COLORADO FOREST RESTORATION INSTITUTE

Colorado State University

# DRAFT

## Co-benefits Calculator Technical User Guide

Version II

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This document provides technical details on the Peaks to People Water Fund Co-benefits Calculator.

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**Table of Contents**

Co-benefits Calculator ........ 4
Introduction ........ 4
Methods ........ 4
Model Design ........ 6
Treatment Plan ........ 7
Resources and Response Functions ........ 8
Raw Output ........ 10
Summary Output ........ 11
Home Loss Model ........ 11
Results ........ 12
Discussion ........ 18
References ........ 20
Appendix I: Home Loss Model ........ 21
Introduction ........ 21
Methods ........ 21
GIS Processing ........ 22
Model Application and Analysis ........ 24
Results ........ 24
Discussion ........ 29
References ........ 32
Appendix II: Pre-loaded Co-benefits ........ 34

## Co-benefits Calculator

### Introduction

The Co-benefits Calculator is designed to estimate the benefits of fuels treatment to resources at risk to wildfire. Wildfire exposure and effects modeling can use different methods depending on the available data, understanding of wildfire impacts, and intended use of risk assessment products. For example, Stevens et al. (2016) used a “cross-platform modeling approach” to estimate fuel treatment effects on fire severity, smoke production, forest heterogeneity, and avian wildlife habitat. Their approach required five different models including Consume, FlamMap, FarSite, BlueSky, and a custom wildlife habitat model. A workflow dependent on multiple software applications is difficult to automate and update for future landscape conditions by anyone other than a GIS analyst familiar with each model. Additionally, not all resources have detailed wildfire effects models, and detailed wildfire effects modeling approaches require abundant data and dependencies on software that are complex to manage, use, and update. Here we demonstrate a simple and flexible platform to uniformly account for co-benefits across resources.

### Methods

The co-benefits calculator utilizes the same principles behind the Wildfire Risk Assessment Framework (Scott et al. 2013), with slight changes to maintain consistency with the Watershed Investment Tool (WIT). Like the Wildfire Risk Assessment Framework, the co-benefits calculator will quantify resource exposure to wildfire behavior (in our case, Crown Fire Activity [CFA]), translate that exposure to value change, and convert to risk (expected value change) using modeled burn probability. The advantages of this approach are flexibility, consistency, and ease of use. The disadvantages are that resource exposure is measured only *in situ* and resource response is considered uniform for a given CFA class.

The primary inputs to the co-benefits calculator are the spatial locations (raster or vector data) of resources and a table of expected loss by fire type (“response functions”) (Figure 1). Treatment effects on fire behavior are quantified using pre- and post-treatment CFA rasters assembled from the WIT, and modeled burn probability from Short et al. (2016). The rest of the inputs consist of either vector or raster resource locations and tabular data containing response functions and optional buffer distances. A generic risk analysis workflow (Figure 2) is used to automate a set of GIS procedures for any number of resources to summarize the treatment plan effects on hazard, risk, and area in different CFA classes. The workflow is analogous to Wildfire Risk Assessment Framework methods (Scott et al. 2013) except that response functions are described for the three levels of CFA instead of six fire intensity levels. The analysis overlays the resources with pre- and post-treatment fire behavior (CFA), converts fire behavior to expected loss using response functions, and calculates risk by multiplying hazard with burn probability. The raster and vector analyses are identical, except for a buffer step for vector input data to assign the area of influence for point and polyline data. This generic structure makes the calculator highly flexible to end user inputs and simplifies the workflow to only a few steps.

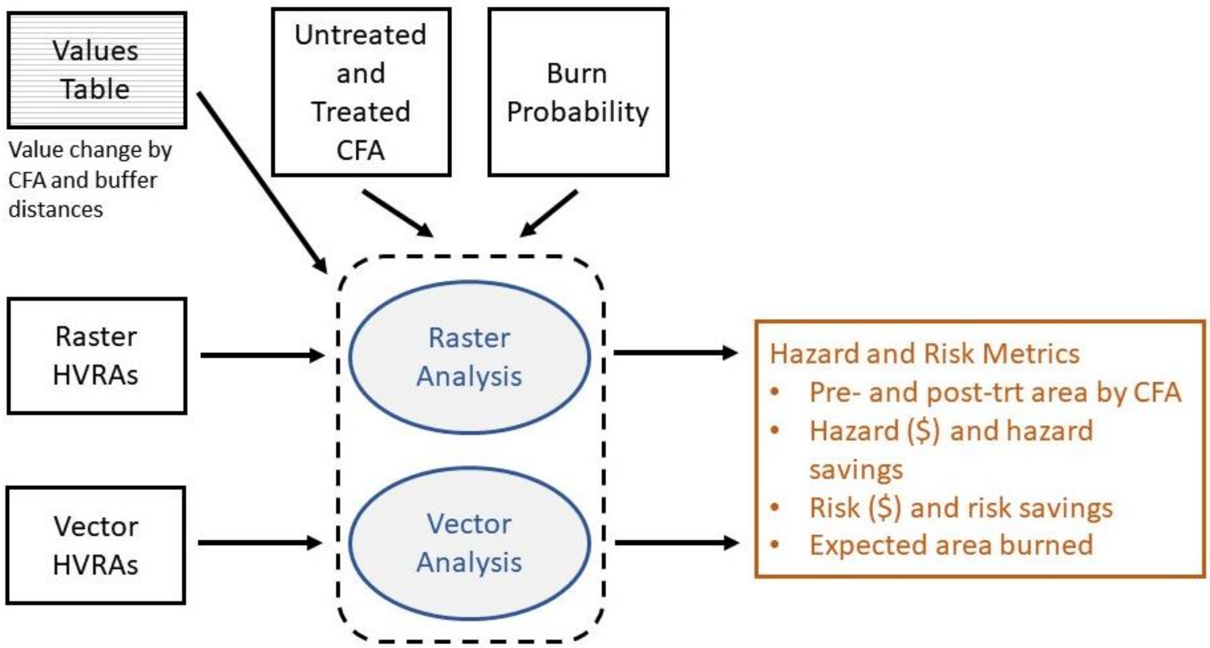


*Figure 1: a generic risk assessment workflow allows great flexibility for accounting for baseline risk and risk reduction for a set of vector or raster resources and assets. HVRA = highly valued resources and assets ("the resources").*

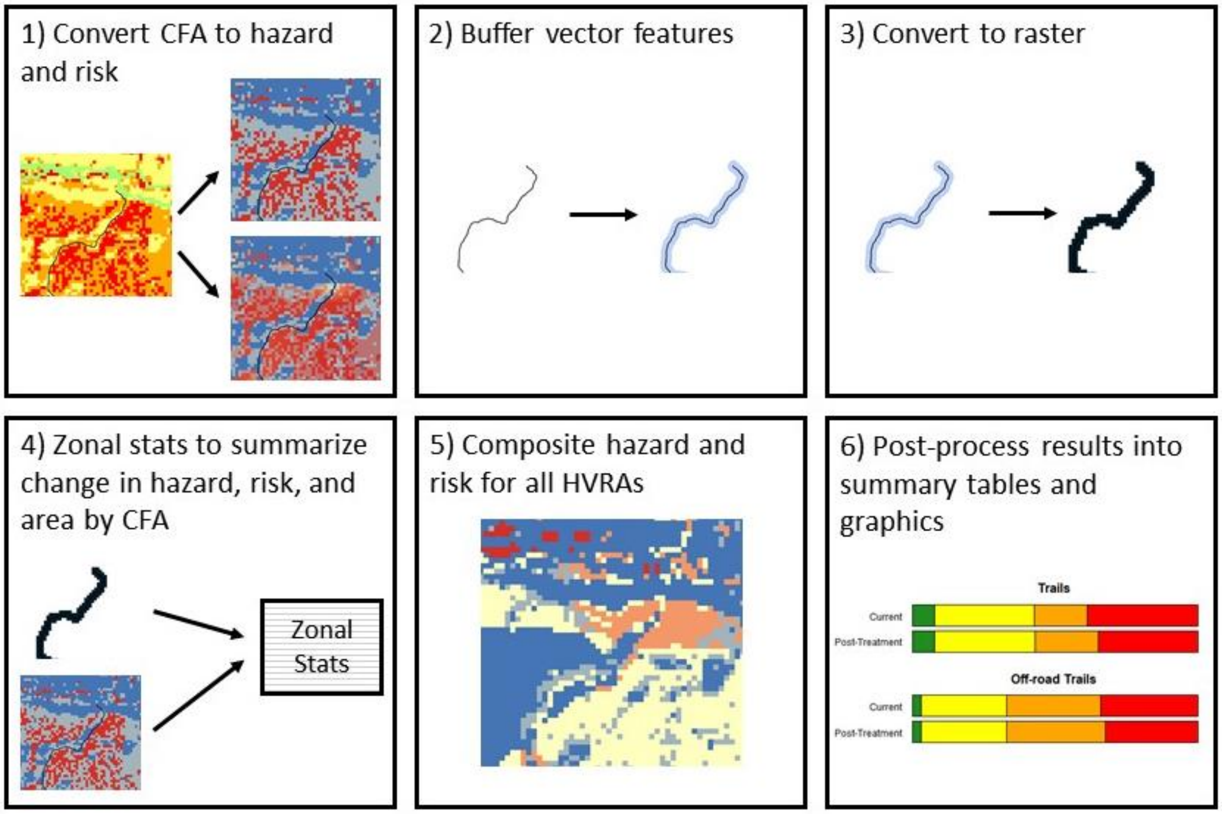


*Figure 2: generic analysis workflow for vector and raster resources.*

### *Model Design*

The co-benefits calculator consists of a graphical user interface (Figure 3) that walks the user through a modeling workflow automated with a combination of Python and R. The co-benefits calculator requires an ArcGIS Desktop license and the pandas package for Python. It was developed and tested using ArcGIS 10.3.

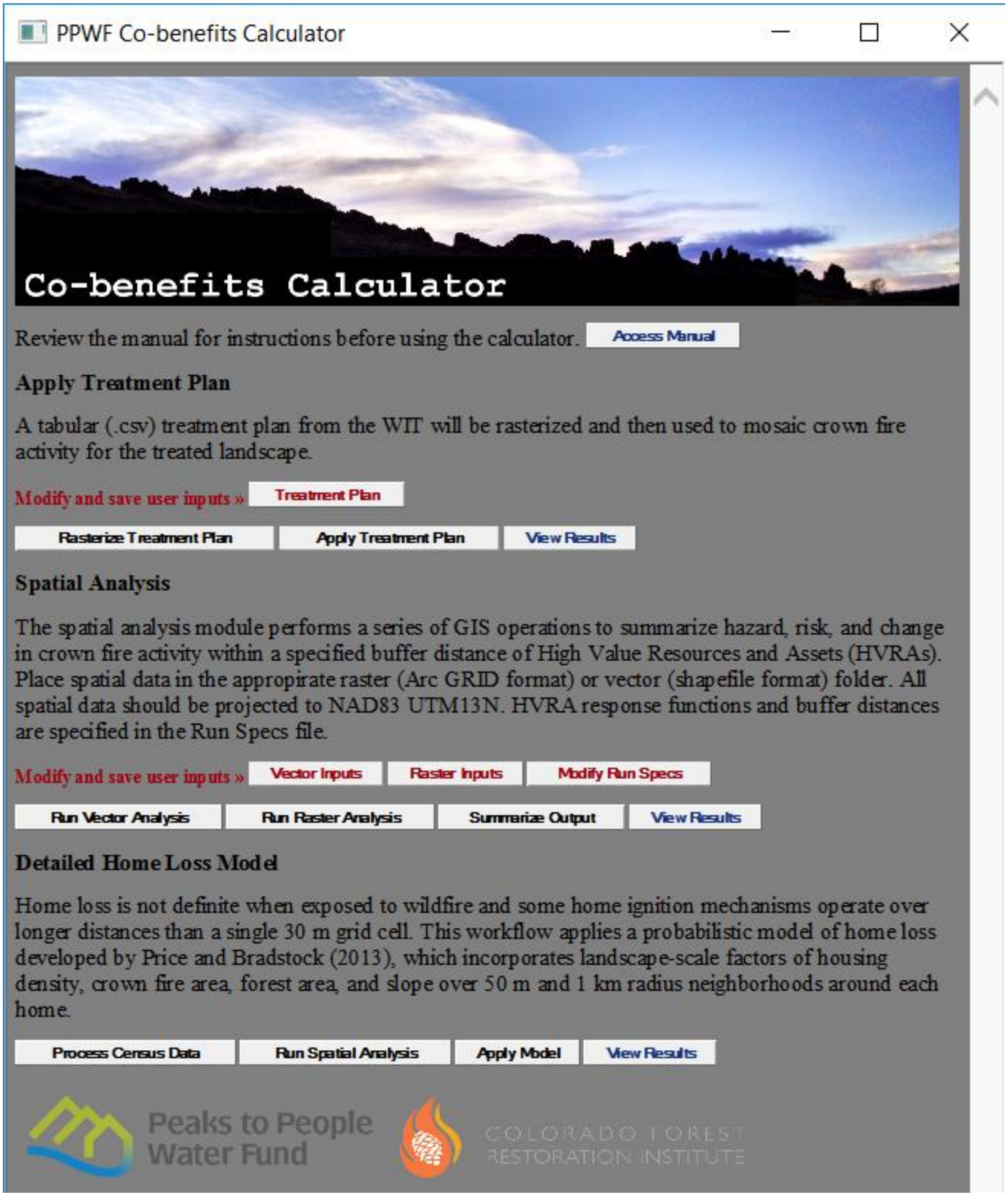

*Figure 3: co-benefits calculator graphical user interface.*

### *Treatment Plan*

This model is intentionally called a calculator because it measures the value of a proposed treatment plan, rather than optimizing a treatment plan for widely-varying resources. The first step is for the user to provide a treatment plan developed with the WIT (e.g., *trt_picks_100000000.csv*). The calculator includes a prompt to the proper input directory, and it includes two automated workflows to convert the treatment plan from vector to raster and then to mosaic modeled fire behavior (CFA) to characterize the treated landscape (Figure 4). The difference between the pre- and post-treatment CFA is the basis for quantifying hazard and risk reduction for each resource in each pixel.

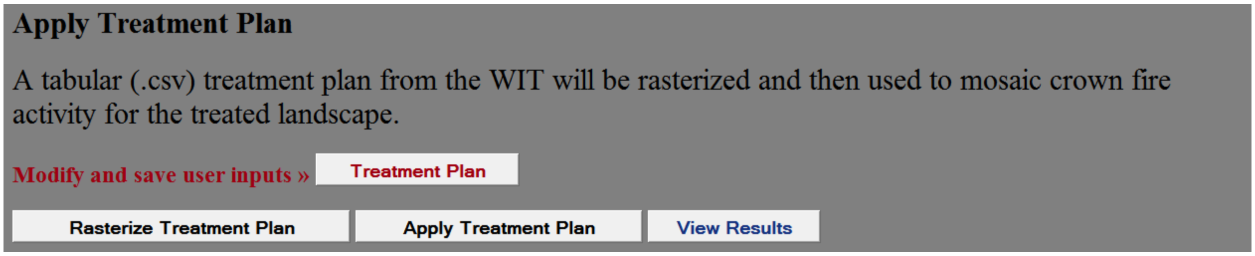


*Figure 4: apply treatment plan module of the co-benefits calculator converts a treatment plan from the WIT to raster and then uses it to mosaic fire modeling results for the treated landscape.*

*Resources and Response Functions*

The second module (Figure 5) is an automated risk analysis procedure that can be applied to any number of vector and raster resources. Vector and raster resources will be treated as presence data only, i.e. no attribute data is used in the analysis. Therefore, any sub-setting must be done outside the calculator to prepare point, polyline, or polygon shapefiles representing only the spatial locations of the resource of interest. The calculator includes prompts to the proper directories to place vector (shapefile format) and raster data (Arc GRID format) (Figure 5). As with any GIS analysis, all spatial data should be projected to the same coordinate system (NAD83 UTM13N). Raster data should be coded as 1 for presence and 0 for absence.

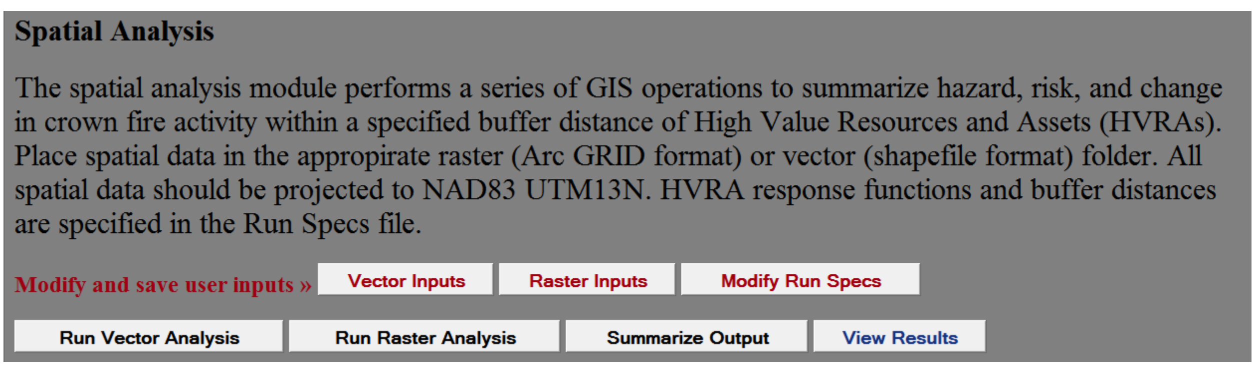


*Figure 5: spatial analysis module of the co-benefits calculator automates vector and raster risk analyses and then summarizes their output.*

All the controls are placed in a single table that is easy to modify by the end user (Table 1: spatial analysis Run Specs file to control both the vector and raster risk analyses.Each vector and raster layer will have a row in the table to store a basic description of the data, the buffer distance required for point and polyline data, and the resource response function. A number of co-benefits are pre-loaded into the calculator (see Appendix II for more details) but they are not meant to be an exhaustive list.

*Table 1: spatial analysis Run Specs file to control both the vector and raster risk analyses.*

Shapefile name that you can change

Specify data type

Specify optional buffer for vector data

1 = include in analysis; 0 = ignore

Planning period (yrs) for risk calculations

Response function = loss per acre of HVRA exposed to different fire behavior

| HVRA | BenefitClass | FileName | Format | Type | Buffer_m | Include | PlanningP | Surface | Passive | Active | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Trails | Recreation | trails.shp | Vector | Polyline | 50 | 1 | 25 | 0 | 50 | 200 | Includes all trail types |
| Off-road Trails | Recreation | offroad.shp | Vector | Polyline | 50 | 1 | 25 | 0 | 50 | 200 | USFS roads from MUVM |
| Recreation Sites | Recreation | recopps.shp | Vector | Point | 400 | 1 | 25 | 0 | 50 | 200 | USFS recreation opportunity site |
| Wild & Scenic Rivers | Recreation | WildScenicRiverSta | Vector | Polygon | 0 | 1 | 25 | 0 | 50 | 200 | USFS wild and scenic river status |
| Parks & Open Spaces | Recreation | parks.shp | Vector | Polygon | 0 | 1 | 25 | 0 | 50 | 200 | CPW, Larimer County, Fort Collir |
| State Wildlife Areas | Hunting | CPW_SWA.shp | Vector | Polygon | 0 | 1 | 25 | 0 | 50 | 200 | CPW |
| State Fishing Units | Fishing | CPW_SFU.shp | Vector | Polygon | 0 | 1 | 25 | 0 | 50 | 200 | CPW |
| Communication Point | Built Environment | com_points.shp | Vector | Point | 50 | 1 | 25 | 5000 | 50000 | 200000 | Homeland Infrastructure Founda |
| Electric Transmission | Built Environment | electric_transmissi | Vector | Polyline | 50 | 1 | 25 | 100 | 1000 | 10000 | Homeland Infrastructure Founda |
| Electric Substations | Built Environment | electric_substatior | Vector | Point | 50 | 1 | 25 | 5000 | 50000 | 200000 | Homeland Infrastructure Founda |
| WAFWA Crucial Habit | Wildlife | WAFWA_CHAT_p1a | Vector | Polygon | 0 | 1 | 25 | 0 | 50 | 200 | WAFWA CHAT priority 1 and 2 ha |
| WUI Structures | Built Environment | WUI_50m | Raster | NA | 0 | 1 | 25 | 5000 | 50000 | 200000 | Caggiano et al. 2016 WUI structu |
| Wetlands | Wetlands | wetland | Raster | NA | 0 | 1 | 25 | 0 | 50 | 200 | NWI non-lake, non-pond, conve |
| Elk Severe Winter Rar | Wildlife | ElkSevereWinterRa | Vector | Polygon | 0 | 0 | 25 | 0 | 50 | 200 | CPW |
| Greater Sage Grouse F | Wildlife | GrSG_priorityhabit | Vector | Polygon | 0 | 0 | 25 | 0 | 50 | 200 | CPW; WY doesn't agree; Placeho |
| WUI Structures | Built Environment | WUI_structures.shp | Vector | Point | 50 | 0 | 25 | 5000 | 50000 | 200000 | Caggiano et al. 2016 WUI structu |
| Pinyon-Juniper Habita | Wildlife | pj_hab | Raster | NA | NA | 0 | 25 | 0 | 50 | 200 | LANDFIRE EVT pinyon and junipe |
| Sagebrush Habitat | Wildlife | sb_hab | Raster | NA | NA | 0 | 25 | 0 | 50 | 200 | LANDFIRE EVT sagebrush types |

*HVRA* – Highly Valued Resources and Assets are the individual resource layers for the analysis. This field will be used to name the resource in any summary tables and figures.

*BenefitClass* – This is a grouping variable for resources to order summary tables and figures.

*FileName* – Enter the exact vector or raster file name so the script can access the proper input data. Any vector data should have the ".shp" extension. Arc GRID files have no file extension.

*Format* – This is used to route raster and vector data into the appropriate spatial analysis scripts. Acceptable values are Raster or Vector.

*Type* – If vector, describe the data type as Point, Polyline, or Polygon. Enter NA for raster data.

*Buffer_m* – This is the buffer distance (m) applied to vector layers to describe the zone of fire influence around each feature. It is a required input for point and polyline features.

*Include* – This is a binary switch to include (1) or exclude (0) the layer from the analysis. Use this to explore alternative resource scenarios without deleting all the row information or spatial data from the input folders.

*PlanningPeriod* – This is the planning period length (years) used to calculate benefits by adjusting annual burn probability to planning period burn probability. We suggest setting this to 25 years as a reasonable estimate of fuel treatment longevity.

*Surface* – This is the expected response ($/ac) of the resource to surface fire exposure. Keep in mind buffer distances applied to vector data.

*Passive* – This is the expected response ($/ac) of the resource to passive crown fire exposure. Keep in mind buffer distances applied to vector data.

*Active* – This is the expected response ($/ac) of the resource to active crown fire exposure. Keep in mind buffer distances applied to vector data.

*Notes* – This is a catch-all text field to describe the data.

Response functions are just tools to describe the expected losses ($/ac) when resources are exposed to different levels of fire behavior. Response functions are often defined on relative scales (range +/- 100) for quantitative wildfire risk assessment due to the difficulty of describing resource response in common currency (Scott et al. 2013). For the co-benefits calculator, the response functions are defined as expected losses ($/ac) because benefits are being measured in terms of avoided loss. This framework could be expanded to look at positive responses to fire (e.g., fire-adapted ecosystems), or to calculate non-fire related benefits (i.e., wildlife habitat improved by the forest management itself).

*Raw Output*

The raw output from the calculator is a table summarizing a variety of metrics that may be useful for communicating co-benefits (Table 2). The summarize output script processes and visualizes the data, but it is all here for additional viewing or analysis.

*Table 2: example RAW output with a variety of metrics that may be useful for communicating co-benefits.*

| HVRA | BenefitClass | n | Length_m | Area_ac | Haz | Haztrt | HazC | Risk | Risktrt | RiskC | eAB_ac | Trt_ac | CFA_0 | CFA_1 | CFA_2 | CFA_3 | CFAtrt_0 | CFAtrt_1 | CFAtrt_2 | CFAtrt_3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Communication Points | Built Environment | 241 | NA | 158.1225 | 7037674 | 5603229 | 1434444 | 27698.5 | 20208.15 | 7490.35 | 7.955806 | 9.562964 | 50.92834 | 59.82412 | 18.23635 | 29.13368 | 50.92834 | 59.82412 | 27.79931 | 19.57072 |
| Electric Transmission Lines | Built Environment | 48 | 210.5646 | 6766.353 | 8216143 | 7627687 | 588455.9 | 35447.71 | 32671.37 | 2776.341 | 546.6962 | 65.38398 | 791.9468 | 4394.515 | 891.3572 | 688.5334 | 791.9468 | 4394.515 | 956.7411 | 623.1494 |
| Electric Substations | Built Environment | 28 | NA | 50.26116 | 890690 | 857330.8 | 33359.17 | 2780.304 | 2656.638 | 123.6667 | 2.630282 | 0.222395 | 10.23015 | 33.58157 | 3.780707 | 2.668734 | 10.23015 | 33.58157 | 4.003101 | 2.44634 |
| WUI Structures | Built Environment | NA | NA | 43241.05 | 1.61E+09 | 1.44E+09 | 1.67E+08 | 5903624 | 5301072 | 602551.6 | 2535.839 | 1115.086 | 11181.55 | 19839.59 | 6231.271 | 5988.639 | 11181.55 | 19840.26 | 7345.023 | 4874.22 |
| State Fishing Units | Fishing | 6 | NA | 628.9316 | 21438.83 | 20604.85 | 833.9794 | 38.92266 | 37.16058 | 1.762079 | 25.65234 | 5.559863 | 141.6653 | 322.0272 | 77.39329 | 87.84583 | 141.6653 | 322.0272 | 82.95315 | 82.28597 |
| State Wildlife Areas | Hunting | 35 | NA | 29653.64 | 1733354 | 1728283 | 5070.595 | 7428.565 | 7418.665 | 9.899749 | 2933.287 | 33.80396 | 1612.805 | 15598.97 | 5033.455 | 7408.406 | 1612.805 | 15598.97 | 5067.259 | 7374.602 |
| Trails | Recreation | 510 | 587.1867 | 21421.26 | 1854859 | 1751446 | 103413.4 | 3411.117 | 3003.923 | 407.1938 | 1028.886 | 689.8677 | 1640.827 | 7481.796 | 4032.457 | 8266.181 | 1640.827 | 7482.463 | 4720.99 | 7576.981 |
| Off-road Trails | Recreation | 935 | 1180.323 | 15626.77 | 1318488 | 1289732 | 28755.61 | 1711.857 | 1570.286 | 141.5704 | 548.2422 | 191.7041 | 482.1513 | 4658.498 | 5191.577 | 5294.546 | 482.1513 | 4658.498 | 5383.281 | 5102.842 |
| Recreation Sites | Recreation | 94 | NA | 10106.5 | 823482.4 | 762034.8 | 61447.6 | 1673.579 | 1491.085 | 182.4941 | 477.4163 | 410.0955 | 1031.021 | 3246.737 | 2281.768 | 3546.97 | 1031.021 | 3247.404 | 2690.529 | 3137.542 |
| Wild & Scenic Rivers | Recreation | 2 | NA | 19896.3 | 1631964 | 1447032 | 184932.2 | 2802.625 | 2241.078 | 561.547 | 922.8008 | 1233.4 | 1908.145 | 7987.743 | 2454.123 | 7546.29 | 1908.145 | 7990.857 | 3682.853 | 6314.447 |
| Parks & Open Spaces | Recreation | 77 | NA | 33949.85 | 1402253 | 1109093 | 293160.4 | 5603.46 | 4196.845 | 1406.614 | 2397.4 | 1955.292 | 7278.305 | 15529.59 | 5507.6 | 5634.365 | 7278.305 | 15530.92 | 7460.224 | 3680.407 |
| WAFWA Crucial Habitat | Wildlife | 637 | NA | 398375.9 | 28849782 | 25799519 | 3050263 | 106430.2 | 92605.62 | 13824.6 | 32133.99 | 20322.41 | 32043.93 | 168849.7 | 70977.87 | 126504.4 | 32043.93 | 168933.1 | 91201.76 | 106197.2 |
| Wetlands | Wetlands | NA | NA | 28287.02 | 1074377 | 1051059 | 23318.06 | 2703.383 | 2594.333 | 109.0502 | 1690.669 | 155.4538 | 3186.913 | 16385.14 | 4457.453 | 4257.52 | 3186.913 | 16385.14 | 4612.907 | 4102.067 |

*n* – Number of input features for the resource (if vector).

*Length_mi* – Length (mi) of resource features (if polyline).

*Area_ac* – Area (ac) of resource influence including the buffer area.

*Haz, Haztrt, HazC* – Baseline Hazard, post-treatment Hazard, and Hazard Change, all in $. Hazard is the expected loss, given exposure to wildfire (ignoring wildfire likelihood).

*Risk, Risktrt, RiskC* – Baseline Risk, post-treatment Risk, and Risk Change, all in $. Risk is the expected loss, accounting for wildfire likelihood.
*eAB_ac* – Expected Area Burned (ac) of the resource influence area over the planning period.

*Trt_ac* – Treatment plan area (ac) within the resource influence area.

*CFA_0, CFA_1, CFA_2, CFA_3, CFAtrt_0, CFAtrt_1, CFAtrt_2, CFAtrt_3* – Crown fire activity area (ac) within the resource influence area in classes of unburned (0), surface (1), passive crown fire (2), and active crown fire (3). Trt = post-treatment.

*Summary Output*

An R script is used to summarize the raw output (Table 2) into tables and graphs. Draft summary outputs are presented in the results section. Ideally, feedback from Peaks to People will be used to tailor the outputs (preferred metrics and data visualizations).

*Home Loss Model*

Homes are the most economically-important resource at risk of loss from wildfire due to a combination of abundance, exposure, and value. Given the intense research focus on wildfire risk to homes and the economic importance, we developed a detailed fire effects and risk analysis workflow for home loss. The Home Loss Model applies the Price and Bradstock (2013) model of landscape-scale factors of home loss to individual wildland urban interface structures mapped by Caggiano et al. (2016). It consists of a workflow to process census data to estimate home prices, spatial analysis to estimate each of the Price and Bradstock (2013) model parameters for each structure in the untreated and treated landscape, and a script to apply the model and summarize the results (Figure 6). Detailed information and results for the Home Loss Model presented in Appendix I.

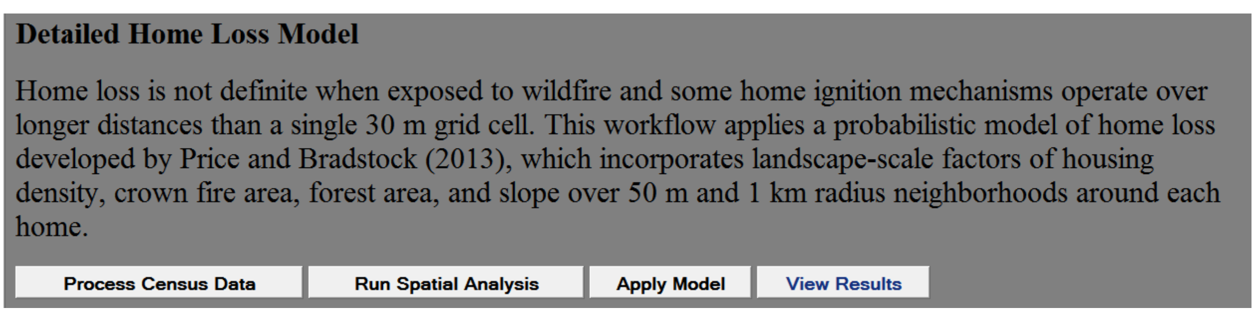

*Figure 6: the home loss module applies a statistical process model of home loss based on landscape-scale factors to individual WUI structures, combined with census home values, and burn probability to estimate treatment plan risk reduction.*

**Results**

The co-benefits calculator was tested on a variety of vector and raster inputs with draft response functions including wetlands, crucial wildlife habitat, parks and open spaces, wild and scenic rivers, recreation sites, off-road trails, non-motorized trails, state wildlife areas, state fishing units, wildland urban interface structures, electric substations, electric transmission lines, and communication points. Response functions are currently a mix of replacement values, economic impact, and contingent valuation estimates (Table 1). In general, the response functions for natural resources like trails, parks and open spaces, wildlife, etc. are assumed to have no impact with surface fire, and increasing levels of loss as the higher intensity passive and active crown fire significantly modify the vegetation. Dead trees following wildfire are considered a safety hazard to public use (K. Cannon, Canyon Lakes Ranger District, personal communication) so it is reasonable to assume trails and parks and open spaces will see increasing levels of impact with higher intensity fire that kills more trees. Built environment features like electric transmission infrastructure and communication points have higher value and are assigned some level of loss with exposure to any fire type.

Risk to the entire set of resources is mapped relative to the assessed treatment plan (Figure 7) to provide spatial awareness of where risk is concentrated on the landscape and the degree to which a treatment plan optimized for water supply protection overlaps with other resource protection goals. Many of the co-benefits have substantial overlap with water supply protection goals, which is also highlighted in Figure 8.

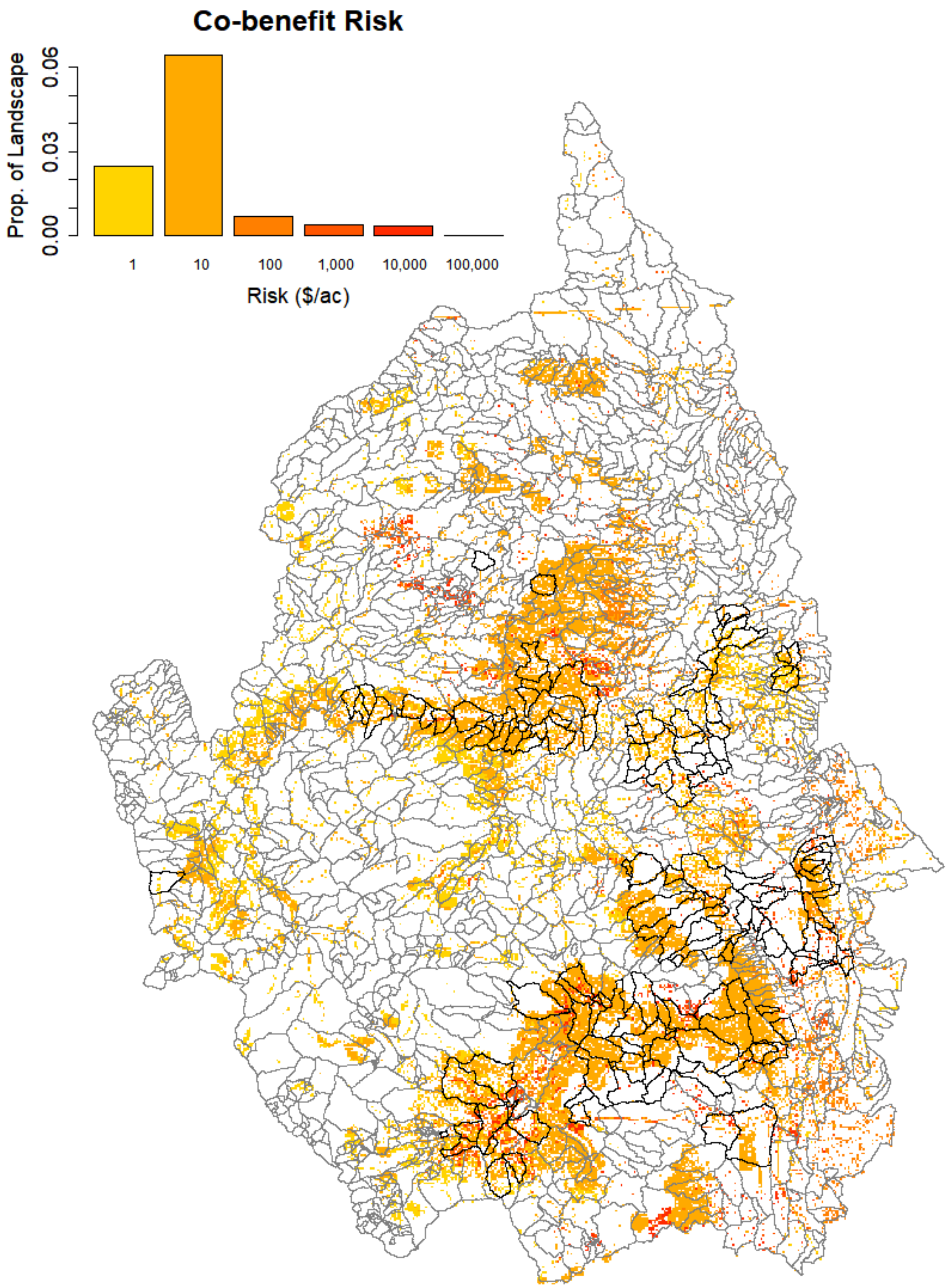


*Figure 7: cumulative risk to all resources (hue). Catchments picked in the WIT treatment plan are shown with black borders.*

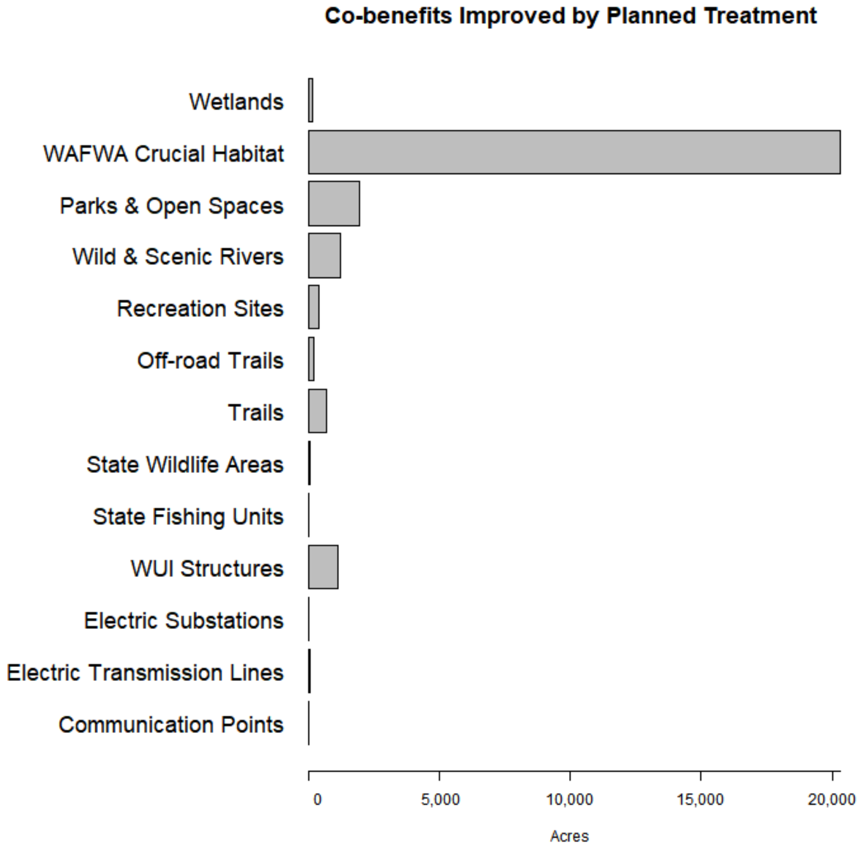


*Figure 8: treatment plan overlap with resource influence areas.*

Numerous options are available to summarize and visualize the metrics produced by the risk analysis workflow (Table 2). The critical information to convey is how exposed each resource is to wildfire and how much risk reduction was achieved by the treatment plan for each resource (Figure 9). Here, we can see that crucial wildlife habitat occupies the largest area, but greater risk reduction was achieved for wildland urban interface structures because of their higher monetary value. Similar summary graphics can be produced by benefit class, i.e. built environment, wildlife, etc.

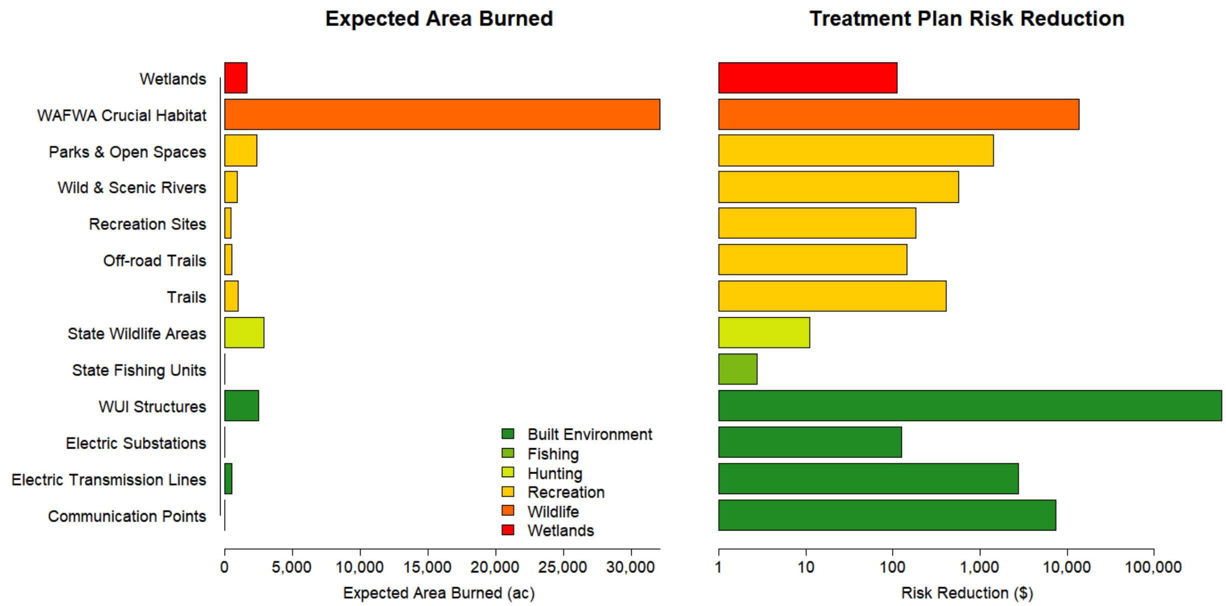


*Figure 9: expected area burned (ac) within the resource influence area (LEFT) and treatment plan risk reduction (RIGHT). Note log scale on risk reduction axis.*

Although response functions are defined in monetary terms ($/ac), resource values reported in the literature are highly variable and based on different valuation techniques. Accounting for risk in absolute terms (Figure 9) can be useful for conveying the potential magnitude of impacts, but it is important to express the large uncertainty around these estimates due to imperfect characterization of the resource, fire exposure, and fire effects. If resource functions convey the relative impacts to resources across exposure to different fire behavior levels (CFA), the accounting of proportional risk reduction should be robust. We find that a $100M investment in fuel treatment to protect water supplies substantially reduces the total risk to other resources (Figure 10). In particular, there are large proportional risk reductions to parks and open spaces, which tend to border reservoirs, and communication points, which are clustered within a high priority catchment in Horsetooth Mountain Open Space.

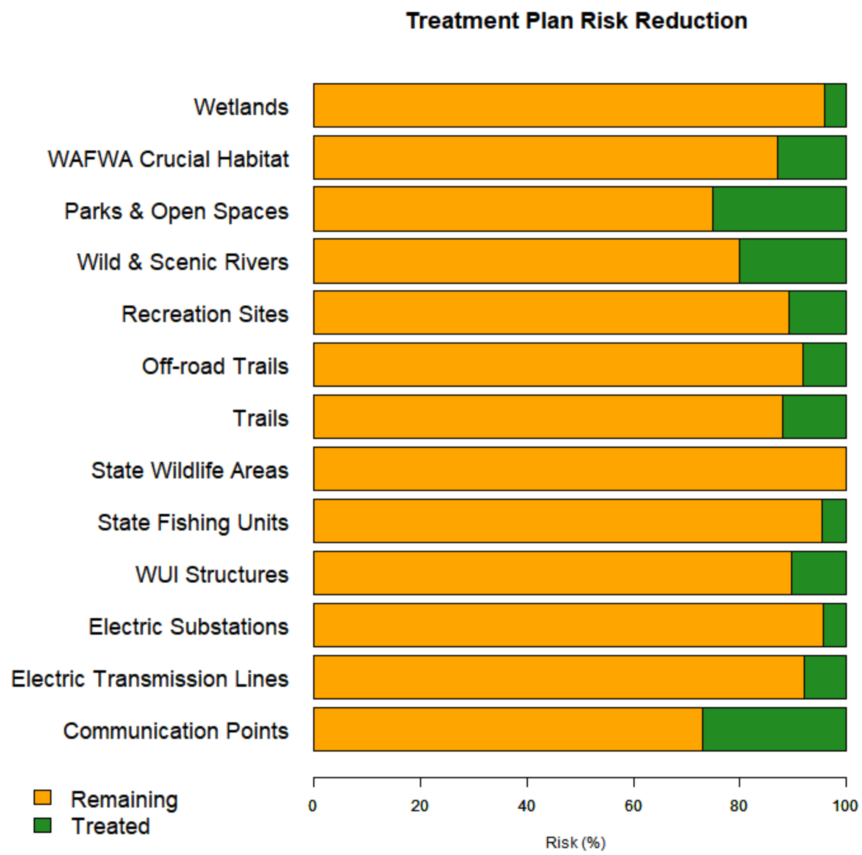


*Figure 10: percent risk to each resource addressed by the treatment plan.*

We can also account for the change in area expected to burn with different fire behavior (CFA) within the resource influence area for the baseline and treated conditions (Figure 11). Since losses are highest for active crown fire, it can also be helpful to focus on treatment effects at reducing active crown fire (Figure 12).

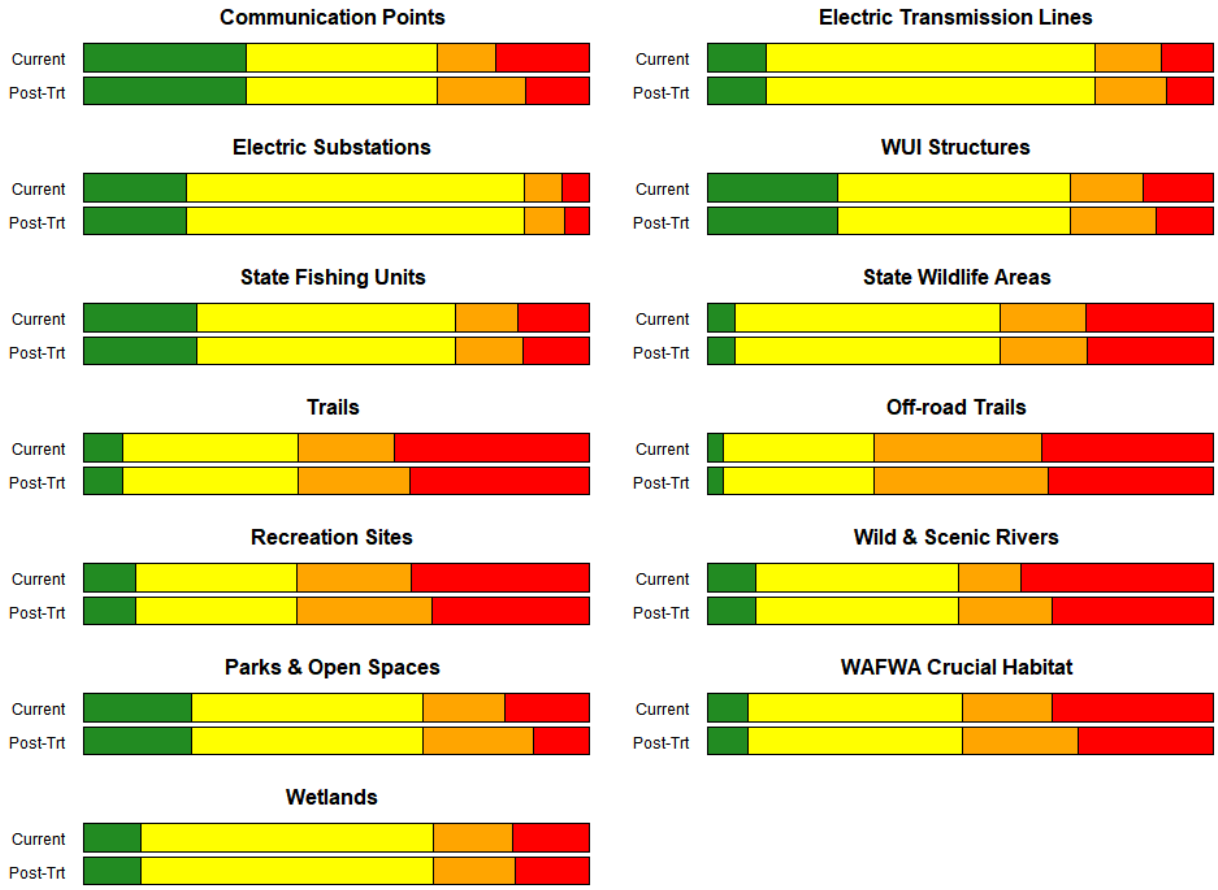


*Figure 11: proportion of resource influence area by crown fire activity. Green = unburned, Yellow = surface fire, Orange = passive crown fire, and Red = active crown fire.*

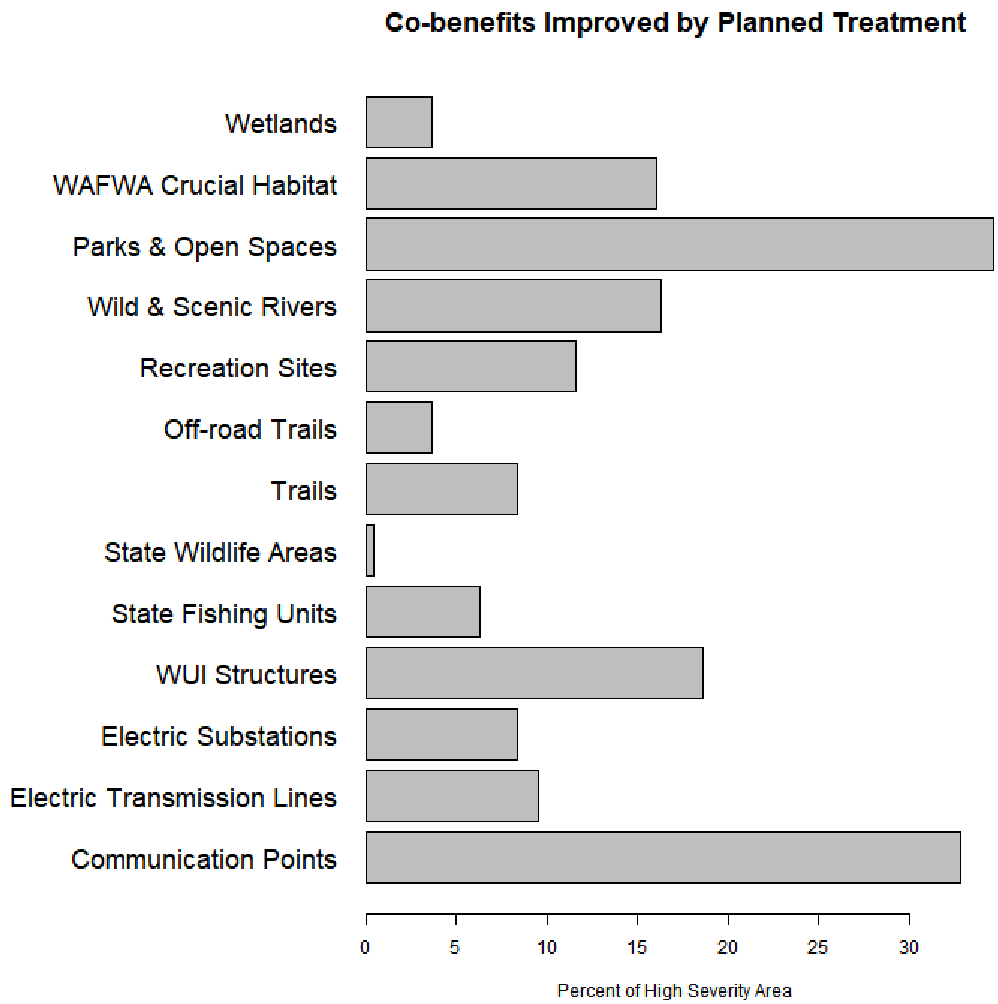


*Figure 12: percent reduction in resource influence area burning as active crown fire.*

Resource benefit from fuels reduction is a function resource extent, its overlap with the proposed treatment (Figure 8), and its value and response to fire (Table 1; Figure 9). Resources with large extents (e.g. crucial wildlife habitat), will overlap with many planned treatments so the potential benefit is high regardless of the expected losses (Figure 9), but the proportional reduction to risk is not high because the resources are dispersed over large areas that will not be treated (Figure 10). In contrast, built environment resources are spatially concentrated and high value, so treatments can have significant benefits where they overlap these resources (Figure 9).

**Discussion**

The co-benefits calculator is a flexible tool for estimating wildfire risk to multiple resources and the benefit of fuels treatments. It can be operated with minimal technical experience; if a user can move vector and raster data to the appropriate input folder and populate a row in the run specifications file, they can run the tool. We put valuation controls in the hands of the user to easily test the effects of different scenarios and to update the analysis when conditions change or understanding evolves. Outputs are communicated in tabular form to facilitate further analysis and custom reporting. We have also piloted a variety of graphics to communicate to different audiences and will use feedback from Peaks to People refine the metrics and presentation style.

Co-benefits have substantial overlap with areas of high priority for water supply protection (Figure 7). This is because most of our roadways are in canyon bottoms, so homes tend to cluster close to rivers, and recreation opportunities are located around reservoirs. Most of the crucial wildlife habitat is in montane forests, where the WIT prioritizes treatment due to higher burn probabilities and proximity to water infrastructure. Of the 33,612 ac that are prioritized for treatment with a $100M budget, approximately 20,000 ac overlap crucial wildlife habitat and > 1,000 ac are treated within the influence areas of parks and open spaces, wild and scenic rivers, and WUI structures (Figure 8).

We estimate that the greatest monetary savings is from wildfire risk reduction to WUI structures, followed by wildlife habitat, and communication infrastructure (Figure 9). This reveals an important contrast between resource abundance and resource value; wildlife habitat is abundant with the treated area, but cheap, and WUI structures cover less land within the treated area, but are very expensive. Given the uncertainty in valuation techniques and the limitations of the economic analysis, metrics of resource overlap and relative risk reduction are more robust than estimates of avoided cost. We found notable reductions in wildfire risk to co-benefits, despite the singular focus on only water supply values when optimizing fuels treatments (Figure 10). Greater than 15% risk reduction was achieved for communication infrastructure, parks and open spaces, and wild and scenic rivers. We also present metrics of area by fire behavior type (CFA) to communicate metrics that don't rely on the valuation (Figure 11, Figure 12). The amount of active crown fire within the resource influence areas of six different resources were reduced by greater than 10%.

We presented many options for metrics and presentation forms to communicate co-benefits. The choice of what to communicate should be informed by the messaging goals of the Peaks to People steering committee, board, and director, but also by the quality of the data and analysis. We assembled co-benefits that can be quantified with a mix of replacement costs (built infrastructure), consumer surplus estimates from contingent valuation studies (recreation, wildlife habitat), or economic impact models (recreation, hunting, fishing). Our simplified risk analysis framework also places equal value on each unit of a resource, but we know values vary within resource. We also know some resources can be substituted for each other in the event of a localized disturbance, e.g. recreationists may not lose any consumer surplus if they can substitute their use of a fire-damaged trail system with a nearby, unburned trail system. Ultimately, each co-benefit could be quantified with its own complicated risk analysis framework that considers these issues, but the data requirements are high, the analyses are complex, and the results may still have a high degree of uncertainty. It is most important to consider what message Peaks to People wants to convey, and the analysis and reporting can be tailored to provide realistic estimates, given reasonable data and analytical demands.

## References

Caggiano, M.D., W.T. Tinkham, C. Hoffman, A.S. Cheng, and T.J. Hawbaker. 2016. High resolution mapping of development in the wildland-urban interface using object based image extraction. Heliyon, 2(e00174):1-19. DOI: http://dx.doi.org/10.1016/j.heliyon.2016.e00174

Price, O. and R. Bradstock. 2013. Landscape scale influences of forest area and housing density on house loss in the 2009 Victorian bushfires. PLoS ONE 8(8): e73421. DOI: 10.1371/journal.pone.0073421

Scott, J.H., M.P. Thompson, and D.E. Calkin. 2013. A wildfire risk assessment framework for land and resource management. Gen. Tech. Rep. RMRS-GTR-315. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.

Stevens, J.T., B.M. Collins, J.W. Long, M.P. North, S.J. Prichard, L.W. Tarnay, and A.M. White. 2016. Evaluating potential trade-offs among fuel treatment strategies in mixed-conifer forests of the Sierra Nevada. Ecosphere 7(9): e01445. DOI: 10.1002/ecs2.1445

Short, K.C., M.A. Finney, J.H. Scott, J.W. Gilbertson-Day, and I.C. Grenfell. 2016. Spatial dataset of probabilistic wildfire risk components for the conterminous United States. Fort Collins, CO: Forest Service Research Data Archive. DOI: https://doi.org/10.2737/RDS-2016-0034

## Appendix I: Home Loss Model

### Introduction

Most wildfire research suggests that local characteristics of the home and its immediate surroundings, or the home ignition zone (HIZ), drive home loss. Home characteristics such as the materials used for siding and roofing; the presence and condition of attached wood decks and fences; the presence and condition of windows and vents; the proximity to adjacent homes; and the cleanliness of gutters, sills, and porches can all contribute to home ignitions (Cohen 1995, Cohen 2000, Price and Bradstock 2013, Maranghides et al. 2015).

Risk reduction to the Wildland Urban Interface (WUI) from off-site or "wildland" fuel treatments has been questioned, given the much stronger role HIZ characteristics play in home loss (Schoennagel et al. 2009), yet most home loss research has focused on the proximity, type, and amount of fuels near the home, and their contribution to radiative and convective heat fluxes (Cohen 1995, Cohen 2000). Radiation and convection are only capable of heat fluxes sufficient to ignite common building materials over a relatively short distance, generally 20-40 m, given typical fuel complexes and residence times. Alternatively, homes can also be lost from piloted ignition from firebrands that are transported longer distances from either urban or wildland fuels, especially during extreme fire behavior (Koo et al. 2010, Wang 2011). The physics of firebrand transport have been well described by Koo et al. (2010) and Wang (2011) and landscape-scale factors of forest condition and/or proximity to extreme fire behavior are significant predictors of home loss during extreme fire events, which has been interpreted as representing the firebrand ignition mechanism (Price and Bradstock 2013, Caggiano et al. 2015).

The science of wildfire home loss is further complicated by the very important, yet difficult to describe, firefighter response efforts. Numerous factors including staffing, decisions of where and when to deploy what resources, the presence of defensible space, and the condition of ingress and egress routes, determine if defensive actions will occur and at what intensity. Home ignitions from firebrands over longer distances may create challenging suppression scenarios that can overwhelm firefighter response if multiple structures are ignited (Cohen 2000, Maranghides et al. 2015).

The Peaks to People watershed restoration strategies don't emphasize defensible space projects within the HIZ, so we need a tool to estimate the landscape-scale effects of fuels treatments on home loss. We demonstrate an approach for applying a model of landscape drivers of home loss to a dataset of WUI structures mapped with remote sensing to estimate baseline risk of home loss, and home loss risk reduction from a large watershed restoration program proposed by Peaks to People.

### Methods

Price and Bradstock (2013) developed a model of home loss from the Black Saturday Fires in Victoria, Australia based on landscape factors calculated in different neighborhood sizes around each home. Home loss was most highly correlated with the proportion of crown fire and forest cover within a 1 km radius zone around the home. They used an AIC-based approach for selection of the best multiple logistic regression model for home loss; the final model (Figure 13) includes the proportion of crown fire and forest cover within a 1 km radius zone, the count of homes within a 50 m radius zone (called home “density”), and the local slope in degrees. These factors are similar to those identified by Caggiano et al. (2015) for the High Park Fire, but the advantage of using the Price and Bradstock (2013) model is that it provides a probability of home loss given extreme fire occurrence, which is better suited for risk calculations.

**Table 2.** Model estimates table for the best model of house loss at 1 km radius (n = 1942, pseudo-$r^2$ = 0.230).

| Term | Estimate | Std. Error | z value | P |
|---|---|---|---|---|
| **(Intercept)** | -2.352 | 0.179 | -13.114 | 0.000 |
| **House density** | 0.068 | 0.051 | 1.338 | 0.181 |
| **Crown fire 1k** | 3.697 | 0.547 | 6.761 | 0.000 |
| **Forest area 1k** | 1.935 | 0.281 | 6.895 | 0.000 |
| **Slope** | 0.063 | 0.013 | 4.996 | 0.000 |
| **House densityxCrown fire 1k** | 1.317 | 0.356 | 3.700 | 0.000 |

The estimates column gives the predictive equation I, where probability of house loss = exp(I)/(exp(1+I). The term ‘House density x Crown fire 1k’ is an interaction: the product is used.

doi: 10.1371/journal.pone.0073421.t002

*Figure 13: exact copy of table from Price and Bradstock (2013) reporting model variables and coefficients. Used without permission for this draft.*

We applied the Price and Bradstock (2013) model to a dataset of individual structures that was created as part of a high-resolution WUI mapping project (Caggiano et al. 2016). Caggiano et al. (2016) used an object-based image classification technique to extract individual structure locations from NAIP imagery, which in some cases represent homes, but may also represent other outbuildings such as large sheds, garages, stables, or shops. We treated these structures as homes for application of the Price and Bradstock (2013) model.

*GIS Processing*

GIS processing involved several input datasets (Table 3) and summary processes to estimate the variables for the Price and Bradstock (2013) home loss model for both the baseline (existing landscape conditions) and treated conditions.

*Table 3: spatial datasets utilized in the GIS-processing to estimate variables for the Price and Bradstock (2013) home loss model.*

| Input Variable | Data Type | Source |
|---|---|---|
| WUI Structures | vector point | Caggiano et al. 2016 |
| Census Tracts | vector polygons | US Census 2015 |
| Canopy Cover | 30 m raster | LANDFIRE 2016 |
| Slope | 30 m raster | LANDFIRE 2016 |
| Crown Fire Activity | 30 m raster | This study |
| Crown Fire Activity Treated | 30 m raster | This study |
| FSim Burn Probability | 30 m raster | Short et al. 2016 |

House density (really count) was estimated by buffering each structure point by 50 m and then using a tabulate intersection to count the number of homes within each buffer zone. The result was then joined back to the original points and house density was calculated as count minus one to remove the target home from the calculation.

Crown fire behavior was estimated for current and treated landscapes under 97$^{th}$ percentile fuel and weather conditions and winds blowing upslope using FlamMap 5.0. Crown Fire Activity (CFA) was calculated using the Scott and Reinhardt (2001) method and class 3 (active crown fire) was treated as crown fire for the purposes of these calculations. The CFA rasters for the untreated and treated landscape were each reclassified as 0 = no crown fire and 1 = crown fire. The Focal Stats tool was then used to calculate the proportion of crown fire within a 1 km radius of each pixel and the pixel values were extracted to each structure using extract values to points.

Forest area was estimated for the current landscape (and considered unchanged in the treated landscape) using the canopy cover raster layer from LANDFIRE (2016). The percent canopy cover raster was reclassified as 0 = non-forest and 1 = forest, using canopy cover greater than or equal to 10% as forest. The Focal Stats tool was then used to calculate the proportion of forest within a 1 km radius of each pixel and the pixel values were extracted to each structure using extract values to points.

Slope (in degrees) from LANDFIRE (2016) was extracted to each structure using extract values to points.

The Price and Bradstock (2013) model predicts the probability of home loss given the home is exposed to extreme fire behavior, which was interpreted as experiencing fire within the larger 1 km radius neighborhood size. To calculate risk of home loss, we also need to know the likelihood of fire occurring within the neighborhood. Burn probability from the National Large Fire Simulator (FSim) modeling project (Short et al. 2016) was used to describe fire likelihood. The Focal Stats tool was then used to calculate the mean burn probability within a 1 km radius of each pixel and the pixel values were extracted to each structure using extract values to points.

The lower quartile, median, and upper quartile values ($) of owner-occupied housing units at the census tract-level (US Census 2016) were assigned to the structures using an intersect.

*Model Application and Analysis*

We applied the Price and Bradstock (2013) model to each of the WUI structures (Caggiano et al. 2016) to calculate the probability of home loss given fire, the expected home loss (n homes) over a 25 year period, and the expected home loss value ($) over a 25 year period, for both the untreated and treated conditions.

$P(\text{Home Loss})_{\text{Fire}}$ = Price and Bradstock (2013) model

$E(\text{Home Loss})_{25\text{yr}} = P(\text{Home Loss})_{\text{Fire}} * \text{Mean 25 yr Burn Probability}_{1\text{km}}$

$E(\text{Home Loss Value})_{25\text{yr}} = P(\text{Home Loss})_{\text{Fire}} * \text{Mean 25 yr Burn Probability}_{1\text{km}} * \text{Median Census Value}$

The effect of fuel treatment was calculated as the difference between expected home loss for the untreated and treated scenarios and expected home loss value for the untreated and treated scenarios.

**Results**

The probability of home loss from extreme wildfire for 61,147 structures included in the study has a bi-modal distribution that is strongly related to the spatial distribution of structures relative to forest cover and crown fire potential (Figure 14).

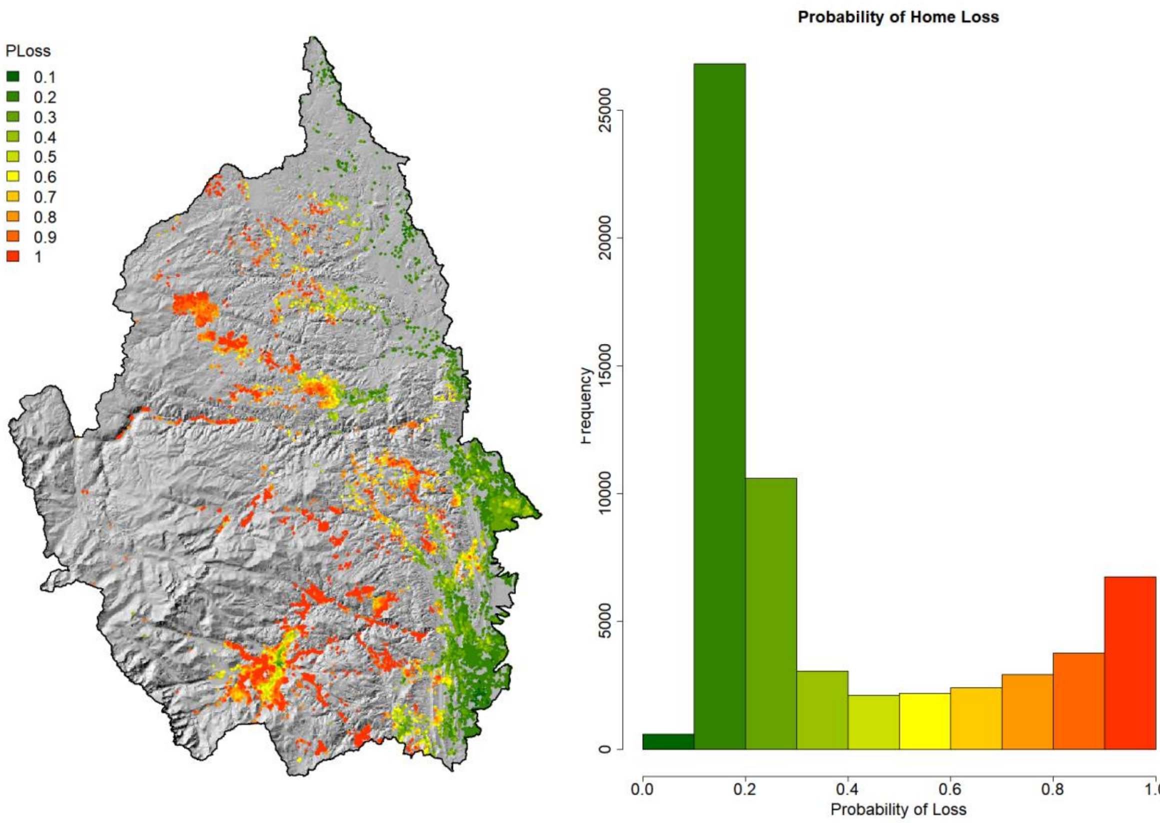


*Figure 14: map and histogram of home loss probability from extreme fire using the Price and Bradstock (2013) model. Most of the higher home loss probabilities are associated with urban interface and intermix with high proportions of modeled active crown fire and forest cover.*

Figure 15 shows the effect of each of the four predictor variables on the probability of home loss from extreme wildfire. The model is most sensitive to crown fire area (Figure 13).

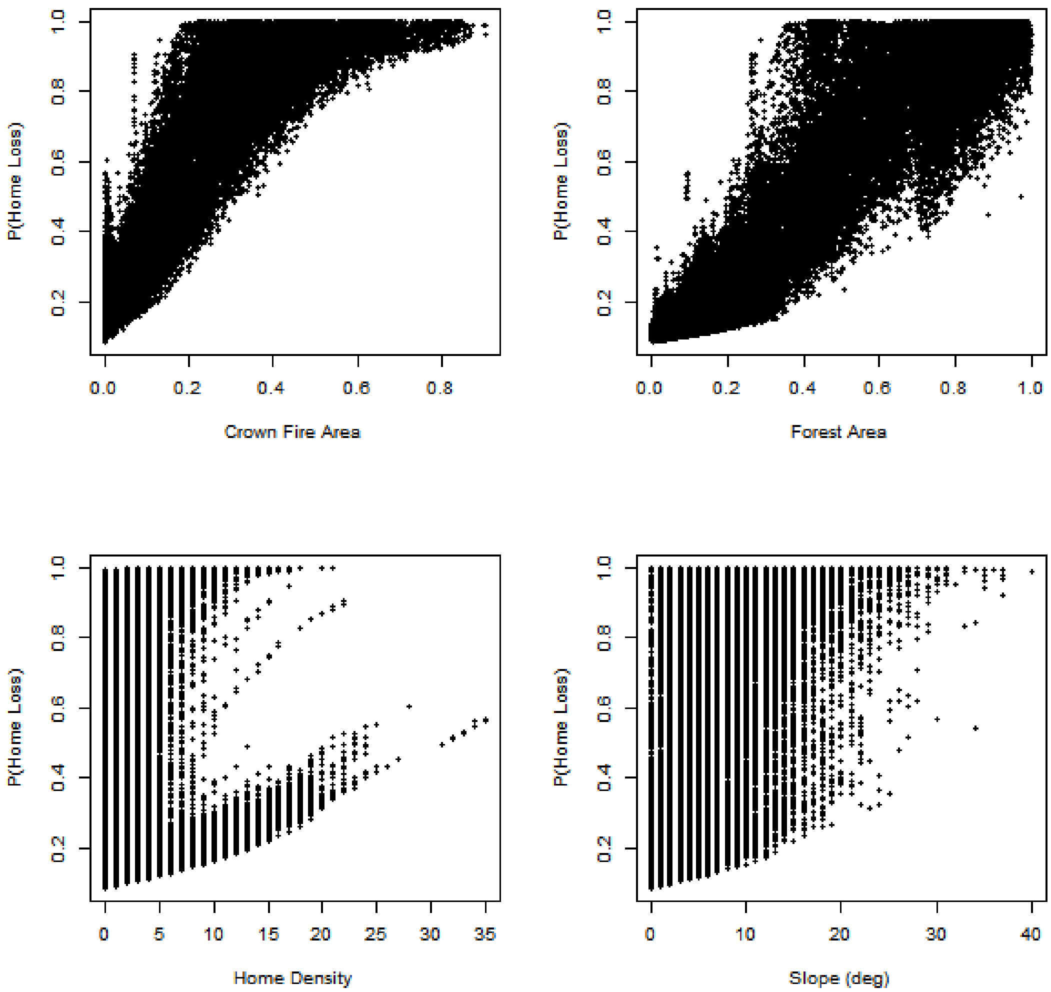


*Figure 15: scatterplots of home loss probability as calculated in Price and Bradstock (2013) for the range of each of the four predictor variables used in the model. Home density and slope are integer values, hence the vertical striping. The model is most sensitive to crown fire area (Figure 13).*

Home loss probability change from treatment is limited to areas within 1 km of treated fuels. Loss probability change ranges from no change to a maximum 0.35 reduction in probability of loss (Figure 16). Most structures had only minor change in probability of loss (<= 0.05). Spatially, areas of high change in home loss probability were associated with intermix and the WUI portion of Estes Park, where surrounding wildlands have higher potential for crown fire and high proportions of forest cover than the WUI of Fort Collins and Loveland.

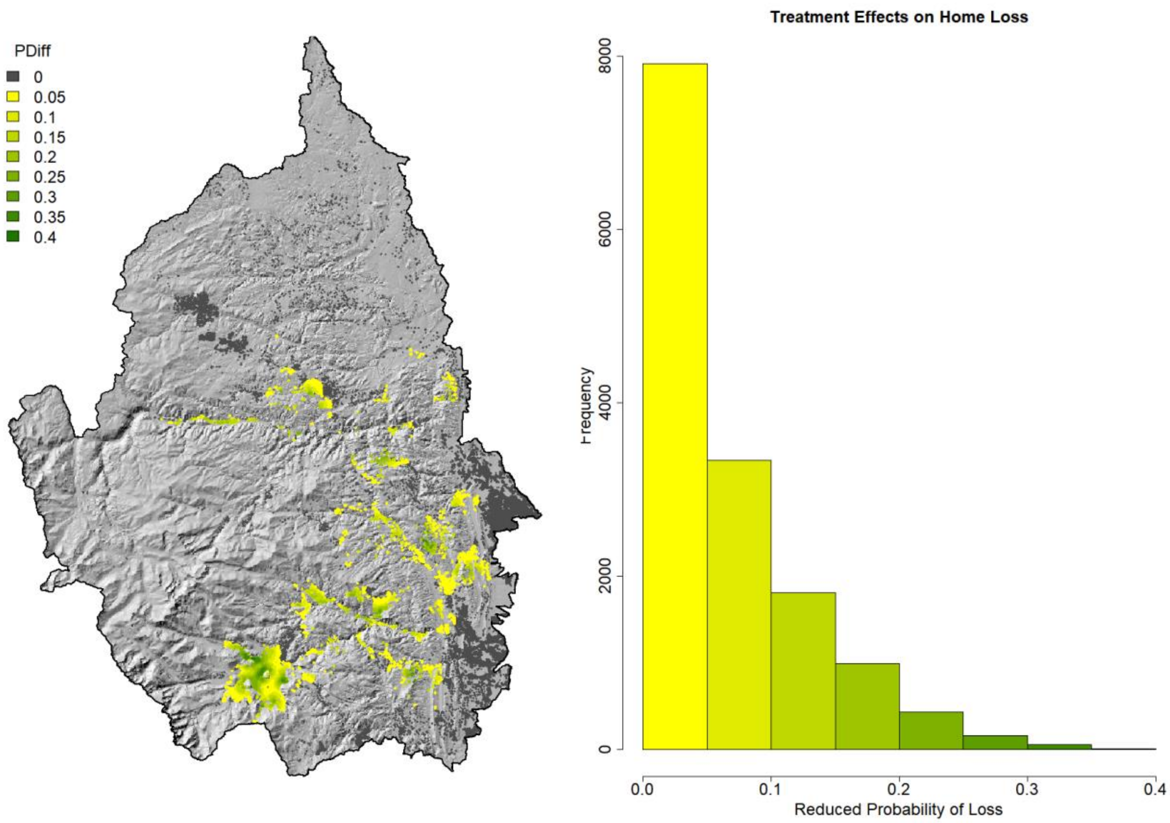


*Figure 16: the effect of treatment on home loss probability from extreme wildfire was calculated as the different between untreated and treated home loss probability. Here we show just the structures that were affected by treatment (<= 1 km from treated forest) and the distribution of effects from treatment. The maximum reduction in home loss probability from treatment was ~ 35%, but the distribution is strongly J-shaped with many structures only experiencing a 5% decrease in probability of loss.*

The treatment plan was not optimized for reducing risk of home loss, but it still reduced the risk of loss for 14,671 homes (Figure 17). The reduction in home loss risk was distributed across a range of pre-treatment risk (Figure 17), but the absolute risk reduction from treatment for individual homes is rather modest, rarely more than 0.020 home loss/25 yr, which equates to saving 63.9 homes from wildfire over a 25-year period. The estimated home loss risk for the untreated landscape is 1,479 homes/25 yr, so saving 63.9 homes equates to a 4.3% reduction. It should be noted that we are not predicting the fate of individual structures, but rather assuming the small reductions in probability of home loss will add up to homes saved from wildfire across the landscape.

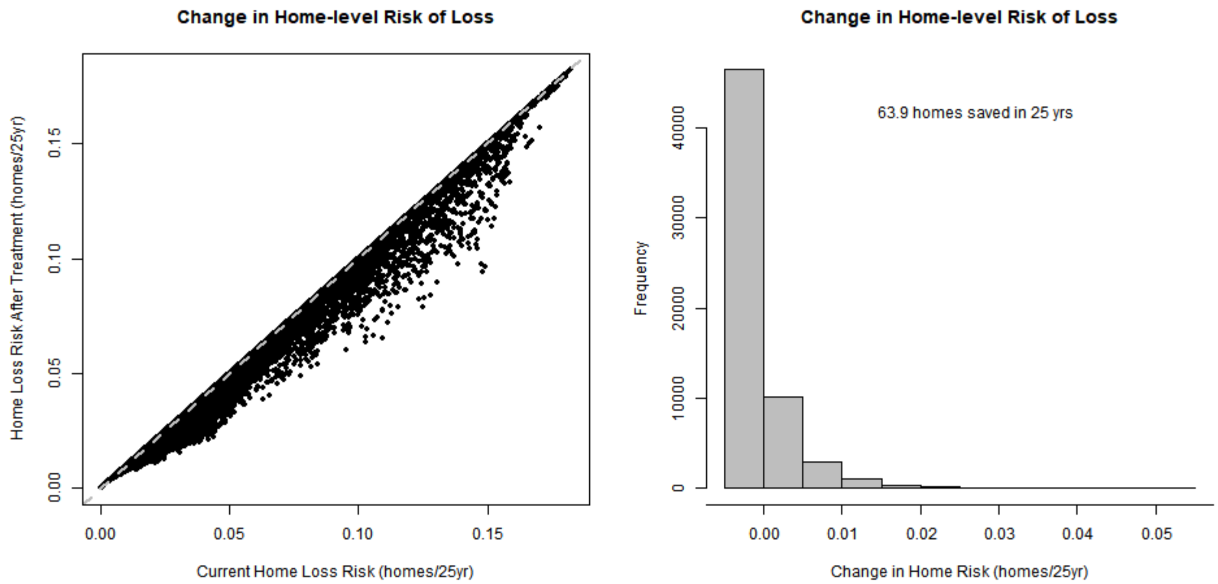


*Figure 17: scatterplot of current and treated home loss risk (homes/25 yr) and change in home risk for effected structures. When accounting for burn probability the change in home risk is much lower than the change in home loss probability.*

The reduction in home loss value risk, using the median value for housing units, was distributed across a range of pre-treatment risk (Figure 18). The risk reduction from treatment for individual homes is between 0 and \$15,416/25 yr, but the majority of risk reduction comes from relatively small changes in estimated risk reduction (< \$2,000/ 25 yr) for many homes.

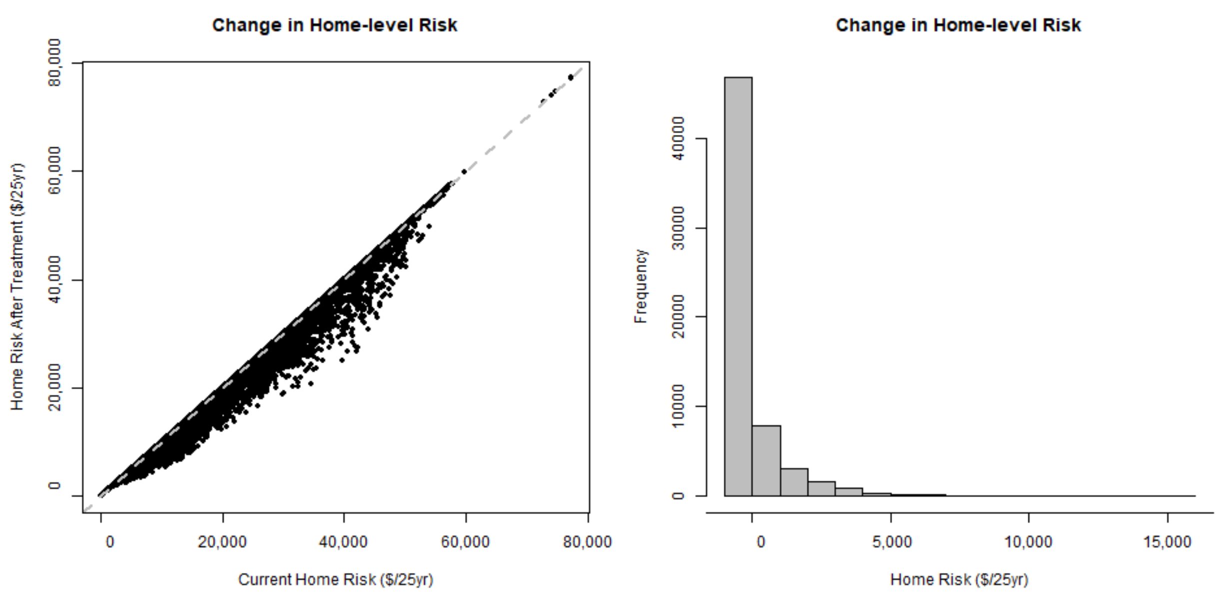


*Figure 18: scatterplot of current and treated home value risk ($/25 yr) and change in home value risk for effected structures.*

The total reduction in home loss value risk is substantial (Figure 19), but it does not balance out the investment in fuels treatment (\$100M). The total home loss value risk reduction, estimated using the median value for housing units, is \$19,996,971 over 25 years. Given the uncertainty associated with using housing unit values from large census tracts, these estimates should be bound by the lower and upper quartile estimates, which span $14,660,704 to $27,660,814 over 25 years (Figure 19).

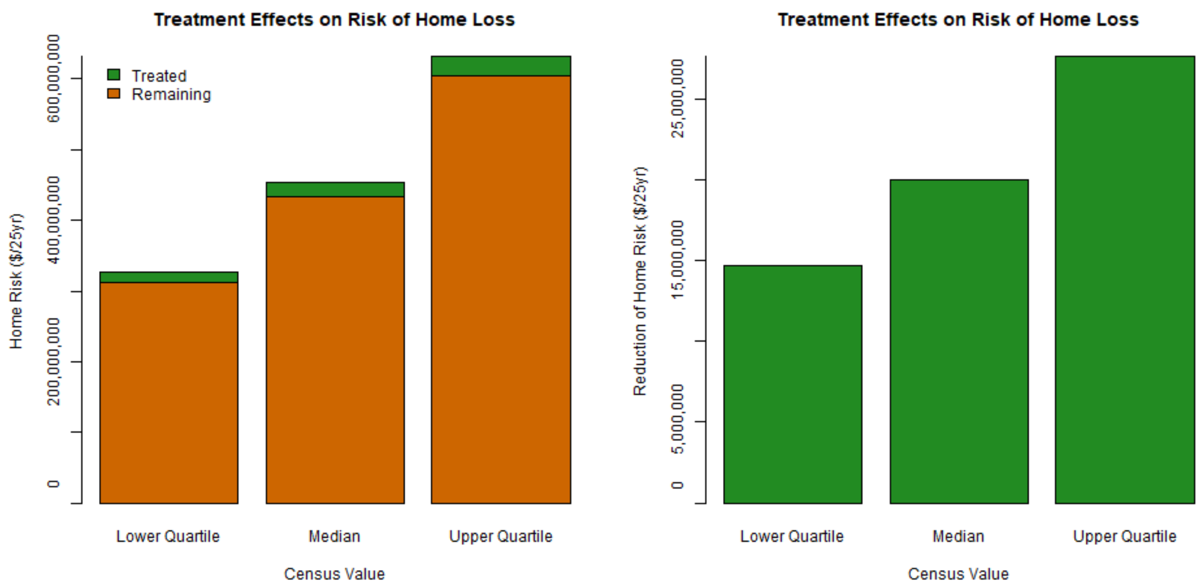


*Figure 19: barplots of untreated and treated home value risk and change in home value risk for estimated structure values using the lower quartile, median, and upper quartile estimates of owner-occupied housing units value.*

**Discussion**

Consistent with previous assessments of wildland fuel treatment programs (Schoennagel et al. 2009), we estimate only modest reductions in home loss risk (Figure 17, Figure 18) and home loss value risk (Figure 18, Figure 19). Like many of the fuel treatment projects included in the Schoennagel et al. (2009) study, the treatment plan we assessed here was designed to achieve other natural resource objectives (reduce wildfire risk to water supplies). Still we found modest reduced risk of home loss (avoided loss of 63.9 homes/25 yr) and risk of home loss value (avoided loss of $19,996,971 over 25 years). Considering that the fuel treatment plan assessed here cost $100M, the reduction in home loss value risk accounts for about a quarter of the treatment cost, even using the upper quartile housing unit values. Risk reduction to homes should be viewed as a significant, but modest co-benefit of fuel treatment programs in wildland settings.

An obvious critique of this work is that we applied a model built from observed home loss data in Victoria, Australia (Price and Bradstock 2013) to the Colorado Front Range, which differs in climate, vegetation, and socioeconomic factors. Few large datasets exist for analyzing landscape-scale factor effects on home loss, but an analysis of home loss from the High Park Fire, which occurred within this same study site, points to similar driving factors (Caggiano et al. 2015). The spatial distribution of home loss probability (Figure 14) has fair agreement with other WUI risk assessments, given the differences in input data. Applying the Price and Bradstock (2013) model to our data, resulted in an estimated risk of loss of 1,479 homes/25 yr.

For comparison, 438 homes were lost in the High Park Fire (Caggiano et al. 2015) and the impacts of recent Colorado Front Range wildfires are reported in Table 4. The estimates are reasonable, and we stress the relative difference between a treated and untreated landscape, rather than a focus on the absolute amount of risk.

*Table 4: NOTE: these numbers primarily came from Wikipedia and some contrast with other sources. Review of formal documents should probably be done to refine and verify these numbers. The discrepancy is likely due to different definitions of homes (primary versus secondary residences).*

| Fire | Area (acres) | Homes lost | Reported losses |
|---|---|---|---|
| Hayman | 138,114 | 133 | $40.4M in private property losses |
| Waldo Canyon | 18,247 | 346 | $453.7M in insurance claims |
| High Park | 87,284 | 438 | |
| Four Mile Canyon | 6,181 | 169 | $217M in insurance claims |
| Black Forest | 14,280 | 509 | |

This analysis was facilitated by a unique, high-resolution WUI structure dataset (Caggiano et al. 2016), which provides greater precision in determining the location of structures compared to other WUI mapping methods. We know that many of these structures are not homes, but rather outbuildings of varying size, built with a variety of materials. Assigning housing unit values from census data to these structures, in many cases with overestimate their worth, although secondary structures on some properties can be quite expensive (e.g. stables or shops). The Price and Bradstock (2013) model assigns greater probability of loss to homes located in areas of high house "density", with the interpretation being that nearby homes are also fuel sources. We treated the WUI structures as homes for application of the model, but some of these structures are probably large sheds, garages, or shops, which are sometimes built with fire-resistant metal roofing and siding. Our application of the Price and Bradstock (2013) model will overestimate the risk of home loss for homes that have fire-resistant secondary structures located within a 50 m neighborhood of the home. The influence of house density is less than other variables in the model (Figure 13, Figure 15), so the uncertainty in structure type is of relatively minor concern when interpreting these results. We are also not predicting the fate of individual structures, but assuming that many small reductions in home loss probability will add up to homes saved across the landscape.

The valuation method used here could be improved to capture the full effect of wildfire impacts on home replacement costs and property values. The study area includes portions of 48 census tracts, many of which are small tracts in the WUI of Fort Collins and Loveland. Some of these tracts capture a diversity of property types, ranging from moderately-priced urban and suburban homes to high value homes and ranchettes in the foothills, which are also most exposed to wildland fire. Similarly, the census tracts in the mountainous western portion of the study area are large, because of the low population density, also capturing a wide range of property types. Parcel data from counties could be used to assign more accurate values to structures to improve the accuracy of risk estimates. Home replacement cost may also underestimate the loss in value due to wildfire impacts to other characteristics of the property. Wildfire accelerated erosion of building sites and access roads may cause additional direct costs, or indirect costs on home rebuilding due to access and material transport challenges to the site. Property values may also be lowered due to the change in aesthetic qualities of the surrounding landscape.

The effect of fuel treatment is manifested in the model as change in the proportion of crown fire occurring within the 1 km radius neighborhood around each home (Figure 15, Figure 20). Since the area of this neighborhood is 776.3 acres, the cost to treat just 10% is $194,075 assuming a cost of $2,500/ac. The effect of decreasing the proportion of crown fire area by 0.1 varies, depending on the other variables in the model (Figure 20), but is generally not higher than 0.15 probability of home loss for median conditions. Given the maximum home value we used is $664,800 (a census tract upper quartile value), and the maximum neighborhood mean 25 yr burn probability is 0.185, the estimated home-level value risk reduction from 10% neighborhood treatment is at best only $18,448 over 25 years. The 25-year planning horizon being used here is our current best estimate of fuel treatment longevity for the dry and unproductive Colorado Front Range. The economics of wildland fuel treatment to reduce risk of home loss, or risk of home loss value, is clearly not efficient for protecting a single structure, but fuel treatment value improves when many structures have overlapping influence neighborhoods.

As others suggest (Cohen 2000, Schoennagel et al. 2009), the most efficient ways to reduce the probability of home ignition from wildland fire are hardening assets and reducing fuels within the HIZ. We estimate that wildland fuel treatments can have measurable benefits by reducing risk of home loss, but these benefits are not projected to exceed the cost of treatment for our study area. Factors that will make wildland fuel treatments within 1 km of home values at risk more economical are: 1) higher burn probabilities, 2) lower treatment costs, 3) higher home values, and 4) abundant WUI edge, where adjacent wildland fuels are primarily forested and prone to crown fire. Models like Price and Bradstock (2013) can be used in the planning phase to site fuel projects where they are expected to have the highest impact on home loss risk reduction, or to measure the home loss risk reduction as a co-benefit of fuel treatments or forest restoration work being done to benefit other resources.

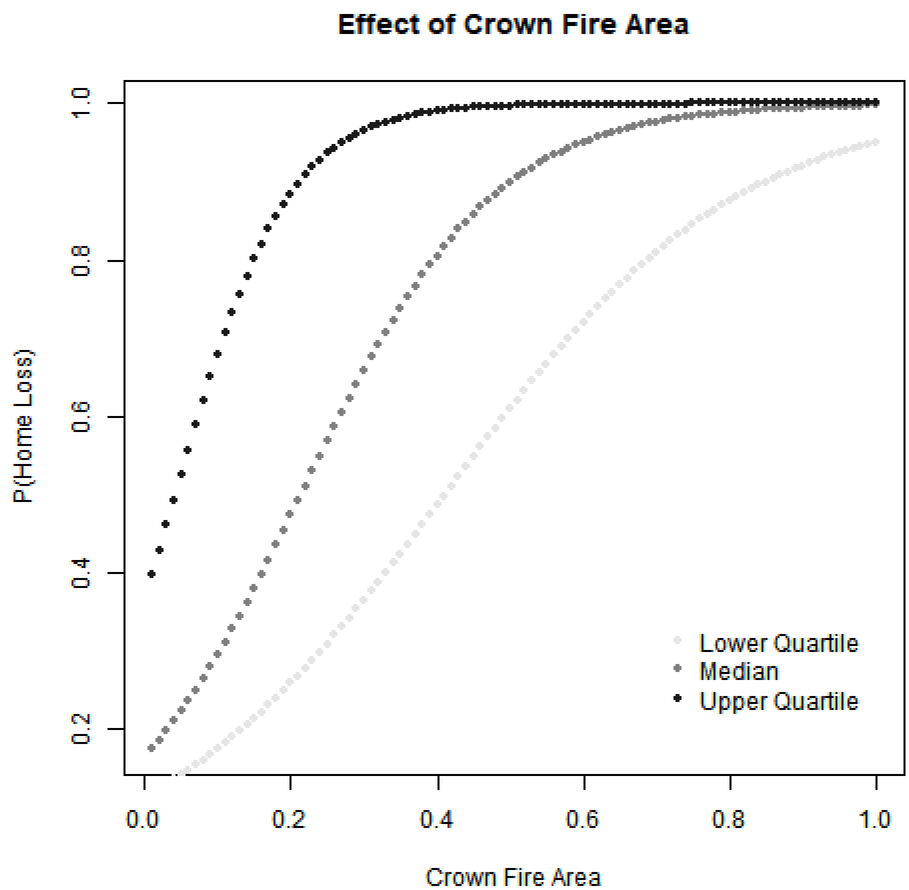


*Figure 20: in our implementation of the Price and Bradstock (2013) model, the only variable that is being changed by fuel treatments is the proportion of area burning as crown fire. The probability of home loss is calculated here for varying levels of crown fire area with all other variables set to the lower quartile, median, or upper quartiles of their respective distributions.*

**References**

Caggiano, M., C. Hoffman, A.S. Cheng, F.W. Smith, R. Reich, and W.T. Tinkham. 2015. The impact of county building codes on home loss in the High Park Fire. Wildland-Urban Interface Center Brief, Colorado State University, Fort Collins, CO. 8 p.

Caggiano, M.D., W.T. Tinkham, C. Hoffman, A.S. Cheng, and T.J. Hawbaker. 2016. High resolution mapping of development in the wildland-urban interface using object based image extraction. Heliyon, 2: e00174. DOI: http://dx.doi.org/10.1016/j.heliyon.2016.e00174

Cohen, J.D. 1995. Structure ignition assessment model (SIAM). In Proceedings of Biswell Symposium: Fire Issues and Solutions in Urban Interface and Wildland Ecosystems, 85-92. General Technical Report PSW-158. Albany, CA: USDA Forest Service, Pacific Southwest Research Station.

Cohen, J.D. 2000. Preventing disaster: home ignitability in the wildland-urban interface. Journal of Forestry, 98:15-21.

Koo, E., P.J. Pagni, D.R. Weise, and J.P. Woycheese. 2010. Firebrands and spotting ignition in large-scale fires. International Journal of Wildland Fire, 19(7): 818-843. DOI: 10.1071/WF07119

Maranghides, A., D. McNamara, R. Vihnanek, J. Restaino, and C. Leland. 2015. National Institute of Standards and Technology Technical Note 1910, 213 p. http://dx.doi.org/10.6028/NIST.TN.1910

Price, O. and R. Bradstock. 2013. Landscape scale influences of forest area and housing density on house loss in the 2009 Victorian bushfires. PLoS ONE 8(8): e73421. DOI: 10.1371/journal.pone.0073421

Schoennagel T., C.R. Nelson, D.M. Theobold, G.C. Carnwath, and T.B. Chapman. 2009. Implementation of National Fire Plan treatments near the wildland-urban interface in the western United States. Proc Natl Acad Sci USA 106: 10706–10711.

Wang, H. 2011. Analysis on downwind distribution of firebrands sourced from a wildland fire. Fire Technology, 47(2): 321-340. DOI: 10.1007/s10694-009-0134-4

## Appendix II: Pre-loaded Co-benefits

The co-benefits calculator comes pre-loaded with spatial data to represent values of the built environment, fishing, hunting, recreation, wetlands, and wildlife that may benefit from wildfire risk reduction activities (Table 5; Figure 21 to Figure 38). Default response functions are provided for each co-benefit (expected losses in $/ac) to reflect their general values and responses to surface, passive crown, and active crown fire. Typically, response functions are defined in terms of relative loss or gain of resource value due to the difficulty of precisely defining losses for resources with poorly understood responses to fire and imperfect data on baseline resource conditions (Scott et al. 2013).

*Table 5: spatial co-benefits data pre-loaded into the calculator, with the default response functions (expected losses when exposed to surface, passive, and active crown fire), source, and description of data.*

| Benefit Class | HVRA | File Name | Response Function | Source and Description |
|---|---|---|---|---|
| **Built Environment** | Communication Points | com_points.shp | 5000, 50000, 200000 | Point shapefile of Homeland Infrastructure Foundation - Level Data AM, FM, Microwave, Cellular, and TV Analog and Digital communication infrastructure. |
| | Electric Transmission Lines | electric_transmission.shp | 100, 1000, 10000 | Polyline shapefile of Homeland Infrastructure Foundation - Level Data major electric transmission lines. |
| | Electric Substations | electric_substations.shp | 5000, 50000, 200000 | Point shapefile of Homeland Infrastructure Foundation - Level Data electric substations. |
| | WUI Structures | WUI_structures.shp | 5000, 50000, 200000 | Point shapefile of Caggiano et al. 2016 WUI structures. Using this in the vector workflow provides a count of structures impacted. Superseded by the Detailed Home Loss Model, but available for use. |
| | WUI Structures | WUI_50m | 5000, 50000, 200000 | Raster of Caggiano et al. 2016 WUI structure database with WUI presence assigned to pixels within 50 m of structures. Superseded by the Detailed Home Loss Model, but available for use. |
| **Fishing** | State Fishing Units | CPW_SFU.shp | 0, 50, 200 | Polygon shapefile of CPW state fishing units. |
| **Hunting** | State Wildlife Areas | CPW_SWA.shp | 0, 50, 200 | Polygon shapefile of CPW state wildlife units. |
| **Recreation** | Trails | trails.shp | 0, 50, 200 | Polyline shapefile of non-motorized trails from multiple agencies. |
| | Off-road Trails | offroad.shp | 0, 50, 200 | Polyline shapefile of USFS roads from Motor Vehicle Use Map. |
| | Recreation Sites | recopps.shp | 0, 50, 200 | Point shapefile of USFS recreation opportunity sites including campgrounds, picnic areas, trailheads, etc. |

| | | | | |
|---|---|---|---|---|
| | Wild & Scenic Rivers | WildScenicRiverStatus.shp | 0, 50, 200 | Polygon shapefile of USFS wild and scenic river status including a 0.25 mile buffer around river. |
| | Parks & Open Spaces | parks.shp | 0, 50, 200 | Polygon shapefile of parks and open spaces compiled from CPW, Larimer County, and Fort Collins data sources. |
| **Wetlands** | Wetlands | wetland | 0, 50, 200 | Raster of NWI non-lake, non-pond wetlands that may be sensitive to wildfire impacts. |
| **Wildlife** | WAFWA Crucial Habitat | WAFWA_CHAT_p1and2.shp | 0, 50, 200 | Polygon shapefile of WAFWA CHAT priority 1 and 2 crucial habitat. |
| | Elk Severe Winter Range | ElkSevereWinterRange.shp | 0, 50, 200 | Polygon shapefile of CPW elk severe winter range that may be negatively impacted by loss of canopy cover. |
| | Greater Sage Grouse Priority Habitat | GrSG_priorityhabitat.shp | 0, 50, 200 | Polygon shapefile of CPW priority sage grouse habitat. |
| | Pinyon-Juniper Habitat | pj_hab | 0, 50, 200 | Raster of LANDFIRE EVT pinyon and juniper woodland unique habitat types. |
| | Sagebrush Habitat | sb_hab | 0, 50, 200 | Raster of LANDFIRE EVT sagebrush unique habitat types. |

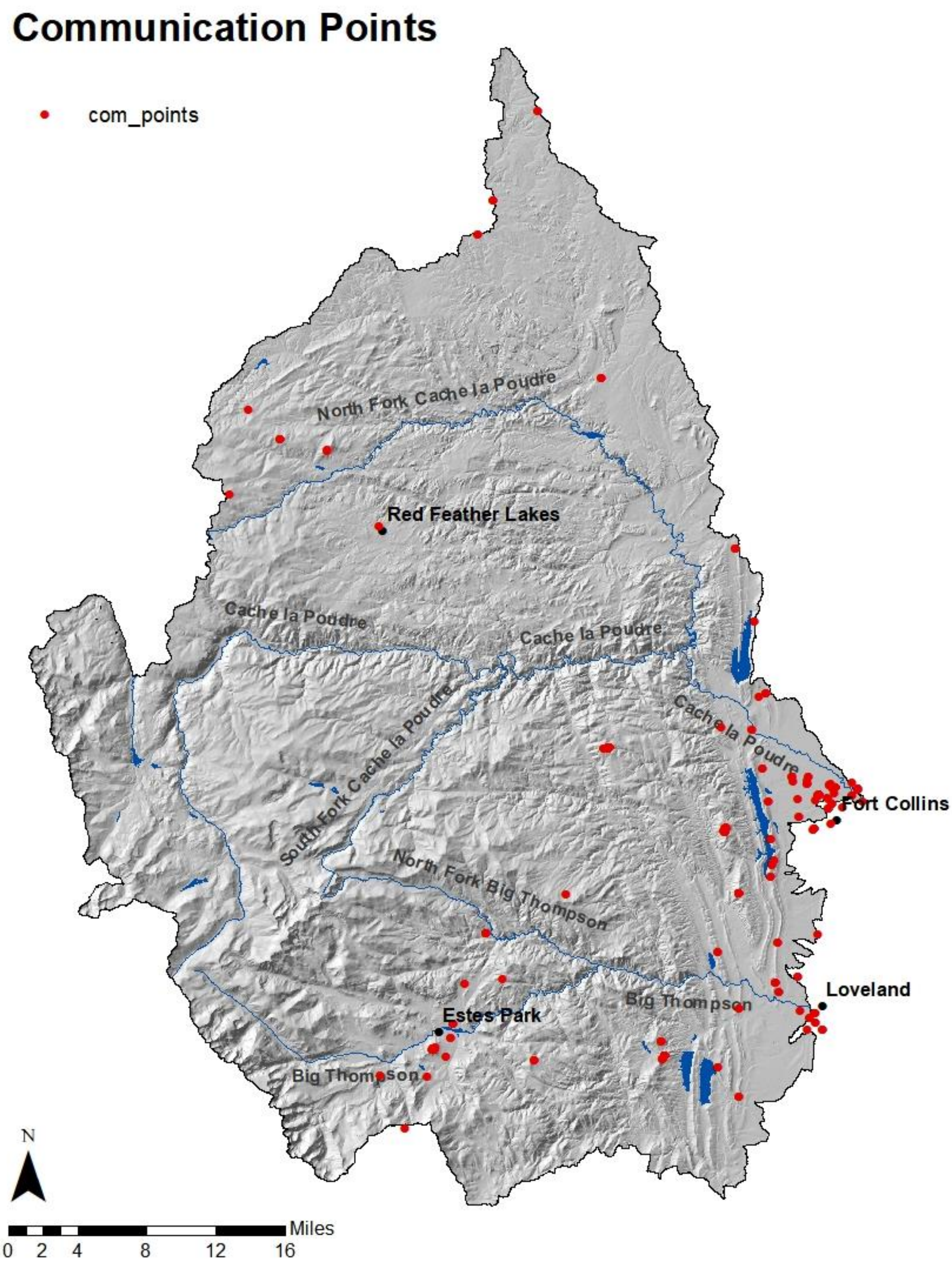


*Figure 21: Homeland Infrastructure Foundation - Level Data AM, FM, Microwave, Cellular, and TV Analog and Digital communication infrastructure.*

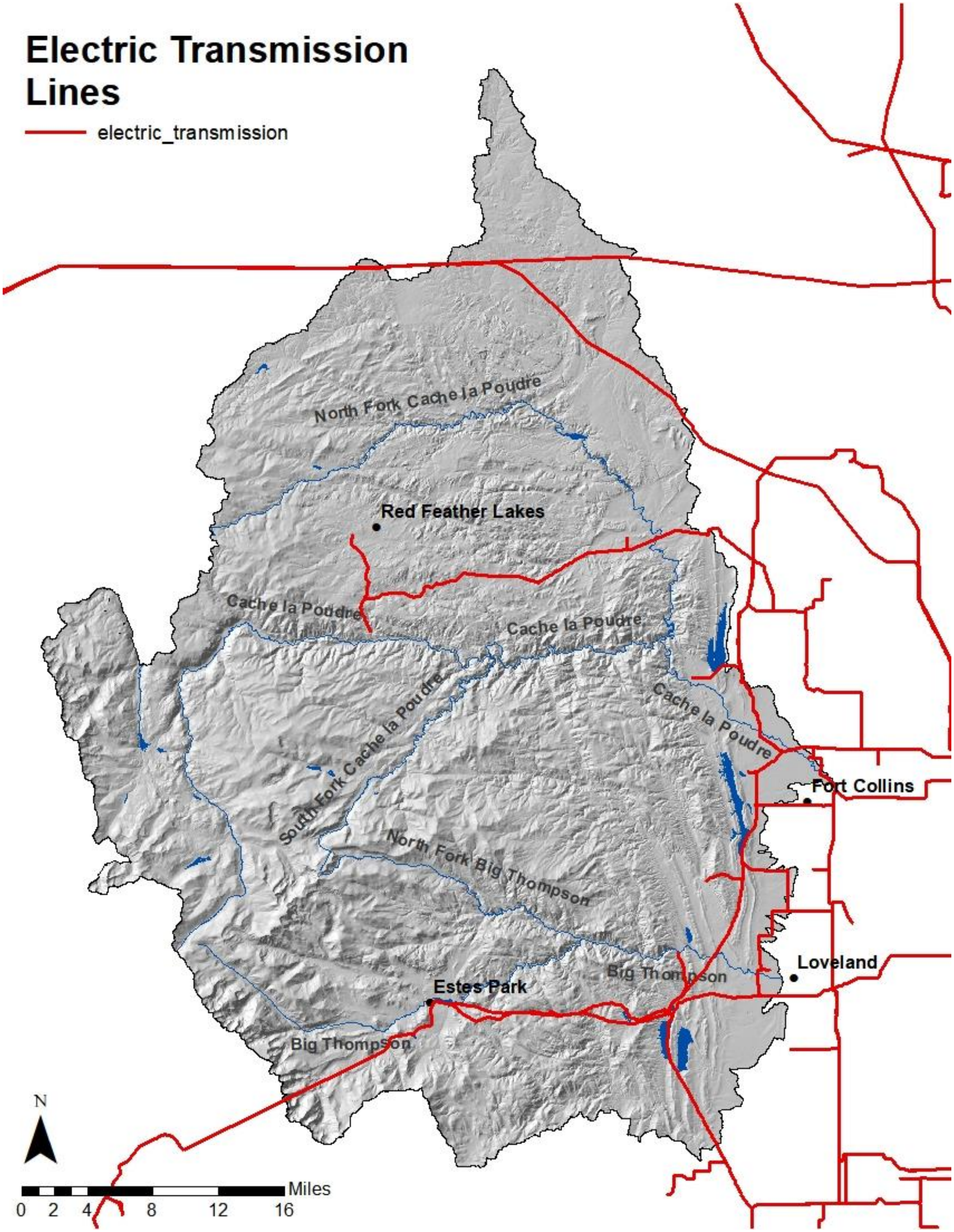


*Figure 22: Homeland Infrastructure Foundation - Level Data major electric transmission lines.*

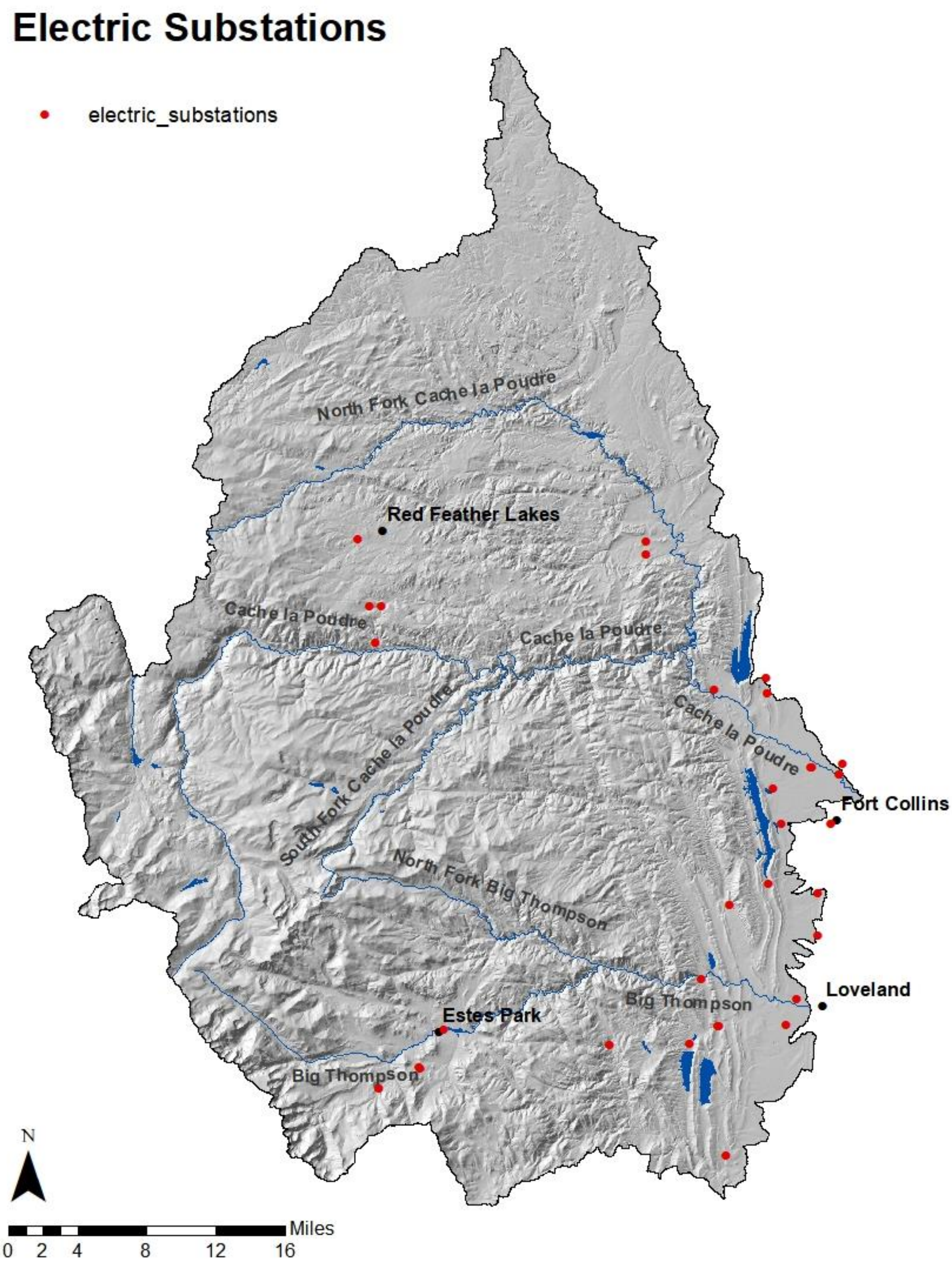


*Figure 23: Homeland Infrastructure Foundation - Level Data electric substations.*

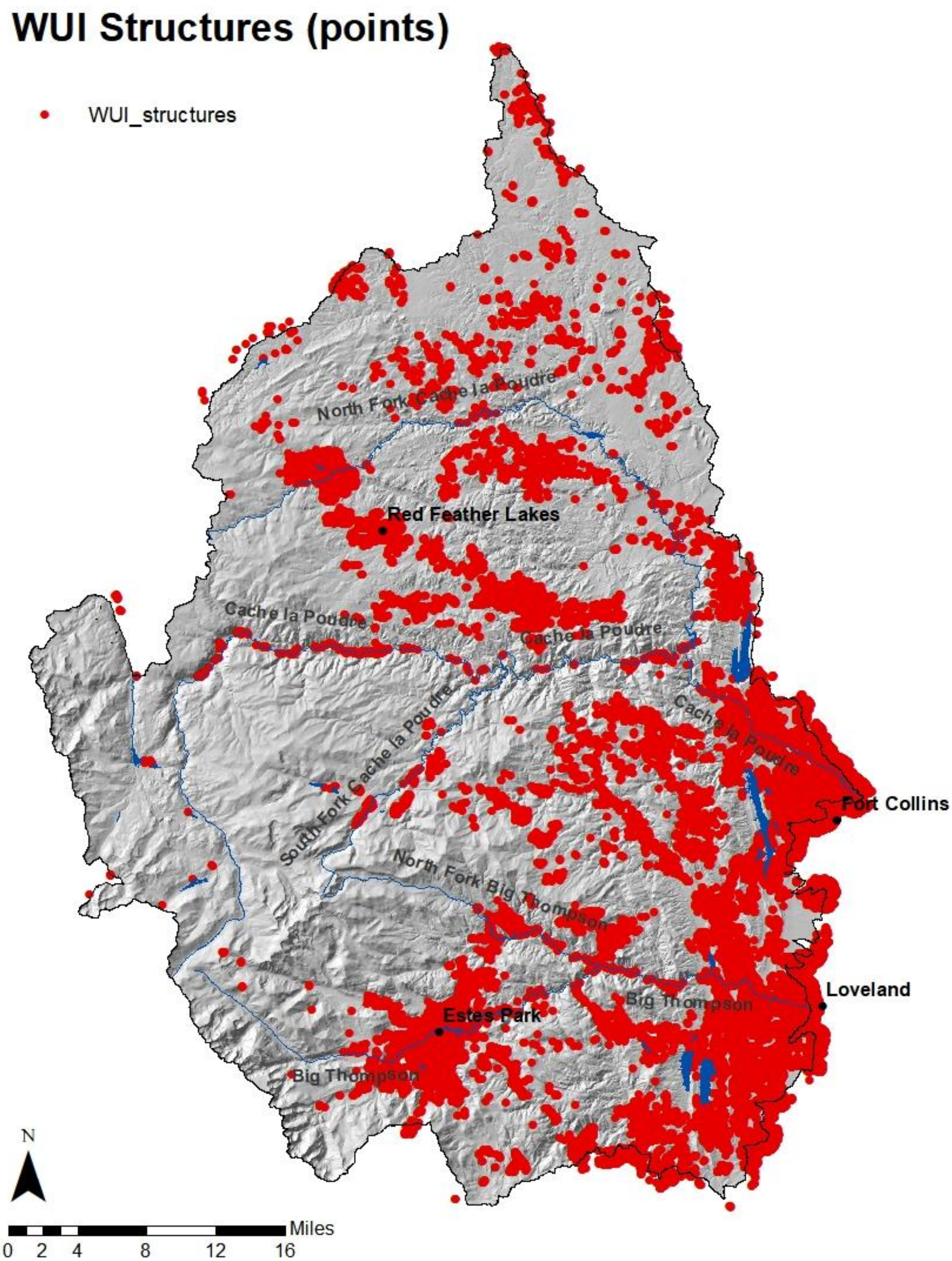


*Figure 24: Caggiano et al. 2016 WUI structure points.*

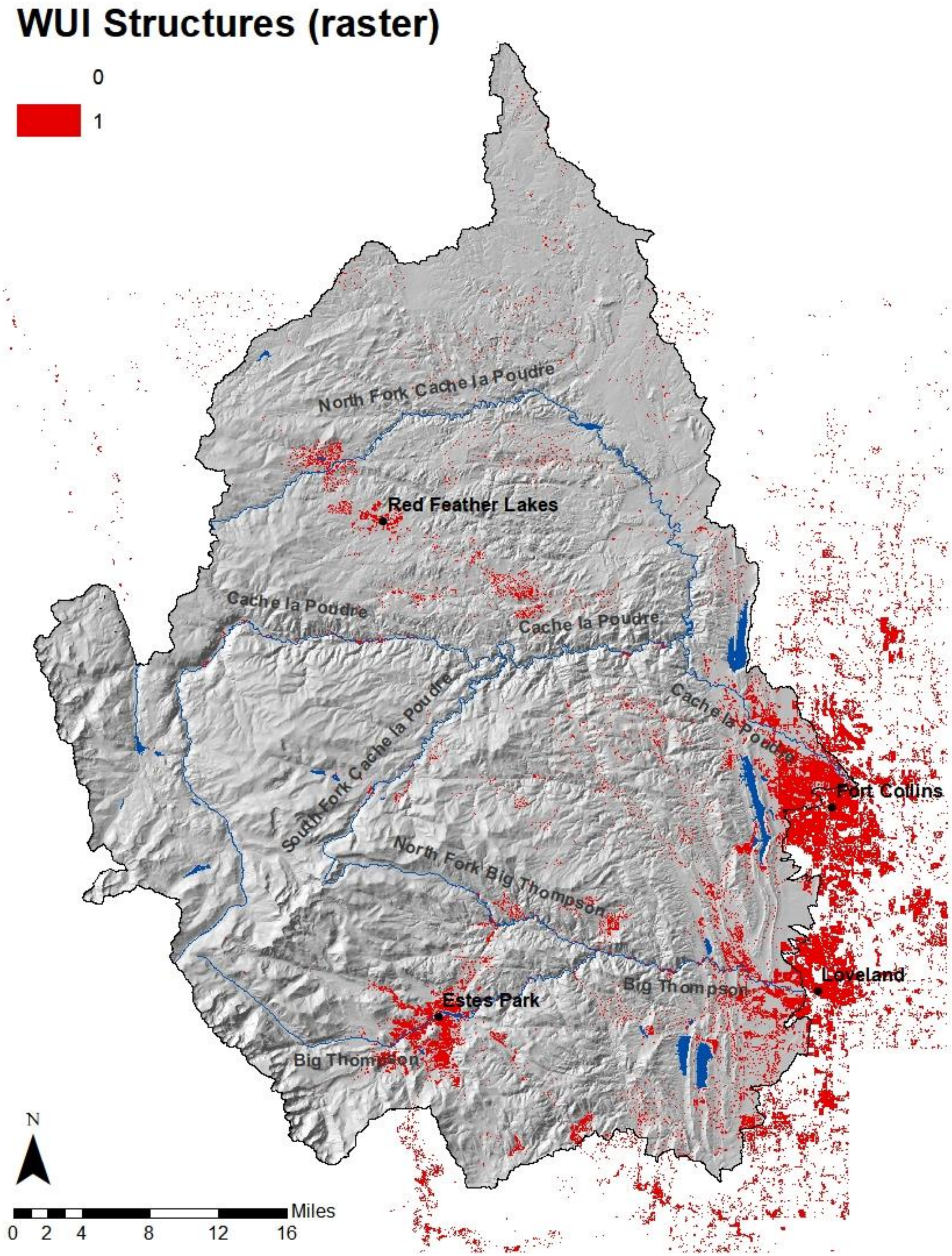


*Figure 25: Raster of Caggiano et al. 2016 WUI structure database with WUI presence assigned to pixels within 50 m of structures.*

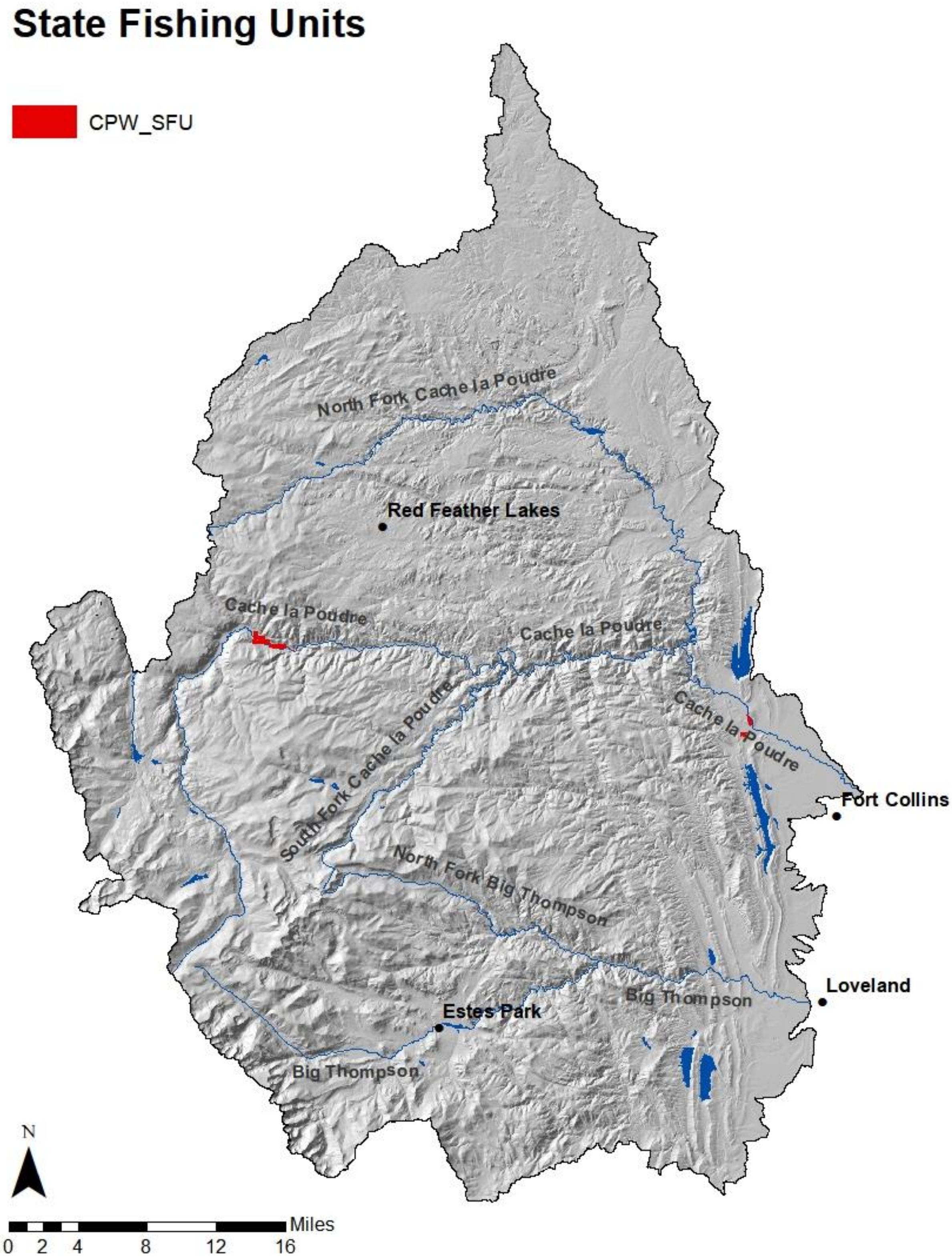

Figure 26: CPW state fishing units.

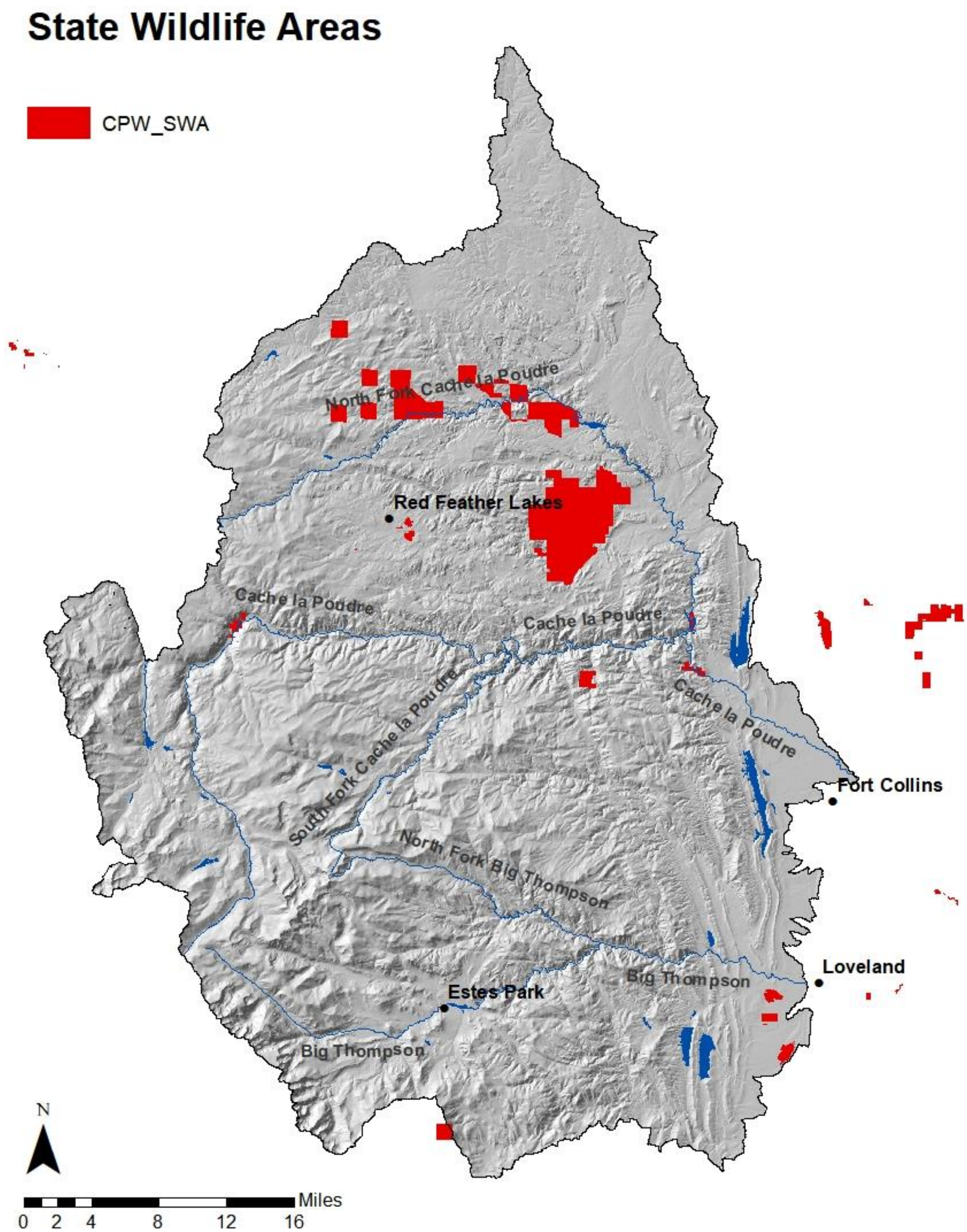


*Figure 27: CPW state wildlife areas.*

# Trails

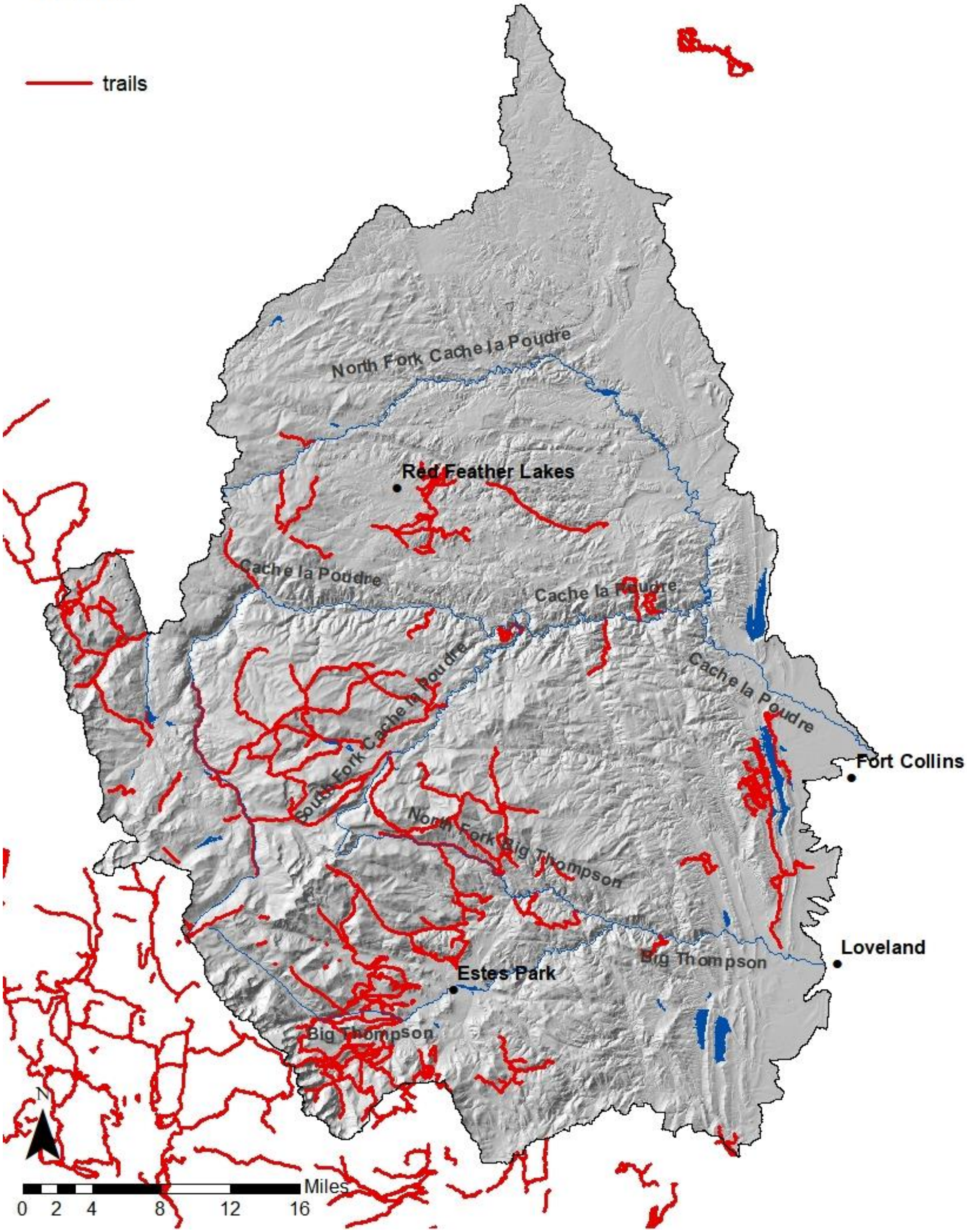


Figure 28: non-motorized trails from multiple agencies.

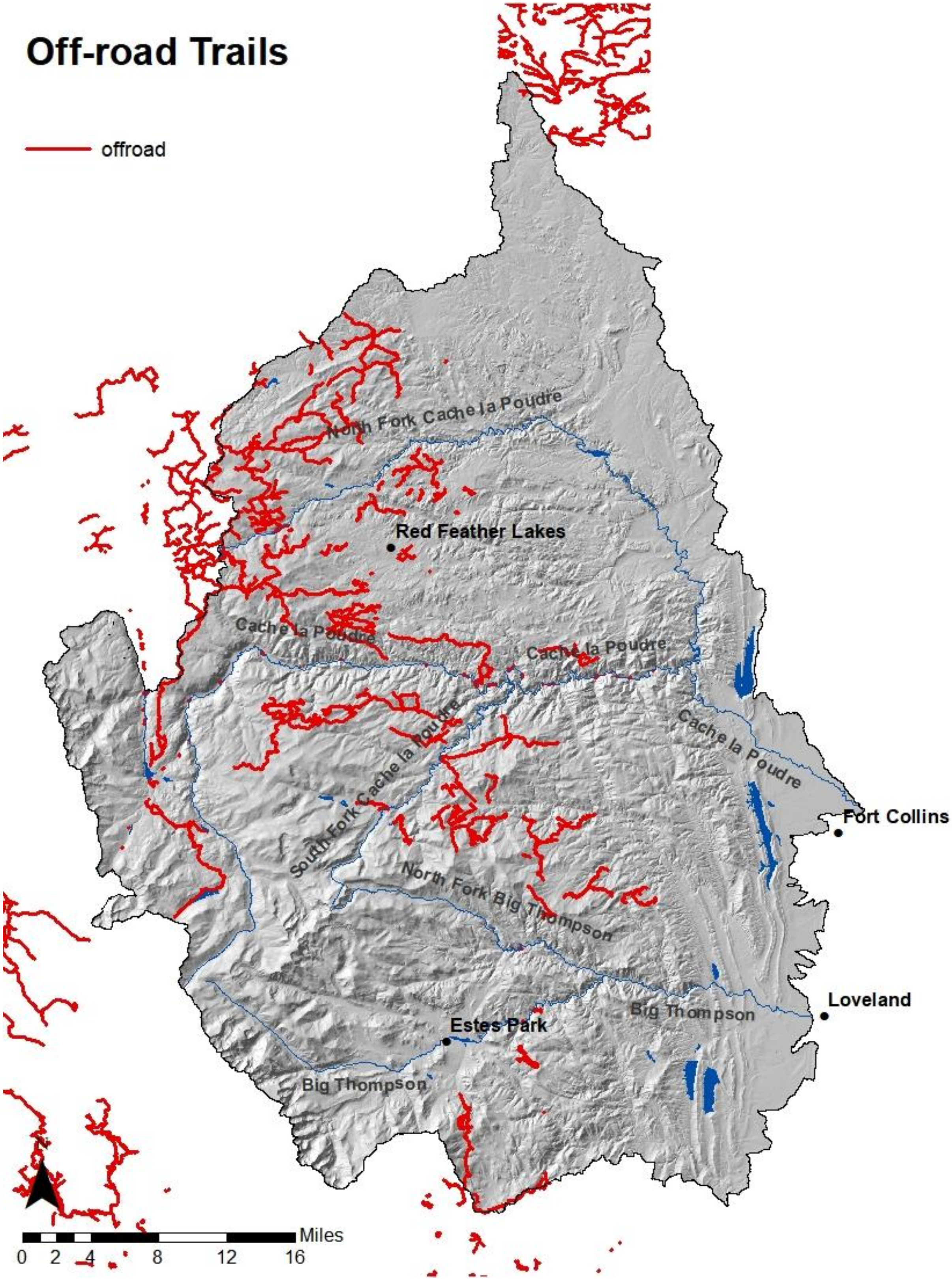

*Figure 29: USFS roads from Motor Vehicle Use Map.*

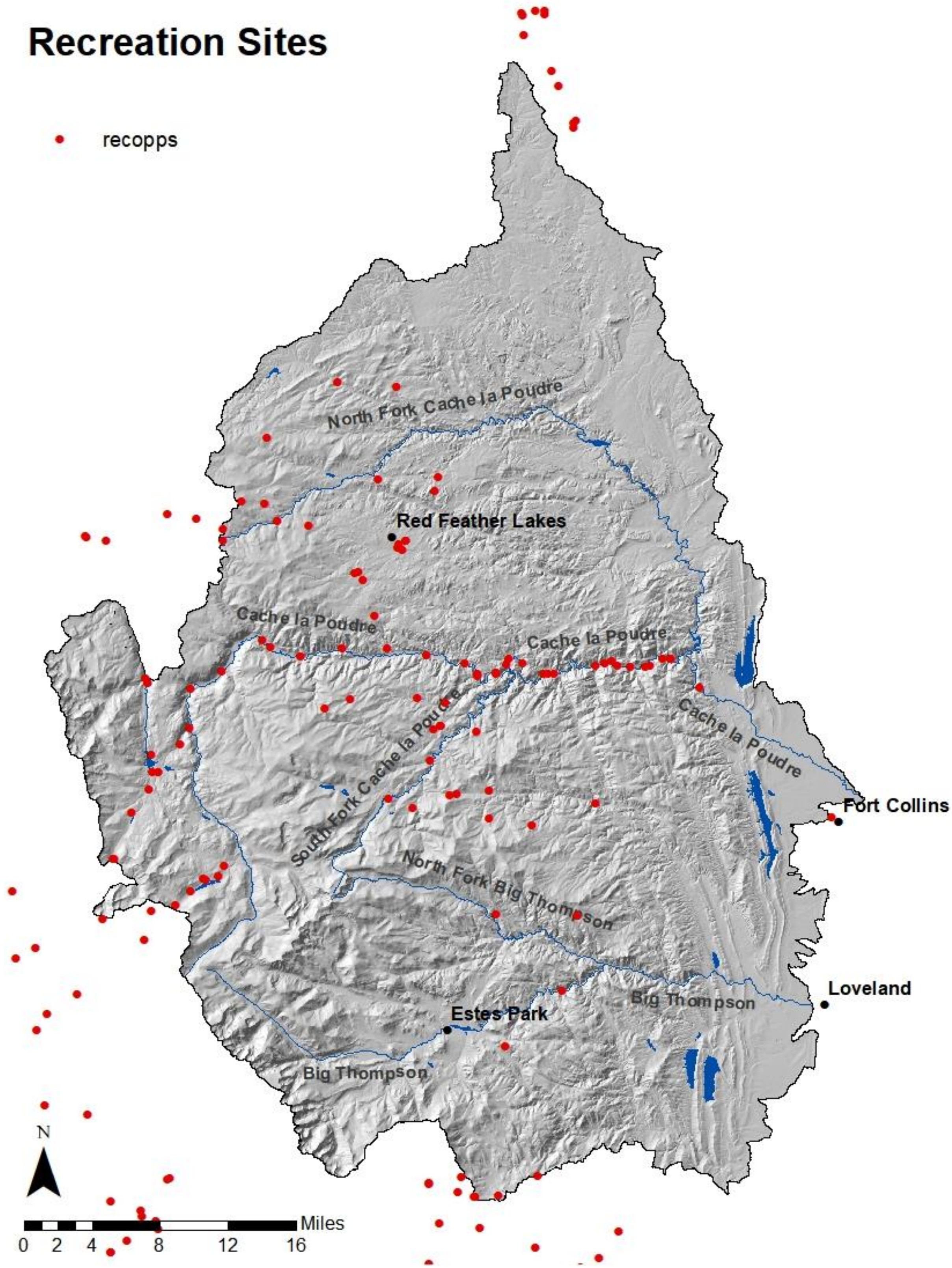


*Figure 30: USFS recreation opportunity sites including campgrounds, picnic areas, trailheads, etc.*

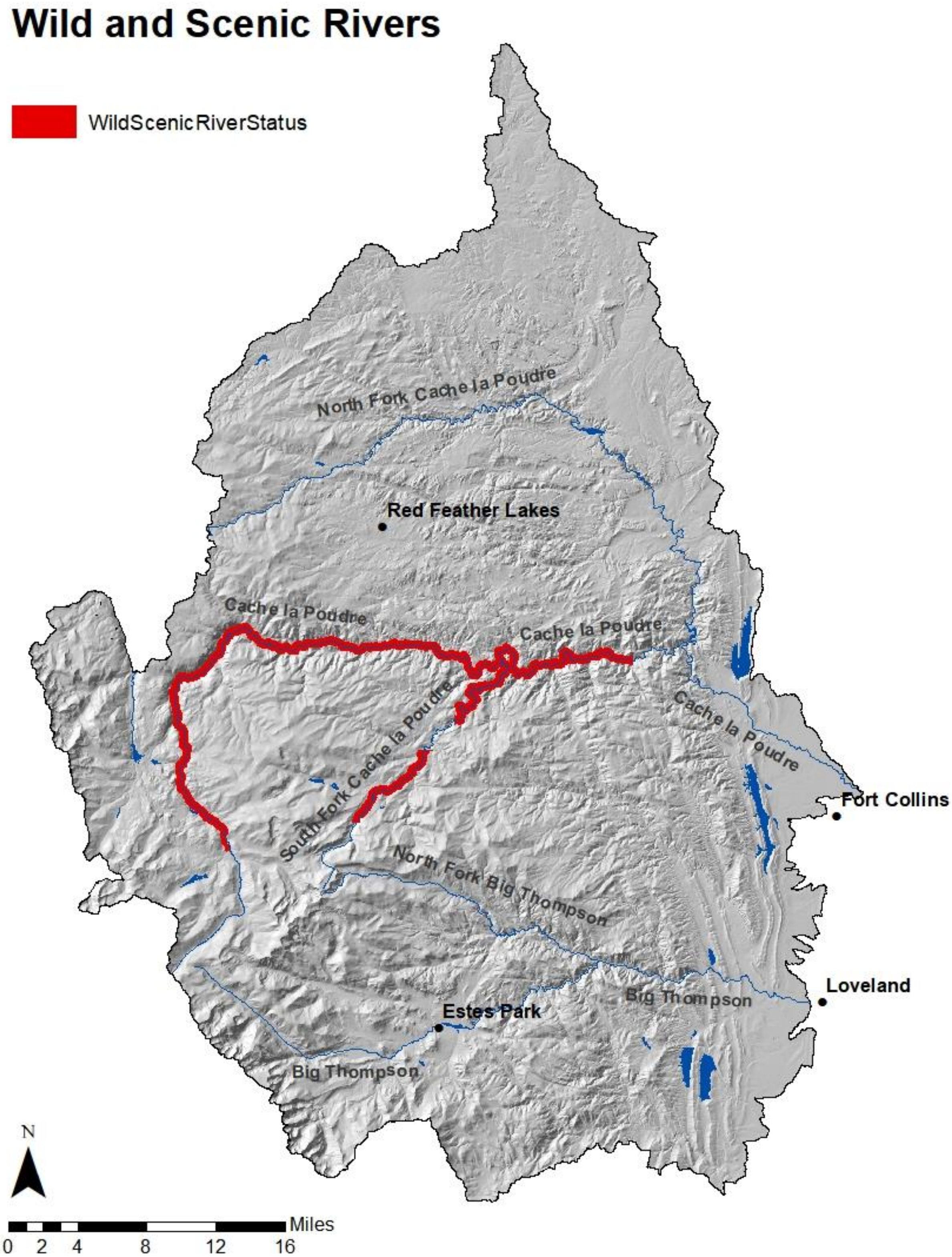


*Figure 31: USFS wild and scenic river status including a 0.25 mile buffer around river.*

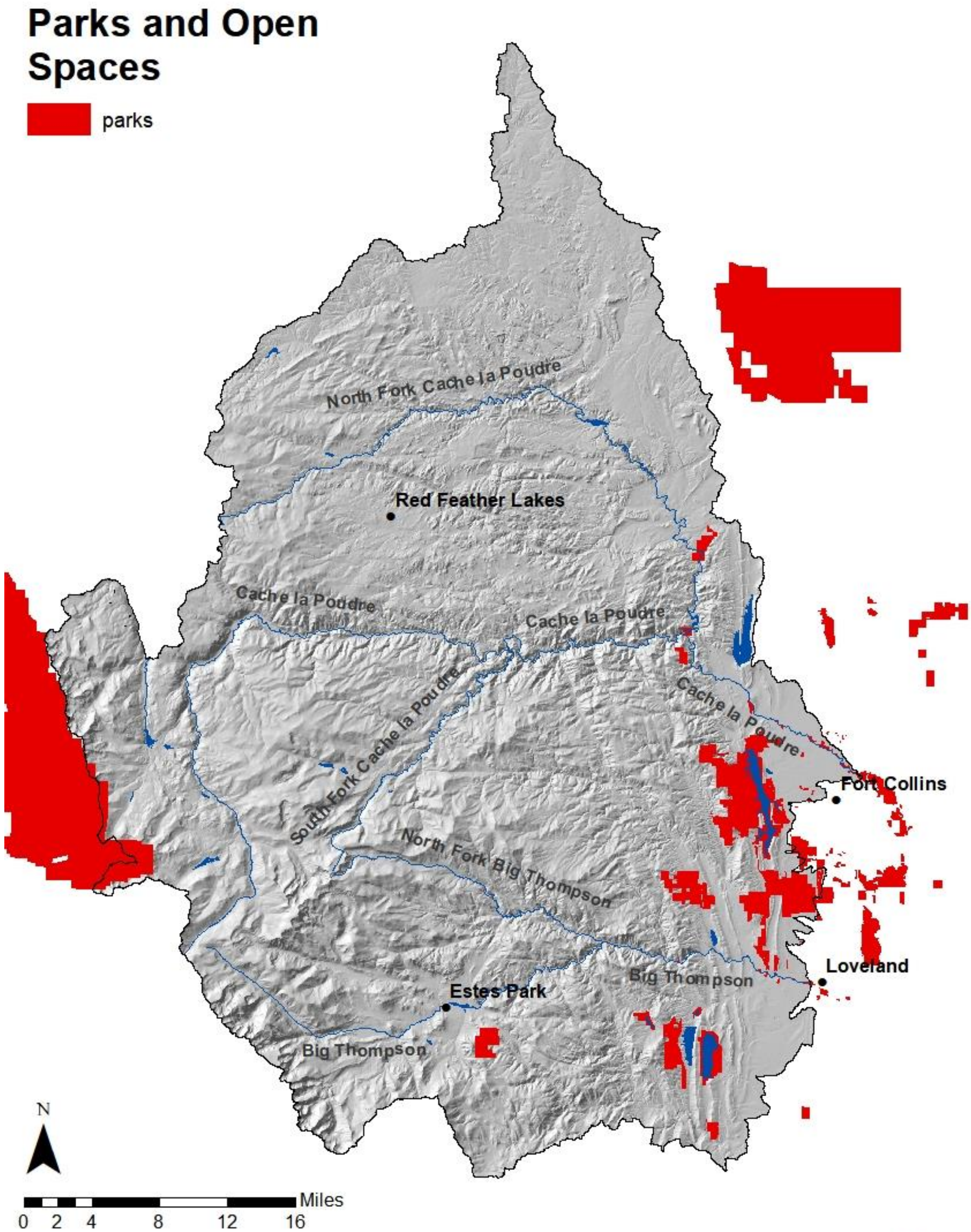


*Figure 32: parks and open spaces compiled from CPW, Larimer County, and Fort Collins data sources.*

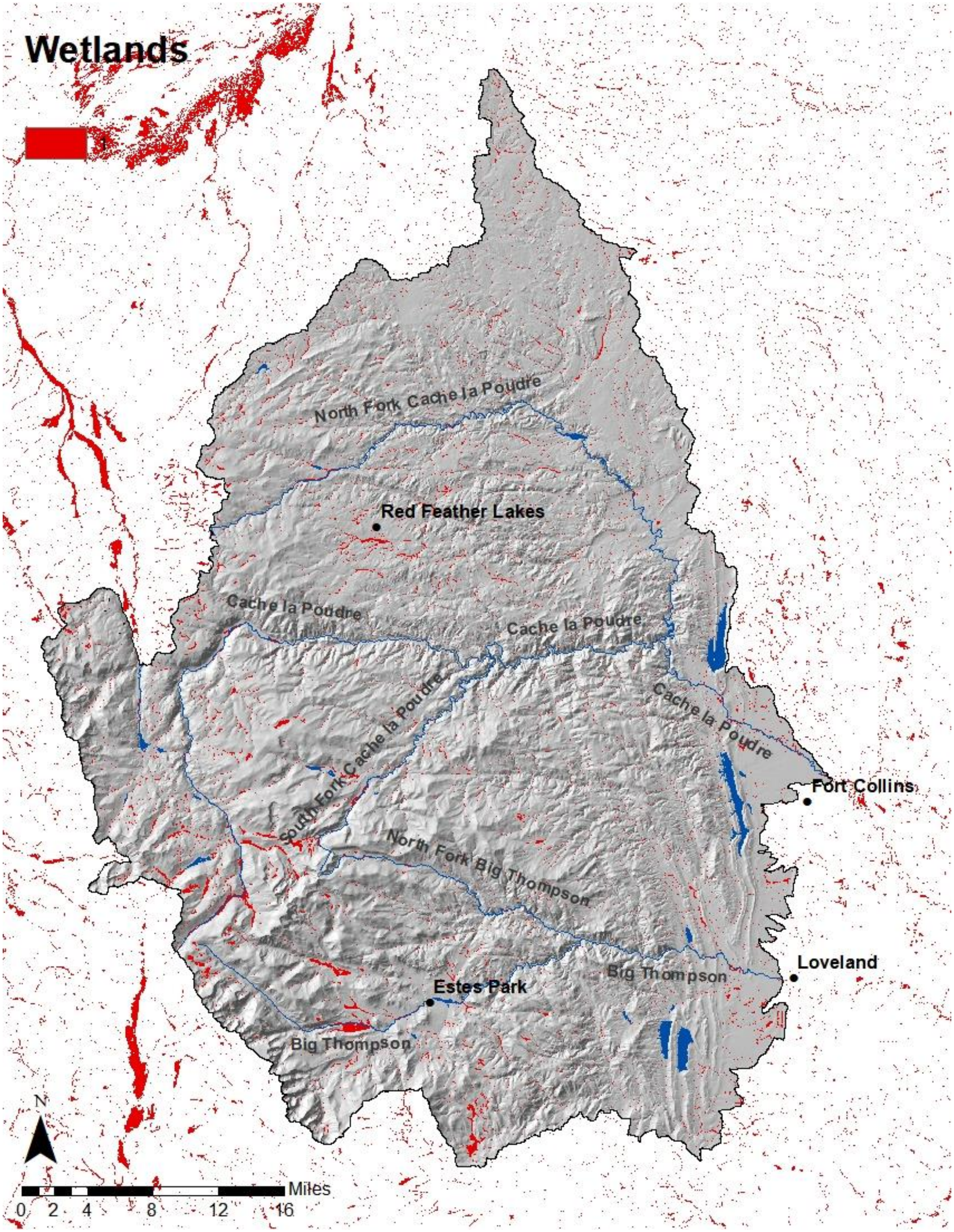


*Figure 33: NWI non-lake, non-pond wetlands that may be sensitive to wildfire impacts.*

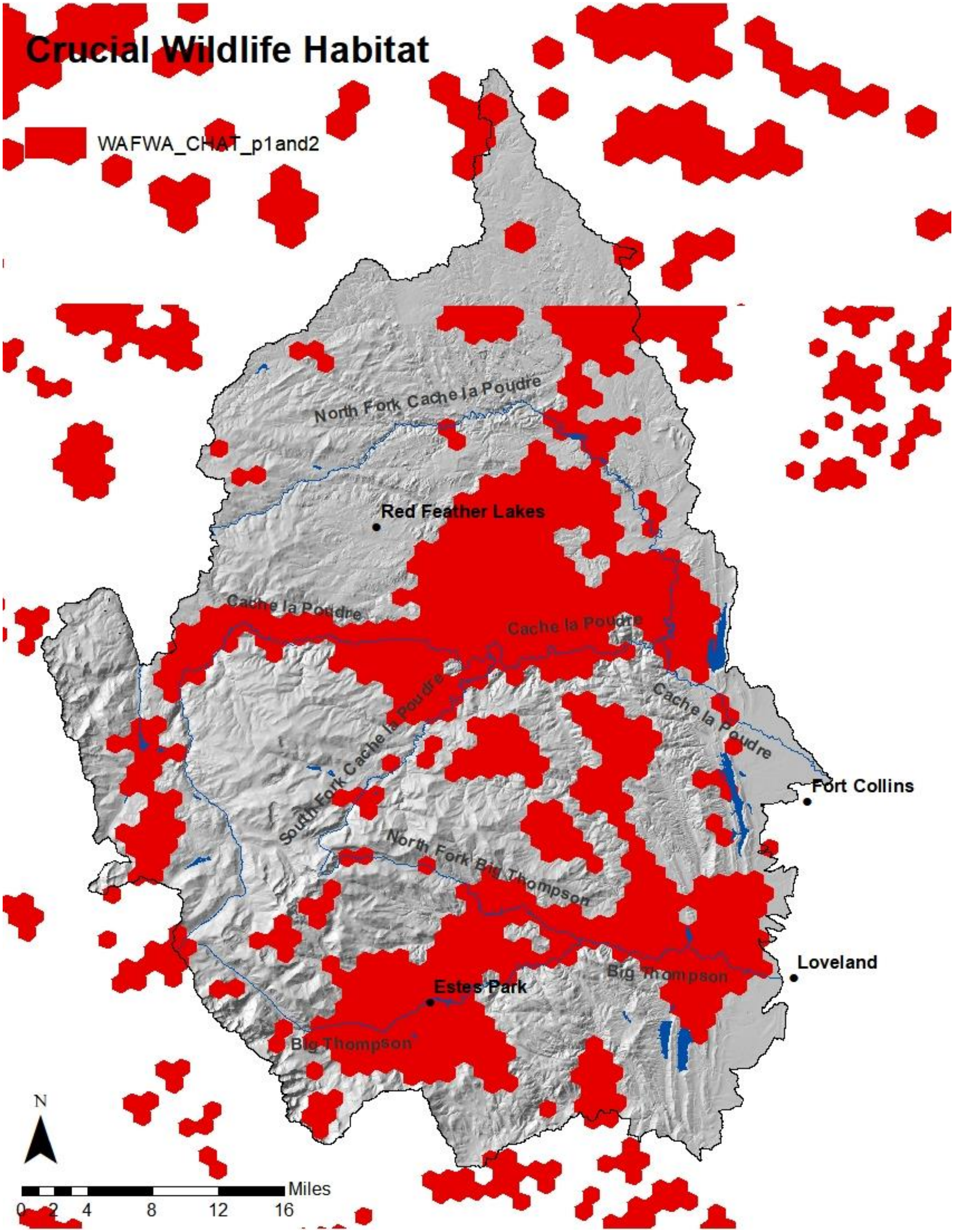


Figure 34: WAFWA CHAT priority 1 and 2 crucial habitat.

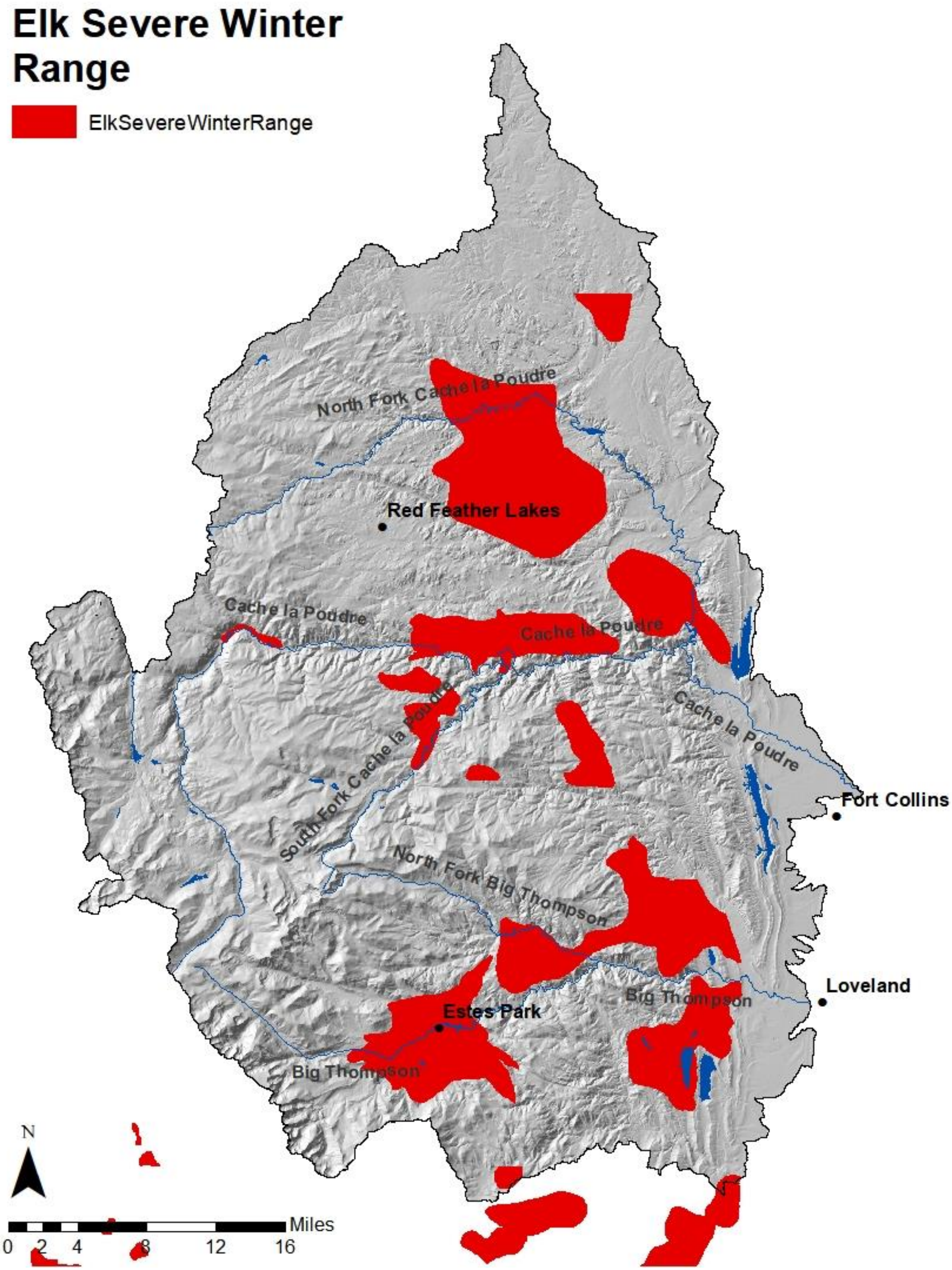


*Figure 35: CPW elk severe winter range that may be negatively impacted by loss of canopy cover.*

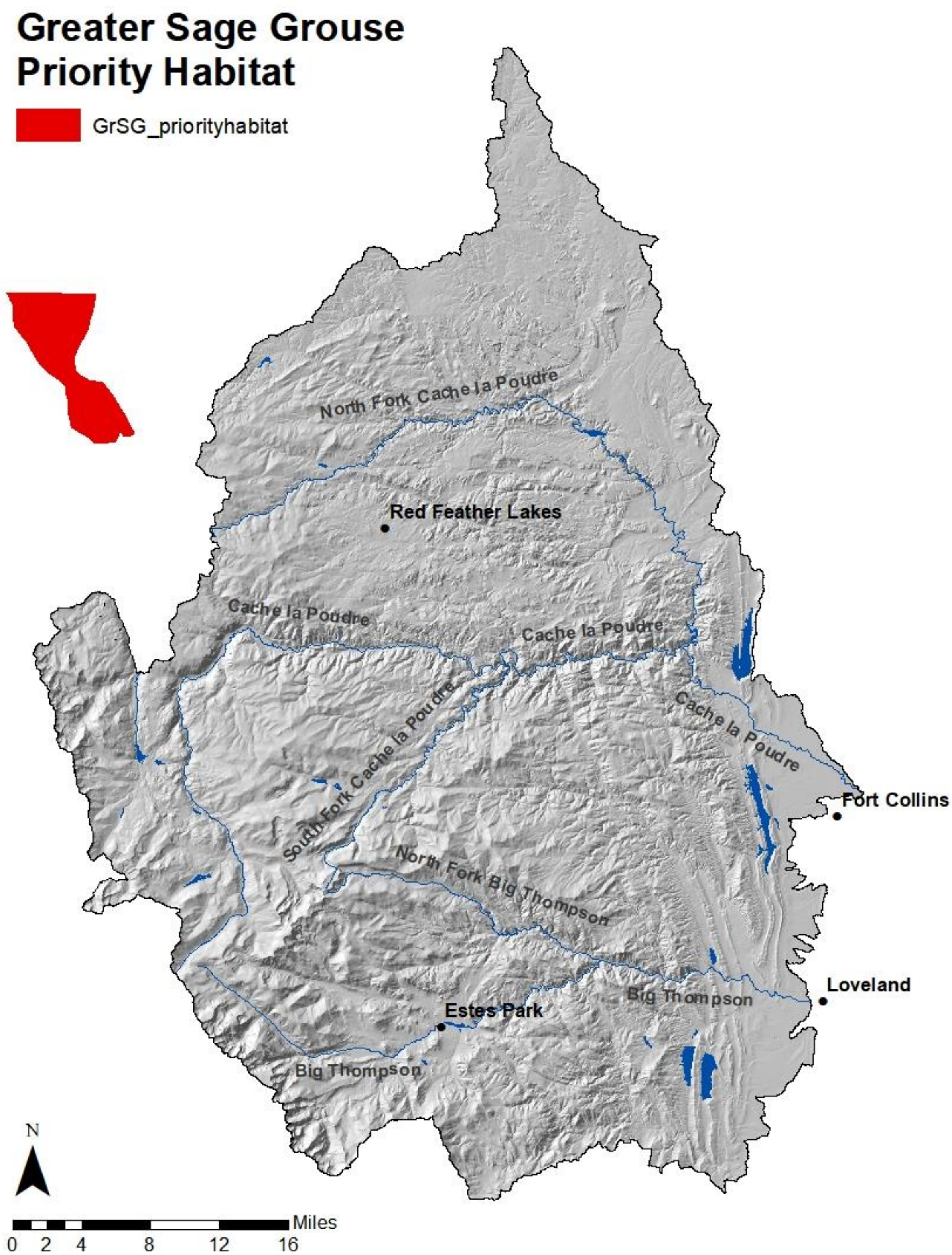


*Figure 36: CPW priority sage grouse habitat.*

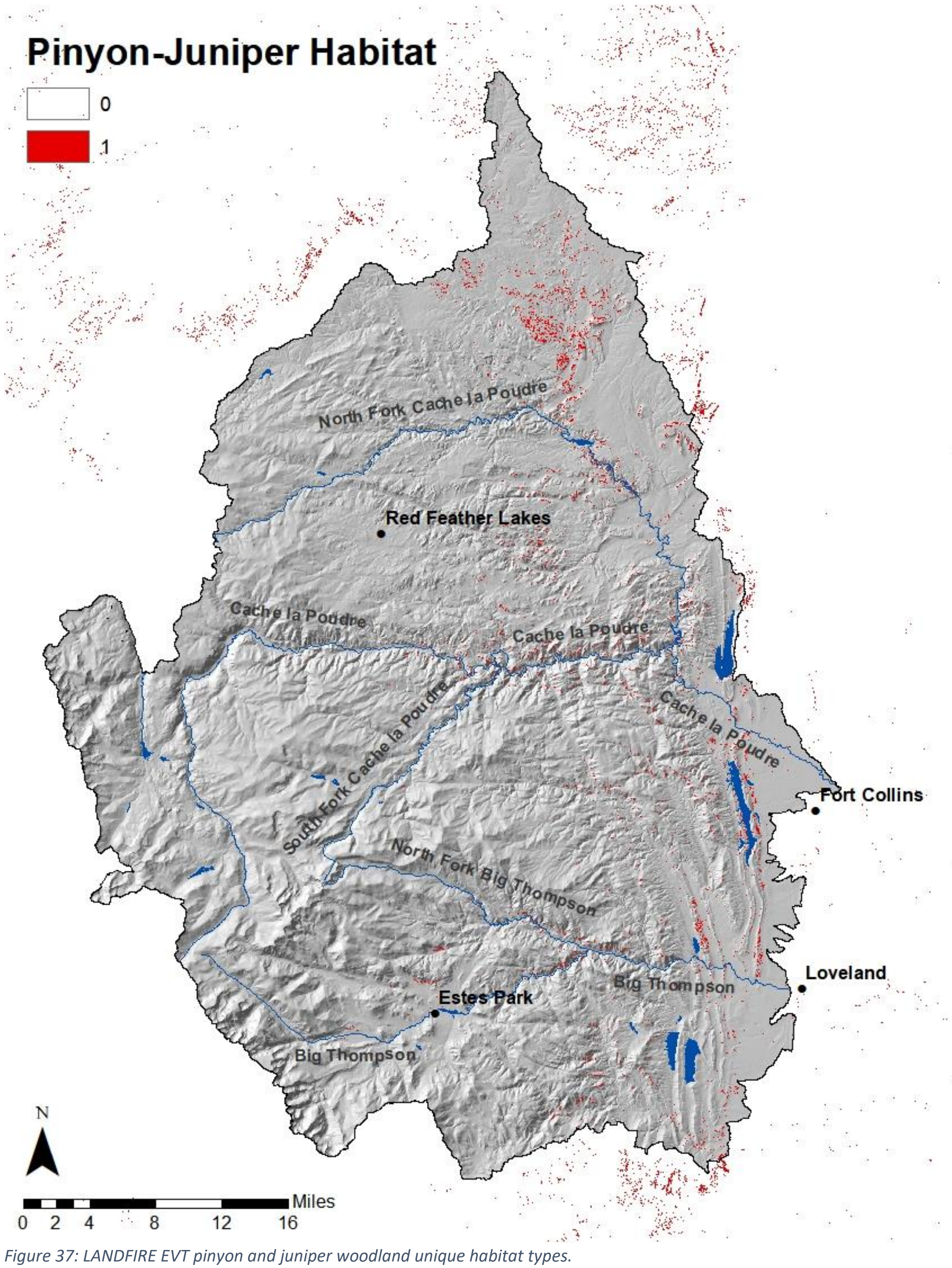


*Figure 37: LANDFIRE EVT pinyon and juniper woodland unique habitat types.*

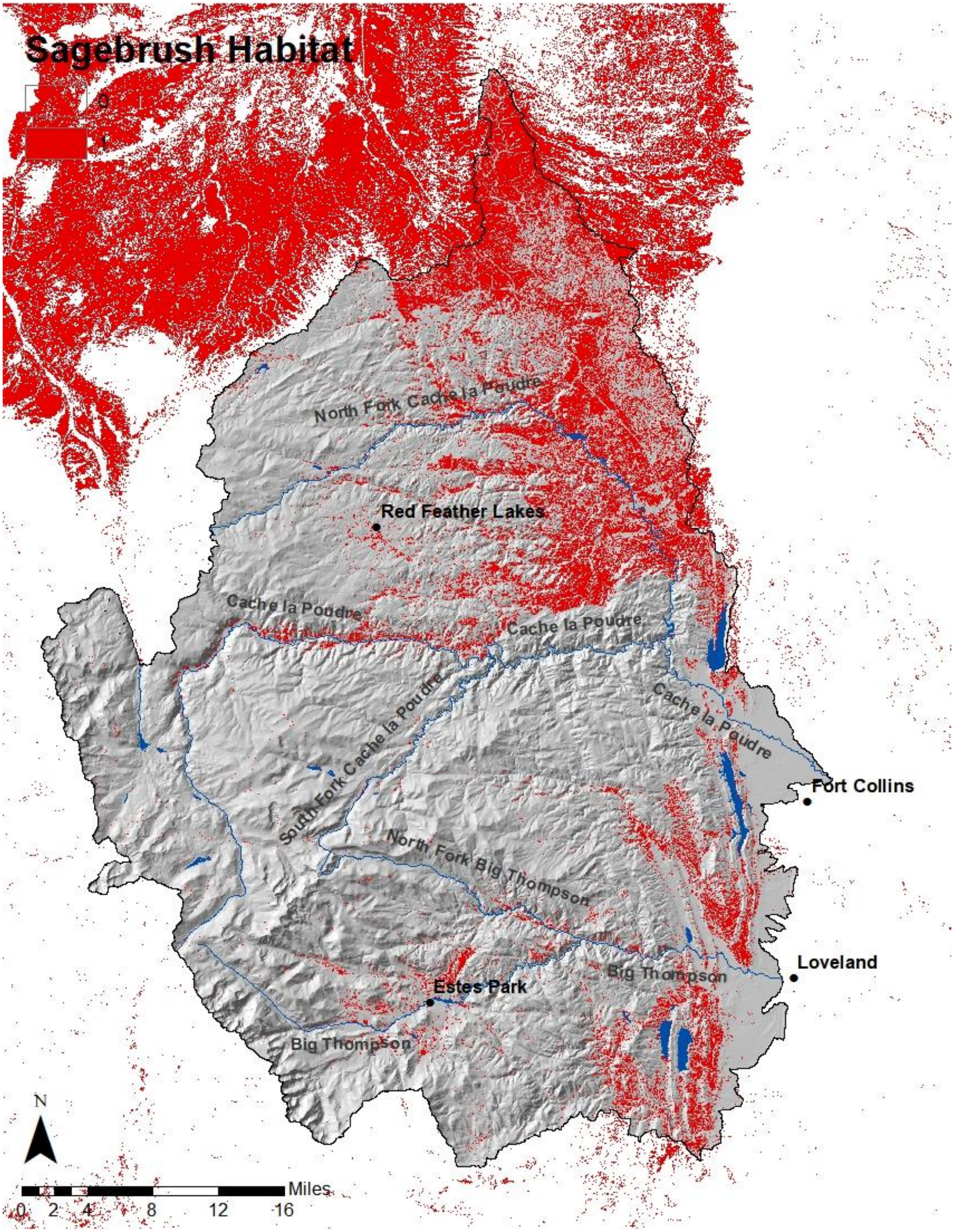


*Figure 38: LANDFIRE EVT sagebrush unique habitat types.*