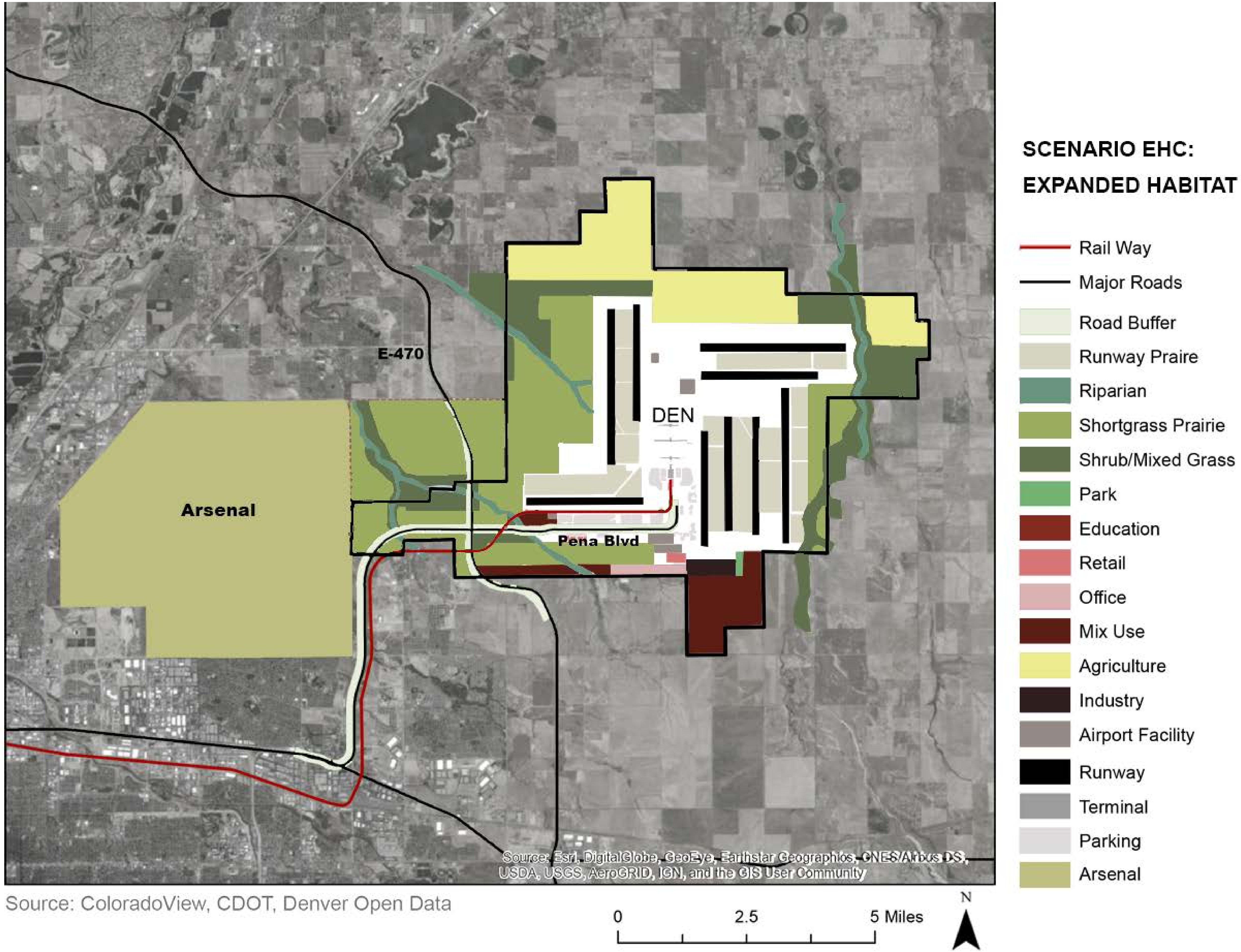
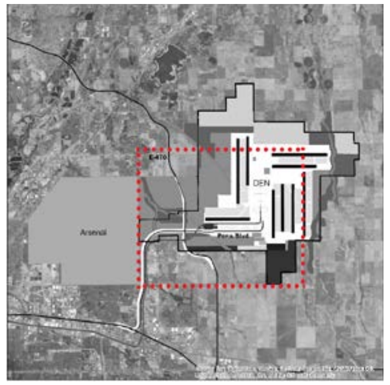


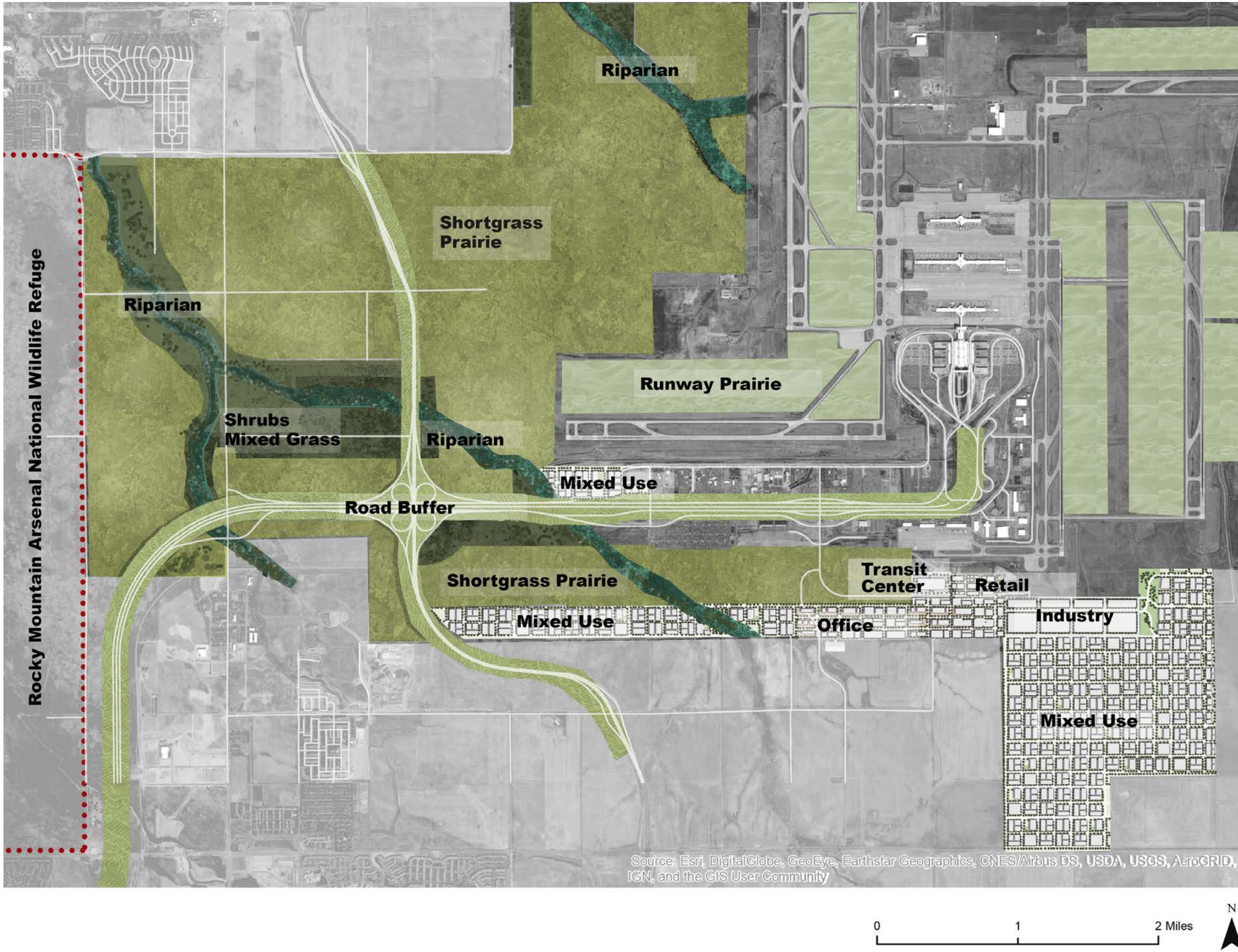
Figure 33. The detailed landcover pattern of scenario Expanded Habitat Corridor (EHC), addressing the location and distribution of both development area and potential habitat area.



Source: ColoradoView, CDOT, Denver Open Data

Figure 34. Detailed landcover pattern along Peña Boulevard in Expanded Airport City (EAC). The landcover pattern with the current scope remains the same as Airport City (AC), while in the expanded area the same pattern repeats to cover a broader area.





Development Pattern

Thte locations of new development will be different from the Airport City scenarios in order to respond to the priority of the expansion of high quality pollinator habitat. South part of the DEN property will become the main urban area. Compared to the Airport City scenarios, the available land for development is much smaller, so the size of different districts need to be adjusted in a more concentrated way. Block sizes for each of the districts described below are detailed in Figure 35.

- Mixed-use
  This district will be located in the south part of the property to provide living, working and shopping space for the people who work in the new development area or short-term visitors. Public parks will be introduced into the mixed-use area as well. The block size is 580' x 580', based on the Schipol Airport.

- Office
  The office district will help achieve the airport's development goals for housing more headquarters for Fortune 500 companies in Denver. The district will be located in south edge of the DEN property and closer to the new public transit center to provide multiple means of access. The office district will be more consolidated compared to the Airport City scenarios. The block size is 800' x 410'.

- Retail
  The retail district will be located around the new public transit center to create a new unique public space. The size is referred to retail districts next to Denver Union Station, size is 300' x 400'.

- Industrial
  The industrial district will be located closer to the airport facilities and the airport itself to provide a easier access for the shipping industry. The The block size is 1390' x 990', which is based on the Lincoln Park Industrial Area in Denver.

- Public Transit Center
  As the development will be consolidated into the south part of the DEN property, an extension of the transit system will be necessary, not only moving people between airport and the new developed areas, but also connecting the new south hub area to the future surrounding developments and neighborhoods. A new circulation pattern will be created to accommodate with fast-paced growth of development and access to the airport. A new public transit center will be built, providing the public transportation to connect visitors and future residents between new development areas the airport, and surroundings. The dimensions of this center are based on Denver Union Station, with a size of 750' x 255'.

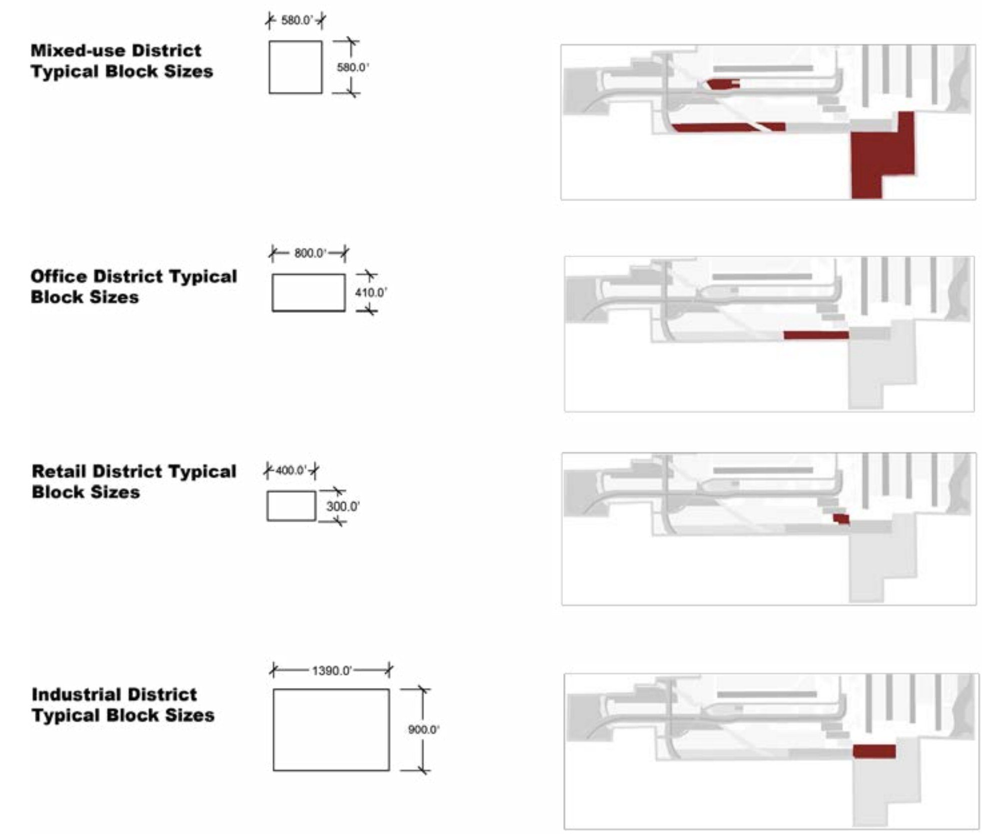


Figure 35. Diagrams showing typical block sizes for different landuse in Habitat Corridor scenarios (units in feet), based on precedents of the same type.

Figure 36. Precendents of different development patterns in Habitat Corridor scenarios.

Landscape Element Typologies

The Habitat Corridor scenarios employ many of the same typologies as the Airport City scenarios. These include: Pocket Gardens, Riparian, Shortgrass Prairie, Shrub/Mixed Grass, and Agriculture. Information on the planting design for each of these typologies can be found in the previous section. The Habitat Corridor scenarios also introduce two additional typologies, the Road Buffer and the Runway Prairie, which are described below.

IIHC: Road Buffer

The primary function of this 1000' buffer along Pena Blvd is to mitigate the effects of road rather than providing a scenic view.

Common Name	Scientific Name	Bloom Color	Bloom Period
Showy Milkweed	*Asclepias speciosa*	Pink	Summer
Japanese Tree Lilac	*Syringa reticulata*	Purple	Spring
Autumn Joy Sedum	*Hylotelephium herbst-freude AUTUMN JOY*	Pink	Summer-Fall
Russian sage	*Perovskia atriplicifolia*	Purple	Summer-Fall
Narrow-Leaved Purple Coneflower	*Echinacea angustifolia*	Purple	Spring-Summer
Blue Heaven Little Blue-stem	*Schizachyrium scoparium 'MinnBlueA'*	Graminoids	
Prairie Junegrass	*Koeleria macrantha*		
Slender Wheatgrass	*Elymus trachycaulus*		

Table 13: Species chosen to mitigate road effects on pollinator habitats.

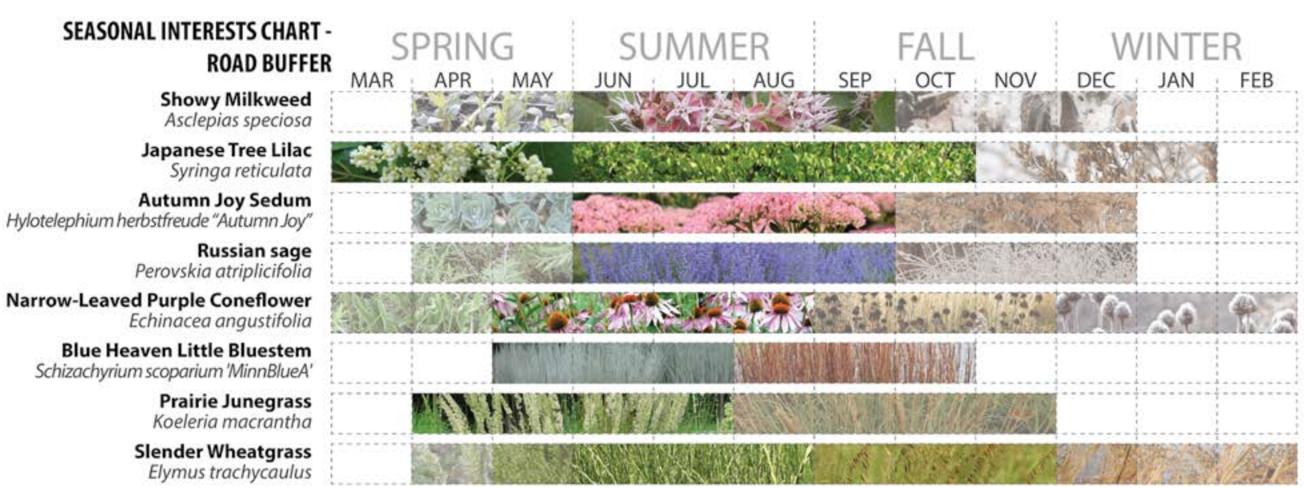
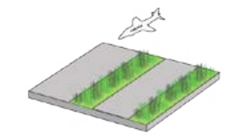


Figure 37. Seasonal interest chart of landscape element typology *IIHC: Road Buffer.*



IIIHC: Runway Prairie

In order to provide an unique landing and taking-off experience of nature landscape of denver, the runway gardens will be planted with mixed grass seeds to reflect shortgrass prairie. It will also provide a potential opportunities to create underground stormwater storage.

Common Name	Scientific Name	Bloom Color	Bloom Period
Dotted Gayfeather	*Liatris punctata*	Purple	Summer
Golden Crownbeard	*Verbesina encelioides*	Yellow	Spring-Fall
Narrow Leaf Purple Cone-flower	*Echinacea angustifolia*	Purple	Spring-Summer
Narrow-Leaved Beard-tongue	*Penstemon angustifolia*	Blue, Purple	Spring-Summer
Plains Coreopsis	*Coreopsis tinctoria*	Yellow	Spring-Summer
Prairie Aster	*Aster tanacetifolius*	Purple	Summer-Fall
Prairie Coneflower	*Ratibida columnifera*	Yellow	Spring-Fall
Prairie Sunflower	*Helianthus petiolaris*	Yellow	Summer
Prairie Spiderwort	*Tradescantia occidentalis*	Purple	Summer
Scarlet Globemallow	*Sphaeralcea coccinea*	Red	Spring-Summer
Blue Grama	*Bouteloua gracilis*	Graminoids	
Prairie Junegrass	*Koeleria macrantha*		
Sideoats Grama	*Bouteloua curtipendula*		

Table 14: Runway prairie seed mixture with flower colors and bloom period

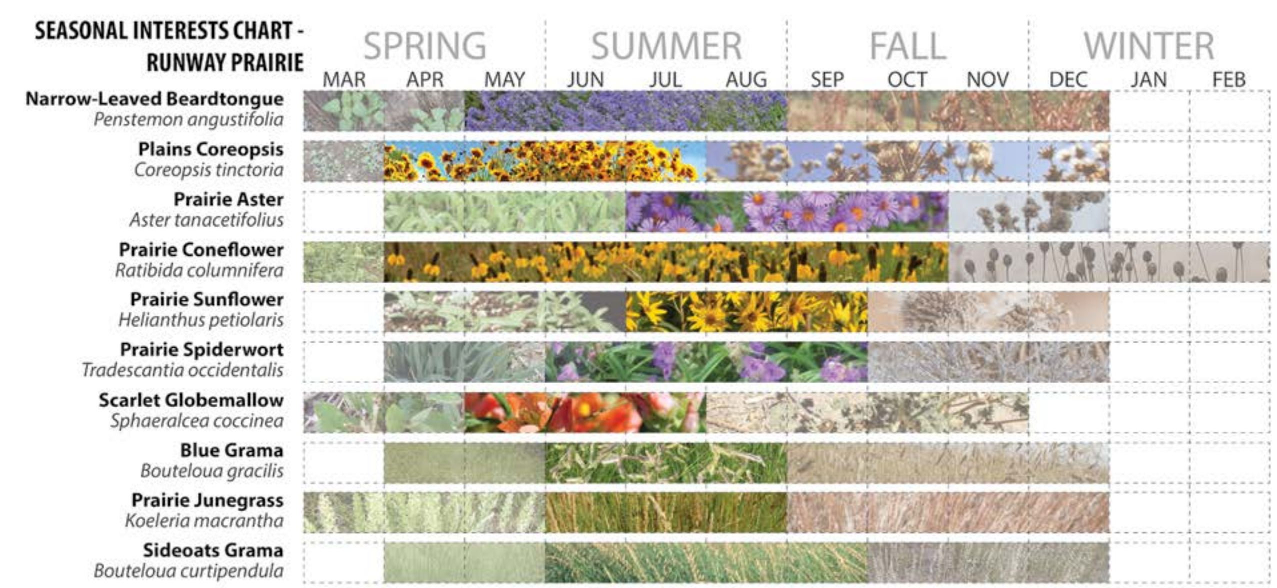


Figure 38. Seasonal interest chart of landscape element typology *IIIHC: Runway Prairie.*

Scenario Assessment

InVEST Crop Pollination Model

Each alternative landscape future was assessed to determine pollinator abundance using the InVEST Crop Pollination model. This spatially explicit model was developed by Lonsdorf et al. (2009), and predicts pollinator abundance based on nesting habitat and floral resources. It requires three inputs (Natural Capital Project, 2017):

1. A landcover map (GIS raster), with a land use code for each cell;
2. Table of pollinator species or guilds, with information about nesting requirements, flight distance, seasonal activity levels, and relative abundance for each;
3. A biophysical table, containing data for each land use code in the landcover map, including nesting suitability and seasonal floral resources.

Pollinator Guild Table

Because the model has been effectively used to predict bee abundance, we focused our assessment on bees. We used guilds instead of individual species because there are so many individual species of pollinators present in the Denver region and few data available about their relative abundances. For each major guild present in the Denver region, we created a representative proto-pollinator (Table 15). We used the information gathered about each guild in our literature review in order to estimate the nesting needs and activity level for each guild. Because we do not have data on the relative abundance of each guild in the Denver region, we weighted them equally. Those proto-pollinators are listed in the table below, along with their nesting needs, average flight distance, and seasonal activity.

Guild	Ground nesting	Cavity nesting	Flight distance (m)	Spring activity	Summer activity	Fall activity	Relative Abundance
Andrenidae	1.00	0.00	850	0.75	0.75	0.25	1.00
Apidae (Bombus)	1.00	1.00	950	1.00	1.00	0.00	1.00
Halictidae	1.00	0.00	500	1.00	1.00	0.50	1.00
Megachilidae	1.00	1.00	700	1.00	1.00	0.25	1.00

Table 15: Pollinator guild table for the InVEST pollination model, showing the four guilds used to assess the alternative landscape futures, as well as their nesting needs, flight distance, activity levels in each season, and relative abundance in the region.

For bees, flight distance can be estimated using the size of the bee. Because each proto-pollinator represents a guild, we used a median size (based on the range of sizes of species in that guild). We were then able to use that median to estimate the flight ranges based on Bilot's guidelines (Fig. 39) (Bilot, 2014). Due to the wide range of body sizes present in Apidae guild, we chose to use only bumblebees (Bombus) in the size calculation. The large size of bumblebees relative to other bees allowed us to capture the higher portion of the size range in our model.

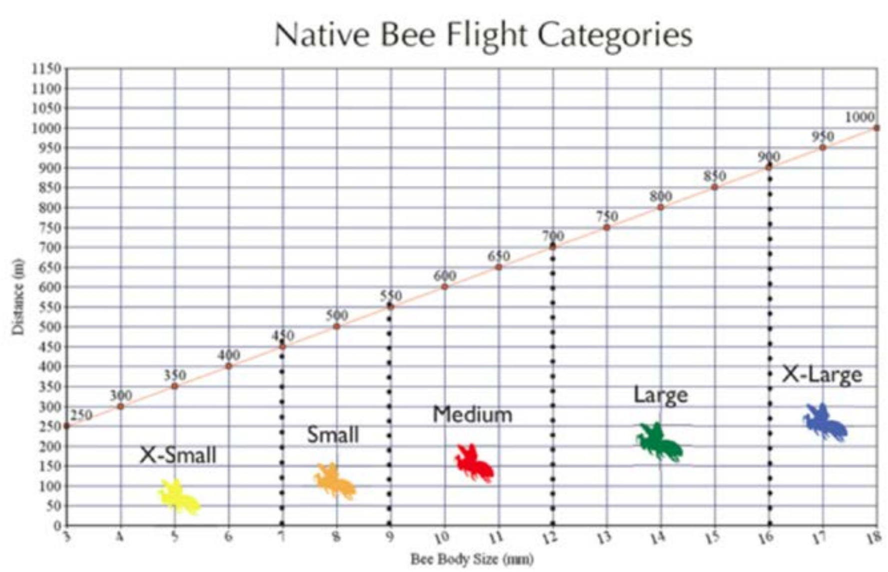


Figure 39: Bee size and flight distance (Bilot, 2014).

Bees were classified as either ground nesters or cavity nesters. If all species in a guild fell into the same category, we gave that category a value of 1 and the other a value of 0. If some bees from a guild were cavity nesters while others were ground nesters, we gave each a category a value of 1 (Natural Capital Project, 2017).

Level of activity during each season was determined by compiling the active months of each genus within the family in Region IV, which includes eastern half of Colorado (Wilson & Carril, 2015). If all genuses are active in a given season, the season received a score of 1. If there is no activity, the season was be scored a 0. In cases in which there are some active genuses or the family is only active for part of a season, intermediate scores (0.25, 0.5, 0.75) were given based on the number of active genuses and time length of activity.

Biophysical Table

In order to run the model, each of the future landscape patterns was created as a shapefile and then transformed into raster data in ArcGIS. Then for each cell of the raster data, nesting sites and floral abundance were determined based on the landcover designation of that cell. We calculated the nesting site availability in two categories: ground nesting sites and cavity nesting sites. The ground nesting site availability index was determined using four variables: soil stability, bare ground availability, drainage, and aspect (Appendix A). The cavity nesting site availability index was determined as a binary variable, based on the presence or absence of woody plants (trees and shrubs) or manmade cavity nesting sites in pocket gardens.

We estimated the floral abundance for each season based on the seed mix indicated for each landscape element type employed in the landscape futures for each scenario. For each season, the number of species blooming was divided by the total number of species planted to give the percentage of flowering species in bloom at that time.

Using the overlay of soil and typology layers, all the combinations were identified, scored and assigned a landuse code (lucode). The final results are listed in the table below (Table 16).

Lucode	Nesting_ cavity_ availability_ index	Nesting_ ground_ availability_ index	Floral_ resources_ spring_ index	Floral_ resources_ summer_ index	Floral_ resources_ fall_index	Typology	Soil
1	0	0.166	0.2	0.3	0	Agriculture	No info
2	0	0.243	0.2	0.3	0	Agriculture	Somewhat excessively drained
3	0	0.294	0.2	0.3	0	Agriculture	Well drained
4	0	0.872	0.66	0.66	0.34	Agriculture converted to prairie	No info
5	0	0.949	0.66	0.66	0.34	Agriculture converted to prairie	Somewhat excessively drained
6	0	1	0.66	0.66	0.34	Agriculture converted to prairie	Well drained
7-A1	0.000122	0.000066	0.000053	0.000099	0.000043	Education	Well drained
7-A2	0.000121	0.000065	0.000052	0.000098	0.000042		
8	1	0.817	0.54	0.8	0.14	Mixed grass/shrub	No info
9	1	0.894	0.54	0.8	0.14	Mixed grass/shrub	Somewhat excessively drained
10	1	0.945	0.54	0.8	0.14	Mixed grass/shrub	Well drained
11	0	0.872	0.54	1	0.24	Shortgrass prairie, Arsenal	No info
12	0	0.949	0.54	1	0.24	Shortgrass prairie, Arsenal	Somewhat excessively drained
13	0	1	0.54	1	0.24	Shortgrass prairie, Arsenal	Well drained
14-A1	0.000232	0.000096	0.0001	0.000188	0.000081	Mixed Use	No info
14-A2	0.000099	0.000041	0.000043	0.00008	0.000035		
14-B	0.000127063	0.000052	0.000055	0.000103	0.000044		
15-A1	0.000232	0.000125	0.0001	0.000188	0.000081	Mixed Use	Well drained
15-A2	0.000099	0.000053	0.000043	0.00008	0.000035		
15-B	0.000127063	0.000069	0.000055	0.000103	0.000044		

16	0	0	0	0	0	Non-nesting sites	No info
17	0	0.077	0	0	0	Non-nesting sites	Somewhat excessively drained
18	0	0.128	0	0	0	Non-nesting sites	Well drained
19-A1	0.000138	0.000074	0.000059	0.000111	0.000048	Office	Well drained
19-A2	0.000136	0.000073	0.000058	0.00011	0.000048		
19-B	0.000150443	0.000081	0.000065	0.000122	0.000053		
20	1	0.596	0.2	0.3	0.1	Park	Well drained
21-A1	0.000182	0.000098	0.000078	0.000147	0.000064	Retail	Well drained
21-A2	0.000178	0.000096	0.000077	0.000144	0.000062		
21-B	0.000263119	0.000142	0.000113	0.000213	0.000092		
22	1	0.698	0.72	0.53	0.09	Riverside	No info
23	1	0.774	0.72	0.53	0.09	Riverside	Somewhat excessively drained
24	1	0.826	0.72	0.53	0.09	Riverside	Well drained
25	0	0.523	0.2	0.3	0.1	Road Buffer	No info
26	0	0.6	0.2	0.3	0.1	Road Buffer	Somewhat excessively drained
27	0	0.651	0.2	0.3	0.1	Road Buffer	Well drained
28	0	0.468	0.2	0.3	0.1	Scenic Buffer	No info
29	0	0.545	0.2	0.3	0.1	Scenic Buffer	Somewhat excessively drained
30	0	0.596	0.2	0.3	0.1	Scenic Buffer	Well drained
31	0	0.349	0.27	0.83	0.5	Runway gardens	No info
32	0	0.426	0.27	0.83	0.5	Runway gardens	Somewhat excessively drained
33	0	0.477	0.27	0.83	0.5	Runway gardens	Well drained
34	0	0.404	0.66	1	0.3	Runway prairie	No info
35	0	0.481	0.66	1	0.3	Runway prairie	Somewhat excessively drained
36	0	0.532	0.66	1	0.3	Runway prairie	Well drained

Table 16: The biophysical table used in the InVEST pollination model, with ground and cavity nesting site availability, floral resources in each season of study, landscape element type, and soil type.

Based on these data, we were able to use the model to produce a abundance indices for each guild of native bees, in each season, in each of our four scenarios. Abundance indices are reported as values ranging from 0 (few bees) to 1 (many bees) (Meehan et al., 2013). Indices were averaged across each landscape, although the maps produced by the model allow us to determine areas of high and low abundance.

Evaluation Results

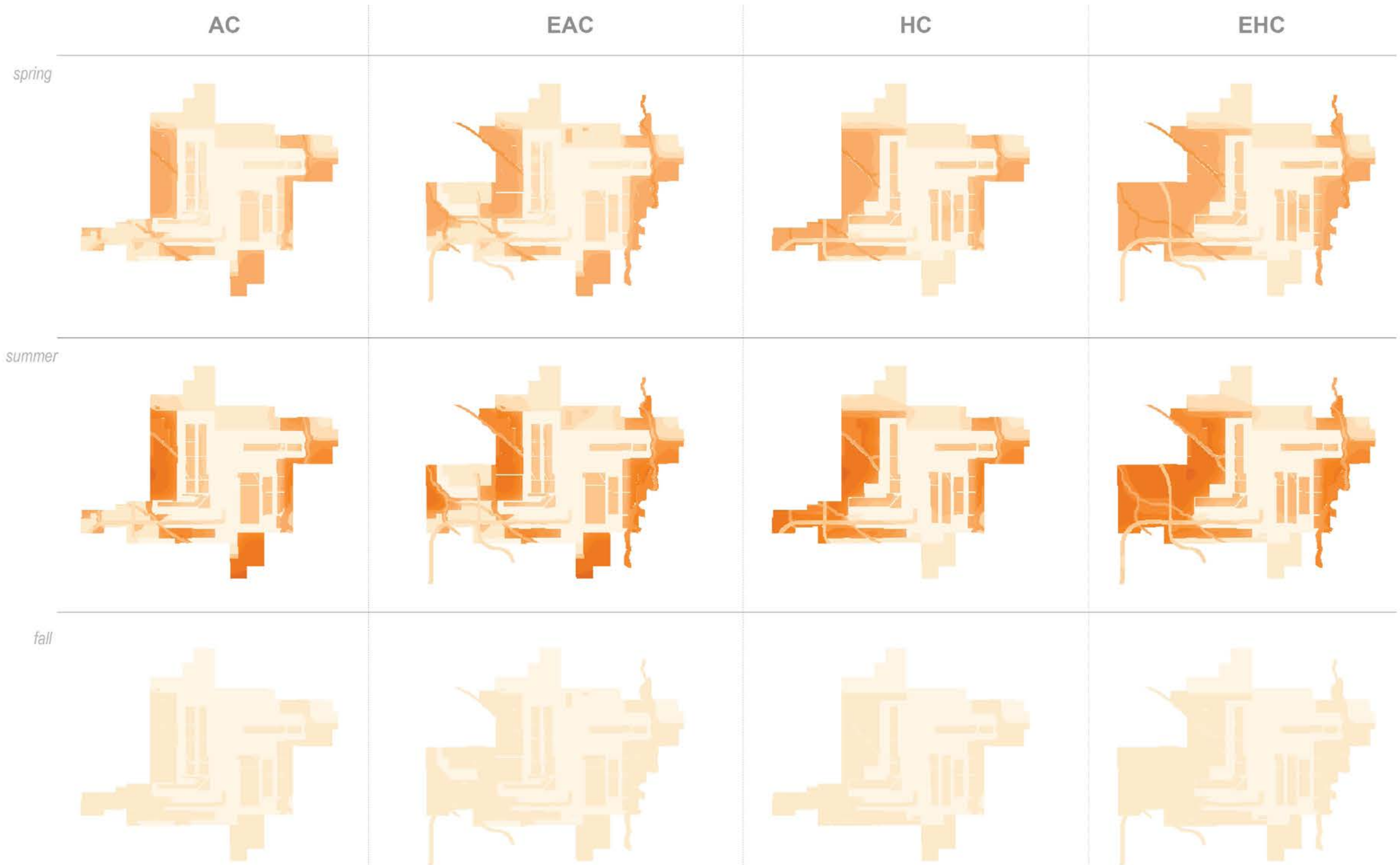
We ran the model four times; once for each scenario. The predicted average relative abundance indices for each of those scenarios are tabulated below (Table 17). The Habitat Corridor landscapes had higher abundance indices for all guilds than the Airport City landscapes. The two expanded boundary scenarios had higher abundance indices for all guilds than their corresponding current boundary scenarios.

Season	Guild	Airport City (AC)	Expanded Airport City (EAC)	Habitat Corridor (HC)	Expanded Habitat Corridor (EHC)
Spring Abundance Index	*Andrenidae*	0.0149	0.0177	0.0188	0.0242
	Apidae (Bombus)	0.0177	0.0213	0.0224	0.0291
	Halictidae	0.0147	0.0174	0.0185	0.0233
	Megachilidae	0.0163	0.0196	0.0205	0.0264
	Average	0.0159	0.0190	0.0201	0.0258
Summer Abundance Index	*Andrenidae*	0.0267	0.0297	0.0301	0.0384
	Apidae (Bombus)	0.0315	0.0355	0.0358	0.0461
	Halictidae	0.0263	0.0291	0.0296	0.0371
	Megachilidae	0.0290	0.0326	0.0328	0.0417
	Average	0.0284	0.0317	0.0321	0.0408
Fall Abundance Index	*Andrenidae*	0.0025	0.0026	0.0022	0.0028
	Apidae (Bombus)	0.0000	0.0000	0.0000	0.0000
	Halictidae	0.0036	0.0038	0.0033	0.0041
	Megachilidae	0.0020	0.0021	0.0018	0.0023
	Average	0.0020	0.0021	0.0018	0.0023

Table 17: Abundance indices for each guild, averaged across the landscape. The average row in each season represents the average of the four guilds for that scenario.

For each guild, the InVEST Crop Pollination model produces a pollinator supply map, which indicates where pollinators originate in the landscape, as well as maps that show pollinator abundance in each season (visitors to each cell in the landscape) (Appendix C). The maps below (Fig. 40) represent index values, averaged across the four guilds, and show areas of high and low pollinator abundance across the landscape. Although there are differences in the range of average abundances in the three seasons, the areas of highest abundance are restored native prairie. The areas of lowest abundance are the paved surfaces of the airport.

Fig 40. These maps spatially show pollinator abundance indices, averaged across all guilds, under the four scenarios in spring, summer, and fall. Darker colors indicate higher abundance indices, while lighter colors indicate lower abdundances. The areas of highest abundance are generally restored prairie and shrubland.



Human Dominance

The Habitat Corridor scenario prioritized native shortgrass prairie habitat over the development of an airport city. This landscape future reflected reduced human dominance in the DEN landscape by shrinking the land area devoted to mixed-used, office, and retail development . All of the land along the strategic Peña Boulevard corridor was devoted to restored native prairie. Under the current boundaries, Habitat Corridor scenario performed slightly better than Airport City in terms of pollinator abundance, in all seasons except fall (Fig.41). This result suggests that reducing the dominance of human development in the landscape results in increases in pollinator abundances.

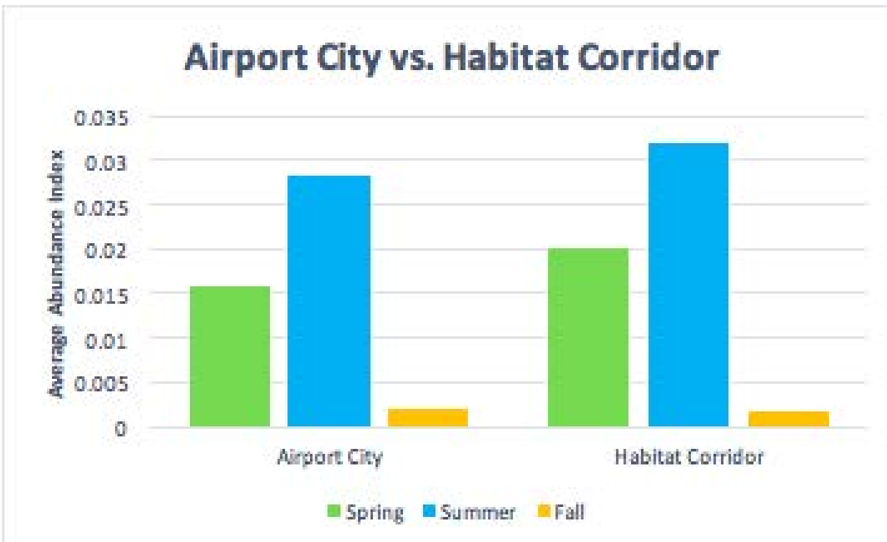


Figure 41. A comparison of the pollinator abundance index, averaged across the landscape and across all guilds, between the Airport City and Habitat Corridor scenarios, using the airport property's current boundaries. Although there are seasonal differences in the abundance index, the Habitat Corridor generally shows higher abundances than the Airport City.

Boundary Expansion

Expanded boundary scenarios had higher predicted abundances than their current boundary counterparts for both the Airport City and the Habitat Corridor (Fig. 42). Expanding the boundary of the airport bounder results in a greater increase in pollinator abundance in the habitat corridor scenarios than in the airport city scenarios. It is important to note the increase in the index from the current boundary to the expanded boundary indicates how expanding the boundary raises the average abundance across the landscape. The expansion had a greater impact on the Habitat Corridor scenarios than the Airport City scenarios. For example, in the summer, the boundary expansion increased the HC average abundance index by 27.4%, while the same expansion of the same area only increased the AC average abundance index by 11.8%.

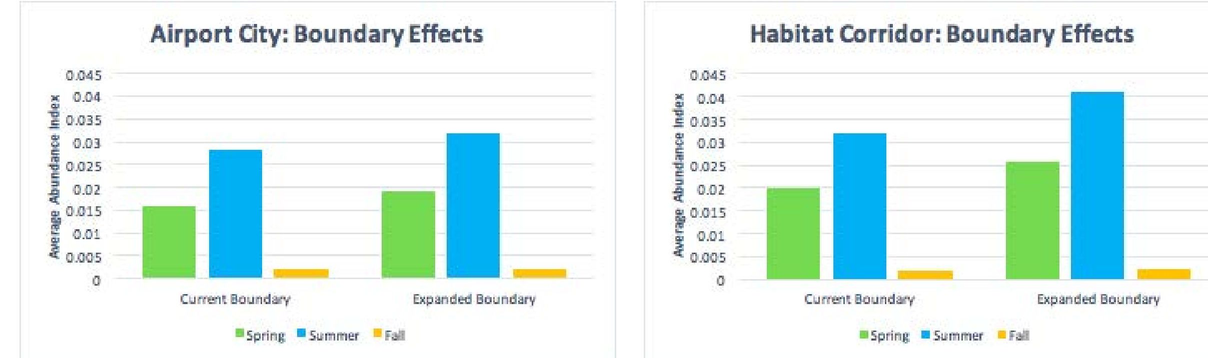


Fig 42. A comparison of the pollinator abundance index, averaged across the landscape and across all guilds, the between the current and expanded airport boundary, for the Airport City and Habitat Corridor scenarios.

Seasonal Pattern of Abundance

Under all four scenarios, average abundance indices peak in the summer and decline sharply in the fall (Fig. 43). The greatest differences can be seen in the summer, while fall scores are very similar across the four scenarios.

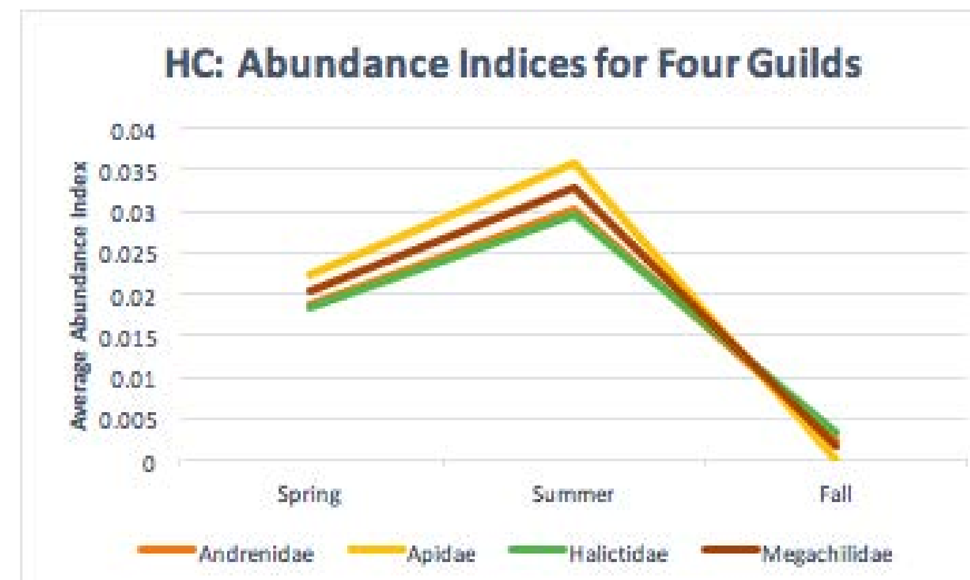


Figure 43: The seasonal pattern of the pollinator abundance index, averaged across the landscape, represented by the Habitat Corridor scenario. All three other scenarios followed similar seasonal patterns. Each guild is shown separately.

Guilds

Apidae (Bombus) and Megachilidae have higher predicted average abundances in spring and summer in all four scenarios (Fig. 44). Both of these guilds are both ground- and cavity-nesting, and Apidae is the largest-bodied and farthest-flying guild represented in this study. The guilds that are ground-nesting only, Andrenidae and Halictidae, have generally lower abundances. In spring and summer, Halictid bees, which have the smallest bodies and shortest flight distances, have the lowest average abundance. In fall, this trend is reversed--Halictidae has higher abundances than all other bees in every scenario.

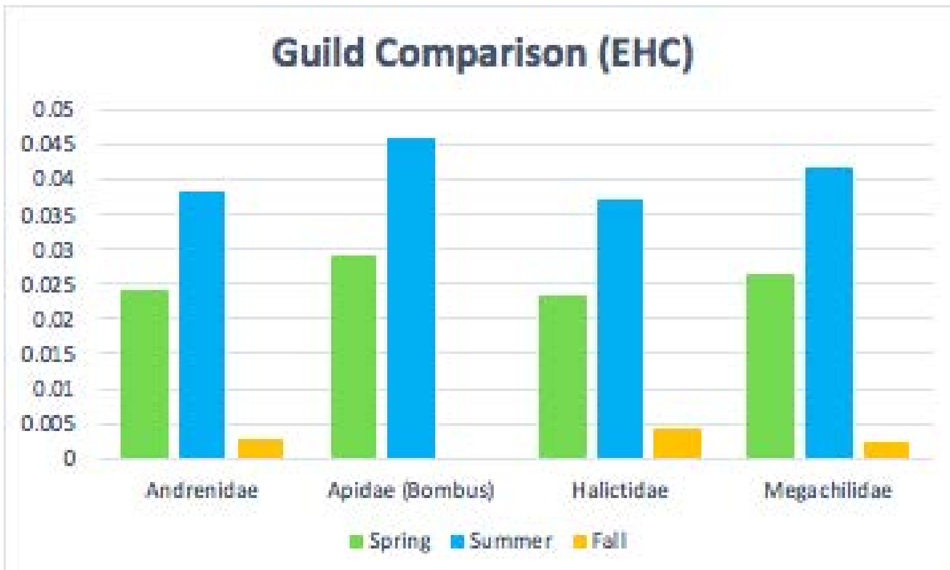


Figure 44. Comparison of the pollinator abundance index of the four guilds in EHC scenario. All other scenarios show similar pattern.

Discussion

Human Dominance

We found that human dominance negatively impacted predicted average pollinator abundance. The Airport City scenarios (AC and EAC) have greater development spread out along Peña Boulevard, so pollinator habitat in that area takes the form of pocket gardens. These gardens are small and relatively distant from one another (spaced at 700 meters). Although small urban patches, like gardens and parks with dense floral resources, can provide habitat for pollinators (Osborne et al., 2008; Williams and Winfree, 2013), in this case they were not able to compensate for the loss of habitat associated with the increase in development.

However, there may be other opportunities to increase the quantity of high quality prairie habitat for pollinators while developing the land along Peña Boulevard. We considered the possibility that land outside this strategic corridor could be converted to habitat, allowing the Airport City to coexist with more extensive prairie restoration. In order to determine the effect on pollinator abundance, we simulated converting the agricultural lands in the north part of the property to restored prairie (Appendix B). The pollinator abundance maps make the change visually clear: the northern part of the property is much darker, indicating a higher abundance, when it is converted to prairie (Fig. 45, 46).

Figure 45: Summer average pollinator abundance map (all guilds) for the original Airport City (AC) scenario, current boundary.

Figure 46: Summer average pollinator abundance map for an alternative Airport City landscape, in which agricultural areas in the north part of the property are converted to prairie, current boundary.

When we modeled the Airport City scenario with this change using the airport property's current boundary (AC Ag-Prairie), it outperformed the Habitat Corridor scenario, in which the prairie is located along Peña Boulevard, and the agricultural areas remain under agricultural cultivation (Fig. 47). When we used the expanded boundary (EAC Ag-Prairie, the EAC landscape in which agriculture was converted to prairie outperformed the Expanded Habitat Corridor in spring and fall, but not summer (Fig. 48).

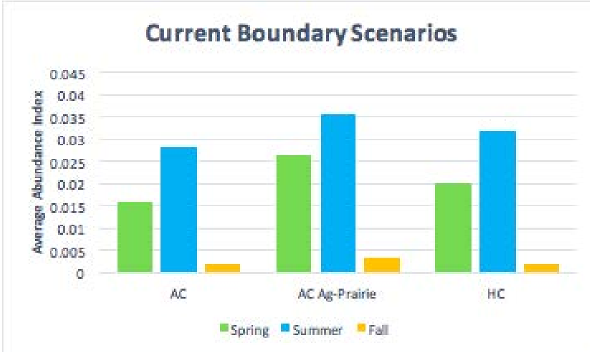


Figure 47: A comparison of the current boundary scenarios, including AC Ag-Prairie, in which the agricultural portion of the property was converted to prairie. The average abundance indices are averaged across the landscape and across all guildes.

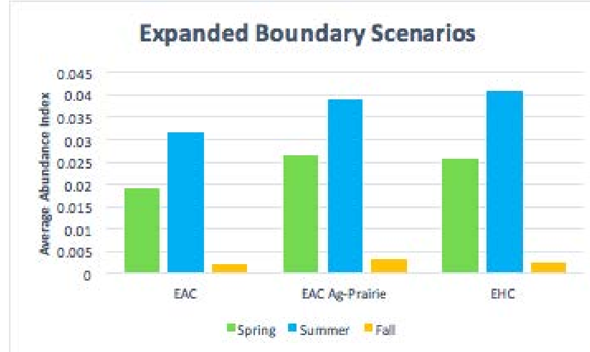


Figure 48: A comparison of the expanded boundary scenarios, including EAC Ag-Prairie, in which the agricultural portion of the property was converted to prairie. The average abundance indices are averaged across the landscape and across all guildes.

This indicates that a scenario with more development can perform better in terms of pollinator abundance than one with less development when the change is offset by restoring other land in the property to native prairie. Because the land along Peña Boulevard has strategic value for development, it might be prudent to consider options like this one, where that development is offset by restoration in another area of the property that is farther from high-traffic corridors like Peña Boulevard.

Boundaries

For both the Airport City and Habitat Corridor scenarios, we found that expanding the airport's property boundary increased the pollinator abundance index score. The expansion provided a greater benefit to pollinators, as measured by the increase in the abundance indices, when the expanded land was prairie (as in the EHC scenario) compared to development (as in the EAC scenario). However, even when the expansion occurred in the developed area, the increase in land increased the average pollinator abundance index across the landscape, suggesting that expanding the boundary would be highly beneficial to pollinator populations. There are also opportunities to "mix and match" between the scenarios we have modeled here. For example, it might be strategic to develop along the Peña Boulevard corridor, but use the land expansion for a restored prairie, rather than more development farther from the primary access roads. In this development pattern, the restored prairie in the expanded could be access from educational campus, an important component of the Airport City.

Expanding the boundary could also provide other benefits that the Crop Pollination model cannot measure. In the Habitat Corridor scenarios, the expansion would provide a greater connection between Arsenal and the airport property. It is likely that this corridor would be used by other wildlife, in addition to pollinator species. Expanding the property boundary might also create opportunities for partnership with other local landowners and stakeholders. Even if the land in question cannot be purchased, it may be possible to cooperatively manage it for enhanced pollinator habitat.

Guilds

Halictid bees, with the shortest average flight distance, have the lowest abundance in all scenarios (spring and summer). Bombus, which has the longest average flight distance, has the highest summer abundance in all scenarios. This difference is likely a consequence of the distance between nesting habitat and floral resources. Bombus has more potential nesting sites, because this guild uses both ground and cavity sites for nesting, and a greater flight distance to access floral resources. In the future, if conservation of smaller bees is indicated, pocket gardens should be spaced to match their flight distance. Nesting sites should also be enhanced to match their needs, and spaced within the same flight distance from floral resources.

Study Limitations

The InVEST pollination model does not account for the presence of pesticides or pesticide drift from agricultural areas, which may be a significant factor influencing pollinator abundance in areas of the property that border agricultural fields. The pollinator abundances for areas that border agricultural land (conventional farms) may therefore be inflated in our model.

Recommendations

General Recommendations

Based on our literature review and research in the course of developing each landscape future and landscape element typology, we developed a list of recommendations that can be applied to pollinator habitat across diverse regions.

1. Plan for all seasons

In order to increase the abundance of pollinators at a site, it is important to be aware of the seasonal duration of activity for native pollinators. The bloom period of flowering species should be temporally matched to the activity period of pollinators in the system. Pollinator activity usually begins in early spring, peaks in the summer, and declines in the fall. Planting designs should follow a similar pattern, with floral resources available throughout the entire period so there are no gaps in resources for pollinators.

2. Prioritize native plants and pollinators

Although the honey bee is a popular and well-known species, there are many more species of native pollinators, including wild bees, butterflies, and moths, whose populations have experienced significant declines over the last decades. Because honey bees are domesticated and managed for agricultural production, conservation efforts should focus on native pollinator species, which often have strong mutualistic relationships with native flowering plants and host species.

3. Incorporate climate change resilience

In order to maintain the stability of pollinator populations over time, it is important to select flowering species that a resilient to the effects of climate change and present a low risk of local extinction. In the Denver region, the most severe impacts of climate change change are predicted to be an increase in average temperature, heat waves, and both the frequency and severity of drought (Finch, Smith, LeDee, Cartron & Rumble, 2012). With this in mind, most of our landscape element typologies include plants that are drought-resistant and adapted to low water conditions, which enhances the likelihood that they will persist in the region over the coming decades.

4. Increase nesting site availability

While flowers are showy and increase a landscape's visual appeal to visitors, nesting sites may not be as aesthetically pleasing. Patches of bare ground, for example, might seem out of place in a garden or park. However, if nesting sites are not located within flight range from sites like gardens and parks, pollinators will not have access to those dense floral resources. We recommend the use of strategically designed nesting sites, as well as natural nesting sites in restored prairie areas, in order to maintain the aesthetics of the site while increasing pollinator abundances. Educational signage around nesting sites in pollinator gardens may also increase public acceptance (Fig. 49).

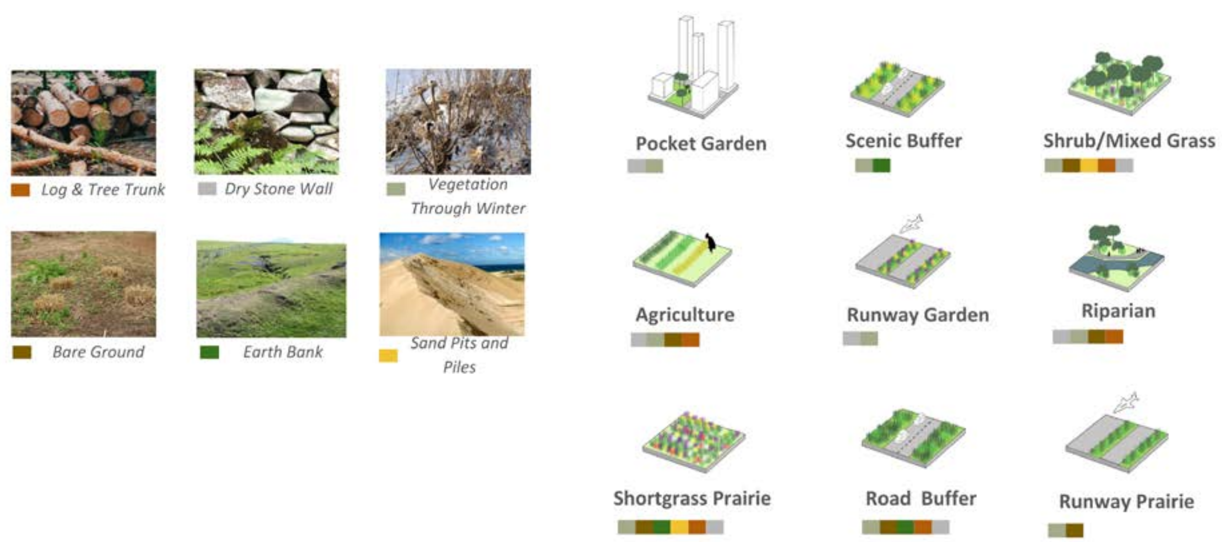


Figure 49. Examples of nesting sites and their corresponding potential applicable landscape element typologies.

5. Provide host plants for butterflies and moths

Larval food sources are a necessary component of pollinator habitat, and help maintain and grow populations of butterflies and moths. Many butterfly and moth larvae require specific host plants in order to feed. For native pollinators, these plants will be native plant species that are already well-adapted to the region. However, many consider the leaf damage caused by feeding caterpillars unsightly, and this should be taken into account in the planting design. For example, it might be prudent to place host plants in the prairie areas rather than the pocket gardens of the Airport City.

6. Consider small-bodied pollinators

Small-bodied pollinators have shorter flight distances, and are disadvantaged by large distances between habitat patches. In order to increase abundances of smaller pollinators, resources must exist in patches spaced within their flight range. An awareness of the size of the smallest pollinators in the system and their corresponding flight range is key to creating a planting design that allows them to access both nesting sites and floral resources.

Site-Specific Recommendations

Based on the pollinator abundances indices predicted by the InVEST Crop Pollination model for each scenario, we developed a second set of recommendations particular to the DEN site.

1. Survey current plant diversity

Our planting typologies were designed based on an understanding of the native species of the region as well as an eye towards the regional consequences of climate change. However, without a survey of the plants currently present on the site, it is difficult to know exactly what degree of restoration is necessary. An understanding of the plant diversity currently at the site would also improve our ability to predict what plants might thrive in each sector in the future. Before any restoration is undertaken, it is advisable to survey the site as well as a neighboring reference site. In this case, the restored prairies at Arsenal would likely work well as a reference.

2. Prioritize restoring large patches of native prairie

Our landscape futures with larger patches of restored prairie and shrubland performed better, in terms of predicted pollinator abundance, than landscape futures with more development and smaller restored prairies. All four scenarios include the restoration of the west side of the property, which is currently under agricultural cultivation, to shortgrass prairie with native grasses and flowering plants. With this in mind, the ideal method of enhancing pollinator abundance is to restore the region's native natural communities.

The abundance of pollinators on the airport property may depend on the amount of land that can be restored to prairie. In our alternative Airport City scenario, in which the northern and eastern agricultural areas were also converted to prairie, pollinator abundance was higher than in the Habitat Corridor Scenario. While it is likely not possible to convert all of the agriculture on the property to prairie, these results suggest the as restoration increases, pollinator abundance will increase. The option to restore these northern and western segments of the property also provides a way in which pollinator abundance could be maximized while still developing the strategic Peña Boulevard corridor.

3. Consider expanding the boundaries of the property

The pollination model results suggest that operating under an expanded boundary results in higher pollinator abundances, even if the expansion region is developed as part of the Airport City. If it is possible to purchase or cooperatively manage land that is adjacent to both the airport property and Arsenal, we recommend expanding the corridor that links the two sites. Expanding the boundary provides the greatest boost to pollinator abundance when the expansion is prairie, so even if the Airport City is built along Peña Boulevard, we recommend an expansion of prairie rather than development.

Appendix A: Ground Nesting Availability Index

The ground nesting availability index is based on four variables: soil stability, bare ground availability, drainage, and aspect. The weights are determined by pairwise comparison. Each cell in the following matrix is the importance of row relative to column. (1= equal importance, 3 = slightly more important, ⅓ = slightly less important, etc.) The cells were then standardized with the sum of corresponding column. The row average of the standardized matrix is the weight to use in the final calculation.

	Bare Ground	Soil Stability	Drainage	Aspect
Bare Ground	1	1/3	3	5
Soil Stability	3	1	5	7
Drainage	1/3	1/5	1	3
Aspect	1/5	1/7	1/3	1
Total	4.53	1.68	9.33	16

Table 18: matrix with pairwise comparison of the importance of four variables.

	Bare Ground	Soil Stability	Drainage	Aspect	Weight
Bare Ground	0.22	0.20	0.32	0.31	0.26
Soil Stability	0.66	0.60	0.54	0.44	0.56
Drainage	0.07	0.12	0.11	0.19	0.12
Aspect	0.04	0.09	0.04	0.06	0.06

Table 19: standardized matrix with final weights. Cell value = cell value in table 1/ column total; The weight is the average of each row

A consistency check was also performed to ensure the relative importance of the variables remained consistent in the process. The consistency is measured by consistency ratio, CR, the ratio between the consistency index of the matrix (CI) and that of a randomly generated matrix (RI). For 4 variables, CI = (sum of column total * corresponding weight-4)/3, and RI = 0.9. The resulting CR= 0.065 < 0.1. Therefore, the weights are consistent and can be applied. The final result runs as follows: soil nesting availability index = 0.56*soil stability + 0.26*bare ground availability + 0.12*drainage + 0.06*aspect.

Each of the four variables is scored from 0-5, where 0 stands for very poor nesting condition, and 5 for very good. The soil stability score and bare ground availability score are estimated from the proposed typology. The drainage and aspect are obtained from USGS survey data. The calculated index were then rescaled from 0-1 for use in the model. The scores for each category are listed in the tables below.

Name	Stability Score	Bare Ground Score
Non-nesting sites (Paved areas)	0	0
Roadside Buffer	3	3
Showy Flowers	2	2
Riverside	4	4
Shortgrass Prairie	5	5
Mixed gras/shrub	5	4
Park	3	2
Pocket Gardens	3	1
Agriculture converted to Prairie	5	5
Arsenal	5	5
Agriculture	0	3

Table 20: soil stability and bare ground availability for each typology

Drainage	Score
No information	0
Poorly/ Excessively Drained	1
Somewhat poorly/ excessively Drained	3
Well Drained	5

Table 21: drainage scores

Aspect	Score
North	1
East/ West	3
South	5

Table 22: aspect scores

However, such scoring method is not suitable for developed areas with pocket gardens, as only a small portion of the area is gardens. In this case, we calculated the percentage of land occupied by pocket gardens for each of these typologies in each scenario, and used them to multiply the scores calculated with the above method.

	Scenario AC	Scenario EAC	Scenarios HC & EHC
Education	0.000122217734	0.000121	NA
Mixed Use	0.000231647	0.000099	0.000127063
Office	0.000137635	0.000136	0.000150443
Retail	0.000181531	0.000178	0.000263119

Table 23: ratio of pocket garden- covered land of different typologies in each scenarios.

Appendix B: Agriculture Converted to Prairie

Alternative VII: Agriculture Converted to Prairie

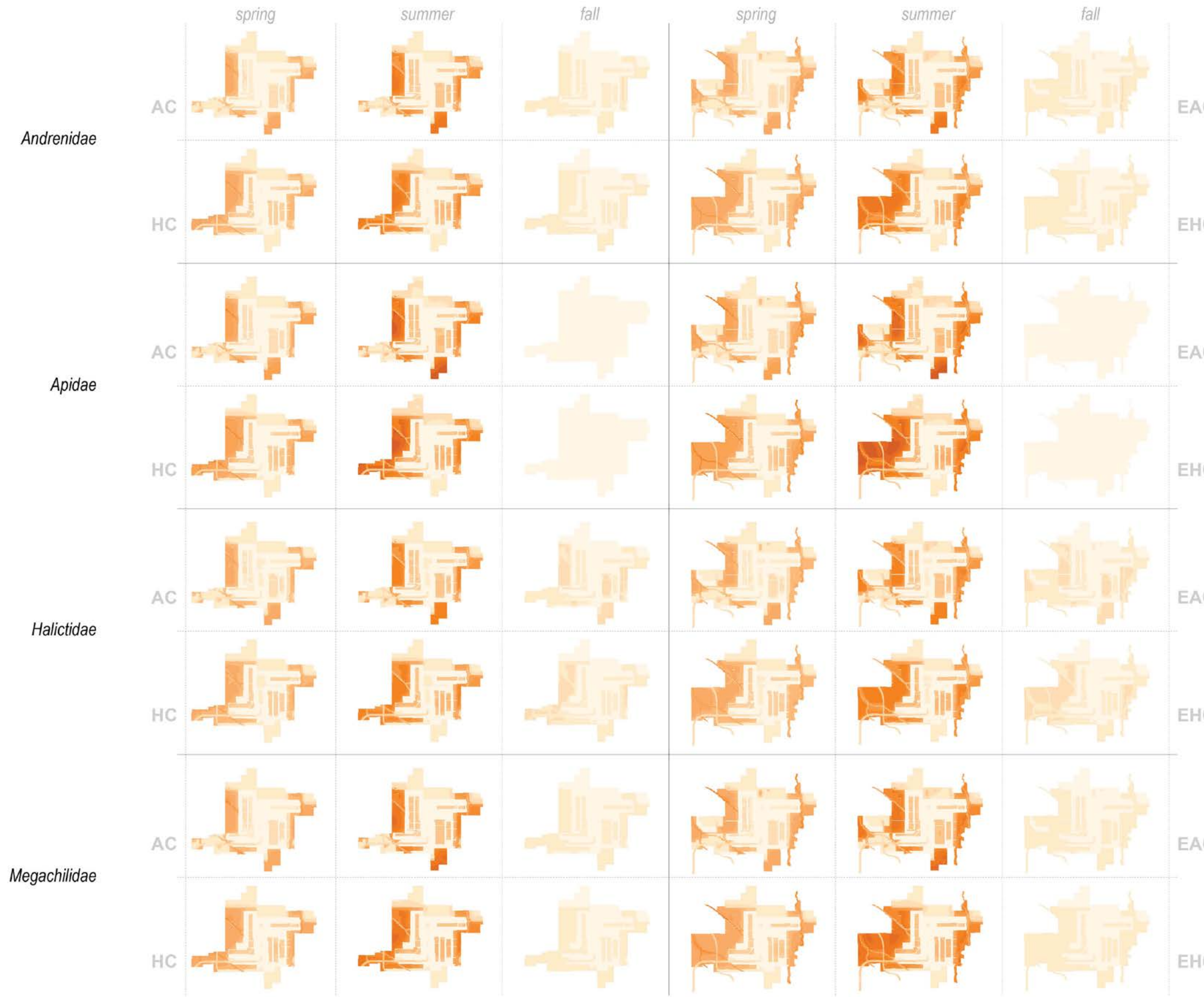
The prairie will be created on the previous agriculture land. Species we chose here will be easily established, with a greater focus on grasses in the first years of the restoration. As the restoration progresses, more flowering species can be planted. Species marked with an asterisk (*) are noted for tolerating high nitrogen levels in former agricultural land. Prairie Junegrass is also quick to establish, which prevents non-native species from taking over during the process of restoration.

<table>
<tr><th>Common Name</th><th>Scientific Name</th><th>Bloom Color</th><th>Bloom Period</th></tr>
<tr><td>Blue Grama</td><td>Bouteloua gracilis</td><td rowspan="4" colspan="2">Graminoids</td></tr>
<tr><td>Prairie Junegrass</td><td>Koeleria macrantha</td></tr>
<tr><td>Sideoats Grama</td><td>Bouteloua curtipendula</td></tr>
<tr><td>Slender Wheatgrass</td><td>Elymus Trachycaulus</td></tr>
<tr><td>Golden Crownbeard*</td><td>Verbesina encelioidea</td><td>Yellow</td><td>Spring-Fall</td></tr>
<tr><td>Greenthread*</td><td>Thelesperma filifolium</td><td>Yellow</td><td>Spring-Summer</td></tr>
<tr><td>Spreading Buckwheat*</td><td>Eriogonum effusum</td><td>White</td><td>Summer</td></tr>
</table>

Table 24: Species list for agriculture lands converted to prairie

Appendix C: Pollinator Abundance Maps

Figure 50: 48 detailed maps by guild by season, spatially comparing the performances of four scenarios in terms of the potential to support pollinators. Darker color indicates higher pollinator abundance index.



References

Asakawa, S., Yoshida, K., & Yabe, K. (2004). Perceptions of urban stream corridors within the greenway system of Sapporo, Japan. *Landscape and urban planning*, 68(2), 167-182.

Aviation Environment Federation. (n.d.). Biodiversity and Wildlife. Retrieved from https://www.aef.org.uk/issues/biodiversity/

Aviation Environment Federation. (n.d.) Aviation Environment Federation Planning Guide. Retrieved from http://www.aef.org.uk/uploads/PlanningGuide2.pdf

Baker, Douglas C. & Freestone, Robert (2010). The airport city : a new business model for airport development. In Macario, Rosario & Van de Voorde, Eddy (Eds.) *Critical Issues in Air Transport Economics and Business*. Routledge/Taylor and Francis Group, Oxon, United Kingdom, 150-164.

Barash, S., Covington, J., & Tamulonis, C. (2000). Preliminary Data Summary Airport Deicing Operations (Revised) Report EPA-821-R-00–016. *United States Environmental Protection Agency, Washington*.

Baska, H. (2017, August 6). *Bee colonies take flight once more, with some help from airport apiaries.* CNBC. Retrieved from: https://www.cnbc.com/2017/08/04/bee-colonies-take-flight-once-more-with-some-help-from-airport-apiaries.html

Baxter, G., Wild, G., & Sabatini, R. (2014). A sustainable approach to airport design and operations: Case study of Munich airport. *PRCC 2014 Engineers Australia Convention*, 227-237.

Bernos, M. (2009). Underground wetlands reduce deicing fluid disposal at Buffalo Int'l. *Airport Improvement*. Retrieved from: http://www.airportimprovement.com/article/underground-wetlands-reduce-deicing-fluid-disposal-buffalo-intl

Bilot, D. (2014). Pollinators & the City. *The Field: ASLA Professional Practice Networks Blog*. Retrived from: https://thefield.asla.org/2014/12/12/pollinators-the-city/

Bradfield, K. N. E. (1945). Development and Design. Some Notes on Australian Airports. Aircraft, 11–13.

Brenner, K. (May 26, 2011). Pollinator profile: the painted lady. *Pollinator Pathway.* Retrieved from http://www.pollinatorpathway.com/pollinator-profile-the-painted-lady/

Buffalo Grass. (n.d.). Retrieved January 15, 2018, from http://www.illinoiswildflowers.info/grasses/plants/buffalo_grass.htm

Burel, F., & Baudry, J. (1995). Social, aesthetic and ecological aspects of hedgerows in rural landscapes as a framework for greenways. *Landscape and Urban Planning*, 33(1-3), 327-340.

Cane, J. H. & Tepedino, V. J. (2001). Causes and extent of declines among native North American invertebrate pollinators: Detection, evidence, and consequences. *Ecology and Society*, 5(1), online.

Carvalho, I. D. C., Calijuri, M. L., Assemany, P. P., Silva, M. D. F. M., Moreira Neto, R. F., Santiago, A. D. F., & Souza, M. H. B. D. (2013). Sustainable airport environments: a review of water conservation practices in airports. *Resources, Conservation and Recycling*, 74, 67-75.

Chance, W. (n.d.) Ground or Digger Bees Attack Landscapes. Retrieved from http://caes2.caes.uga.edu/commodities/turfgrass/georgiaturf/LandscapeAlert/Digger%20Bees%20(5-10).html

Chandu, A. (2017). The world's first purpose-built Airport City: Melbourne Airport, Tullamarine. *Planning Perspectives*, 32(3), 373-400.

Chappell, M. A. (1982). Temperature regulation of carpenter bees (Xylocopa californica) foraging in the Colorado Desert of southern California. *Physiological Zoology*, 55(3), 267-280.

Chicago Department of Aviation (n.d.). Apiary. Retrieved from http://www.flychicago.com/community/environment/apiary/pages/default.aspx

City and County of Denver Department of Aviation. (2008). Accessed Nov. 5th, 2017 via https://www.flydenver.com/about/administration/airport_master_plans

City and County of Denver Department of Aviation. (2012). Accessed Nov. 5th, 2017 via https://www.flydenver.com/sites/default/files/masterplan/masterPlanBrochure.pdf

City and County of Denver, Department of Aviation. (2013). Accessed Nov. 25th, 2017 via https://www.flydenver.com/sites/default/files/environmental/sustainReport2013.pdf

City and County of Denver Financial Report. (2016). Accessed Nov. 5th, 2017 via https://www.flydenver.com/about/financials/financial_reports

City and County of Denver Department of Aviation. (2017). DEN Sustainability Policy. Accessed Nov. 5th, 2017 via https://www.flydenver.com/about/administration/stewardship

City and County of Denver Department of Aviation. (2017). Environmental Management . Accessed Nov. 15th, 2017 via https://www.flydenver.com/about/administration/environmental_management

Clement, S. L. (1973). The nesting biology of Melissodes (Eumelissodes) rustica (Say), with a description of the larva (Hymenoptera: Anthophoridae). *Journal of the Kansas Entomological Society*, 516-525.

Coeterier, J. F. (1996). Dominant attributes in the perception and evaluation of the Dutch landscape. *Landscape and urban planning*, 34(1), 27-44.

Conway, T. (2006). Can Broad Land Use Policies Maintain Connections Between Protected Green Spaces in an Urbanizing Landscape? *Landscape Journal*, 25, 218-227.

Corbet, S. A., & HUANG, S. Q. (2016). Small bees overheat in sunlit flowers: do they make cooling flights?. *Ecological Entomology*, 41(3), 344-350.

Countryman, W. & Murrow, C. (2000). Economic analysis of contour tree buffer strips using present net value. *Journal of Soil and Water Conservation*, 55, 152–160.

City and County of Denver Department of Aviation (2011). Denver Airport Layout Plan Narrative Report. Accessed Nov. 5th, 2017 via https://www.flydenver.com

Denver, Colorado, Denver Zoning Code art. IX, § 9.5.1 (2017).

City and County of Denver Department of Aviation (n.d.). Retrieved January 22, 2018, from https://www.flydenver.com/about/press_kit/ranking

Drecker, K. (2007). Central Mixedgrass Prairie Ecological System (Central Shortrgrass Prairie Ecoregion Version) Ecological Integrity Assessment. Prepared for: Colorado Natural Heritage Program, Colorado State University.

Environment Colorado. (n.d.). Bee Friendly Food Alliance. Retrieved December 13, 2017 from: https://www.fws.gov/refuge/Rocky_Mountain_Arsenal/wildlife_and_habitat/index.html

Finch, D. M., Smith, D. M., LeDee, O., Cartron, J. L. E., & Rumble, M. A. (2012). Climate change, animal species, and habitats: Adaptation and issues (Chapter 5).

Fisher, D. J., Turley, S. D., Turley, B. S., Yonkos, L. T., Ziegler, G. P., & Knott, M. H. (1995). The acute whole effluent toxicity of storm water from an international airport. *Environmental Toxicology and Chemistry*, 14(6), 1103-1111.

Flughafen München GmbH. (2013). Perspectives: sustainability and annual report 2012. Retrieved from http://www.munich-airport.de/media/download/general/publikationen/en/ib2012.pdf

Flughafen Zürich AG. (2011). *Annual Report of Flughafen Zürich AG*. Zurich: Zurich Airport.

Flughafen Zürich AG. (2008). *2008 Sustainability Report*. Zurich: Unique.

Frankie, G. W., Thorp, R. W., Schindler, M., Hernandez, J., Ertter, B., & Rizzardi, M. (2005). Ecological patterns of bees and their host ornamental flowers in two northern California cities. *Journal of the Kansas Entomological Society*, 78(3), 227-246.

Front Range Wild Ones. (n.d.) Native Plants, Natural Landscapes. Retrieved December 13, 2017 from: https://frontrangewildones.wordpress.com/

Fry G. L. A. (2001). Multifunctional landscapes-- towards transdisciplinary research. *Landscape and Urban Planning*, 31,99-115

Geuze, A. & Buijs, M. (2014). West 8 Airport Landscape: Schiphol, Scenario 04: Building the Urban Forest, Spring 2014. Retrieved from: https://scenariojournal.com/article/airport-landscape/

Giustozzi, F., Toraldo, E., & Crispino, M. (2012). Recycled airport pavements for achieving environmental sustainability: an Italian case study. *Resources, Conservation and Recycling*, 68, 67-75.

Gobster, P. H., Nassauer, J. I., Daniel, T. C., & Fry, G. (2007). The shared landscape: what does aesthetics have to do with ecology?. *Landscape ecology*, 22(7), 959-972.

Gobster, P. H., & Westphal, L. M. (2004). The human dimensions of urban greenways: planning for recreation and related experiences. *Landscape and Urban Planning*, 68(2), 147-165.

Goulson, D., Hughes, W. O. H., Derwent, L. C., & Stout, J. C. (2002). Colony growth of the bumblebee, Bombus terrestris, in improved and conventional agricultural and suburban habitats. *Oecologia*, 130, 267-273.

Goverde, M., Schweizer, K., Baur, B. & Erhardt, A. (2002). Small-scale habitat fragmentation effects on behavior: experimental evidence from the bumblebee Bombus veteranus on calcareous grasslands. *Biological Conservation*, 104(3), 293-299.

Graham, A. (2014). Sustainability and the Small Airport. In: *Seventh International Forum on Shipping, Ports and Airports (IFSPA)*, Hong Kong.

Graham, J. B. (2016). Working landscapes: transdisciplinary research on bioenergy and agroforestry alternatives for an Illinois watershed. Retrieved from U-M Deep Blue. Accessed 12 February 2018.

Graham, J. B., Nassauer, J. I., Currie, W. S., Ssegane, H., & Negri, M. C. (2017). Assessing wild bees in perennial bioenergy landscapes: effects of bioenergy crop composition, landscape configuration, and bioenergy crop area. *Landscape Ecology*, 32, 1023-1037.

Hands, D. E., & Brown, R. D. (2002). Enhancing visual preference of ecological rehabilitation sites. *Landscape and Urban Planning*, 58(1), 57-70.

Hatfield, R., Jepsen, S., Lee-Mäder, E., Black, S. H., & Shepherd, M. (2012). *Conserving Bumble Bees: Guidelines for Creating and Managing Habitat for America's Declining Pollinators*. Xerces Society for Invertebrate Conservation.

Helfand, G. E., Park, J. S., Nassauer, J. I., & Kosek, S. (2006). The economics of native plants in residential landscape designs. *Landscape and Urban Planning*, 78(3), 229-240.

Helzer, C. (September 20, 2017). The painted lady butterfly: this year's poster child for insect migration. The Prairie Ecologist. *Retrieved from https://prairieecologist.com/2017/09/20/the-painted-lady-butterfly*-this-years-poster-child-for-insect-migration/

Hendrix, S. D., Kwaiser, K. S., & Heard, S. B. (2010). Bee communities (Hymenoptera: Apoidea) of small Iowa hill prairies are as diverse and rich as those of large prairie preserves. *Biodiversity Conservation*, 19(6), 1699-1709.

Heppner J.B. (2008). Skipper Butterflies (Lepidoptera: Hesperiidae). In: Capinera J.L. (eds) E*ncyclopedia of Entomology*. Springer, Dordrecht.

Idaho Museum of Natural History. (n.d.). Insects of Idaho: Butterfly Families. *Digital Atlas of Idaho*. Retrieved from: http://imnh.isu.edu/digitalatlas/bio/insects/insefr.htm

Ison, J. L., Wagenius, S., & Jacquemyn, H. (2014). Both flowering time and distance to conspecific plants affect reproduction in *Echinacea angustifolia*, a common prairie perennial. *Journal of Ecology*, 102(90), 920-929.

IUCN Red List of Threatened Species. Version 2017-1. <www.iucnredlist.org>. Downloaded on 29 August 2017.

Jorgensen, A., Hitchmough, J., & Calvert, T. (2002). Woodland spaces and edges: their impact on perception of safety and preference. *Landscape and urban planning*, 60(3), 135-150.

Jorgensen, A., Hitchmough, J., & Dunnett, N. (2007). Woodland as a setting for housing-appreciation and fear and the contribution to residential satisfaction and place identity in Warrington New Town, UK. *Landscape and Urban Planning*, 79(3), 273-287.

Kalinke, L. (2013). Innovations in Sustainable Airport Planning Efforts: A Case Study of Hartsfield-Jackson International Airport. Retrieved from: https://smartech.gatech.edu/handle/1853/48763

Kaplan, R., & Austin, M. E. (2004). Out in the country: sprawl and the quest for nature nearby. *Landscape and urban planning*, 69(2), 235-243.

Kasarda, John D. Airport cities and the aerotropolis: The way forward. *Global Airport Cities,* ed. J. Kasarda (2010): 1-31.

Kazda, T, Caves, B & Kamenický, M. (2007). Environmental control. *Airport design and operation*. Kazda, A. & Caves, R. E. (eds). Emerald Group Publishing, Bingley, UK, 457-500.

Keane, T. D. (1990). The role of familiarity in landscape aesthetics: A study of tallgrass prairie landscapes (Doctoral dissertation).

Kearns, C. A., Oliveras, D. M., & Lay, C. R. (2017). Monitoring the conservation status of bumble bee populations across an elevation gradient in the Front Range of Colorado. *Journal of Insect Conservation*, 21(1), 65-74.

Keasar, T. (2002). Conservation of native pollinators via honeybee conservation. *Ecology and Society,* 5(2), [online]. URL: http://www.consecol.org/vol5/iss2/resp5/

Koch, J., Strange, J., & Williams, P. H. (2012). *Bumble bees of the western United States*. San Fransisco, CA: US Forest Service.

Lewis, J. L. (2008). Perceptions of landscape change in a rural British Columbia community. *Landscape and urban planning*, 85(1), 49-59.

Lindemann-Matthies, P., & Bose, E. (2007). Species richness, structural diversity and species composition in meadows created by visitors of a botanical garden in Switzerland. *Landscape and Urban Planning*, 79(3), 298-307.

Lindemann-Matthies, P., Junge, X., & Matthies, D. (2010). The influence of plant diversity on people's perception and aesthetic appreciation of grassland vegetation. *Biological Conservation*, 143(1), 195–202.

Liner, M. O. (2011). ADF treatment system: Buffalo niagara int'l. *Airport Business*, 25(24).

Lonsdorf, E., Kremen, C., Ricketts, T., Winfree, R., Williams, N., & Greenleaf, S. 2009. Modelling pollination services across agricultural landscapes. *Annals of Botany*, 103, 1589– 600.

Lyster, C. (2013). The Future of Mobility: Greening the Airport. *Places Journal*. Retrieved from: https://placesjournal.org/article/the-future-of-mobility-greening-the-airport/

Mahmoud, M., Liu, Y., Hartmann, H., & Winter, L. (2009). A formal framework for scenario development in support of environmental decision-making. *Environmental Modelling & Software*, 24, 798-808.

McFrederick, Q. S. & LeBuhn, Q. (2006). Are urban parks refuges for bumble bees Bombus spp. (Hymenoptera: Apidae)? *Biological Conservation*, 129(3), 372-382.

Meehan, T. D., Gratton, C., Diehl, E., Hunt, N. D., Mooney, D. F., Ventura, S. J., Barham, B. L., & Jackson, R. D. (2013). Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PLoS One*, 8(11).

Metro Denver. (2017). Metro Denver Economic Development Corporation. Accessed Nov. 5th, 2017. Retrieved from http://www.metrodenver.org/do-business/demographics/

Michener, C. D. (2000). *The bees of the world* (Vol. 1). JHU press

Moir, W. H. & Trlica, M. J. (1976). Plant communities and vegetation pattern as affected by various treatments in the shortgrass prairies of Northeastern Colorado. *The Southwestern Naturalist*, 21(3), 359-371.

Moissett, B., & Buchanan, S. (2010). *Bee basics: an introduction to our native bees*. USDA, Forest Service. (n.d.). Retrieved January 20, 2018, from http://www.inchem.org/documents/icsc/icsc/eics0595.htm

Nassauer, J. I. (1995). Messy ecosystems, orderly frames. *Landscape journal*, 14(2), 161-170.

Nassauer, J. I. (2011). Care and stewardship: From home to planet. *Landscape and Urban Planning*, 100(4), 321-323.

Nassauer, J. I. & Corry, R. (2004). Using normative scenarios in landscape ecology. *Landscape Ecology*, 19, 343-356

Nassauer, J. I., Wang, Z., & Dayrell, E. (2009). What will the neighbors think? Cultural norms and ecological design. *Landscape and Urban Planning*, 92(3), 282-292.

National Academies of Sciences, Engineering, and Medicine. (2008). *Airport Sustainability Practices*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13674.

Noy-Meir, I. (1973). Desert ecosystems: environment and producers. *Annual review of ecology and systematics*, 4(1), 25-51.

Oliver, T. H., Heard, M. S., Isaac, N. J., Roy, D. B., Procter, D., Eigenbrod, F., ... & Proença, V. (2015). Biodiversity and resilience of ecosystem functions. *Trends in ecology & evolution*, 30(11), 673-684.

Osborne, J. L., Martin, A. P., Shortall, C. R., Todd, A. D., Gouson, D., Knight, M. E., Hale, R. J., Sanderson, R. A. (2008). Quantifying and comparing bumblebee nest densities in gardens and countryside habitats. *Journal of Applied Ecology*, 45, 784-792.

Pazwash, H. (2011). *Urban storm water management*, CRC Press, Boca Raton, FL.

Pitt, M., & Smith, A. (2003). Waste management efficiency at UK airports. *Journal of Air Transport Management,* 9(2), 103-111.

Ramanujan, K. (2012 May 22) Insect pollinators contribute $29 billion to U.S. farm income. Retrieved from http://news.cornell.edu/stories/2012/05/insect-pollinators-contribute-29b-us-farm-income

Ratnieks, F. L., & Carreck, N. L. (2010). Clarity on honey bee collapse?. *Science*, 327(5962), 152-153.

Reddy, V. R. R., Verghese, A., Sridhar, V., & Rajan, V. V. (2013). Plant-pollinator interactions: a highly evolved synchrony at risk due to climate change. In: Sing, H., Rao, N., & Shivashankar, K. (eds). C*limate-Resilient Horticulture: Adaptation and Mitigation Strategies*. Springer, India.

Rosenzweig, M. L. (2003). Reconciliation ecology and the future of species diversity. *Oryx*, 37(2), 194-205.

Rozen, J. G. (1964). The biology of Svastra obliqua obliqua (Say), with a taxonomic description of its larvae (Apoidea, Anthophoridae). American Museum novitates; no. 2170.

Rozen, J. G. (1991). Evolution of cleptoparasitism in anthophorid bees as revealed by their mode of parasitism and first instars (Hymenoptera, Apoidea). American Museum novitates; no. 3029.

Salisbury, A., Armitage, J., Bostock, H., Perry, J., Tatchell, M., & Thompson, K. (2015), EDITOR'S CHOICE: Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species?. *Journal of Applied Ecology,* 52, 1156–1164.

Samson, F. B., & Knopf, F. L. (Eds.). (1996). P*rairie conservation: preserving North America's most endangered ecosystem*. Island Press. (p68-69)

Scott, V. L., Ascher, J. S., Griswold, T., & Nufio, C. R. (2011). The bees of Colorado. *Natural History Inventory of Colorado*, 23, 1-100.

Shearer, A. (2005). Approaching scenario-based studies: three perceptions about the future and considerations for landscape planning. *Environment and Planning B: Planning and Design*, 32, 67-78.

Shearer, A., Mouatb, D., Bassett, S., Binford, M., Johnson, C., & Saarinen, J. (2006). Examining develotpment-related uncertainties for environmental management: Strategic planning scenarios in Southern California. *Landscape and Urban Planning*, 77, 359-381.

Stefanescu, C., Páramo, F., Åkesson, S., Alarcón, M., Ávila, A., Brereton, T., Carnicer, J., Cassar, L. F., Fox, R., Heliölä, J., Hill, J. K., Hirneisen, N., Kjellén, N., Kühn, E., Kuussaari, M., Leskinen, M., Liechti, F., Musche, M., Regan, E. C., Reynolds, D. R., Roy, D. B., Ryrholm, N., Schmaljohann, H., Settele, J., Thomas, C. D., van Swaay, C. and Chapman, J. W. (2013). Multi-generational long-distance migration of insects: studying the painted lady butterfly in the Western Palaearctic. Ecography, 36: 474–486.

Sulej, AM, Polkowska, Z & Namieśnik, J. (2012). Pollutants in airport runoff waters, *Critical Reviews in Environmental Science and Technology*, 42(6), 1691-1734.

Swetnam R.C., Ragou P., Firbank L.G., Hinsley S.A. and Ballamy P.E. (1998). Applying ecological models to altered landscapes: scenario-testing with GIS. *Landscape and Urban Planning*, 41, 3–18.

Taylor, L. (n.d.). Bouteloua gracilis (H.B.K.) Lag. ex Steud. Retrieved January 15, 2018, from http://jan.ucc.nau.edu/plants-c/bio414/species%20pages/bouteloua%20gracillis.htm

The Grassland Biome. (n.d.). Retrieved January 15, 2018, from http://www.ucmp.berkeley.edu/glossary/gloss5/biome/grassland.html

Thomas, C & Hooper, P. (2013). Sustainable development and environmental capacity of airports, in NJ Ashford, HPM Stanton, CA Moore, P Coutu & JR Beasley (eds), *Airport operations*, 3rd edn. McGraw-Hill, New York, 553-578.

Todorova, A., Asakawa, S., & Aikoh, T. (2004). Preferences for and attitudes towards street flowers and trees in Sapporo, Japan. *Landscape and urban planning*, 69(4), 403-416.

Tonietto, R., Fant, J., Ascher, J., Ellis, K., & Larkin, D. (2011). A comparison of bee communities of Chicago green roofs, parks, and prairies. *Landscape and Urban Planning*, 103(1), 102-108.

Torchio, P. F., & Trostle, G. E. (1986). Biological notes on Anthophora urbana urbana and its parasite, Xeromelecta californica (Hymenoptera: Anthophoridae), including descriptions of late embryogenesis and hatching. *Annals of the Entomological Society of America*, 79(3), 434-447.

US EPA. Colony Collapse Disorder (n.d.) Retrieved from https://www.epa.gov/pollinator-protection/colony-collapse-disorder#main-content

US Fish and Wildlife Service. (September 14, 2017). Butterfly migration identification. Medium. Retrieved from https://medium.com/@USFWS/butterfly-migration-identification-366e3b76ea5f

U.S. Fish & Wildlife Service. (2017). Accessed on Nov. 15th, 2017 via https://www.fws.gov/refuge/Rocky_Mountain_Arsenal/

US Fish and Wildlife Service. (n.d.). *Wildlife & Habitat. Rocky Mountain Arsenal Wildlife Refuge*. Retrieved from: https://www.fws.gov/refuge/Rocky_Mountain_Arsenal/wildlife_and_habitat/index.html

Van Haveren, B. P. (1974). S*oil water phenomena of a shortgrass prairie site* (Doctoral dissertation, Colorado State University. Libraries).

Vanker, S., Enneveer, M. & Mäsak, M. (2013). Implementation of environmentally friendly measures at *Tallinn Airport, Aviation*, 17(1), 14-21.

Velthuis, H. H., & Van Doorn, A. (2006). A century of advances in bumblebee domestication and the economic and environmental aspects of its commercialization for pollination. *Apidologie*, 37(4), 421-451.

Venner, M. (2014) Habitat approach to streamlining Section 7: Colorado Department of Transportation's shortgrass prairie initiative. T*ransportation Research Record: Journal of the Transportation Research Board,* 1792, 109-117.

Voskaki, A. (March 23, 2015). Airport Environmental Impacts. *Green Clean Guide.* Retrieved from: http://greencleanguide.com/airport-environmental-impacts/

Williams, N. M. & Winfree, R. (2013). Local habitat characteristics but not landscape urbanization drive pollinator visitation and native plant pollination in forest remnants. *Biological Conservation*, 160, 10-18.

Williamson, J. (2013). Digger bee. Retrieved from http://www.clemson.edu/extension/hgic/hot_topics/2013/05digger_bees.html

Wilson, J. S., & Carril, O. J. M. (2015). *The Bees in Your Backyard: A Guide to North America's Bees*. Princeton University Press.

Winfree, R., Aguilar, D. P., Vázquez, G., & LeBuhn, M. A. (2009). A meta-analysis of bees' responses to anthropogenic disturbance. *Ecology*, 90, 2068-2076.

Xiao, Y., Li, X., Cao, Y, & Dong, M. (2016). The diverse effects of habitat fragmentation on plant-pollinator interactions. *Plant Ecology*, 217(7), 857-868.

Xerces Society. Pesticide Causes Largest Mass Bumble Bee Death on Record. (2013, June 21). Retrieved from: http://

xerces.org/2013/06/21/pesticide-causes-largest-mass-bumble-bee-death-on-record/

Young, S. B. & Wells, A. T. (2011). *Airport planning and management*, 6th edn, McGraw-Hill, New York.