Technical report for

# Permeable landscapes for climate change adaptation in and around Boulder and northern Jefferson Counties

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December 16, 2020

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17 December 2020

Incompatible land uses, compounded by recent and likely future climate change have impacted our natural ecosystems and reduced the permeability of open space and park lands in Boulder and northern Jefferson Counties by roughly two-thirds. A primary climate-smart strategy to conserve biodiversity is to allow species to adapt to habitat change by ensuring a connected landscape. As such, this project is designed to inform decision making about opportunities to maintain, protect, restore, and manage for wildlife connectivity across. Potential opportunities to facilitate movement within and surrounding the open space and parks, habitats, and landscapes are identified by mapping "hot spots" across four major ecosystems using spatial modeling of landscape permeability. This can help inform management by identifying:

- restoration or management activities to facilitate wildlife movement;
- protection of additional adjacent or nearby lands to complement the existing system of protected lands;
- partnering opportunities with adjacent land managers; and
- subsequent analyses to evaluate conservation strategies and for specific situations.

This report benefited from the helpful guidance and feedback from the team of technical advisors: M. Kobza, S. Spaulding, K. vanDenBosch: *Boulder County Parks & Open Space*
B. Anacker, W. Keeley, H. Swanson: *City of Boulder Open Space & Mountain Parks*
C. Beebe, H. King: *Jefferson County Open Space*

## Abstract

This research is designed to inform decision making about the opportunities to maintain, protect, restore, and manage open space and park lands to ensure wildlife connectivity across Boulder and northern Jefferson Counties, Colorado. A primary strategy to address the impacts of climate change on natural systems and biodiversity is to allow ecological systems to adapt to climate change by ensuring a connected landscape. One approach to understanding landscape connectivity is to model climate-induced habitat shifts for specific wildlife species. This is challenging because data are limited on: species-specific life history characteristics, sensitivity to new climate conditions, and capacity to adapt. Moreover, there is high uncertainty in future climate predictions at management relevant scales, especially in a landscape that contains numerous ecotones. As a result, this project measured connectivity using an indicator called landscape permeability, which measures the ability of movement through a landscape while avoiding developed areas with high human activity. Overall, permeability has declined by two-thirds from "natural" (no humans) conditions. Not surprisingly, upper and lower montane areas are much more permeable than lower elevation grassland/shrubland ecosystems, while permeability in riparian/valley bottoms is variable. The resulting maps were analyzed to identify potential opportunities ("hot spots") to facilitate movement through: (a) restoration or management activities; (b) protection of additional adjacent or nearby lands to complement the existing system of protected lands; and (c) partnering with adjacent land managers. The datasets provide a foundation for subsequent analyses to evaluate additional conservation strategies and for specific situations.

Keywords: wildlife connectivity, landscape permeability, climate adaptation, habitat types

## Introduction

The goal of this project is to inform decision making about wildlife connectivity on open space lands in and adjacent to Boulder County, which includes lands managed by Boulder County Parks & Open Space (POS), the City of Boulder Open Space & Mountain Parks (OSMP), and Jefferson County Open Space (OS). A primary strategy to adapt to climate and land use change is to maintain and restore ecological connectivity (i.e. for wildlife movement, plant dispersal, ecological processes such as disturbances like wildfire, and gene flow; Lawler 2009). This project informs decision making and management by POS, OSMP, and OS by providing information about landscape-level connectivity, as an important way to adapt to climate change effects on ecosystems in and around Boulder and northern Jefferson counties. The terms "protected areas" or "system of protected lands" are used below to refer to the open space, parks, and other properties owned or managed by POS, OSMP, and OS, and by adjacent agencies (e.g., US Forest Service, National Park Service, etc.).

A few climate change adaptation strategies have emerged from the scientific literature (Schmitz et al. 2015; Keeley et al. 2018; Thurman et al. 2020), which are roughly grouped into modeling *functional* connectivity recognizes the behavioral response of species to the structure of the landscape (Theobald 2006; Kindlmann and Burel 2009) and can be used typically characterize the shift in habitat use by single-species due to climate change. This approach can be challenging because data are limited on species-specific life history characteristics, sensitivity to new climate conditions, and the capacity to adapt quickly enough. There is high uncertainty in future climate predictions at management relevant scales, especially in a landscape that contains numerous ecotones. *Structural* connectivity, on the other hand, is based on the spatial arrangement of habitats on a landscape and characterizes broader ecosystem and landscape naturalness to understand the "stage" on which species' movements occur (Anderson and Ferree 2010). These strategies are considered to be complimentary, and the choice here of using the structural, coarse-filter conservation approach (Noss 1990) is a precautionary and pragmatic one, as it recognizes the relatively high uncertainty about how future wildlife and broader habitats will evolve with climate change in the coming decades, particularly at management-relevant scales.

Briefly, structural, coarse-filter conservation is rooted in the idea that ecological systems operate within landscapes and are typically understood in terms of composition, structure, and function (Noss 1990). A landscape with high ecological integrity supports and maintains a community of organisms and ecological processes that are comparable to natural habitats within a region (Parrish et al. 2003). Central to landscapes with high ecological integrity is connectivity, which is commonly defined as the degree to which a landscape facilitates movement of species, populations, and genes among resource patches (Taylor et al. 1993). Providing connectivity is the most common strategy recommended for ecological adaptation to climate change (Heller and Zaveleta 2009; Keeley et al. 2018).

In this project, landscape permeability is defined as an indicator of how easily wildlife can move across the landscape while avoiding human modified areas (Theobald et al. 2012). This indicator is particularly valuable in situations and landscape contexts that have high biogeographic variability and a mixture of management agencies involved (Spencer et al. 2010; Theobald et al. 2012). Permeable landscapes are needed to maintain ecological processes, genetic diversity, and the potential for communities and populations of species to adapt as the climate and land use change (Anderson et al. 2016). Recently, Keeley et al. (2018) found that evaluating for climate change adaptation provides a practical approach as a proxy for movement patterns of a wide range of species that has relatively low uncertainty. By mapping the permeability of the landscape, insight and understanding can be gained about how natural ecosystems adapt to climate change impacts (Keeley et al. 2018).

The central premise of this work is that *landscapes with higher permeability will allow wildlife and plant communities to adapt more easily to the effects of climate and land use changes to the landscape*. Mapping and assessing landscape permeability then is intended to inform landscape planning and management by identifying potential protection, mitigation, and/or restoration actions to maintain or improve habitat connectivity patterns and corridors, and to understand potential priorities and opportunities when collaborating with adjacent land owners/managers. It is a trans-boundary approach, recognizing that the dynamics of the ecological systems transcend political and administrative boundaries. This work potentially benefits all land management agencies in the study area because adaptation to climate change will likely require wildlife movement and ecological flows that cross political boundaries.

This report describes: (1) the study area composed of open space and surrounding lands; (2) spatial data used to map open space and parks (and other managed natural lands) and the degree to which lands are natural (i.e. are have less urban or residential use, lower road density, etc.); (3) modeling of the landscape permeability indicator; (4) potential management applications (i.e. scenarios) to explore the gaps, vulnerabilities, and opportunities to maintain, protect, or mitigate; and (5) key results and a brief discussion with recommendations. Because the maps are numerous and detailed, a basic map viewer can be used to view the data online at: https://davidtheobald8.users.earthengine.app/view/landscape-permeability-BoJeffCo.

## Methods

### Study area

The core of the study area was defined as all lands (open space and adjacent privately-owned areas) within Boulder County and northern Jefferson County (Figure 1a). Based on discussions with the technical advisory team, the study area was extended north to approximately US 34 and south to US 6 and I-70. To account for cross-boundary wildlife movement and ecological flows to and through the complex of city, county, and adjacent parks and open space lands, lands within roughly 5 miles of the core area were included in the study area. The analysis of landscape permeability naturally applies to lands beyond this study area, but the study area as defined here attempts to balance the trade-offs between extent (more inclusive of surrounding lands) and resolution (features relevant to management).

Table 1 provides a summary of the spatial data compiled and used to represent habitat types, designated protected areas with a legal guidance to protect natural qualities, and land use pressures such as built-up areas, roads, croplands, and energy development (referred to as the degree of human modification). A map of the overall study area, major habitat types (i.e. life-zones), designated protected lands (e.g., open space, parks, conservation easement), and land use patterns (e.g., built-up areas, roads, trails, etc.) are provided in Figure 1.

## Modeling permeability

This study follows a common framework to analyze landscape connectivity that identifies: the purpose, features to be connected, resistance to movement, movement process or model, output indicator, and evaluation. Permeability was measured by connecting within protected lands (i.e. OSMP, POS, OS, US Forest Service and National Park Service lands) and out into adjacent areas, for the full study area and then separately for four habitat types (roughly analogous to “life zones”). Separate permeability analyses were conducted for each habitat type to provide habitat-specific results for the upper montane, lower montane, grassland/shrubland, and valley bottom (riparian) habitat types (Table 2, Figure 1b). To map the four habitat types, we grouped individual biophysical settings into one of the life-zones or habitat types (Landfire v1.4 www.landfire.gov; Appendix 1). For example, *Southern Rocky Mountain Ponderosa Pine Woodland* was placed into the lower montane habitat class. Note that valley bottoms were mapped directly from the Landfire land cover classes, which typically represent mainstem, perennial rivers and some smaller order (~2nd) streams, and riparian systems narrower than 30 m are not represented. The full study area provides an overall perspective, and complements habitat type-specific results -- particularly because with future climates the habitat types will likely shift higher in elevation and hence habitat in the future may occupy different locations than they do currently.

We focused on movements and ecological processes in response to human modification -- that is, assuming that movement is restricted by more intense land uses and increased human activities -- (i.e. a “naturalness” approach; Theobald et al. 2012; Keeley et al. 2018). To represent human land use, we used a map of the degree of human modification (Figure 1d), which is a comprehensive representation of human threats, organized as a parsimonious list of stressors, includes estimates of uncertainty, and combined using a robust formula to generate a map of overall modification that ranges from 0.0 to 1.0 (Theobald 2013; Kennedy et al. 2019; Theobald et al. 2020). Primary stressors mapped here include: built-up areas, roads, croplands, and human accessibility/use (see Appendix 2 for a full list of stressors). This modeling approach accounts explicitly for the footprint of land cover as well as the intensity of land use and human activities. Note that data and analyses of trails and visitor use was not investigated here due to pragmatic constraints.

In addition, we also incorporated energetic costs of movement by assuming that moving across steeper slopes is avoided. Also, movements into adjacent habitats incurred additional resistance beyond the originating ecosystem (e.g., species that use lower-montane habitat would avoid moving through grasslands because of lack of cover). The ratio of the length of shared boundary between habitat types was used to adjust the resistance weights (Appendix 3). Note that the results for the full landscape are different than if all habitat types were simply combined, because the probability values are max-normalized and specific to each habitat type.

To model landscape permeability, we used a gradient-based application of the least-cost distance method (Theobald 2006; Theobald et al. 2012). This method calculates cost-distance across a resistance surface that reflects the degree of human modification and topography, with higher accumulated “cost distance” in areas of higher modification and/or slope, where natural and flat locations are equivalent to simple euclidean distance (see Appendix 4). The cost-distance values were used to calculate a “dispersal” probability assuming an exponential function reflecting typical dispersal distances of 5, 10, and 20 km (Urban and Keitt 2001; Saura and

Hortal 2007). The “dispersal” probabilities were then summarized into a landscape permeability indicator by calculating statistics on the permeability values. A strength of this method is that results are easily interpreted, robust, and rigorous because they quantify connectivity based on probabilities and underlying ecological processes (Saura and Hortal 2007; Theobald et al. 2012; Cushman et al. 2014).

Because spatial and environmental data very rarely are normally distributed, the permeability indicator is calculated as the *median* of the dispersal probability values within the full study area and for each ecosystem (along with the median absolute deviation, see Appendix 5). The main results presented below assume moderate movement ability (10 km median distance) and moderate sensitivity to human land use/activities (see Appendix 6 for a sensitivity analysis).

## Identifying adaptation opportunity areas

Three applications of the landscape permeability maps were conducted to identify locations with high opportunity to maintain landscape connectivity (i.e. for wildlife and other processes):

1. “hot spots” or key locations within the system of protected lands that are critical to maintain landscape permeability;
2. locations that are currently not part of the system that are key to landscape permeability; and
3. opportunities to coordinate and partner with managers of adjacent lands.

To highlight “hot spots”, the permeability values were normalized using a z-score, calculated using the median and median absolute deviation (MAD) statistics. These results and datasets support a variety of additional management and policy questions through subsequent analysis of the datasets.

## Results

Landscape permeability within and between the protected lands varies substantially across the study area, with values occuring across the full range of possible values (0.0 to 1.0). Figure 2 shows the pattern of permeability across the entire study area, and that the upper and lower montane areas generally have high permeability values while grassland/shrubland areas have much lower values. The median value for the landscape permeability representing current conditions was 0.2245 (MAD=0.2129; Table 3). This is significantly lower than the permeability indicator for a “natural” landscape with no human modification included, which was 0.7773 MAD=0.3066 (shown in Figure 3a). Figure 3b shows where permeability has been “lost” due to current land uses (human modification) as compared to the natural scenario.

Figure 4 shows the landscape permeability results that were modelled separately for each habitat type. The median of the degree of human modification for the upper-montane, lower-montane, grasslands, and riparian/valley bottom habitat was 0.2363, and was 0.0682, 0.1972, 0.7246, and 0.5682 respectively. Permeability values were reasonably consistent with the degree of human modification values, but permeability provides critical information about the landscape context and pattern of connectivity beyond the general patterns of land use. Appendix 7 provides summary statistics specific to each of the protected area properties (i.e., open space and parks).

## Adaptation opportunity areas

To identify potential opportunities where management of currently protected lands could focus to increase or maintain permeability on protected areas, z-scores of the permeability values -- *just for the protected lands* -- were calculated (Figure 5a). This helps to highlight key locations within the system of protected lands that may be valuable beyond their in-situ level of naturalness (Figure 5b). Figure 6 shows the z-scores for each of the four habitat types, and Table 4 provides the median values for the properties of OSMP, POS, and OS.

To identify key potential opportunities to add additional protected lands to the system of currently protected lands that aim to maximize permeability amongst the protected lands, for example through acquisition or easement, highly permeable non-protected lands (mostly privately owned) are shown in Figure 7.

To identify key potential opportunities to coordinate and partner with managers of adjacent protected lands, Figure 8 shows permeability values along the shared boundaries of land managers, and the z-score maps provide visuals of "hot-spot" locations.

# Discussion

Not surprisingly, human modification has strongly fragmented the landscape of Boulder and northern Jefferson Counties, reducing permeability by two-thirds compared to a landscape devoid of humans. Also not surprising is that upper- and lower-montane habitats have higher permeability than the lower elevation habitats. It is somewhat surprising, however, that there remain vestiges of areas that are well connected and fairly natural. One of those areas is the headwaters of the north St. Vrain and West Fork of the Little Thompson river, with very high permeability values (>0.8) and z-scores (>2.2). Some fragmentation is indicated along Highway 36 just southeast of Estes Park (in Larimer County) and around Allenspark on Highway 7. Another cluster of permeable lands of note is south of Coal Creek canyon along Drew Hill road, with key "bridging" locations just south of Rollinsville on 119, and between Centennial Cone Park and Douglas Mountain Study area (OS). Another important permeable area crossing the lower montane and grass/shrubland habitat is along US 36 between Altona and Lyons (that is well protected with POS and OSMP lands).

## Recommendations and next steps

The novel results generated in this study provide guidance on specific opportunity areas to protect, mitigate, restore, and manage for wildlife connectivity to maintain a permeable landscape. This information, complemented with other data on high biodiversity areas, forest structure and condition, etc., would provide a strong platform to inform conservation planning activities with relevant partners. Further development of an analysis specific to riparian areas at a higher resolution and more detail on cover, species composition, and current and future upstream flow conditions would help refine and bolster the analysis conducted here, particularly for the riparian/valley bottom habitat type. While the study boundary transcends many political and ecological boundaries, it remains too small to adequately capture the overall functioning of the landscape. Potential future studies should expand on the study boundary, identifying the boundary more strongly based on ecological processes, such as the Protected Area Centered Ecosystem approach (Hansen et al. 2011). Including potential impacts of visitor use to open space and park lands on wildlife connectivity in an analysis would also be valuable to inform open space management and decision making. This issue was explored initially, and here we recommend that more consistent and detailed data on visitation patterns (e.g., on and off-trail use) coupled with detailed habitat data are needed. Inclusion of wildlife fencing in the permeability modeling was also explored initially, but because of time constraints was not included in this project. Again, a more thorough and consistent dataset on fencing location, type, height, etc. is needed.

The results of landscape connectivity modeling remain challenging to evaluate and test, particularly for structural connectivity models that aim to be more general and informative for conservation planning. An overlay analysis of the permeability surfaces with elk and mule deer corridors, migration patterns, and highway crossings showed largely consistent patterns. Subsequent work should seek additional ways to quantify the results of the model, or to use the results to identify locations for which additional data (especially field-collected) could be collected to test the results of the permeability model.

This report was focused on investigating the connectivity among protected lands in the study area. Three additional scenarios would be valuable to explore to complement this work: connecting known important wildlife habitat areas (e.g., using Potential Conservation Areas from Colorado Natural Heritage Program), connecting large blocks of land with high ecological integrity (e.g., Theobald et al. 2012), and incorporating climate change data to map riparian climate corridors (Krosby et al. 2018) as another key climate-wise adaptation strategy.

Incompatible land uses, compounded by recent and likely future climate change have impacted our natural ecosystems and reduced the permeability of open space and park lands and the broader landscapes. The results of this project were designed to inform decision making about opportunities to maintain, protect, restore, and manage for wildlife connectivity across landscapes. Potential opportunities to facilitate movement within and surrounding the open space and parks, habitats, and landscapes were identified by mapping "hot spots" across four major ecosystems using spatial modeling of landscape permeability. We believe that these analyses will be valuable to inform management by identifying restoration and management activities to facilitate wildlife movement; protection of additional adjacent or nearby lands to complement the existing system of protected lands; and partnering opportunities with adjacent land managers.

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Table 1. Spatial datasets compiled and used in the landscape permeability analysis.

| Group | Name | Source | Scale |
|---|---|---|---|
| Priority conservation | Important habitat areas | CNHP Potential Conservation Areas v4, 2019 (link) | 1:24,000 |
| Habitat types | Biophysical Setting | LANDFIRE v2.0 (2014) | 30 m |
| Designated protected lands | Management area designations | City of Boulder OSMP (link); downloaded 7/27/2020 | 1:10,000 |
| | Open space | Boulder County (link); downloaded 10/15/2020 | 1:10,000 |
| | Land use classification | Jefferson County (link); downloaded 7/29/2020 | 1:10,000 |
| | State and federal protected lands | USGS PAD-US v2.0 (link); downloaded 5/7/2019 | 1:100,000 |
| Land use pressures | *Degree of human modification (2016) | See Theobald (2020) for methods. Datasets used include: built-up and impervious surfaces from National Land Cover Dataset (2016); agriculture from USDA Cropland Data Layer (2018); transportation (roads and railroads from Census TIGER 2018); energy infrastructure (powerlines, night-lights); and human intrusion | 30 m |
| | Visitor use - trails** | OSMP (link); downloaded 7/27/2020 | 1:10,000 |
| | Visitor use - trails** | OS (link); downloaded 7/27/2020 | 1:10,000 |
| Wildlife movement features | Fences** | OSMP; downloaded 8/10/2020 | 1:10,000 |
| | Wildlife fences** | OS fences (from CPW); downloaded 7/29/2020 | 1:10,000 |

*See Appendix 2 for more details.

**Results in this report do not include these data due to limited project scope.

Table 2. Summaries for each of the ecosystem types by area, proportion, and median elevation, for full study area and for just Boulder County. Elevation is measured as the median value in feet.

| | **Study area** | | **Core area** | | **Boulder County** | | |
|---|---|---|---|---|---|---|---|
| **Ecosystem** | **Acres** | **Percentage** | **Acres** | **Percent age** | **Acres** | **Percentage** | **Elevation** |
| Upper montane | 488,171 | 31.00% | 289,025 | 26.50% | 126,450 | 26.60% | 10,170 |
| Lower montane | 480,206 | 30.50% | 414,687 | 38.00% | 158,426 | 33.40% | 7,586 |
| Grass/shrub | 513,970 | 32.60% | 325,868 | 29.90% | 157,771 | 33.20% | 5,240 |
| Riparian/valley bottoms | 92,069 | 5.80% | 61,646 | 5.60% | 31,996 | 6.70% | 5,273 |
| Total | 1,574,416 | 100.00% | 1,091,227 | 100.00% | 474,643 | 100.00% | 7,339 |

Table 3. Summaries of the landscape permeability indicator calculated from protected areas (e.g., open spaces) within the study area, for the four habitat types and all four combined. “Natural” permeability is calculated to reflect the natural permeability of the landscape devoid of human land uses (but does include energetic costs of movement), while “modified” incorporates the additional resistance to movement due to human modification of the landscapes.

| | **"Natural" permeability** | | **"Modified" permeability** | | **Human modification** | |
|---|---|---|---|---|---|---|
| **Ecosystem** | **Median** | **MAD** | **Median** | **MAD** | **Median** | **MAD** |
| All combined | 0.7773 | 0.3066 | *0.2245 | 0.2129 | 0.2363 | 0.1895 |
| Upper montane | 0.5508 | 0.4511 | 0.2402 | 0.2325 | 0.0682 | 0.0096 |
| Lower montane | 0.6054 | 0.2753 | 0.1855 | 0.1465 | 0.1972 | 0.0957 |
| Grass/shrub | 0.2851 | 0.2226 | *0.0005 | 0.0007 | 0.7246 | 0.1543 |
| Valley bottoms | 0.4492 | 0.2168 | *0.0605 | 0.0601 | 0.5682 | 0.2989 |

*Statistically significant difference with “natural” permeability results.

Table 4. Summaries of metrics for the protected lands for City of Boulder (OSMP), Boulder County (POS), and Jefferson County (OS). Human modification (H) characterizes the land use and human activities, naturalness is the complement of human modification (1-H), and the landscape permeability indicator for the full study area and the four habitat types. Note that naturalness and permeability values are not directly comparable.

| Median values of metric | City of Boulder | Boulder County | Jefferson County |
|---|---|---|---|
| Human modification | 0.6619 | 0.5410 | 0.6980 |
| Naturalness | 0.3381 | 0.4590 | 0.0446 |
| Permeability (overall) | 0.0545 | 0.0875 | 0.1052 |
| Permeability (upper montane) | 0.0000 | 0.0152 | na |
| Permeability (lower montane) | 0.0005 | 0.1439 | 0.1052 |
| Permeability (grass/shrub) | 0.1298 | 0.1120 | 0.0093 |
| Permeability (riparian/valley) | 0.0008 | 0.0144 | 0.0002 |

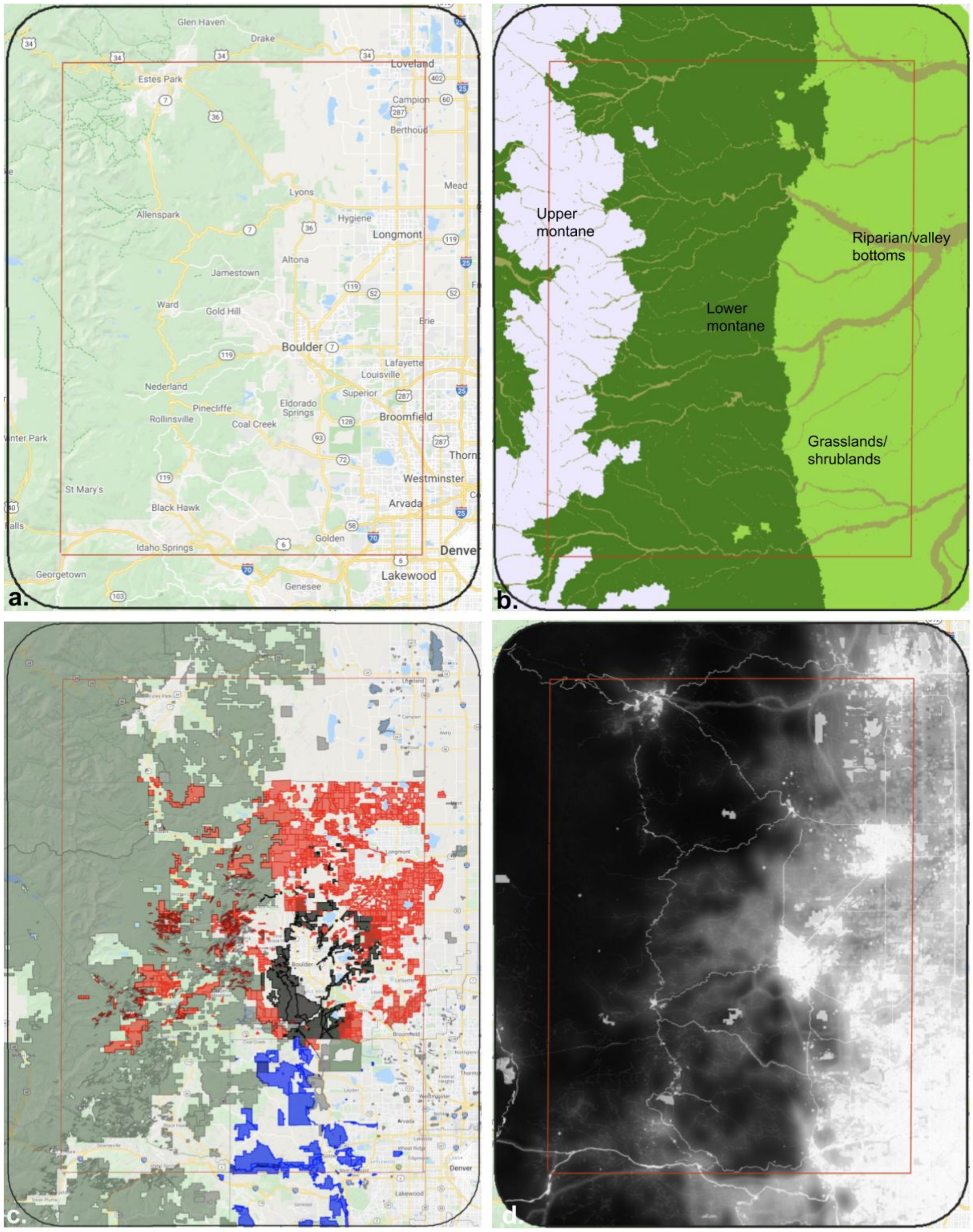


Figure 1. The study area of this project is defined on the northern Front Range of Colorado, focused on Boulder County and adjacent areas. Specifically, this figure shows (a) the "core" of the study area inside the red rectangle, with a 2 mile buffer to minimize artifacts in model results due to edge effects; (b) major habitat types: upper montane, lower montane, grassland/shrublands, and riparian/valley bottoms; (c) open space and park lands including the City of Boulder OSMP (black), Boulder County (red), Jefferson County (blue), and other state and federal lands in grey; (d) the degree of human modification (black low, white high).

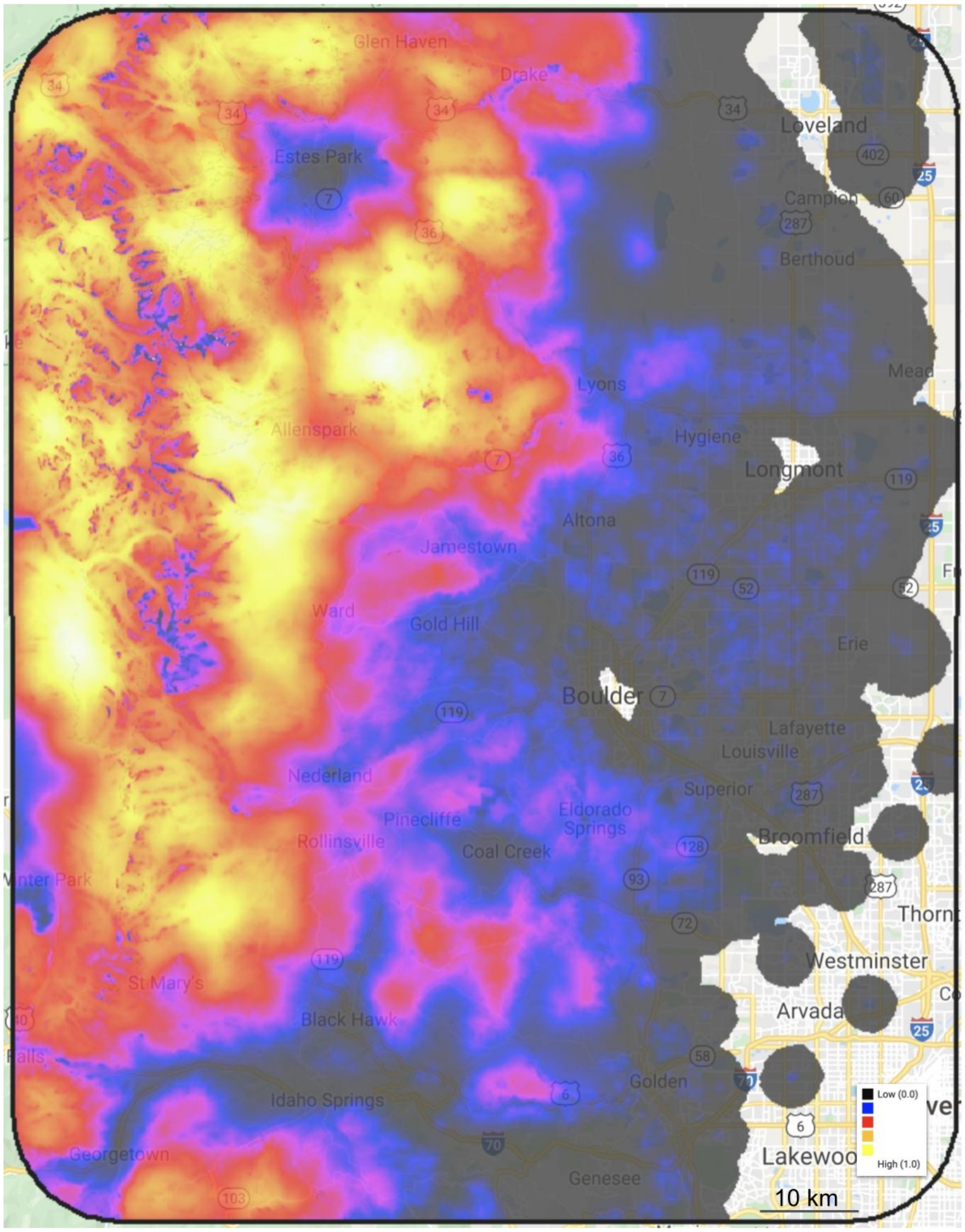


Figure 2. A map of the landscape connectivity of the City of Boulder, Boulder County, and Jefferson County open space and parks, and other formally protected lands. Connectivity is quantified here as the permeability of movement across the landscape, which is reduced in locations with high human development and activities, and higher in more “natural” areas. Upper and lower montane habitat types are generally more permeable, with some reduced permeability nearing highways. Grass and shrubland habitat in the lower elevations have very low permeability. Values can range from 0 to 1.0, and the median value is 0.22 (MAD=0.21) for the full study area. The detailed data underlying this map can be analyzed to identify potential opportunities for various conservation actions, such as potential “corridors” to connect open space and park lands.

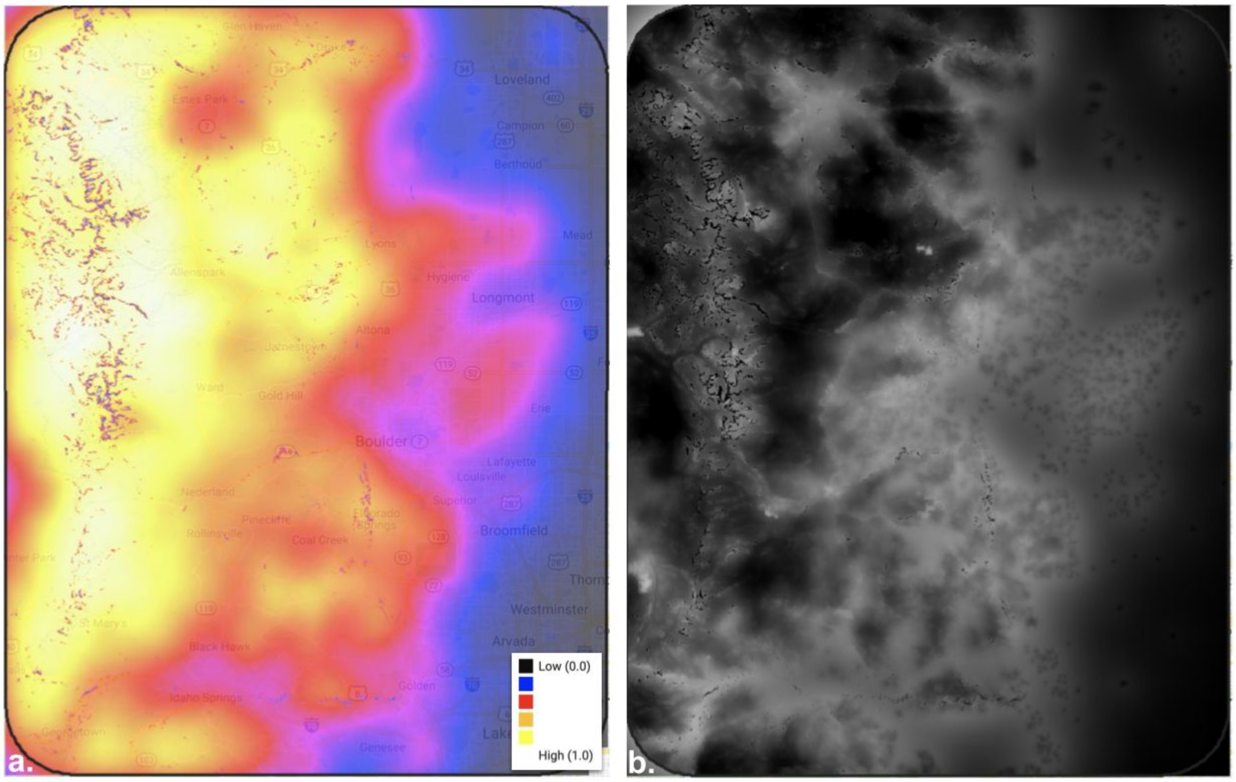


Figure 3. Landscape permeability reflecting “potential natural” conditions, that is devoid of human modification (a), and in (b) the landscape fragmentation or permeability “lost” due to human modification (black lower loss, white higher loss).

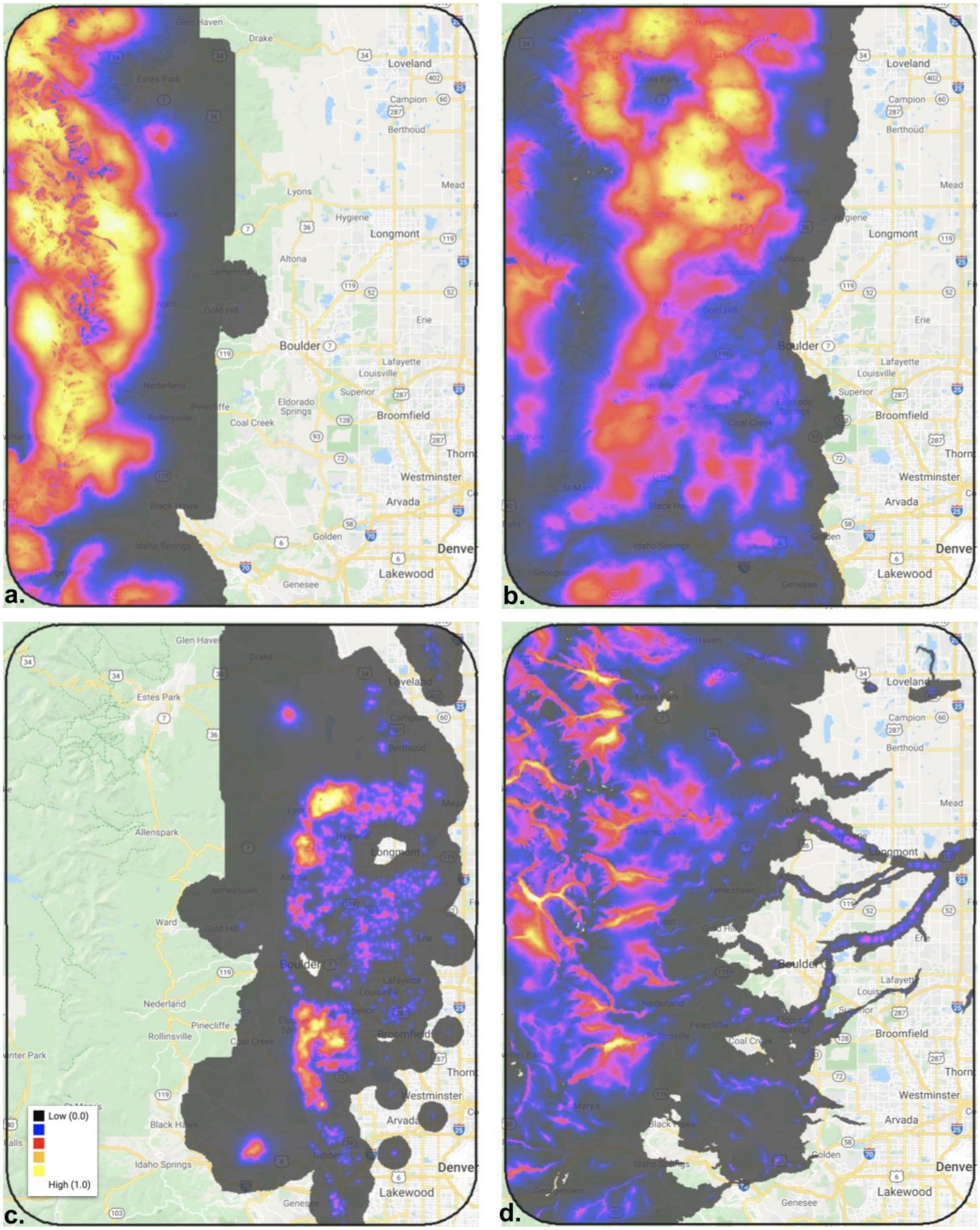


Figure 4. These maps show the landscape permeability values (similar to Figure 2), but modeled separately for each major habitat type: (a) upper montane, (b) lower montane, (c) grassland/shrublands, and (d) riparian/valley bottoms. Note that the permeability results shown here assume a 10 km maximum movement distance and moderate sensitivity to human land use, so connectivity can cross the ecotones between major habitat types.

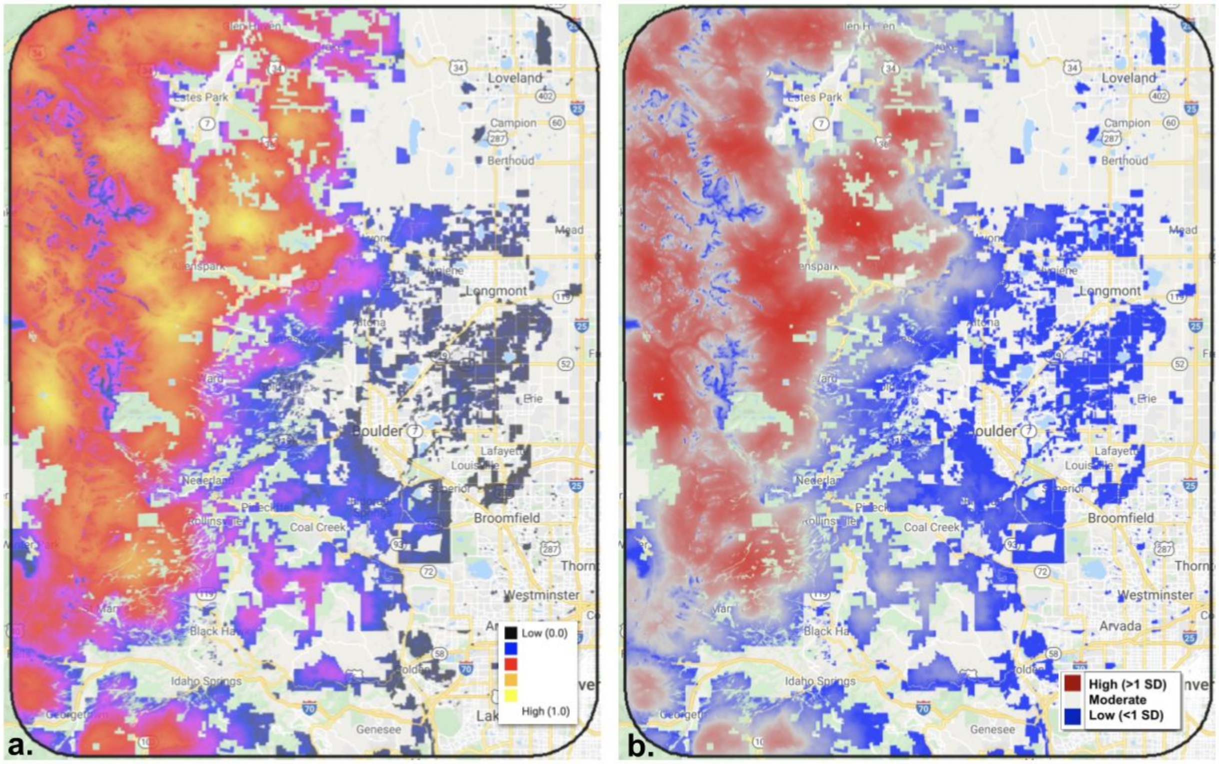


Figure 5. These maps show (a) the permeability values only for the protected lands of the City of Boulder (OSMP), Boulder County (POS), and Jefferson County (OS), and the z-scores normalized for the permeability just for the protected lands.

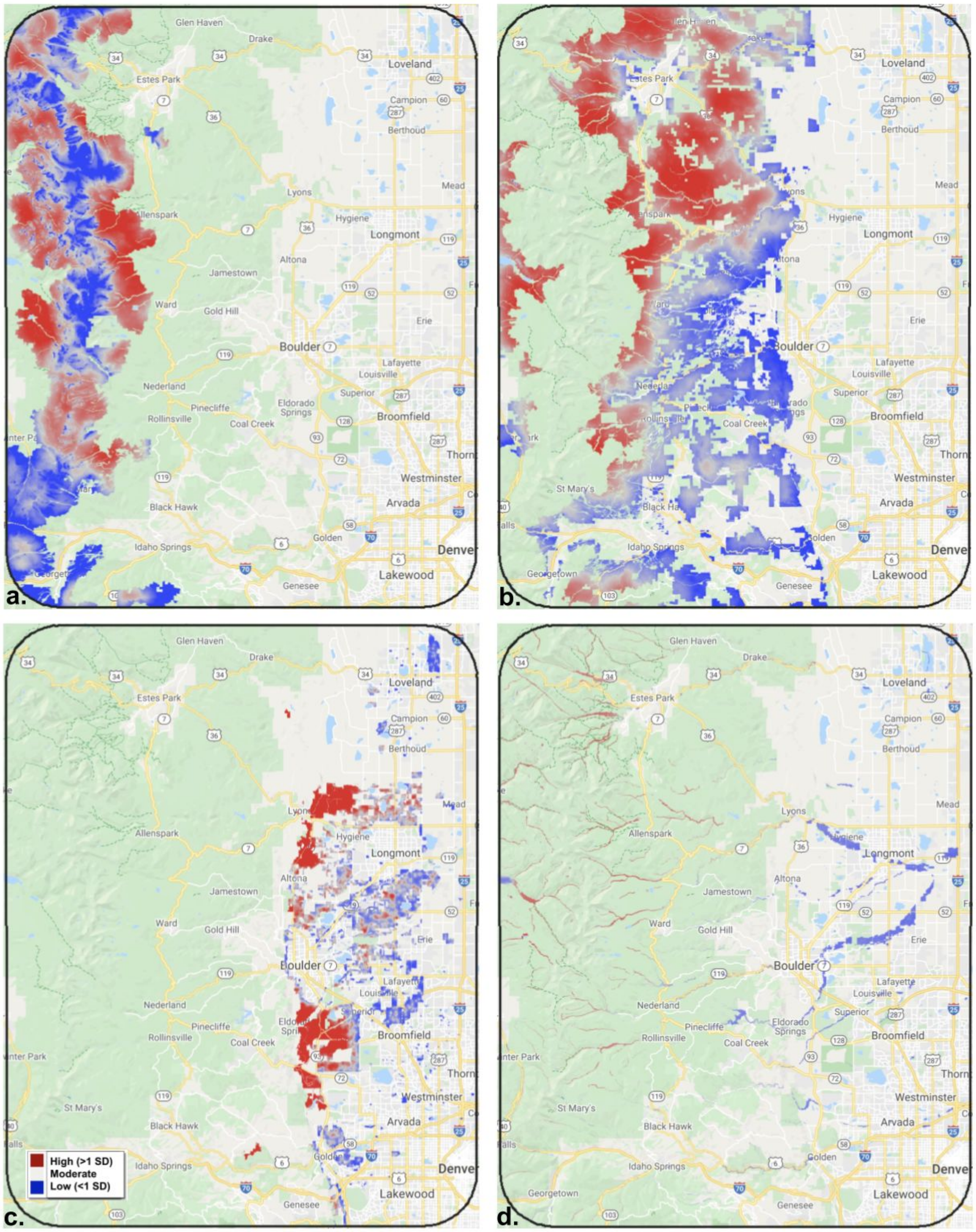


Figure 6. These maps show the "hot spots" or high values (in red), relative to the raw permeability values on protected lands within each major habitat type: (a) upper montane, (b) lower montane, (c) grassland/shrublands, and (d) riparian/valley bottoms. Locations shown in blue can be highly permeable -- but are relatively lower than the permeability values at other locations within a given habitat type.

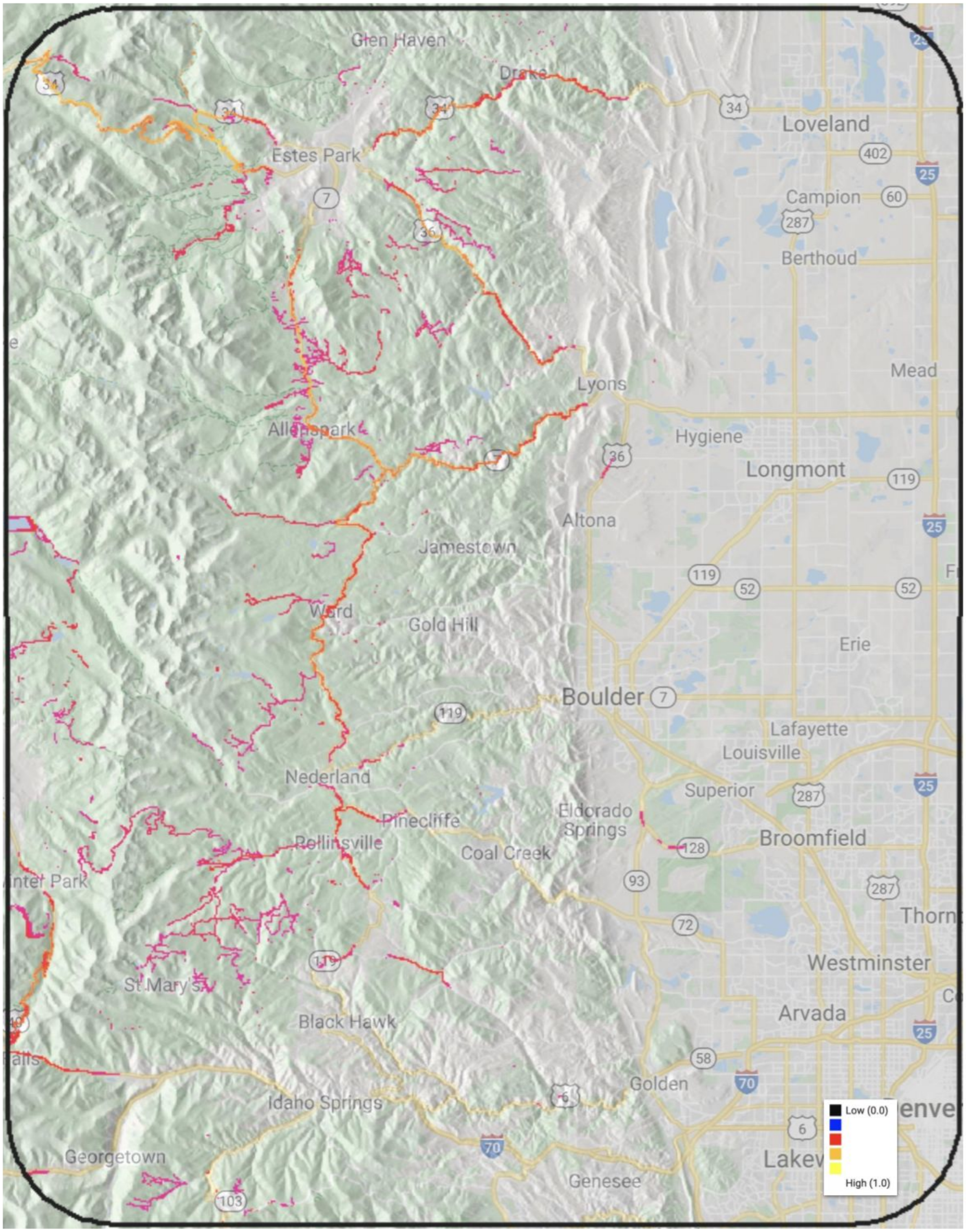


Figure 7. Permeability values for locations adjacent to protected lands with high permeability and low human modification. These include, and are dominated by, transportation corridors.

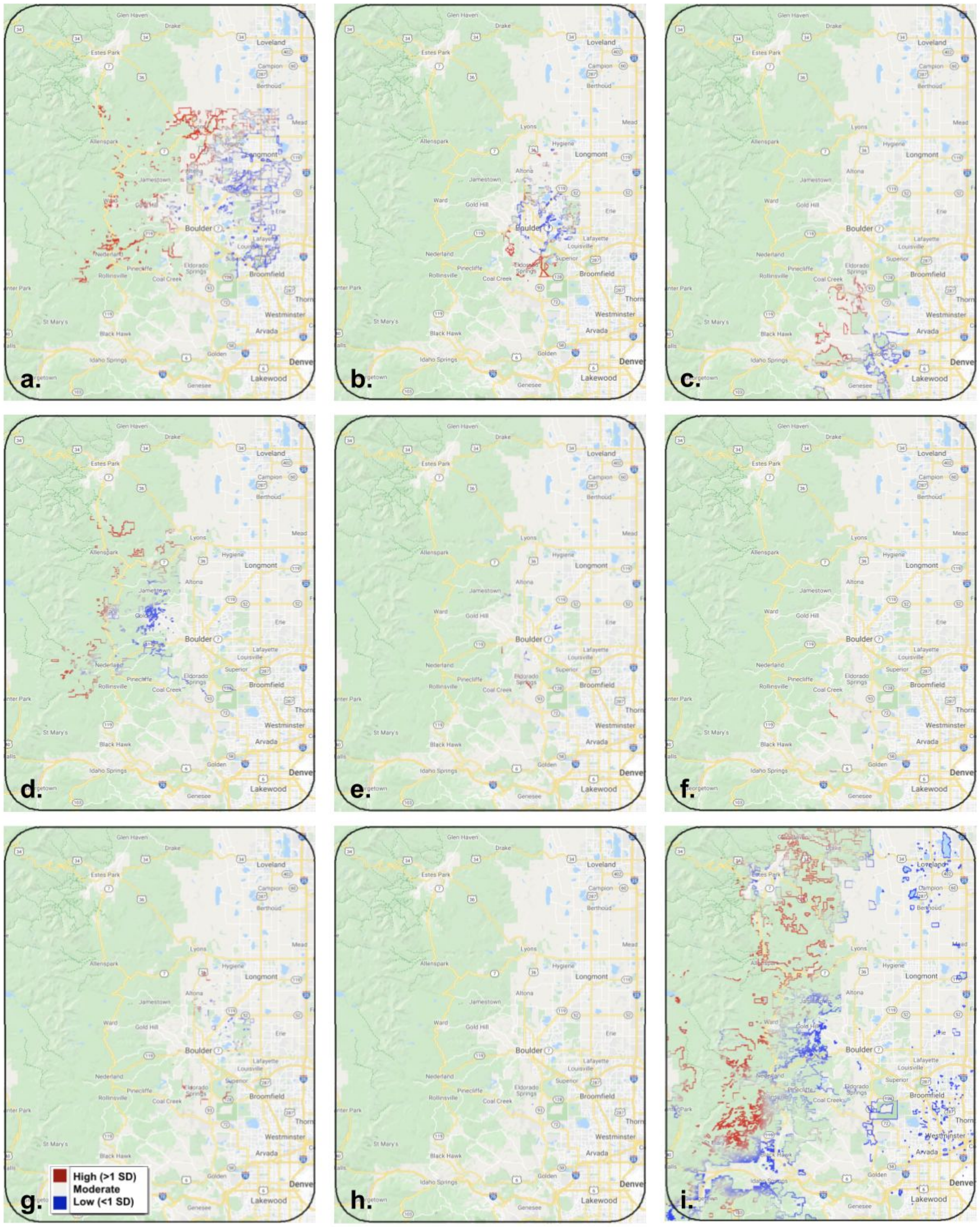


Figure 8. These maps show the z-scores of permeability values specific to the boundaries shared by the City of Boulder (OSMP), Boulder County (POS), and Jefferson County (OS). That is, z-scores are calculated using permeability values within 60 m of shared boundary, specific to a given combination of two entities: (a) POS and private lands; (b) OSMP and private; (c) OS and private; (d) POS and public lands; (e) OSMP and public; (f) OS and public lands; (g) POS and OSMP; (h) POS and OS lands; and (i) protected lands and private lands.