Glance at the sun.
See the moon and the stars.
Gaze at the beauty of earth's greenings.
Now, think.

\- Hildegard Von Bingen

WITH PHILOSOPHY
HE CONTEMPLATES
THE MOUNTAIN…
OLD PROFESSOR FROG

-Issa

7 METHODS FOR CREATING THE WILDLANDS NETWORK

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The Southern Rockies Wildlands Network Design used computer modeling and expert opinion to craft a design that includes the best available data and best meets the overarching goals of rewilding and ensuring persistence of native biodiversity in the ecoregion. Computers models that were used include SITES and least cost path analysis, while expert opinion was incorporated from literature, several expert workshops, individual review by SREP's science team, and regional and national experts.

1. The SITES Model

A wildlands network design asks two basic questions: "where should the network components (especially cores and linkages) be located?" and, "how large should the network be?" One tool to find the answers is the site selection optimization program SITES v1.0 (Andelman et al. 1999). Goals for each target component (special elements, representation, and focal species) are all stated quantitatively as inputs into SITES, and the model highlights the most important areas for a wildlands network (Noss and Harris 1986).

The SITES model was developed for The Nature Conservancy (TNC) by land-use planning experts, and has been used by TNC to develop ecoregional plans for nine different ecoregions. The SITES model attempts to minimize the "cost" of a conservation network while maximizing attainment of conservation goals, usually in a compact set of core areas. This set of objectives constitutes the "objective cost function," in which:

$$\text{Total Cost} = (\text{Cost of selected planning units}) + (\text{Penalty cost}) + (\text{Weighted boundary length})$$

The user of the SITES model determines what the costs are, which may include literal interpretations such as actual cost of acquiring and protecting lands for conservation. In our case the *cost of selected planning units* was determined by an index that represents the relative cost of restoring these areas back to wild land. Another way to look at this index is that it represents the relative level of human-caused ecological degradation of an area. The *penalty cost* is an additional cost for failing to meet stated target goals. SITES automatically calculates a penalty cost for each target that estimates how much more it would cost, in terms of planning unit cost plus weighted boundary length cost, to meet the stated goal. If desired, each target goal can be assigned a unique weight to apply to the penalty cost that reflects its greater or lower intrinsic value to the overall network design. However, we weighted all target elements equally. The *weighted boundary length* is the cost of the spatial dispersion of the selected sites as measured by the total boundary length of the network design multiplied by an arbitrary modifier. Increasing this boundary length modifier has the effect of clumping areas chosen in order to minimize the perimeter to area ratio, and thereby reduce fragmentation of the network.

The entire study area was divided into 1,000-hectare hexagonal areas that were used as the individual planning units so that SITES could create an initial optimized design irrespective of jurisdictional boundaries. A hexagonal shape was selected over other shapes or entities (*e.g.* square cells, watersheds) because the unit size remains constant (planning units that vary widely in size can present problems for the SITES algorithm), it approximates a circle (which has a low edge to area ratio), and provides a relatively smooth output (as compared with similar sized square cells). We chose a planning unit size of 1,000 ha because this was larger than the resolution of the coarsest input data set and provided output that had sufficient resolution for the purposes of this study. Because other Wildlands Network Designs in the Spine of the Continent MegaLinkage are also using the unit size of 1,000 ha, it will facilitate collation of the regional plans into a continental plan.

The SITES algorithm uses a process termed "simulated annealing" (Andelman et al. 1999). Through iterations, this technique gradually "hones in" on a set of planning units that best meet the target conservation goals, while minimizing cost. The annealing process starts with a random set of planning units and then adds and discards planning units via an iterative process in an attempt to maximize conservation target goals while minimizing costs. This method does not necessarily find the "perfect" solution each time, but instead returns a near optimal solution. Thus several runs of the model are recommended in order to determine the best selection output. Each time we ran the model, we did it in sets of ten runs, each with one million iterations. SITES then selected the run that best met the target goals with the least cost as the "best" run for that set of ten. SITES also creates a summary file, which indicates the number of times (out of the ten) that a particular planning unit was included in the final set of planning units. Planning units that are selected in multiple runs of the set, even though they do not necessarily appear in the "best" (lowest cost) solution, may highlight potential linkages between core wild areas and/or areas with more intrinsic value to the overall design (Noss et al. 2002). Therefore, planning units that were chosen at least five out of the ten times and were in groups of at least four adjacent units were used to delineate the final SITES output.

Details of the methods used are below. Preliminary drafts of the focal species inputs and SITES analysis were reviewed by three expert workshops, with participation from the scientific, academic and conservation communities (see list of participants in Acknowledgements). Contributions were evaluated and incorporated in a second run of the SITES model. These data were then made available again for further review. We then used these results, along with the expert opinion of local conservation groups, as the basis of the Network Design.

Planning Unit Cost

To determine the cost of selecting each planning unit, each 1,000 hectare hexagon was assigned a 'cost score' which was compiled from three data inputs: land cover (level of human disturbance), housing density, and road density/edge effect (Figure 7.1). The three inputs were given compatible relative scores and then combined for an overall score that represents the relative degree to which these areas have been removed from their natural state. These scores are relative and subjective and imply natural values rather than dollar amounts. General assumptions of this method for assessing planning unit cost include:

- That a measure of natural value is more relevant to a Wildlands Network Vision than are monetary or political costs.
- That the input data used are sufficient to reflect the relative region-wide pattern of natural values.
- That preserving natural areas before they are degraded is generally more desirable than restoring already degraded areas.

The land cover component of the planning unit cost represents the degree to which each hexagonal unit has been developed or otherwise modified by man. Land cover data is based on The Nature Conservancy's *Southern Rocky Mountain Terrestrial Ecological Systems* map, which was in turn derived from U.S. GAP Analysis land cover information (Neely et al. 2001). We modified the map to account for differences between The Nature Conservancy's Southern Rocky Mountains ecoregion boundary and our ecoregion boundary, which is approximately 500,000 ha larger. Additional data from the Gap Analysis Projects of Wyoming, Colorado, and New Mexico were added to fill in the missing areas. Each category within this layer was then re-classified to a general land cover category (Table 7.1). A cross tabulation was performed to derive a sum of the hectares of each land cover category within each hexagonal planning unit. Each hexagon was then assigned a corresponding cost score according to its perceived level of human disturbance (Table 7.2).

Table 7.1 Land cover reclassification.

GAP Layer Classification	Land cover category
Agriculture categories	Agriculture
Mining and recent clearcuts	Disturbed
All native vegetation community categories	Natural Cover
Water (including reservoirs)	Open Water
Urban	Urban

Table 7.2 Land cover cost.

Land cover category	Criteria	Cost Score
Natural	Hexagon area>= 80% Natural Cover+ Open Water	0
Semi-natural	all other combinations	10
Agriculture	Hexagon area >= 50% Agriculture	15
Disturbed	Hexagon area >= 33% Disturbed	15
Developed	Hexagon area >= 50% Agriculture + Urban	25
Urban	Hexagon area >= 50% Urban	100

Housing density was based on 1990 census data compiled and analyzed by Theobald (2001). Future revisions will use 2000 census data instead. The number of housing units was originally recorded at the block group level, and then converted to units per hectare. Housing density data were intersected with the hexagonal planning units to derive a composite estimate of housing density per hexagon. Levels of housing density were then separated into density classes and given a cost score (Table 7.3).

Table 7.3 Housing density cost.

Category	Units/ha	Cost Score
Undeveloped	0	0
Rural	0 – 0.062	5
Exurban	0.062 – 0.25	25
Suburban	0.25 – 1.25	50
Urban	> 1.25	100

Roads were based on the 2000 census TIGER/Line data. Some obvious coding errors in the data were corrected prior to analysis. This dataset clearly under-represents unpaved roads on federal lands. However, it is more complete and up to date than USGS Digital Line Graph (DLG) road data, so we decided to use it. Roads were classified as Primary (interstates and major highways), Secondary (other paved roads), or Primitive (unpaved). Each classification was then assigned a weight and a level of road/edge influence. These parameters were then used in a kernel line density function (ESRI 2001) to determine the relative road/edge effect contained within each hexagon. This function treats the weights given to each road type as a smooth contour of diminishing value with distance from the road. The full value of the weighting factor is used at the center of the road itself, with the value decreasing to zero at the edge of the stated distance of road edge influence (Table 7.4).

Table 7.4 Road density weights and edge influence.

Classification	Weight	Road edge influence (meters from road)
Primary	100	2000
Secondary	33	800
Primitive	11	300
Urban	>1.25	100

Each hexagon was then given a score that reflected its relative level of road density plus edge effect (Table 7.5).

Table 7.5. Road density and edge effect cost.

Relative Road Density plus Edge Effect (weighted km/sq.km)	RE_Score
0	0
0 – 12.2	5
12.2 – 24.4	10
24.4 – 48.8	20
48.8 – 97.6	35
97.6 – 195.2	50
195.2 – 390.4	65
390.4 – 780.8	80
780.8 – 1561.6	100

The three scores for land cover, housing density, and road density/edge effect were then added within each hexagon, to give each planning unit a relative cost score ranging from 0 to 300.

Weighted Boundary Length

Unlike many previous algorithms, which often neglected the configuration of sites and resulted in fragmented conservation designs that are difficult to manage, the simulated annealing algorithm employed by SITES includes a parameter, the boundary length modifier, which allows planners to achieve a compact design by forcing the clustering of selected sites through weighting of the total boundary length (Andelman et al. 1999, Possingham et al. 2000). Total boundary length is defined as the sum of the perimeters of all planning unit clusters that were selected. A boundary length modifier of 0 results in no influence over clumping, whereas increasing the modifier value gives a relatively greater importance to boundary costs and results in greater clumping. A very high boundary length modifier value would create the extreme of a single clump of planning units in the shape of a circle. Minimizing the perimeter to area ratio helps retain the ecological integrity of protected areas by decreasing the amount of edge effect and decreasing fragmentation. However, an extreme design of a single large circular protected area would not adequately achieve most conservation goals, such as representation of all natural community types. Thus, the appropriate boundary length modifier must compromise between meeting most conservation target goals and minimizing the spatial scattering of selected planning units. We tested several boundary length modifiers and evaluated their effects, as discussed in the Results chapter (see Chapter 8).

Special Elements

We used roadless areas, National Wilderness Areas, and Park Service lands as special elements (Figure 7.2). Roadless areas cover 3,840,000 ha, but only about 40% of these roadless lands are designated Wilderness Areas. Congressionally designated Wilderness Areas comprise 1,538,632 ha or 9.2% of the land area of the Southern Rockies ecoregion (Shinneman et al. 2000). The unprotected 60% of roadless areas (2,301,368 ha) represents 13.8% of all the land in the Southern Rockies ecoregion.

National Wilderness Areas and National Park Service lands were given a target goal of inclusion of 100%, while roadless areas had a target of 75%. We would have preferred a higher target goal for unprotected roadless areas. However, data currently available for roadless area boundaries are incomplete and currently undergoing revision by citizen groups for most of the National Forest lands within the region. We expect some of these changes to be substantive, and so chose not to place too much emphasis within the model on the aerial extent of the currently available data. The final Wildlands Network Design does not rely solely on the output of SITES, but also incorporates information from citizen proposals and local expert opinion, so that we are confident the design includes those areas most valuable and in need of conservation. Future iterations of the Design will make use of the latest inventory results.

Based on the known ecological values of roadless areas (Hitt and Frissell 1999, Wilcove et al. 2000, DeVelice and Martin 2001, Strittholt and DellaSala 2001), we used this category of lands as the focus for special elements. There are other options for special elements, such as old growth or locations of rare and imperiled species. The Nature Conservancy recently used best available data from state Natural Heritage Programs, regional experts, and other sources to include over 600 terrestrial and aquatic ecosystems, plant communities, and individual species, with an emphasis on rare and imperiled species and communities as target elements of their conservation vision for the Southern Rockies (Neely et al. 2001). We chose not to duplicate this tremendous effort, but rather to emphasize the large roadless wild areas that are needed for rewilding and for focal species habitat needs. However, we recognize that future iterations of the Southern Rockies Wildlands Network Design should include a comprehensive old-growth component, among other special elements. This is a difficult assignment because only a few of the National Forests in the region have even attempted an old-growth inventory.

Representation

Special elements and focal species are specific areas of emphasis in our conservation planning. However, the main goal is to preserve the integrity of the Southern Rockies ecoregion as a functioning whole. Representation of all distinct natural communities within conservation landscapes and protected area networks is a long-standing goal of biodiversity conservation (Noss 1987). To that end, all reasonable effort must be made to retain all unique components of the ecoregion in sufficient amounts to promote their persistence over time. It is impossible to account for every species, assemblage, and community with SITES or any other reserve design algorithm. Instead, broad categories of community and ecosystem types are chosen with the assumption that these broad classifications will include most of the biodiversity within the ecoregion.

The Nature Conservancy spent close to two years working with other organizations, agencies, and area experts to derive their target goals for the Southern Rockies region, including representation goals for both terrestrial and aquatic ecological community types (Neely et al. 2001). In this initial version, we have included general target goals for terrestrial communities only. Future revisions will incorporate more specific terrestrial and aquatic community goals, possibly through a cooperative effort with TNC.

We based most of the vegetation community representation target goals for our design on TNC's terrestrial ecological systems representation goals as reported in Appendix 14 in Neely et al. (2001). The goals reported in that appendix represent simple aerial extent within the ecoregion and do not take into account TNC's efforts to disperse target elements evenly through subregions of the total ecoregion. Our vegetation community GIS coverage is based on TNC's *Southern Rocky Mountain Terrestrial Ecological Systems* map, which in turn is based on GAP land cover information (Neely et al. 2001). We modified the map to account for differences between TNC's Southern Rocky Mountains ecoregion boundary and our Southern Rockies ecoregion boundary, which is approximately 500,000 ha larger. Our design includes 30 terrestrial vegetation communities (Table 7.6).

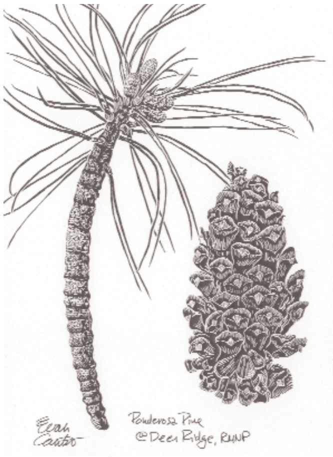
The representation goals for 23 of these communities were based directly on the aerial extent goals used by TNC.

Table 7.6 Vegetation community representation goals.

Community Type	Available Area (Ha)	Representation Goal (%)	Goal (Ha)
Active sand dune & swale complex	10,494.9	38%	4,000
Alpine dry tundra & moist meadow	680,381.3	28%	191,103
Alpine substrate - ice field	206,565.0	30%	61,969
Alpine tundra - dwarf shrub & fell field	125,341.6	38%	47,556
Aspen forest	1,336,482.8	30%	399,827
Bristlecone - limber pine forest & woodland	77,709.7	30%	23,312
Douglas fir - ponderosa pine forest	383,707.9	17%	66,585
Foothills riparian woodland & shrubland	5,283.0	66%	3,487
Gambel's oak shrubland	641,881.9	33%	210,190
Greasewood flat & ephemeral meadow complex	180,650.0	32%	58,457
Intermontane - foothill grassland	837,424.4	35%	290,272
Juniper savanna	312,702.2	30%	93,811
Lodgepole pine forest	1,108,411.7	30%	332,450
Lower montane - foothills shrubland	759,921.5	32%	246,402
Marsh & wet meadow	19,000.6	66%	12,500
Montane - foothill cliff & canyon	21,055.1	29%	6,142
Montane grassland	293,271.6	33%	96,775
Montane mixed conifer forest	616,665.3	28%	172,856
Montane riparian shrubland	13,253.7	66%	8,747
Mountain sagebrush shrubland	1,339,986.6	30%	398,787
North Park sand dunes	342.4	30%	103
Piñon - juniper woodland	1,726,695.7	30%	518,009
Ponderosa pine woodland	1,985,826.5	33%	663,227
Sagebrush steppe	272,676.8	30%	81,803
San Luis valley winterfat shrub steppe	141,259.4	35%	50,047
South Park montane grasslands	221,107.2	33%	72,317
Spruce-fir forest	2,251,858.6	30%	674,148
Stabilized sand dune	38,335.6	29%	11,162
Upper montane riparian forest & woodland	19,380.9	66%	12,791
Winterfat shrub steppe	131,048.1	30%	39,314

Refer to the "Conservation Goals" section of Neely et al. (2002) for an explanation of how these goals were derived. The remaining seven were the three riparian communities (foothills riparian woodland & shrubland, montane riparian shrubland, and upper montane riparian forest & woodland), winterfat shrub steppe, sagebrush steppe, piñon-juniper, and juniper savannah.

Riparian communities were under represented in TNC's terrestrial ecological community goals, probably because they treat riparian areas as special elements that they specifically mapped as element occurrences. The GAP-based mapping efforts are too coarse a scale to include most riparian communities in the ecoregion. Finer scale mapping of riparian areas is currently underway in Colorado by the Colorado Division of Wildlife, and we hope to be able to use this and similar data in future revisions of the Network Design. However, in the interest of time, this initial version of the design includes target goals of 66% (to match the percentage used for the marsh and wet meadow community type) of the aerial extent of each of the riparian vegetation communities as currently mapped in the ecoregion.



Our ecoregional boundary includes the Gunnison River valley, as well as larger portions of the upper Canadian and upper Pecos basins. This results in our boundary containing substantially more piñon-juniper woodland, ponderosa pine woodland, winterfat shrub steppe, mountain sagebrush shrubland, sagebrush steppe, intermontane-foothill grassland, and juniper savannah than TNC's boundary (see Table 7.6). Our vegetation community goals were therefore adjusted to include at least 30% of the available aerial extent of these particular communities.

One of the primary goals for the next iteration of this document will be to more thoroughly study representation needs and to revise the target goals to better reflect viability of the native diversity within the ecoregion over time.

Focal Species

Our Wildlands Network Design will concentrate more heavily on focal species, which provides an interesting comparison and important complement to the map produced by The Nature Conservancy, which did minimal analysis of focal species and did not emphasize connectivity. The suite of focal species was selected so as to achieve a balance of both habitat quality indicators and keystone species representing all the principal community types within the Southern Rockies. This suite was selected by the science team, with justification for each described in Appendix 1. However, not all of these species are appropriate for inclusion as inputs in the SITES selection model, for various reasons explained in Appendix 1. Therefore, the final list of focal species chosen for analysis was reduced to six.

We compiled known location and suitable habitat data for gray wolf (*Canis lupus*), black bear (*Ursus americanus*), pronghorn (*Antilocapra americana*), and cutthroat trout (*Oncorhynchus clarki*). For the cutthroat trout we included the greenback (*O. c. stomias*), Rio Grande (*O. c. virginalis*), and Colorado River (*O. c. pleuriticus*) subspecies. Black bear was used as a surrogate for grizzly bear (*Ursus arctos*). The needs of the two bear species, while substantially different in the Northern Rockies, are considered to be essentially the same within the Southern Rockies (T. Beck pers. comm., L. Craighead pers. comm., and S. Cain pers. comm.). Spatial data representing this information were primarily derived from existing data sources, with the exception of black bear, which had to be created (see below). Data gathered and created were then modified based on expert opinion from several workshops and meetings.

GIS data for the cutthroat trout subspecies came primarily from the Biodiversity Conservation Alliance, which had collected locations of genetically pure populations of each subspecies. Added to these were areas identified by the Colorado Division of Wildlife for the overall known range of the Rio Grande and Colorado River subspecies. Equivalent data were not available for the greenback, and so this subspecies is probably under represented in the data. We took the original stream segments that represented individual trout populations and created subwatersheds for each using 82 meter resolution digital elevation data to derive slope and flow accumulation. The subwatershed polygons, not the linear stream segments, were used as input for SITES (Figure 7.3).

GIS data for gray wolf were provided by Carroll et al. (2003) and used with permission by Carlos Carroll. Wolf data received represented probability of occurrence at a resolution of 500 km^2 over the extended Southern Rockies ecoregion and supporting areas as modeled by PATCH, a dynamic wildlife population modeling software. Wolf core areas are areas suitable for potential reintroduction of wolf populations in the ecoregion and are those areas that Carroll et al. (2003) had identified as likely reintroduction areas, based on a combination of habitat suitability and current land management. Suitable wolf habitat outside of cores were those areas with a 60% or greater probability of occurrence as assessed by Carroll et al. (2003), plus other areas from a static habitat model based on prey densities by Martin et al. (1999, Figure 7.4 [a] and [b]).

Pronghorn data came from the state wildlife/Gap program data from Wyoming, Colorado, and New Mexico. This data was then slightly modified based on expert opinion (Figure 7.5).

We created GIS data representing core areas for bears because of a lack of suitable existing data. The data were created in consultation with Tom Beck, wildlife biologist and regional bear expert. Bear habitat suitability was modeled using the vegetation community layer and unweighted road density. The addition of prey data, such as ungulate concentration areas, was considered but not included because currently existing ungulate GIS data are not considered to be accurate enough (T. Beck, pers. comm.). The following vegetation communities were considered to be primary habitat for bears, based on expert input and literature review (T. Beck, pers. comm., Carroll et al. 1998):

- Gambel's oak shrubland
- Aspen forest
- Riparian communities
- Piñon-juniper woodland
- Ponderosa pine woodland

In addition, all other forest types and all grassland types that were adjacent to each other were considered to be secondary habitat. Primary habitat patches were given a score of 5 and secondary habitat a score of 3. Road density was based on 2000 census TIGER/Line roads. Simple road density was calculated per hectare as averaged over a 3 km^2 area. The 3 km^2 average was used to represent the mean daily movement of adult female black bears (Carroll et al. 1998), which is assumed to be the biologically relevant scale for this analysis. Road density was then classified and scored Table 7.7).

Table 7.7 Road density scores for bear habitat modeling.

Road density (m/ha)	Score
0	0
>0 – 5	1
>5 – 10	2
>10 – 25	3
>25 – 50	4
>50	5

Road density scores were then subtracted from the vegetation scores to derive a habitat suitability layer, with suitability scores ranging from –5 to +5. These data were smoothed using 10 iterations of a majority filter function (ESRI 2001), to help smooth edges and remove isolated patches. Those patches with a suitability score greater than 1 were then selected out as suitable black bear habitat. T. Beck (pers. comm.) considers black bear harvest statistics from the Colorado Division of Wildlife (CDOW) to be strongly correlated with bear population densities. Therefore, the ten-year average of these harvest statistics was compared against the modeled suitable habitat layer. Selecting out suitable habitat patches that are 600,000 ha or larger gave the best match to the CDOW harvest data. These large patches then became the core areas for black bear. These core areas were later only slightly modified by expert opinion at workshops and meetings (Figure 7.6).

Target goals for focal species are meant to represent minimum areas necessary for viable populations of each species to persist over time. Ideally one would use data that identify the size and location of interconnected subpopulations necessary to maintain a metapopulation within the ecoregion and surrounding lands indefinitely. However, at this time the data needed to represent each focal species to this level of detail are not available. Again, this vision is a work in progress and should be considered a hypothesis to test. Future iterations will include more detailed data and research into viability over time. For this initial study, however, the target goals chosen were at least 50% of the available suitable habitat, as represented by the spatial data gathered for each species (Table 7.8).

Table 7.8 Focal species target goals (% available suitable habitat).

Focal Species	Goal (%)
Black/grizzly bear core areas	75
Wolf core areas	100
Other suitable wolf habitat	50
Pronghorn suitable habitat	50
Colorado River cutthroat subwatersheds	100
Greenback cutthroat subwatersheds	100
Rio Grande cutthroat subwatersheds	50

2. Least Cost Path Models for Wolf and Bear Dispersal

A Least Cost Path model was constructed for the wolf and grizzly bear, in part to help identify best linkages between predicted core areas. Methods used were adapted

Table 7.9 Land cover permeability scores for wolves and bears.

Land cover	Wolf	Bear
Active sand dune & swale complex	8	3
Agriculture - dry	8	3
Agriculture - irrigated	5	3
Alpine dry tundra & moist meadow	10	10
Alpine substrate - ice field	7	1
Alpine tundra - dwarf shrub & fell field	7	1
Aspen forest	10	10
Bristlecone - limber pine forest & woodland	10	10
Douglas fir - ponderosa pine forest	10	10
Foothills riparian woodland & shrubland	10	10
Gambel's oak shrubland	10	8
Greasewood flat & ephemeral meadow complex	10	5
Intermontane - foothill grassland	10	5
Juniper savanna	10	5
Lodgepole pine forest	10	10
Lower montane - foothills shrubland	10	8
Marsh & wet meadow	8	10
Mining operation	3	1
Montane - foothill cliff & canyon	5	2
Montane grassland	8	5
Montane mixed conifer forest	8	10
Montane riparian shrubland	10	10
Mountain sagebrush shrubland	10	8
North park sand dunes	8	3
Piñon - juniper woodland	8	10
Ponderosa pine woodland	10	10
Recent clearcut conifer forest	7	3
Sagebrush steppe	10	8
San Luis Valley winterfat shrub steppe	10	8
South Park montane grasslands	8	5
Spruce-fir forest	10	10
Stabilized sand dune	8	3
Upper montane riparian forest & woodland	8	10
Urban	1	1
Water	1	1
Winterfat shrub steppe	10	8

from Singleton et al. (2001). First, we created a 'permeability' layer for each species, representing the relative ease with which an individual can travel through the landscape. Then a weighted cost distance layer was calculated from the permeability layer to represent the cost of traveling through an area such that, the poorer the dispersal habitat, the greater the effective distance an individual would have to travel to get through that area. Finally, we executed a least cost path analysis for both wolves and bears using the weighted cost distance layer to determine the most probable dispersal linkages each species would take to travel between core population areas. It is important to recognize that the results of this analysis represent the probability of successful dispersal between two areas and not necessarily what an individual animal will choose to do. For example, a wolf may choose to disperse through agricultural areas, but its probability for success is low.

The permeability layers were derived from four separate GIS data layers: land cover (categorical), population density (people/km^2), weighted road density (km/km^2), and slope (%). Scores were assigned to each component layer and then combined into the overall permeability layers for each species. Permeability values were adapted from values given for gray wolves and grizzly bears in Singleton et al. (2001), with input from the science team. We used ArcGIS 8.2 for all spatial computations. The data resolution was 100 meters.

Land cover was based on the vegetation community data. We gave each land cover type a relative score for wolves and bears that represents the ease with which an individual can move through an area. Scores ranged from 1-10, with 1 = *extremely difficult* and 10 = *no difficulty*. Land cover categories were not identical with those used by Singleton et al. (2001), therefore some interpretation was required (Table 7.9).

Human population density was based on 1990 census data compiled and analyzed by Theobald (2001). Future

Table 7.10 Human population density permeability scores for wolves and bears

Population density (people/km^2)	Wolf	Bear
0– 26	10	10
26 – 65	5	5
65 – 130	3	3
130 – 260	2	2
> 260	1	1

revisions will use 2000 census data instead. Population data were recorded at the block group level; this was then converted to population density per square kilometer. Permeability parameters used were adapted from Singleton et al. (2001), who determined from their research that wolves and grizzly bears responded in the same way to human population densities (Table 7.10).

Road density was based on 2000 census TIGER/Line data and was calculated using a kernel line density function in ArcGrid to derive weighted kilometers of road per square kilometer. Roads were weighted based on the classifications of primary (Interstates and major highways), secondary (other paved roads), and primitive (unpaved), with the assumption that the higher the road classification, the greater and faster the traffic, and therefore the more difficult it is for an individual animal to successfully cross. Primary roads were given a weight of 5 and secondary roads were weighted 2. This has the practical effect of increasing the road density by a factor of 5 and 2, respectively. Primitive roads were not weighted. Permeability parameters used were adapted from Singleton et al. (2001), although it should be noted that the authors of this paper did not weight roads in their study. Our approach represents a higher relative level of sensitivity to the presence of roads (Table 7.11).

Table 7.11 Road density permeability scores for wolves and bears.

Road density (km/km^2)	Wolf	Bear
0 – 0.6	10	10
0.6 – 1.2	8	8
1.2 – 2.5	5	5
2.5 – 3.7	5	3
3.7 – 6.2	2	2
6.2 – 30	1	1
> 30	impassible	impassible

We calculated percent slope from a composite Digital Elevation Model (DEM) for the ecoregion with a cell resolution of 82 meters. The DEM data originated from the U.S. Geologic Survey. Cell size of the resulting slope grid was recalculated to 100 meters to match all other permeability input grids. According to Singleton et al. (2001), slope does not play a factor in bear dispersal. However, there are certain canyons within the ecoregion that do pose a dispersal barrier because of their sheer drop. Some of these are listed under the Gap layer category of "Cliff and Canyon" but others, most notably the Black Canyon of the Gunnison, are not. Therefore, we decided to incorporate slope for bears, but coded it so that only the sheerest drops posed a barrier to movement. The slope permeability scores for wolves were taken directly from Singleton et al. (2001, Table 7.12).

Table 7.12 Slope permeability scores for wolves and bears.

Slope (%)	Wolf	Slope (%)	Bear
0 – 20	10	0 – 75	10
20 – 40	8	75 – 100	6
> 40	6	> 100	1

The permeability layers for each species were then created by multiplying the individual component layers and then dividing by 10,000 in order to scale permeability between 0 – 1.0. Permeability as a probability function was then transformed into a weighted cost distance function that represented distance traveled in terms of weighted meters. Singleton et al. (2001) used a linearly weighted cost distance, such that, when combined with the cell width in a cost distance function, values ranged from actual cell width to 100x cell width. The equation is:

$$WCD = C * (100 - (100 * V)$$

where WCD = the weighted cost distance, C = the cell width (100 m in this case) and V = the permeability value (range 0-1.0). Permeability values of 1.0 would actually result in a cost distance of 0, but are manually adjusted to 100 to reflect actual cell width. This linear function was tried, but the results appeared unnecessarily restrictive and not reflective of a realistic behavioral response. For example, using the linear model, the hypothetical dispersing individual would travel miles out of its way to avoid crossing even isolated dirt roads. This happens because the linear model allows for no tolerance of minor disturbances or barriers. In the absence of concrete behavioral response data, we decided to use a non-linear cost distance function instead, on the assumption that animal behavior in general follows a response curve that allows minor disturbances to be buffered by adaptive responses. The function used is a power function: $WCD = C * (V)^{-2}$. The resulting weighted cost distance retains the approximate range of the linear function (Figure 7.7).

3. Limitations

Limitations of SITES and Least Cost Path Analysis

Regardless of the model used, output is only as good as the input data. Because nature is complex and available resources are scarce, data can never be wholly complete or without error. Ideally, input data should first be validated with field research, but this is rarely the case due to limitations of time and money. Static models such as SITES, particularly when based on static input data, do not take into account local population and meta-population dynamics and changing environmental conditions over time. The initial design solutions provided by SITES must therefore be reviewed and modified using local knowledge and professional judgment in order for the results to be relevant. The simulated annealing algorithm used by SITES trades a guaranteed optimal solution for computational speed and software accessibility. There are other algorithms that can guarantee optimal solutions, but they require much more computing power, time and cost, particularly with large study areas (Andelman et al. 1999, Pressey et al. 1996). Another limitation to simulated annealing algorithms is a sensitivity to input parameters. Simpler algorithms are more robust, but do not always provide as optimal a solution (Possingham et al. 2000).

There are several limitations to the base cost layer used in our SITES analysis. Not all relevant factors, such as grazing pressure, were incorporated. The three inputs used are not exclusive of each other and are in fact strongly correlated. However, because each input layer is coarse-scale and comes from a different data source, none are wholly complete and accurate. By using all three inputs in a relative scoring scheme, we hope to reach a more representative picture of the costs at the scale of the entire ecoregion. The cost layer as a whole is correlated to some degree to the focal species suitable habitat inputs, *i.e.*, suitable wildlife habitat usually occurs in the more natural and undeveloped lands. We did a simple correlation test of the cost layer with both wolf and black bear suitable habitat inputs. The correlation coefficient was $r = -0.248$ for the wolf suitable habitat layer, and $r = -0.372$ for the bear suitable habitat layer. Therefore, these suitable habitat inputs are only partially redundant to the cost layer. Finally, SITES is sensitive to initial input values (Possingham et al. 2000), so that modifying the planning unit cost in the future will produce different results, even if the relative degree of cost is maintained. Further research on model sensitivity, method assumptions, and confounding effects should be undertaken in future versions of this design.

Least cost path analysis has no direct bearing on what an individual animal (of any species) is actually going to do when trying to get from point A to point B. The analysis makes many untested assumptions about animal behavior and appropriate scale, such as using the non-linear versus linear cost distance functions. In addition, dispersing individuals frequently do not know ahead of time where they are heading or what obstacles lie in their path, whereas the computer model has the advantage of viewing the entire area at once. Results of such an analysis should not be used to make important management decisions, but should rather be used as a way to identify and prioritize further research needs. For a good discussion of least cost path limitations and assumptions as pertains to large mammal dispersal, see Walker and Craighead (1997).

Limitations of expert opinion

This Network Design relies heavily on the expert opinion of area biologists, ecologists, and local activists who are well acquainted with their area of interest. However, as the term implies, expert opinion is based on opinion, and may reflect a personal bias as to what is important. The tendency of most people, including established scientists, is to draw conclusions based on what they have personally observed, rather than what can be concluded through substantiated, empirical studies. In the absence of such studies, however, expert opinion can be a valuable source of information.

4. Synthesis of the Wildlands Network Design

The Wildlands Network Design was created from a combination of the SITES output, least cost path analysis for wolves and bears, expert opinion about additional high value areas from local scientists and activists, and citizen proposed forest management plans from local conservation groups. We also referred to the network design used by the New Mexico Highlands project and the draft SITES results for the Heart of the West project for those areas that overlapped with the Southern Rockies ecoregion. The end result is a collection of core wild areas connected by other areas of various levels of compatible management. Each area was assigned a 'network unit classification' based on its level of recommended protection and management. The network unit classifications are defined in Chapter 9.

Three workshops were held within the region to gather local expert opinion: December 16, 2002 in Denver with 25 participants; January 14, 2003 in Carbondale; and January 16, 2003 again in Denver. The January meetings were identical and had 31 participants total. There were 44 different people in the three meetings, representing scientists and conservation advocates, with a few agency participants. These workshops were used to gather information about areas of importance not included in the models, and the type of threats present in each area, as well as to gather initial feedback about the methods employed.

Citizen proposed management plans, which use the U.S. Forest Service management prescription codes, were translated into the various unit classifications based on the perceived level of protection and type of use (Appendix 2). Areas considered to be high use areas were not included in the network design. In areas where citizen plans were not available, unit classifications were decided initially by using available road and land use data, and then local conservation groups and regional experts reviewed them.

5. Conclusion

The results of these methods are discussed in Chapter 8. They become the basis for the Southern Rockies Wildlands Network Design discussed in Chapter 9.