APPENDIX I
GEOLOGIC HAZARD AND ENGINEERING SUITABILITY MAPPING

Contents

Summary

A GIS-based engineering suitability analysis was performed as a component of the 2012–2022 Cheyenne Mountain State Park Management Plan. Its products are intended to serve as a resource in planning future park enhancements and to assist in the establishment of management zones throughout the park. The quantitative, systematic methodology employed in this analysis marks a departure from previous park management plans, in which engineering suitability was assessed on a far more qualitative basis. Both methods have inherent strengths and weaknesses. The GIS-based weighted sum analysis, however, presents an opportunity to implement more consistent mapping methodologies from one park to another, while still maintaining flexibility to account for the unique characteristics and variable data availability at each. Additionally, the relative weaknesses of this approach can be mitigated almost entirely through post-analysis ground-truthing and a collaborative revision process. Data sources and techniques are related in detail in this appendix to clearly communicate the rationale used in creating each phase of the analysis, as well as provide an adaptable template for planning efforts at other state parks.

Methods Overview

The final engineering suitability map for Cheyenne Mountain State Park represents a composite of five component criteria: slope; soil suitability; proximity to utilities; geologic hazards; and cultural sites (Map 1). The first three criteria are cited as the basis for the engineering suitability maps in the three most recent management plans (North Sterling, Roxborough, and Stagecoach); however, no systematic procedure for weighing these criteria was discussed. Based on the recommendations of the Resource Stewardship Team, two additional criteria–geologic hazards and cultural resources– were considered in the assessment of Cheyenne Mountain. These additional characteristics were selected due to the significant and diverse array of geologic hazards that exist within the park and the presence of cultural sites with potential historical and interpretive values.

The analysis process began by creating data layers for each of the component criteria. With the exception of cultural sites, which were factored in separately at the end of the analysis, the features in each component layer were subjectively classified into five ranked engineering suitability categories, with one representing the most suitable areas and five representing the least suitable. Each of these layers was represented in GIS as a raster image, in which each cell or pixel was assigned a suitability value based on the unique attributes of its spatial location, as illustrated in Maps 2–5. The properties of each component layer are summarized in Table 1. In order to represent the combined influence of each individual criterion on a single map, a weighted sum raster was then generated from the four ranked component layers using the ArcGIS Spatial Analyst, Weighted Sum Tool. Since cell size (5 meters) and alignment were uniform between all component layers, the resulting weighted sum raster simply represents the value of each cell in a given layer, multiplied by the layer's assigned weight, summed with the values of overlapping cells from each of the other layers. In this analysis, all layers were given an equal weight of one.

Cell values in the weighted sum raster ranged from a low score of 4, to a high score of 20 (Map 6). Higher scores corresponded with lower engineering suitability. For ease of interpretation, the range of values was then reclassified into 5 levels, as shown in Table 2. In the final step of the analysis, areas within 100 feet of cultural sites (Map 7) were designated as least suitable, regardless of their underlying suitability score. A diagram summarizing the analysis workflow is shown in Figure 1.

Table 1. Engineering suitability component layers summary.

Engineering Suitability Component	Input Data Sources	Output Layer Format	Output Layer Scale	Metric
Slope	USGS 10 meter DEM; City of Colorado Springs 2-foot contour lines	ESRI GRID raster	5 meter cell size	Percent Slope
Soils	USDA NRCS SSURGO Soils Database and 1981 Soil Survey of El Paso County, CO	ESRI GRID raster	5 meter cell size	Soil Engineering Properties
Utilities	PARKS GIS Server (original data source unknown)	ESRI GRID raster	5 meter cell size	Proximity to Primary Park Utility Corridor
Geologic Hazards	CGS 1:24,000 Geologic Map	ESRI GRID raster	5 meter cell size	Proximity to Fault Lines; Geologic Hazard Level
Cultural Sites	PARKS GIS Server	ESRI Polygon Shapefile	100 foot buffer	n/a

Figure 1. Analysis workflow summary diagram with corresponding map numbers in parentheses.

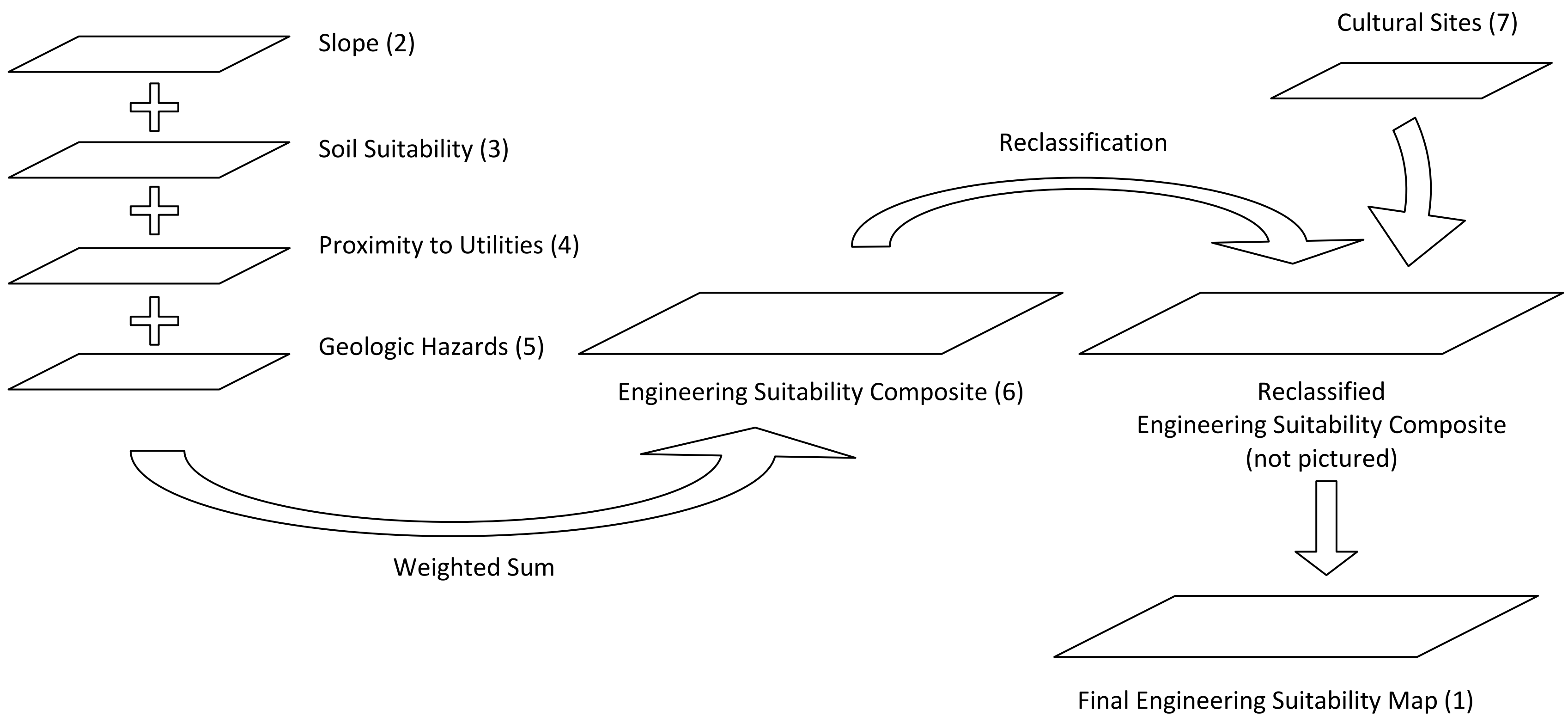

Table 2. Engineering suitability reclassification ranges.

Weighted Sum Raster Value Range	Reclassified Engineering Suitability Level
4 – 8.9	1 – Most Suitable
9.0 – 10.9	2
11.0 – 12.9	3
13.0 – 14.9	4
15.0 – 20.0	5 – Least Suitable

Component Criteria

Slope

To obtain slope information for the park, a composite Digital Elevation Model (DEM) was constructed from a USGS 10m DEM quadrangle and 2-foot elevation contours from the City of Colorado Springs. The higher resolution two-foot contours were only available for the area within the park's original boundaries prior to the 2010 Top of the Mountain acquisition (Map 8). Since much of the park's western reaches are extremely sloped, any loss in fidelity from using lower resolution elevation data in those areas was very minor. To put the elevation data in a common format, the 2-foot contours were converted into a DEM layer using the ArcGIS Spatial Analyst, Topo to Raster tool. Next, the 10m DEM was clipped to exclude areas within the 2-foot contour area, with the exception of a 100-foot area of overlap around its outer boundary. Finally, the two layers were mosaiced together into a single DEM using a blend function in the area of overlap to create a more seamless transition. A slope raster layer was then calculated with the ArcGIS Spatial Analyst, Slope tool.

Cheyenne Mountain State Park has highly sloping topography. Less than 5% of the park has slopes below 20% (11.3°), while approximately 50% has slopes of 100% (45°) or greater. Slope classification scales used in prior management plans were generally derived from parks with more moderate terrain. For instance, the 2011-2021 Stagecoach Management Plan specifies areas with slopes greater than 20% as unsuitable for development, which would preclude most of Cheyenne Mountain. Since the objective of these analyses is to illustrate an engineering suitability spectrum within each park, no single rubric is appropriate for all parks. Thus, the terrain at Cheyenne Mountain was classified into the broader slope ranges shown in Table 3, and depicted in Map 2. It is important to note, however, that an area deemed most suitable for development at Cheyenne Mountain may face significantly more (or possibly fewer) development constraints than an area of the same ranking at another park.

Table 3. Engineering suitability classifications by slope.

Slope Percent	Degree Slope	Engineering Suitability	Description
0 – 20%	0 – 11.3°	1– Most Suitable	Low
20 – 40%	11.3 – 21.8°	2	Low – Moderate
40 – 65%	21.8 – 33.0°	3	Moderate – Steep
65 – 100%	33.0 – 45.0°	4	Steep
> 100%	> 45.0°	5– Least Suitable	Extremely Steep

Soils

NRCS soil data and appended attributes from the 1981 El Paso County Soil Survey were used to subjectively rank soil units within the study area (Map 9) into five engineering suitability levels (Map 3). Attributes considered in determining suitability are listed in Table 4. Corresponding data for all soil units found within the park is located in Reference Table 1 at the end of this appendix. In general, soils with multiple development limitations that were severe in nature were ranked least suitable, while those with no constraints, or a few constraints that were slight in nature, were ranked as most suitable. Soils with intermediate properties between these two extremes were ranked appropriately along this continuum.

The soil types found within Cheyenne Mountain State Park present a plethora of engineering challenges. In fact, nearly all soils require special site preparation or design considerations to overcome their significant development limitations. The continuing subsidence of soils in the park's Swift Puma Campground reinforces the importance of carefully assessing soil suitability prior to development. The Coldcreek-Tolman complex and Chaseville-Midway complex, which cover extensive areas in west and central regions of the park, respectively, are especially unsuitable for development due to a host of undesirable characteristics, including high shrink-swell potential, frost-action, low-strength, and shallow depth to bedrock. These problems are compounded in areas with high slopes. Development on Razor stony clay loam, which covers a substantial portion of the park's eastern half, is limited by depth to shale, stoniness, shrink-swell potential, and clay content. Consequently, Razor soils are generally better suited for trails and other passive recreational uses than supporting structures. The Jarre-Tecolote complex that runs up through the center of the park, then east along the northern boundary, also presents a number of engineering constraints, but is generally suitable for supporting infrastructure in areas of low to moderate slope.

Table 4. Soil suitability attributes properties.

Attribute	GIS Field Name	Data Type/Values	
Map Unit Symbol	MUSYM	Integer	Original Geospatial Data[1]
Map Unit Name	MU_NAME	Text	
Soil Texture	TEX_FULL	Text	
Hydric Properties	HYDRIC1	Yes, No	
Permeability (Low Value)	PERMEL	Continuous (in/hr)	
Permeability (High Value)	PERMEH	Continuous (in/hr)	
Shear Swell	SHR_SWLL	Low, Moderate, High	
Frost Action	FROST_ACT	Low, Moderate, High	
Erodibility	ERODIBILIT	Low, Moderate, High	
Runoff Rate	RNOFFRATE	Slow, Medium, Rapid	Appended Soil Attributes[2]
AASHTO Soil Classification	AASHTO	A1-A7	
Shallow Excavation Building Site Limitations	SHALL_EXCA	Slight, Moderate, Severe (Limitations)	
Dwelling (No Basement) Building Site Limitations	DWELL_NB	Slight, Moderate, Severe (Limitations)	
Small Commercial Building Site Limitations	SCOMM_BUIL	Slight, Moderate, Severe (Limitations)	
Local Roads and Streets Building Site Limitations	ROAD_STRT	Slight, Moderate, Severe (Limitations)	
Camp Area Recreational Development Limitations	CAMP	Slight, Moderate, Severe (Limitations)	
Picnic Area Recreational Development Limitations	PICNIC	Slight, Moderate, Severe (Limitations)	
Paths and Trails Recreational Development Limitations	PATH_TRL	Slight, Moderate, Severe (Limitations)	
Excerpt from soil description describing development limitations	DEV_LIM	Text	

[1] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil survey of El Paso County Area, Colorado [Online WWW]. Available URL: "http://soildatamart.nrcs.usda.gov/Survey.aspx?State=CO" [Accessed on Parks GIS server].

[2] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. 1981. Soil survey of El Paso County Area, Colorado [Online WWW]. Available URL: "http://soils.usda.gov/survey/online_surveys/colorado/" [Accessed 5 December 2011].

Proximity to Utilities

Distance from the park's primary utility corridor was determined using the ArcGIS Multi-Ring Buffer tool (Map 4). Buffer distances were based on a similar analysis performed in the 2003 Thomas & Thomas Master Plan for Cheyenne Mountain State Park, which estimated cost increases associated with the extension of utilities (Table 5). The park's primary utility corridor runs adjacent to park roads and includes all major utility services (water, sewer, electric, and telephone). This analysis did not include other limited service utility easements within the park or consider any major corridors outside the park's boundary that may fall within a 4,000 foot buffer of the park.

Table 5. Engineering suitability by distance from primary utility corridor.

Distance from Primary Utility Corridor	Cost Increase[3]	Engineering Suitability
0 – 1,000'	0-9% increase in cost (Areas North East of Corridor) 0-21% increase in cost (Areas South of Corridor – Includes a bridge for major drainage crossing)	1– Most Suitable
1,000 – 2,000'	21-30% increase in cost	2
2,000 – 3,000'	30-51% increase in cost	3
3,000 – 4,000'	51-60% increase in cost	4
> 4,000'	no estimate	5– Least Suitable

Geologic Hazards

A series of geologic hazard data layers were created by appending data in a 2001 report by K. Houck titled, *Geologic Hazards in Cheyenne Mountain State Park* to 1:24,000 scale geologic data from the Colorado Geologic Survey (Map 10).[4] The report includes an evaluation of various

[3] Thomas & Thomas. Cheyenne Mountain State Park Master Plan. July 21, 2003. Exhibit E: Infrastructure Development Cost Study. pp. AS-7.

[4] Rowley, P. D., Himmelreich, J. W., Jr., Kupfer, D. H., and Siddoway, C. S. 2003. Geologic map of the Cheyenne Mountain Quadrangle, El Paso County, Colorado: Colo. Geological Survey Open-File Report 02-5, Scale 1:24, 000. NR12/20.12/02-5.

hazards that exist within the park including: faults and earthquakes; rockfall; landslides; floods; expanding, collapsing, and heaving soils; and radon.

Fault and earthquake hazard areas were delineated by applying a 20 meter buffer around all fault features based on the recommended fault avoidance zone in a report prepared for the New Zealand Ministry for the Environment on development near fault lines.[5] Areas prone to rockfall and landslides were mapped by isolating regions of specified geologic units with slopes exceeding a literature-determined threshold. Note that rockfall and landslide runout areas were beyond the scope of this analysis and thus these hazards may be underestimated in some areas. Flood, soil, and radon hazard data were appended to corresponding geologic units. The resulting geologic hazard layers are depicted on Maps 11–12. Specific criteria and excerpts from the *Hazards Report* used in the creation of the hazards maps are located in Reference Table 2.

Next, a composite geologic hazard layer was developed to represent the combined influence the hazards discussed individually above. The ArcGIS Union tool was used to create a new polygon layer with the combined attributes from each hazard layer. Each polygon in the resulting layer was given a value of zero or one for each of the six hazard types, with the exception of soil and radon, which were given values of zero, one-half, or one. For soil and radon only, a value of one-half indicated the existence of only one type of soil hazard or moderate radon risk, while a value of one indicated multiple soil hazards and high radon risk. Values for all six hazards were then summed for each polygon. The resulting values were then classified into five engineering suitability levels as shown in Table 6 below and illustrated in Map 5. Note that GIS data was unavailable for the far northwestern reach of the park and was interpolated from the surrounding areas. All fault and flood hazard areas were automatically assigned a rating of five—least suitable.

Numerous faults, generally running north and south, traverse the park's western half, while landslide and soil instability hazards exist across most of the park's eastern half, as evidenced by two recent landslides mapped by Rowley et al (2003).[6] Rockfall danger is most prominent along the eastern face of Cheyenne Mountain, where resistant rock formations emerge along precipitous slopes. Average radon levels above the EPA action limit of 4 pCi/L are common in many of the formations that constitute Cheyenne Mountain, and may be higher than 10 pCi/L in isolated areas. Rare, but potentially damaging floods could occur in deep drainage channels in the eastern half of the park.

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[5] Kerr, J., Van Dissen, R., Webb, P., Brundson, D., and King, A. 2003. Planning for Development of Land on or Close to Active Faults. [Online WWW]. Available URL: "http://www.mfe.govt.nz/publications/rma/planning-development-active-faults-dec04/index.html" [Accessed 2 February 2012].

[6] Rowley, P. D., Himmelreich, J. W., Jr., Kupfer, D. H., and Siddoway, C. S. 2003. Geologic map of the Cheyenne Mountain Quadrangle, El Paso County, Colorado: Colo. Geological Survey Open-File Report 02-5, Scale 1:24, 000. NR12/20.12/02-5.

Table 6. Geologic hazards by engineering suitability.

Hazard Sum Value	Engineering Suitability	Description
0	1– Most Suitable	No Hazard
0.5	2	Slight Hazard
1.0 – 1.5	3	Moderate Hazard
2.0 – 2.5	4	High Hazard
3.0 – 3.5	5– Least Suitable	Extreme Hazard

Cultural Sites

A 100-foot buffer was placed around five areas of cultural interest located within the park for the purpose of reserving them as future interpretive sites (Map 7). All areas within the cultural sites buffer were designated as least suitable in the final engineering suitability map, regardless of their underlying suitability scores. The following cultural sites were considered in the analysis:

Table 7. Areas of cultural interest with Cheyenne Mountain State Park.

Cultural Site	Description	Engineering Suitability
Horse Corral	Site of old horse corral.	5– Least Suitable
Old Ranch Foundation	Site of demolished Tudor style ranch house once owned by the Touzalin and Jones families.	5– Least Suitable
Old Ranch	Site of outbuildings once owned by the Touzalin and Jones families.	5– Least Suitable
Dixon Cabin	Site of Thomas Dixon homestead.	5– Least Suitable
Swisher Cabin	Site of Bert Swisher homestead.	5– Least Suitable

Results and Application

The results of the engineering suitability analysis correspond closely with existing development patterns at the park. Suitability generally declines moving southwest from the park's existing infrastructure hub, becoming nearly homogenously unsuitable in the western third of the park. Table 8 shows the breakdown of park area within each suitability level as classified in the final composite.

Table 8. Areal breakdown of engineering suitability classes.

Engineering Suitability	Acres	Percent
1– Most Suitable	102	4%
2	347	13%
3	607	22%
4	437	16%
5– Least Suitable	1,214	45%
Total Acres	2,707	100%

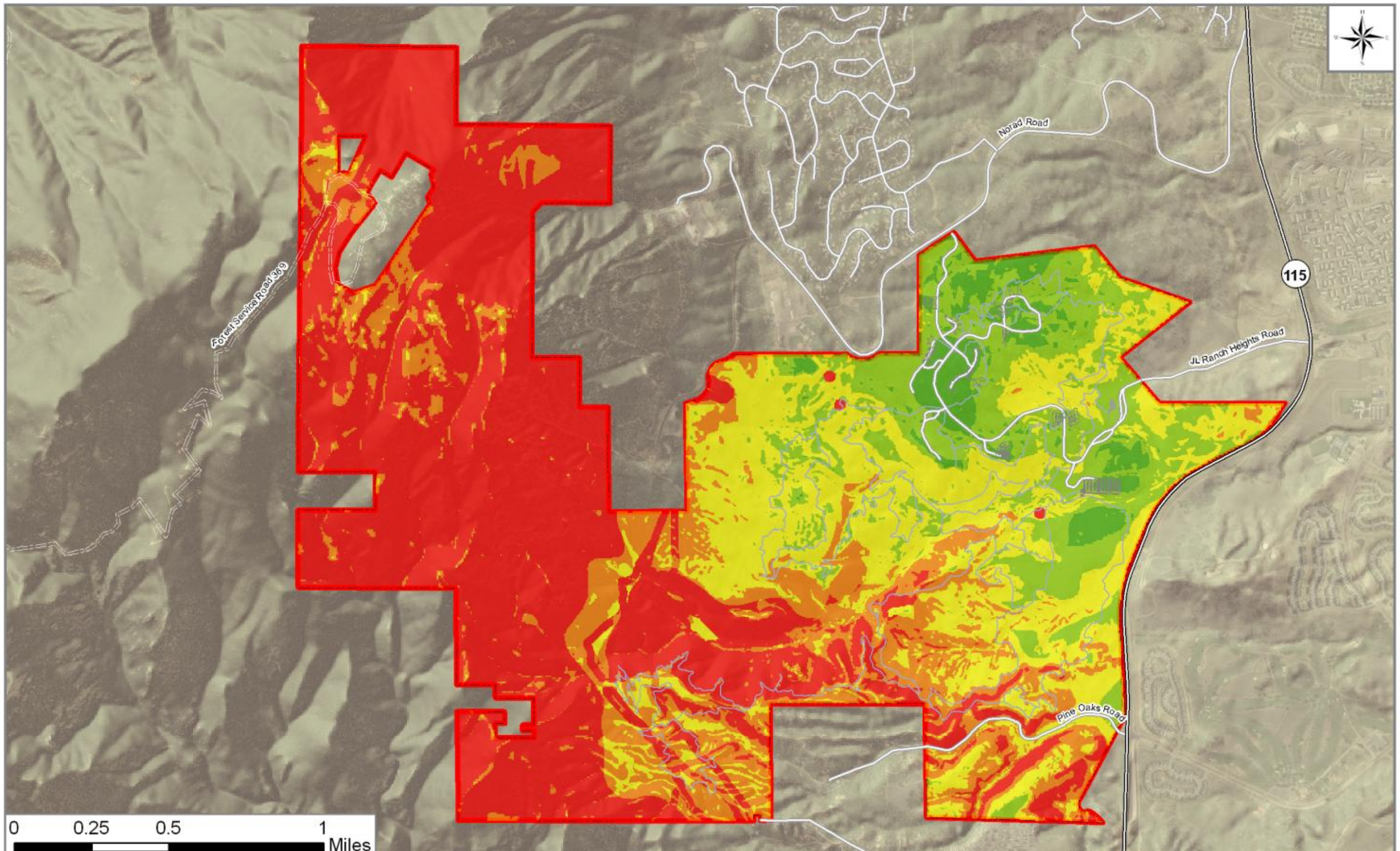
The final map also exhibits similar spatial patterns to an engineering composite map created by Thomas & Thomas consultants for the 2003 Cheyenne Mountain State Park Master Plan (Map 13). This study included geological-engineering constraints, slope limitations, and view-shed data, and utilized similar analysis techniques to those employed here. The availability of additional data, the park's expansion to include Top of the Mountain acquisition area, and the limited availability of GIS data from the 2003 Master Plan prompted this follow-up study. The same conclusions are evident in both analyses, however, that "sustainable development opportunities are highly dictated by the sites' dramatic natural features."[7]

While a concerted effort was made to procure the most current, comprehensive, and highest resolution data available for this analysis, it cannot possibly identify all of the engineering constraints that exist in a given location or guarantee the accuracy of the underlying data. Rather, it is intended to serve as a general guide in planning future park infrastructure and assessing the location of existing development. Detailed site evaluation and planning are thus essential precursors to any future development at the park.

[7] Thomas & Thomas. Cheyenne Mountain State Park Master Plan. July 21, 2003. Appendix A. p.17.

Maps

Map 1. Final engineering suitability composite.



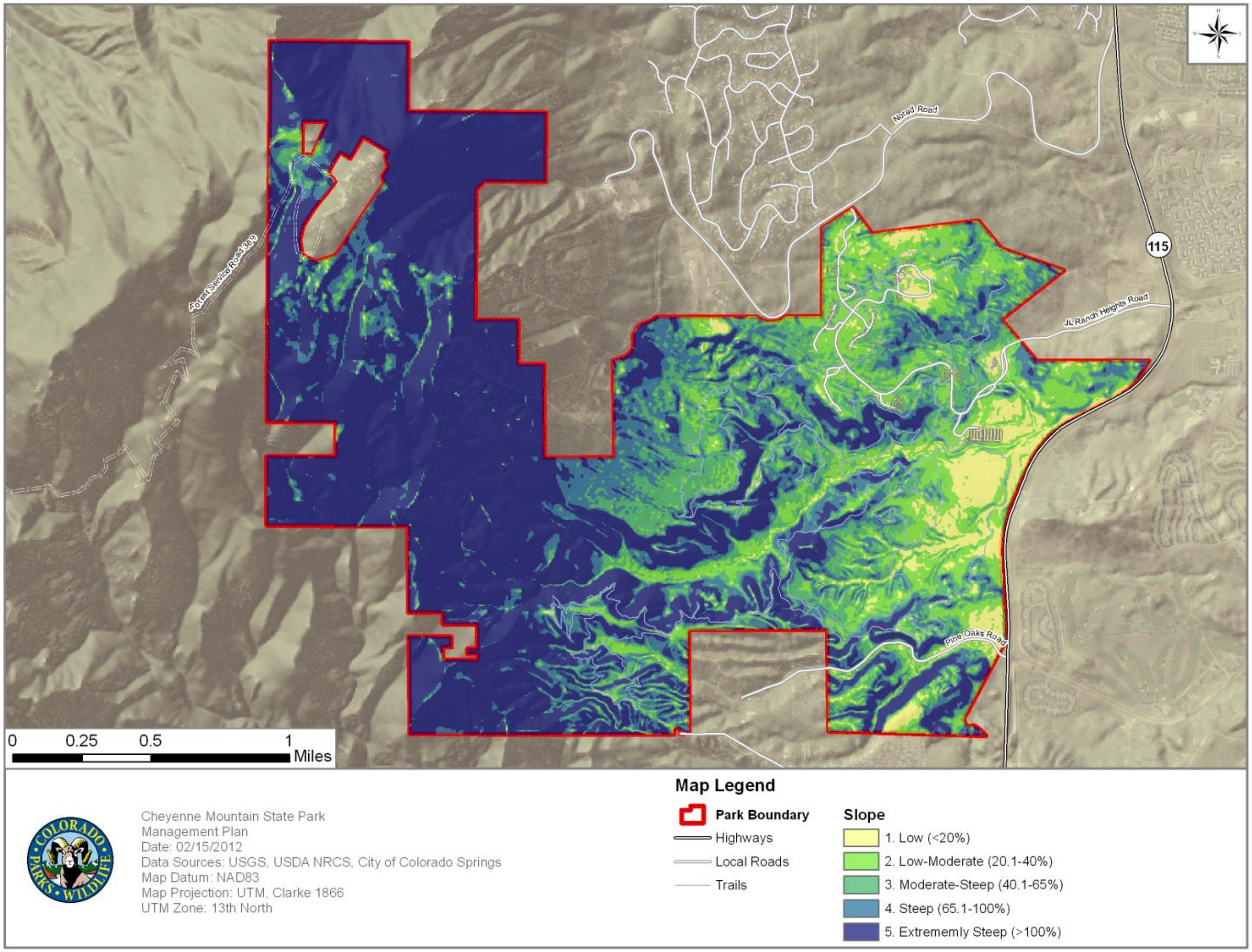
Cheyenne Mountain State Park
Management Plan
Date: 02/15/2012
Data Sources: USGS, USDA NRCS, City of Colorado Springs
Map Datum: NAD83
Map Projection: UTM, Clarke 1866
UTM Zone: 13th North

Map Legend

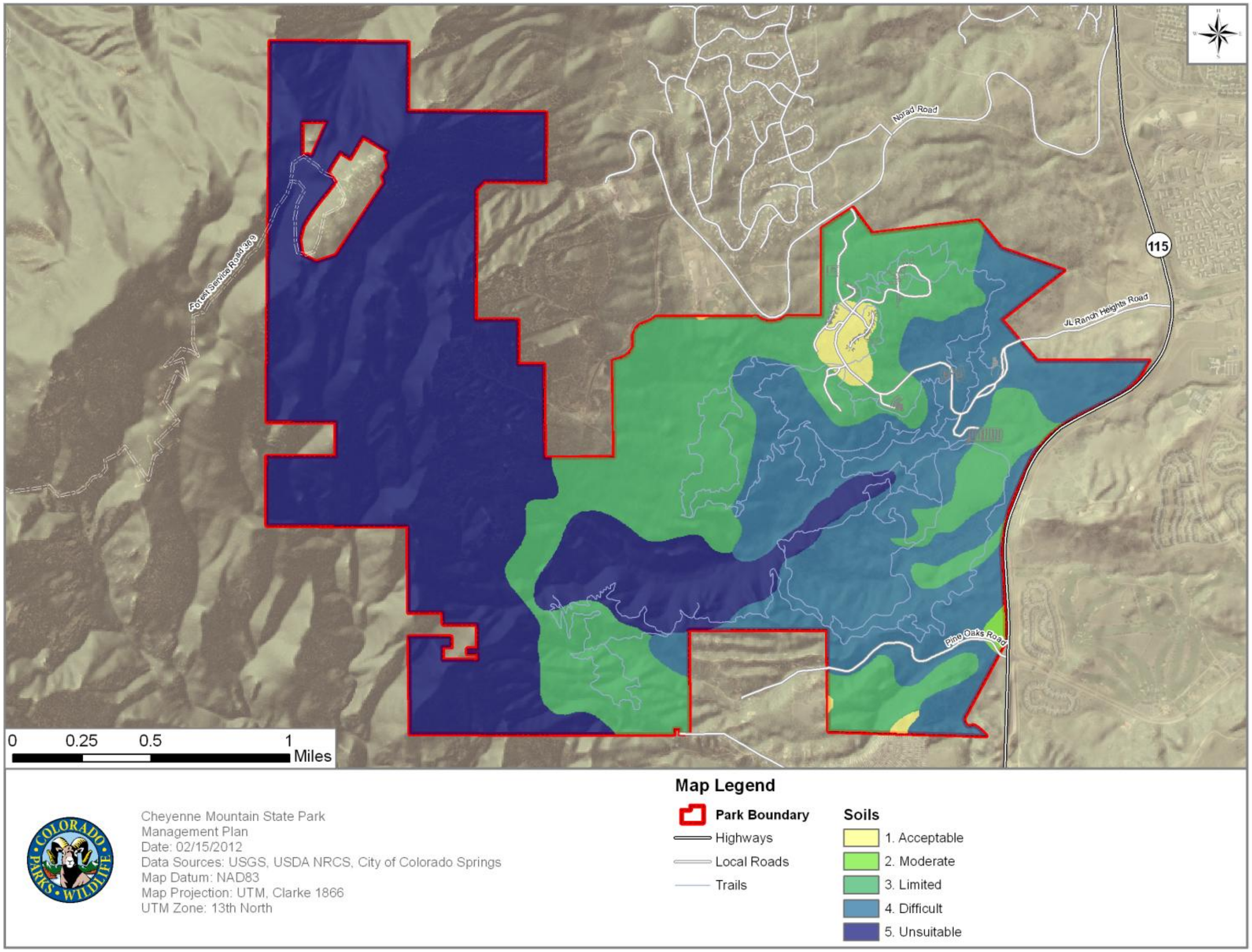
Park Boundary
Highways
Local Roads
Trails

Final Engineering Suitability Composite (with cultural sites)
1- Most Suitable
2
3
4
5- Least Suitable

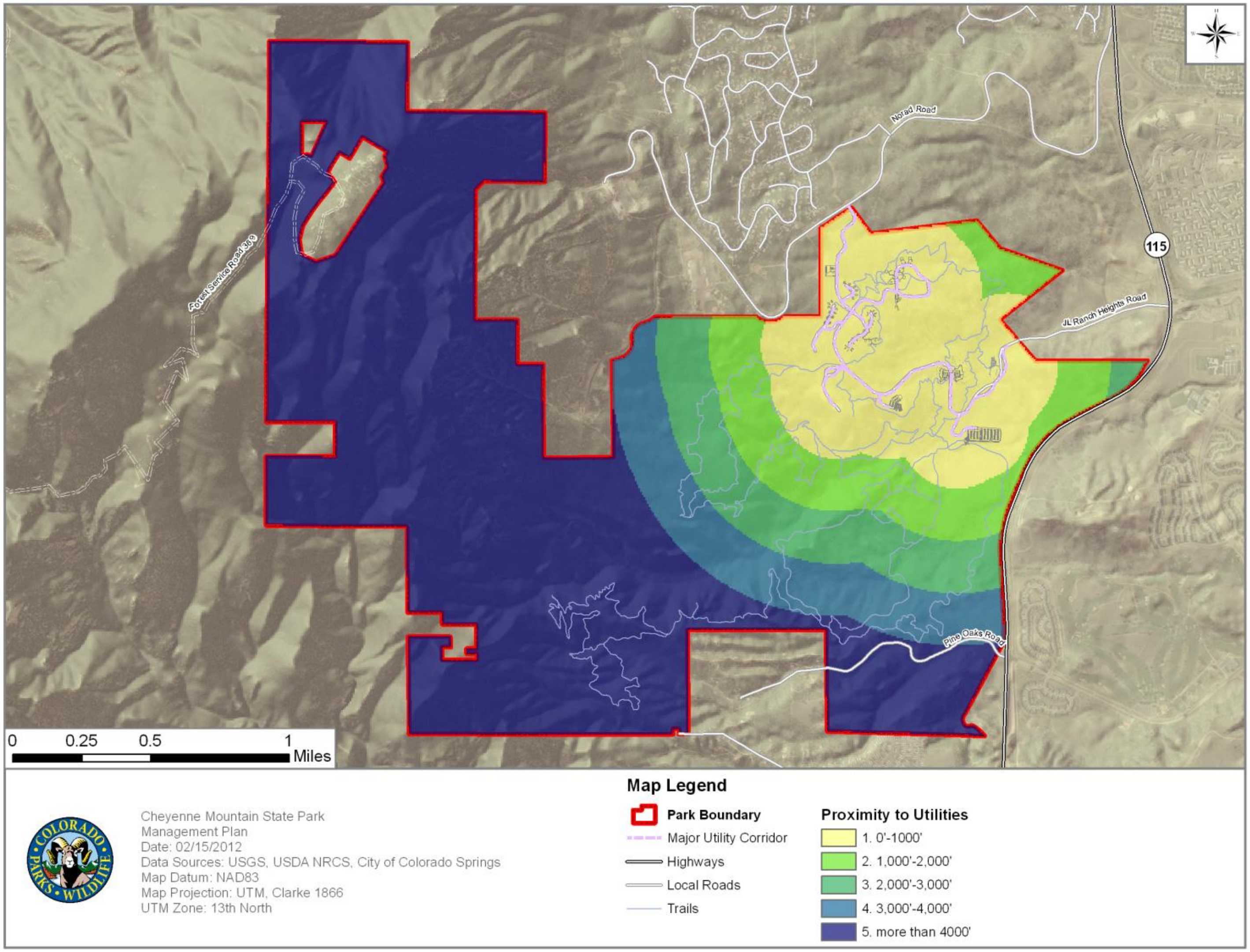
Map 2. Slope suitability.



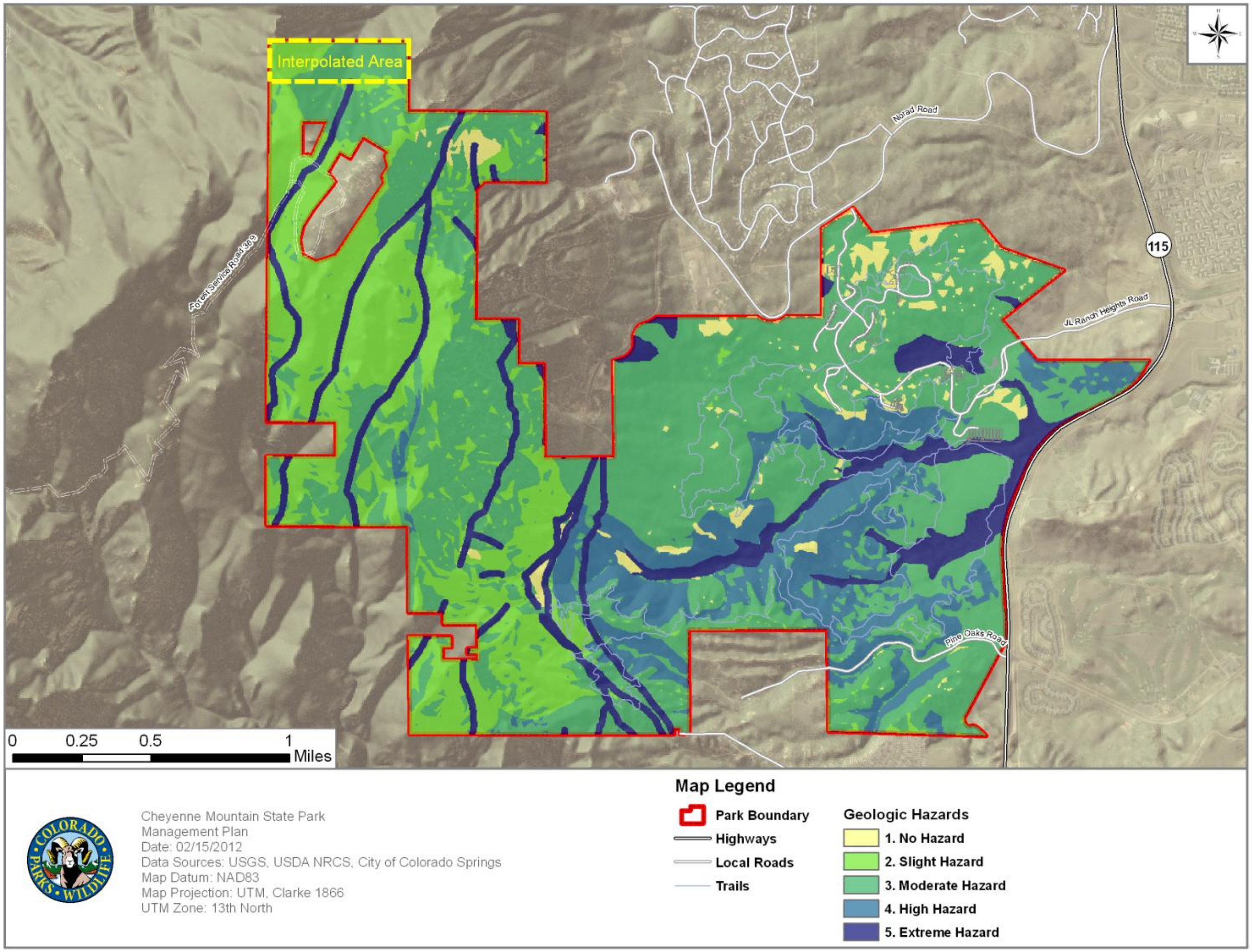
Map 3. Soil suitability.



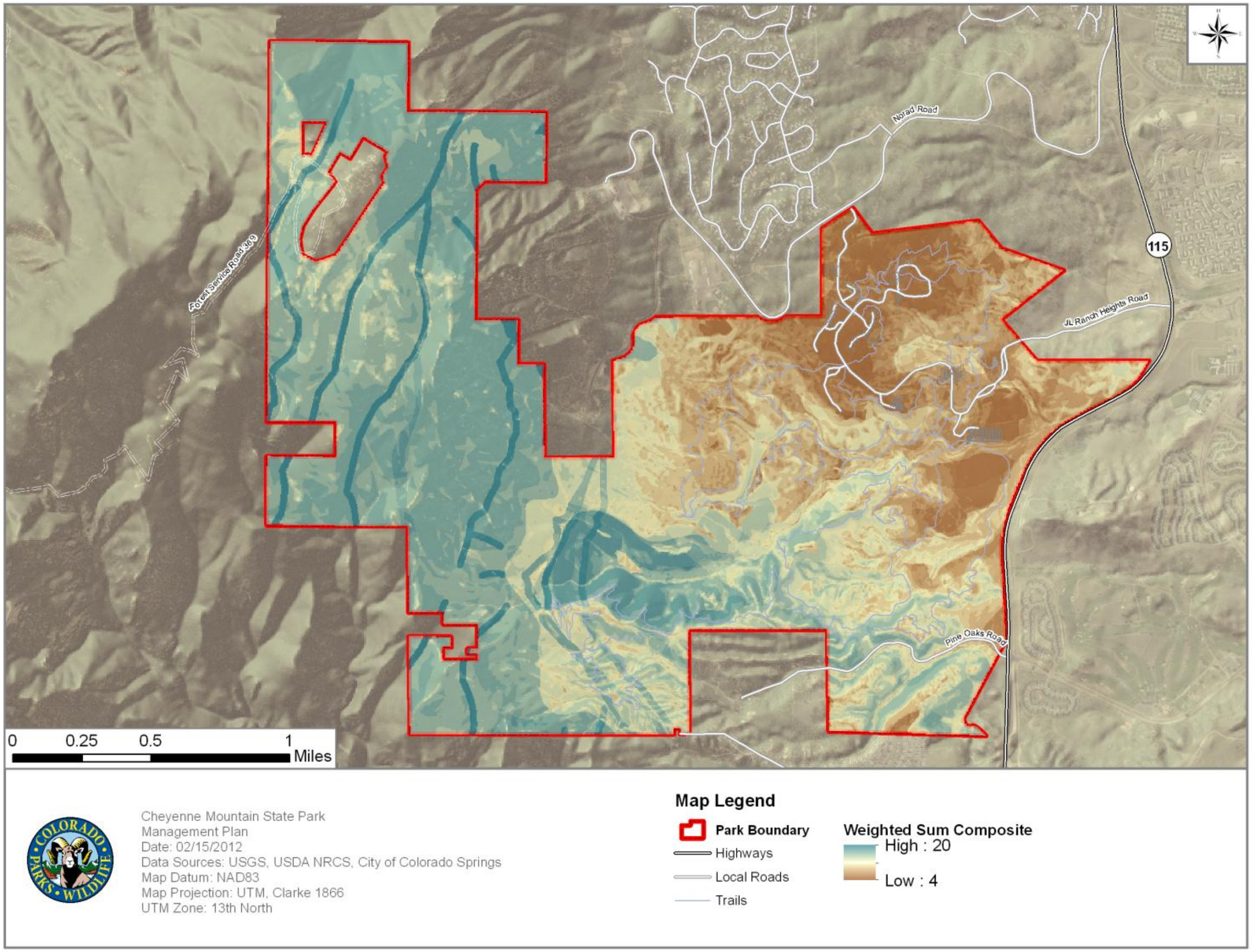
Map 4. Proximity to primary utility corridor.



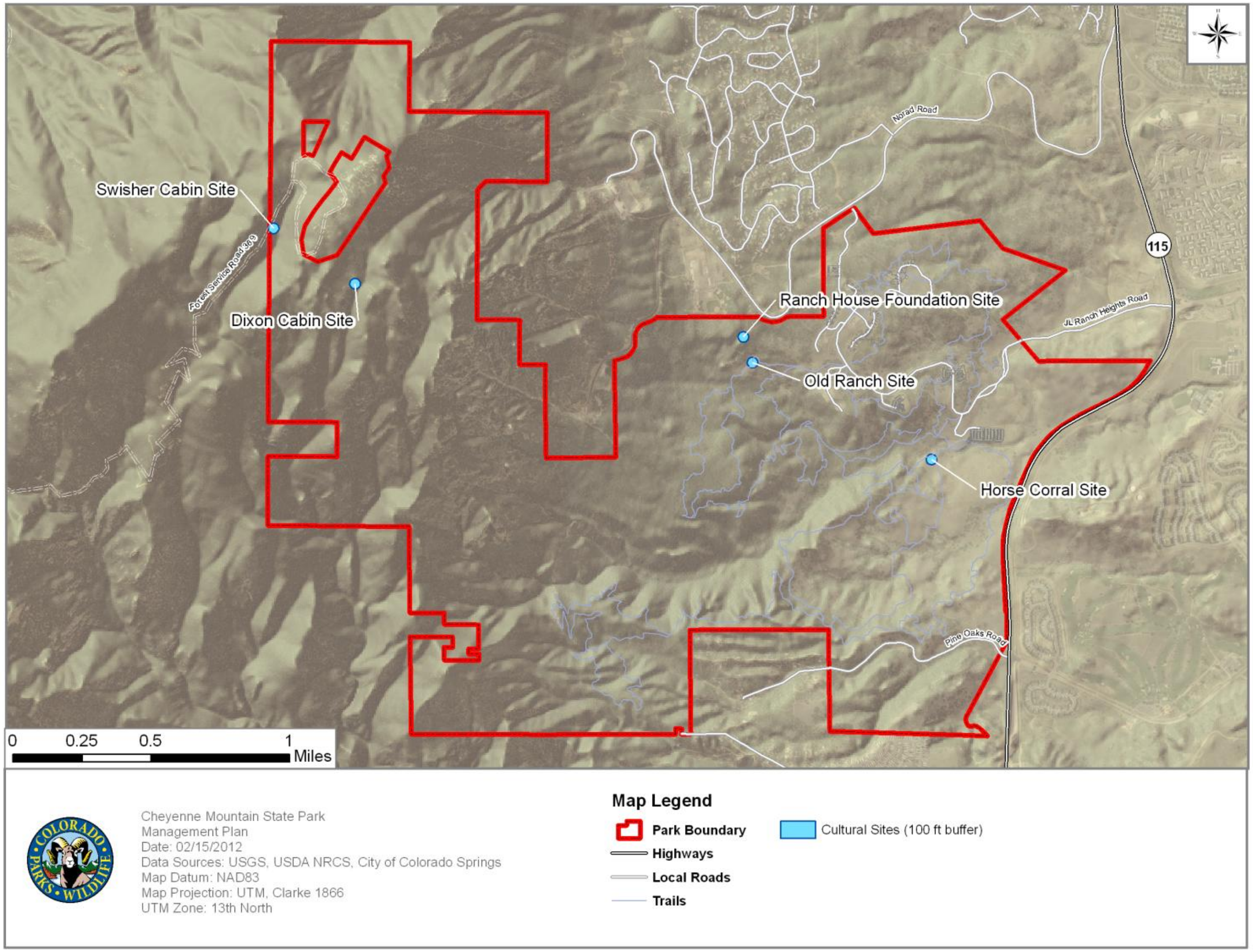
Map 5. Geological hazards composite.



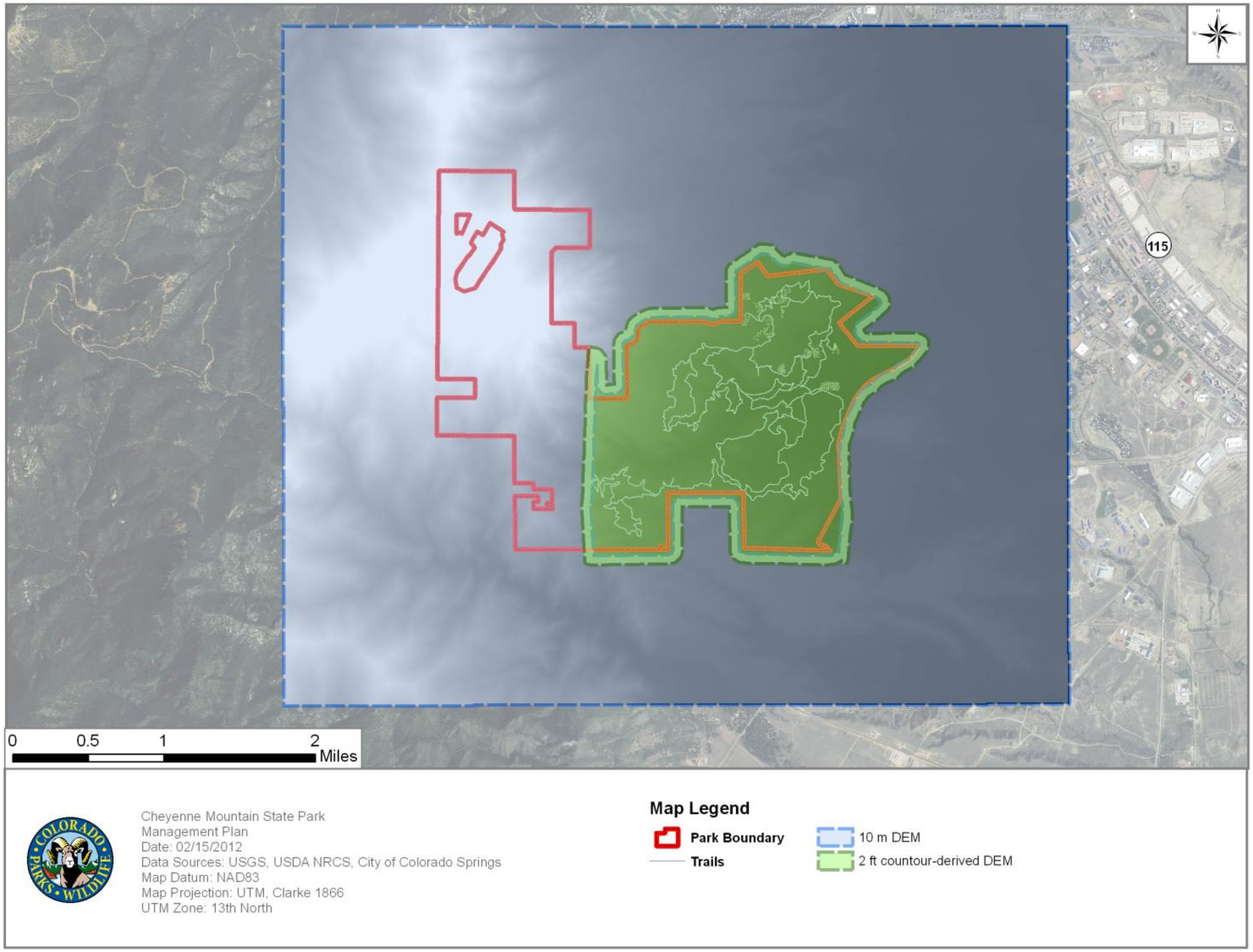
Map 6. Engineering suitability weighted sum composite.



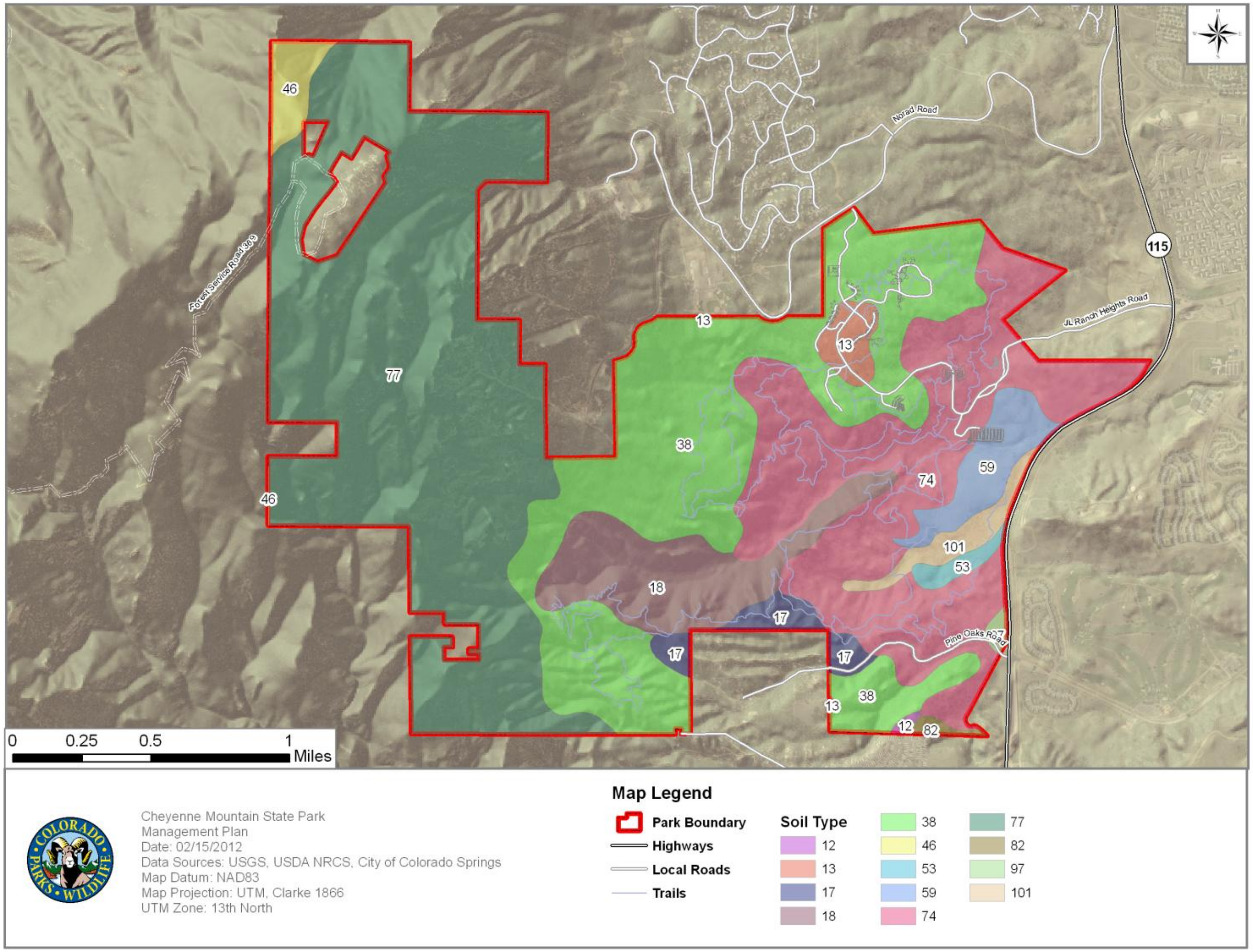
Map 7. Cultural sites.



Map 8. Elevation data coverage areas.



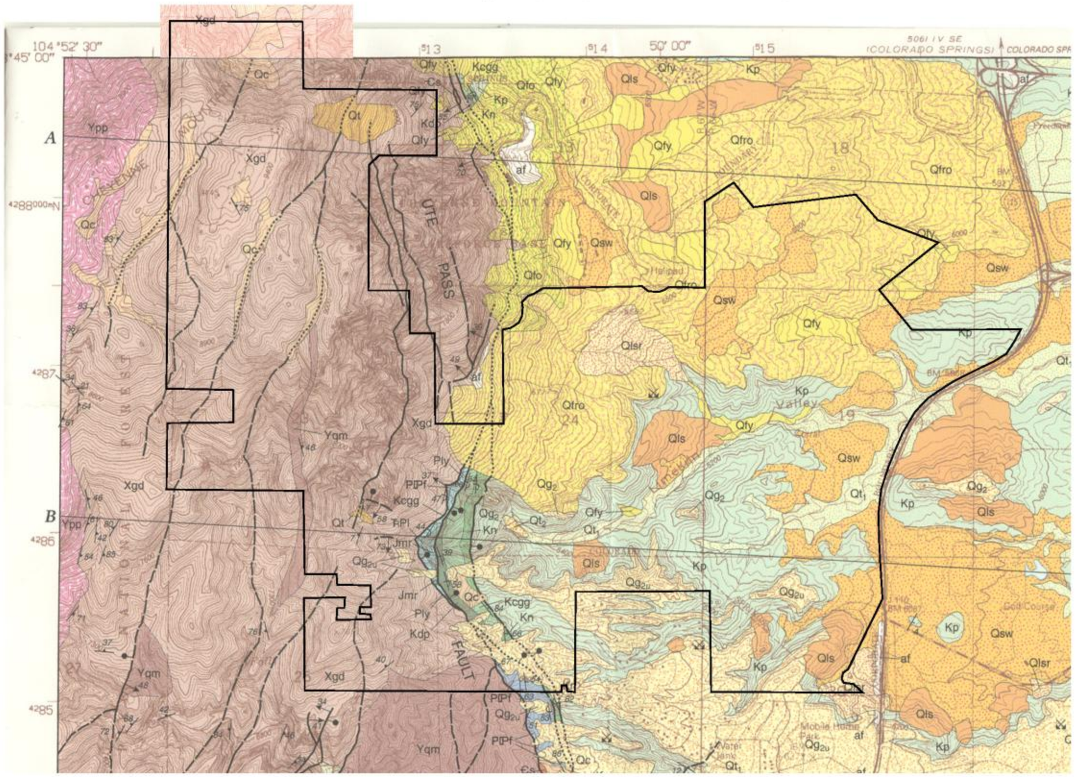
Map 9. Soil type (refer to Reference Table 1 for attribute information).



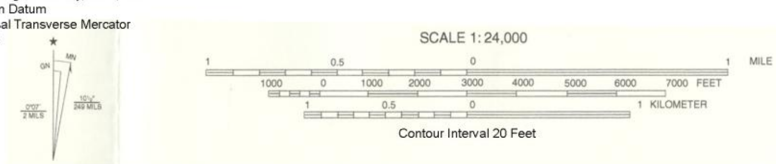
Map 10. 1:24,000 scale geological map of Cheyenne Mountain State Park.

Geological Map of Cheyenne Mountain State Park

Modified from Rowley et al., 2003, and Carroll and Crawford, 2000



Base from U. S. Geological Survey, 1974, 1994
1927 North American Datum
1,000-meter Universal Transverse Mercator
grid ticks, zone 13



Map Units

Alluvial Deposits

- Qt1 Terrace alluvium (Holocene)
- Qsw Sheetwash deposits (Holocene and late Pleistocene)
- Qg2u Pediment gravel deposits (middle Pleistocene)
- Qfy Younger alluvial fan deposits (Holocene)
- Qfo Older alluvial fan deposits (Holocene to middle Pleistocene)

Mass-wasting Deposits

- Qlsr Recent landslide deposits (late Holocene)
- Qls Landslide deposits (Holocene and late Pleistocene)
- Qfro Older landslide, fan, and rockfall deposits, undivided (late to middle? Pleistocene)
- Qt Talus deposits (Holocene and late Pleistocene)
- Qc Colluvium (Holocene and late Pleistocene)

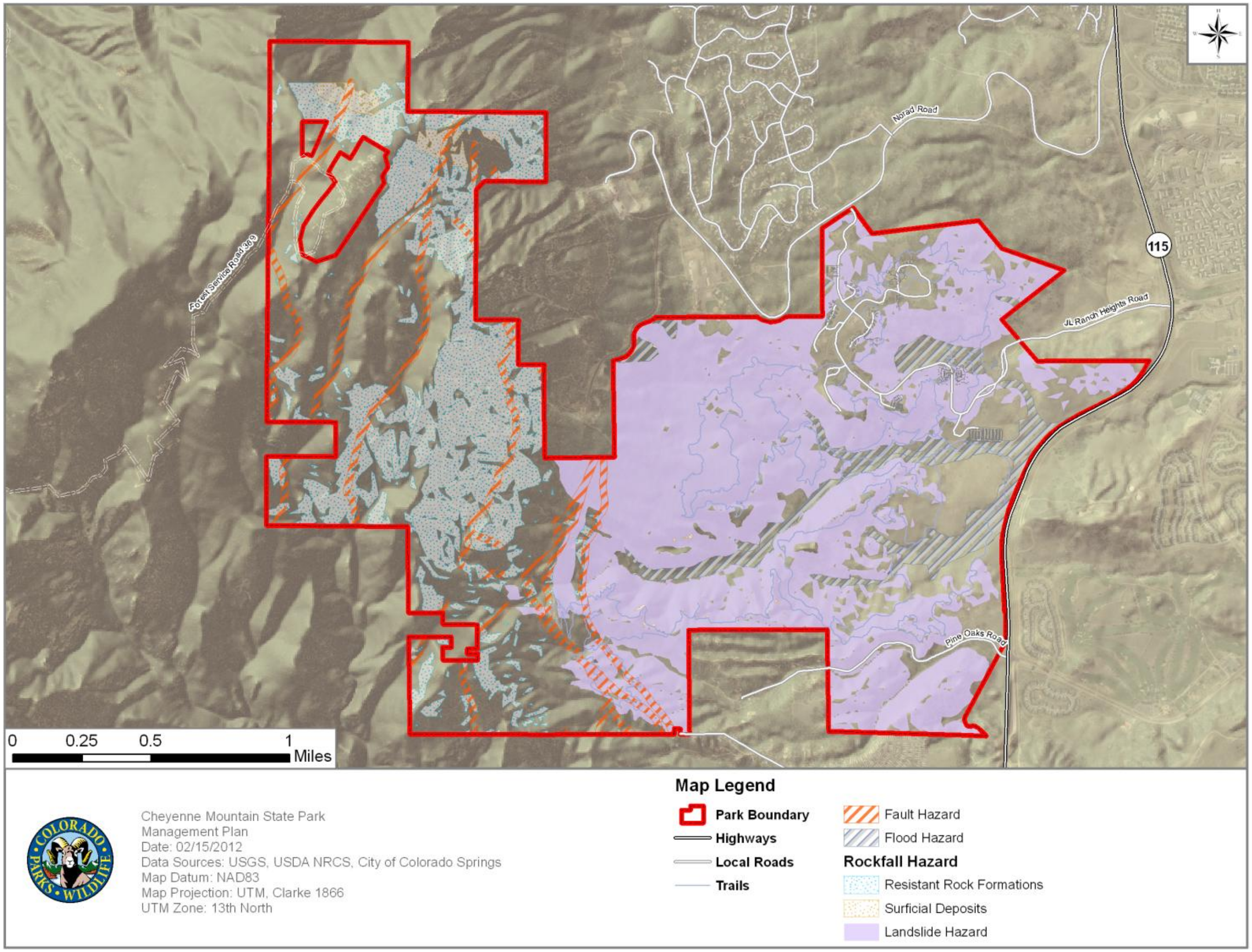
Bedrock

- Kp Pierre Shale (Upper Cretaceous)
- Kn Niobrara Formation (Upper Cretaceous)
- Kcgg Carlile Shale, Greenhorn Limestone, and Graneros Shale, undivided (Upper Cretaceous)
- Kdp Dakota Sandstone and Purgatoire Formation, undivided (Lower Cretaceous)
- Jmr Morrison Formation and Ralston Creek Formation, undivided (Upper Jurassic)
- TrPl Lykins Formation (Lower Triassic? and Upper Permian)
- Ply Lyons Sandstone (Upper and Middle? Permian)
- PPf Fountain Formation (Lower Permian and Pennsylvanian)
- Yqm Quartz monzonite (Middle Proterozoic)
- Xgd Granodiorite (Early Proterozoic)

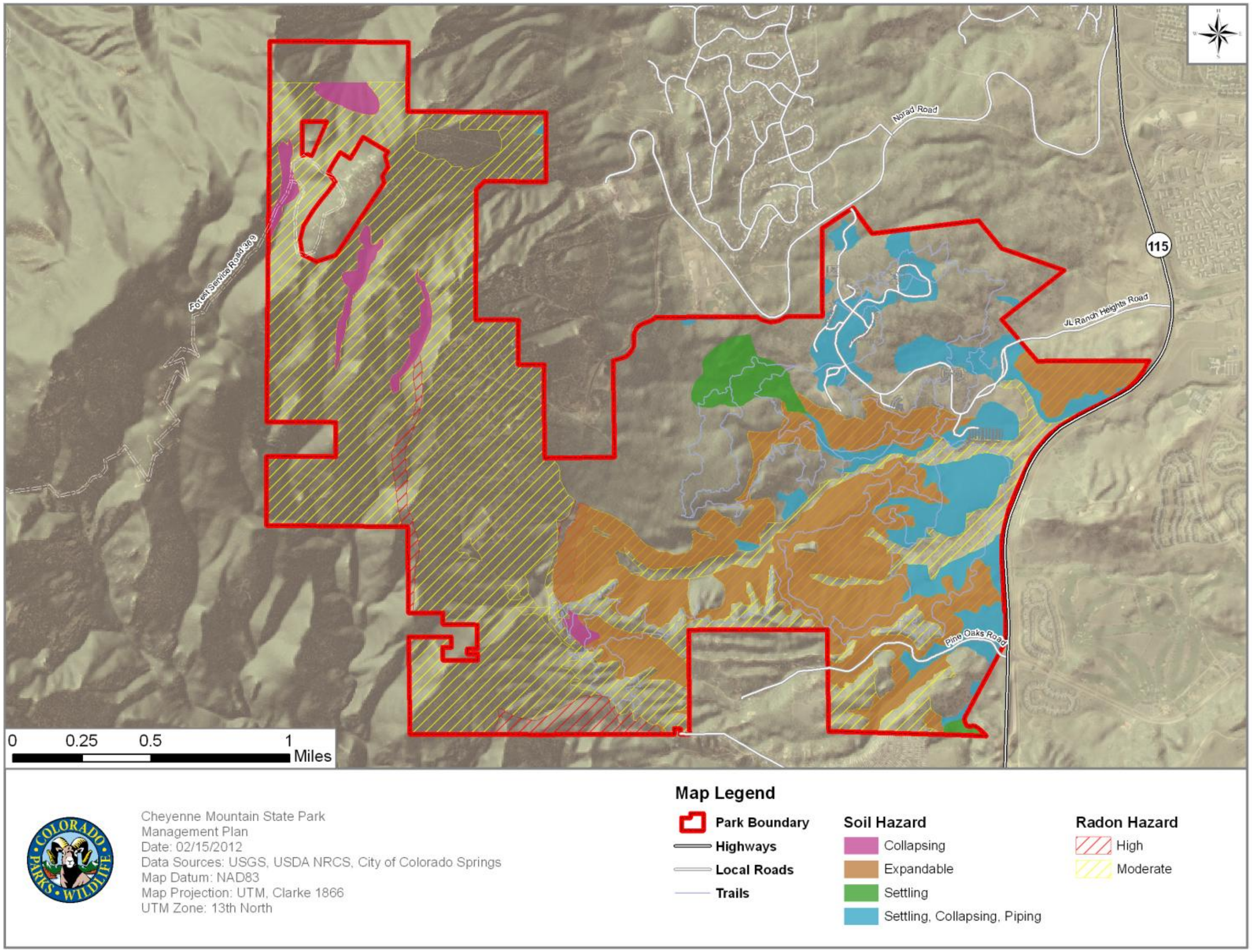
Other Symbols

- Formation or unit contact
- High-angle fault - dashed where approximately located; dotted where concealed; ball and bar on downthrown side. Measured angle of dip is shown in degrees
- Strike and dip of inclined beds - angle of dip shown in degrees
- Strike and dip of overturned beds - angle of dip shown in degrees
- Strike and dip of foliation - angle of dip shown in degrees

Map 11. Geologic hazards (part I).

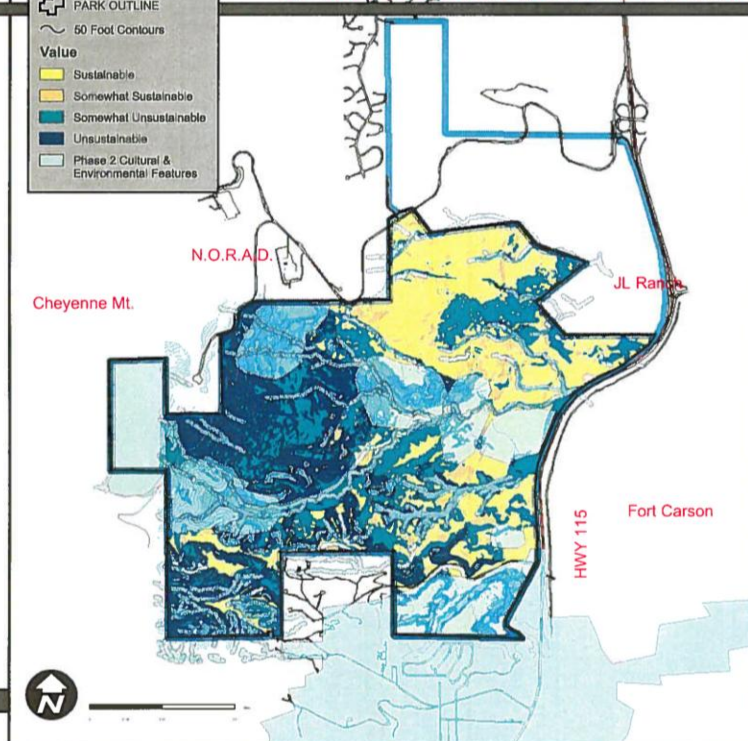


Map 12. Geologic hazards (part II).



Map 13. Thomas & Thomas Consulting land suitability analysis.

EXHIBIT 'A'
LAND SUITABILITY ANALYSIS - PHASE 3



Final Composite

In phase-3 of the land suitability analysis a final composite is made from phase-1 engineering constraints and phase-2 environmental, archeological and natural features mapping. The final map presents degrees of project planning opportunities and constraints to guide the development of the final park master plan.

The goal of the land suitability analysis was to isolate the most suitable land for park development that would assist in meeting the project's sustainable objectives. In terms of sustainable objectives, the project should minimize short-term development liabilities and limit long-term management concerns.

In the final analysis the Land Suitability Analysis identifies key planning opportunities and constraints within the scope of the preliminary project program and outside of a preferred concept master plan. It is also important to remember that in phase-1 the engineering constraints have been identified in four-classification or by degrees of sustainability, and in phase-2 the analysis identified sensitive environmental features and the complied natural and archeological features requiring varies degrees of planning consideration. The key opportunities and constraints focus on sustainable circulation, utility access, watershed/stormwater management, visual resource management, sensitive environmental features and engineering liabilities.

Total Net Acres:	
Sustainable	273.30 acres
Somewhat Sustainable	296.01 acres
Somewhat Unsustainable	272.59 acres
Unsustainable	160.71 acres

Wilson & Company - E.R.O - C.T.L. Thompson

THOMAS & THOMAS

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Reference Tables

Reference Table 1. Soil attributes and engineering suitability determinations.

MUSYM	MU_NAME	TEX_FULL	HYDRIC1	PERMEL	PERMEH	SHR_SWLL	FROST_ACT	ERODIBILIT	RNOFFRATE	AASHTO	SHALL_EXCA	DWELL_NB	SCOMM_BUIL	ROAD_STRT	CAMP	PICNIC	PATH_TRL
12	BRESSER SANDY LOAM, 3 TO 5 PERCENT SLOPES	Sandy Clay Loam	Y	0.20	0.60	LOW	LOW	Low to Moderate	Slow	A2	Slight	Slight	Moderate (slope)	Slight	Slight	Slight	Slight
13	BRESSER SANDY LOAM, 5 TO 9 PERCENT SLOPES	Sandy Loam	N	0.60	6.00	LOW	LOW	Moderate	Medium	A6, A7	Slight	Slight	Moderate (slope)	Slight	Slight	Slight	Slight
17	CHASEVILLE GRAVELLY SANDY LOAM, 8 TO 40 PERCENT SLOPES	Extremely Gravelly - Loamy Coarse Sand	N	6.00	20.00	LOW	LOW	Low	Slow to Medium	A1	Severe (cutbanks cave; slope)	Severe (slope)	Severe (slope)	Severe (slope)	Severe (slope)	Severe (slope)	Moderate (slope; small stones)
18	CHASEVILLE-MIDWAY COMPLEX	Very Gravelly - Loamy Sand	N	6.00	20.00	LOW	LOW TO MODERATE	Low to Moderate	Medium	A1, A7	Severe (cutbanks cave; slope; too clayey; depth to rock)	Severe (slope; shrink-swell; low strength)	Severe (slope; shrink-swell; low strength)	Severe (slope; shrink-swell; low strength)	Severe (slope)	Severe (slope)	Severe (slope; small stones)
38	JARRE-TECOLOTE COMPLEX, 8 TO 65 PERCENT SLOPES	Extremely Gravelly - Loamy Sand	N	6.00	20.00	LOW	MODERATE	Moderate to High	Medium to Rapid	A1, A2, A4, A6	Moderate to Severe (slope; small stones)	Moderate to Severe (slope; shrink-swell; low strength)	Severe (slope)	Moderate to Severe (slope; shrink-swell; low strength)	Moderate to Severe (slope)	Moderate to Severe (slope)	Slight to Severe (slope)
46	KUTLER-BROADMOOR-ROCK OUTCROP COMPLEX, 25 TO 90 PERCENT SLOPES	Weathered Bedrock	Y	0.06	2.00	LOW	LOW	Moderate to High	Rapid	A1, A2	Severe (slope; small stones; depth to rock)	Severe (slope)	Severe (slope)	Severe (slope)	Severe (slope)	Severe (slope)	Severe (slope)
53	MANZANOLA CLAY LOAM, 3 TO 9 PERCENT SLOPES	Clay Loam	N	0.06	0.20	MODERATE	MODERATE	High	Rapid	A4, A6	Moderate (too clayey)	Severe (shrink-swell)	Severe (shrink-swell)	Severe (shrink-swell; low strength)	Moderate (percs slowly; too clayey)	Moderate (too clayey)	Moderate (too clayey)
59	NUNN CLAY LOAM, 0 TO 3 PERCENT SLOPES	Clay Loam	Y	0.06	0.20	HIGH	MODERATE	Low	Slow to Medium	A6	Moderate (too clayey)	Severe (shrink-swell; low strength)	Severe (shrink-swell; low strength)	Severe (shrink-swell; low strength)	Moderate (percs slowly)	Moderate (too clayey)	Moderate (too clayey)
74	RAZOR STONY CLAY LOAM, 5 TO 15 PERCENT SLOPES	Weathered Bedrock	N	0.06	2.00	LOW	MODERATE	Moderate	Medium to Rapid	A7	Moderate (too clayey; large stones)	Severe (shrink-swell)	Severe (shrink-swell; slope)	Severe (shrink swell; low strength)	Moderate (slope; percs slowly; too clayey)	Moderate (slope; too clayey)	Moderate (too clayey)
77	ROCK OUTCROP-COLDCREEK-TOLMAN COMPLEX, 9 TO 90 PERCENT SLOPES	Unweathered Bedrock	N	0.00	0.00	LOW	MODERATE	Moderate	Medium	A1, A2, A4	Severe (slope; small stones; depth to rock; cut banks cave)	Severe (slope; depth to rock)	Severe (slope; depth to rock)	Severe (slope; depth to rock)	Severe (slope)	Severe (slope)	Severe (slope)
82	SCHAMBER-RAZOR COMPLEX, 8 TO 50 PERCENT SLOPES	Silty Clay	Y	0.06	0.20	HIGH	MODERATE	Moderate	Medium to Rapid	A1, A2, A4, A6, A7	Moderate to Severe (slope; cut banks cave; depth to rock; too clayey)	Severe (slope; shrink swell; low strength)	Severe (slope; shrink swell; low strength)	Severe (slope; shrink swell; low strength)	Moderate to Severe (slope; too clayey; percs slowly)	Moderate to Severe (slope; too clayey)	Moderate to Severe (slope; too clayey)
97	TRUCKTON SANDY LOAM, 3 TO 9 PERCENT SLOPES	Sandy Loam	Y	2.00	6.00	LOW	MODERATE	Moderate	Slow to Medium	A2, A4, A6	Slight	Slight	Moderate (slope)	Moderate (frost action)	Slight	Slight	Slight
101	USTIC	Variable	N	0.00	0.00	LOW	MODERATE	Moderate to	Slow		Severe	Severe	Severe	Severe	Severe	Moderate	Slight

	TORRIFLUVENTS, LOAMY							High			(floods)	(floods)	(floods)	(floods)	(floods)	(floods)	

SOURCE: USDA. 1981. Soil Survey of El Paso County. **Soil attributes and engineering suitability determinations.**

MUSYM	MU_NAME	DEV_LIM	Engineering Suitability
12	BRESSER SANDY LOAM, 3 TO 5 PERCENT SLOPES	This soil has good potential for homesites. Adequate erosion control practices are needed to control surface runoff and keep soil losses to a minimum. Limiting the disturbance of the soil and the removal of existing plant cover during construction helps to control erosion.	1
13	BRESSER SANDY LOAM, 5 TO 9 PERCENT SLOPES	The soil has good potential for homesites. Practices are needed to control surface runoff and keep soil losses to a minimum. Limiting the disturbance of the soil and the removal of existing plant cover during construction helps to control erosion.	1
17	CHASEVILLE GRAVELLY SANDY LOAM, 8 TO 40 PERCENT SLOPES	The main limitation of this soil for construction is slope. Special designs for homesites, buildings, and roads are needed to overcome this limitation. The high gravel content may cause problems with excavations because cut banks cave in. A surface dressing of topsoil is desirable where the very gravelly subsoil is exposed during the site preparation. Access roads must be designed to control surface runoff and to help stabilize cut slopes. Caution should be exercised when locating septic tank absorption fields because of the possible pollution of water supplies as a result of the rapid permeability of this soil.	4
18	CHASEVILLE-MIDWAY COMPLEX	The main limitation for construction on the Chaseville soil is slope. Special designs for building sites, buildings, and roads are needed to overcome this limitation. The high gravel content may cause problems with excavations because cut banks cave in. A surface dressing of topsoil may be desireable on the Chaseville soil where the very gravelly subsoil is exposed during site preparation. Access roads must be designed to control surface runoff and help stabilize cut slopes. The Midway soil has poor potential for homesites and roads because of shallow depth to shale, high frost-action potential, and high shrink-swell potential. Special designs are necessary to overcome these limitations.	5
38	JARRE-TECOLOTE COMPLEX, 8 TO 65 PERCENT SLOPES	The main limitations for urban development on the Tecolote soil are steep slopes and the presence of stones. The presence of stones can cause problems when excavating for installation of underground facilities. Heavy equipment can be used to move the stones when preparing building sites or when constructing roads. Plans for homesite development should provide for the preservation of as many trees as possible to maintain the esthetic value of the sites.	3
46	KUTLER-BROADMOOR-ROCK OUTCROP COMPLEX, 25 TO 90 PERCENT SLOPES	The main limitations for the use of these soils for urban development are depth to rock and slope. Measures must be taken to minimize surface runoff and thus keep erosion to a minimum. These soils also require specialsite or building designs because of the slope. Deep cuts, to provide essentially level building sites, can expose the bedrock. The limitation of large stones on the surface can generally be overcome by the use of heavy equipment when preparing building sites. Access roads must have adequate cut-slope grade and be provided with drains to control surface runoff and keep soil losses to a minimum.	5
53	MANZANOLA CLAY LOAM, 3 TO 9 PERCENT SLOPES	The main limitations of this soil for urban uses are slow permeability and high shrink-swell potential. Septic tank absorption fields do not function well because of the slow permeability. Special designs for buildings and roads are required to overcome the limitation of high shrink-swell potential.	3
59	NUNN CLAY LOAM, 0 TO 3 PERCENT SLOPES	The main limitations of this soil for urban use are slow permeability, low strength, and shrink-swell potential. Buildings and roads must be designed to overcome the limitations of low bearing strength and shrink-swell potential. Septic tank absorption fields do not function properly because of the slow permeability.	3
74	RAZOR STONY CLAY LOAM, 5 TO 15 PERCENT SLOPES	The main limitations for homesite development or urban use are the depth to shale, stoniness, shrink-swell potential, and slope. The limitations of soil depth and stoniness can be overcome through the use of heavy equipment when preparing building sites. Special designs for buildings and roads are needed to overcome the limitations of depth to shale, shrink-swell potential, and slope. Septic tank absorption fields do not function properly because of slow permeability and moderate depth to shale.	4
77	ROCK OUTCROP-COLDCREEK-TOLMAN COMPLEX, 9 TO 90 PERCENT SLOPES	The main limitations of the soils of this complex for urban use or homesite development are rock outcrops, stones, depth to bedrock, especially on the Tolman soil, and steep slope. Homesites should be located in places where these limitations are the least severe. Special designs for buildings and roads are required to overcome these limitations.	5
82	SCHAMBER-RAZOR COMPLEX, 8 TO 50 PERCENT SLOPES	The main limitation for construction on the Schambler soil is steep slopes. Because of rapid permeability, there is a hazard of pollution if this soil is used for septic tank absorption fields. The high content of coarse fragments may cause problems with excavations, mainly because cut banks cave in. Special designs for buildings and roads are necessary to offset the limitation of slope. The Razor soil is limited by depth to shale, slow permeability, and limited ability to support a load, shrink-swell potential, and slope. Both soils are limited by frost-action potential. Special designs for buildings and roads are needed to overcome these limitations.	4
97	TRUCKTON SANDY LOAM, 3 TO 9 PERCENT SLOPES	The main limitation of this soil for construction is frost-action potential. Special designs for roads are needed to overcome this limitation. Because of the sandy nature of the soil, practices must be provided to minimize surface runoff and thus keep erosion to a minimum. Access roads must have adequate cut-slope grade and be provided with drains to control surface runoff.	2

101	USTIC TORRIFLUVENTS, LOAMY	The main limitation of these soils for urban use is the hazard of flooding. Building and roads should not be built along drainageways and on flood plains. Access roads must be designed to minimize frost-heave damage.	4

SOURCE: USDA. 1981. Soil Survey of El Paso County.

1 Acceptable 2 Moderate 3 Limited 4 Difficult 5 Unsuitable

Reference Table 2. Geologic hazard mapping rationale.

Hazard	Geologic Feature(s) or Unit(s)	Concerns	Recommendations	Hazard Report* page reference	Engineering Suitability Mapping
Faults and Earthquakes	Faults	Earthquakes, with potential to trigger rockfall and landslides. Introduction of fluids along a fault line can actually trigger an earthquake (Evans, 1966). Groundwater may issue from faults in the form of springs that can trigger landslides downhill (Oborne, 1963).	Structures should not be built on or near faults, and fluids should not be injected into them. Consider building permanent structures to the specifications of the international earthquake building code. Roads and trails built along or across faults may require extra measures to prevent and control erosion, and may require extra maintenance.	pg. 02-05	A 20 meter fault avoidance zone is recommended in a report prepared for the New Zealand Ministry for the Environment on development near fault lines (Kerr et al., 2003). Therefore, a 20 meter buffer will be applied around all fault lines to delineate the hazard area.
Rockfall	Xgd Yqm PPf Ply Kd(p?) Kn Qfro Qg_{2u} Qt Qc	Rock formations: Rockfall hazard below cliffs of resistant rock and on steep slopes (>60% grade) on and below these formations. Surficial Deposits: Large boulders in unit Qfro can roll or move during heavy rains or earthquakes, or when they are undermined by construction (Rowley et al., 2003). Boulders can also roll down steep slopes near the tops of mesas capped by gravel unit Qg2u (Wait and White, 2006). Units Qt and Qc are composed mostly or entirely of fallen rocks, so a clear rockfall hazard exists where these units occur on the map.	It is best to avoid locating trails, roads, or buildings where units Qt and Qc are mapped, or at the bases of cliffs and steep slopes. Trails located on steep slopes below boulders in units Qrfo and Qg2u may require extra monitoring and maintenance.	pg. 05-07	Hazard areas include purple and green units with slopes greater than 60%.
Landslides	Kp Kcgg Qg_{2u} Qlsr Kp Qls Qfro	Landslides in units Kp and Cgg are especially common on slopes with angles greater than seven degrees (White and Wait, 2003), as well as steep slopes around the edges of unit Qg_{2u}, recent landslide areas (Qlsr), and older landslide deposits, such as Qfro and Qls, that can still be active, or can reactivate on slopes as low as five to six degrees (Carroll and Crawford, 2000).	Ideally it is best to avoid building in landslide-prone areas or on existing landslide deposits. However, that is probably not practical in this park. At a minimum, avoid building on or near landslide deposits that are known to be active (unit Qlsr), and avoid building on or near steep slopes of unit Kp. Avoid undercutting the toes of landslide deposits and Kp slopes during road or trail construction. Keep water and sewer lines maintained in good repair and avoid lawn watering or irrigation in the eastern half of the park. Be aware that heavy rains, brushfires, earthquakes, and natural geological processes like weathering, erosion, and deposition can potentially trigger landslides in the park despite human efforts to prevent them. Budget some extra money for repair of future landslide-related damage to the park's infrastructure. Have a qualified geotechnical engineering company carefully evaluate any proposed building sites on units Kp, Qls or Qfro.	pg. 07-10	Hazard Areas include: 1) Units Kp and Kcgg with slopes greater than 7°. 2) Units Qg_{2u}Qlsr, Qfro, and Qls with slopes more than 5 degrees.

Hazard	Geologic Feature(s) or Unit(s)	Concerns	Recommendations	Hazard Report* page reference	Engineering Suitability Mapping
Floods	Qt_1 Qfy Qfo	Flood hazard exists in areas covered by surficial deposits Qt_1, Qfy, and Qfo and low-lying areas underlain by Qt_1. Units Qfy and Qfo (older fan deposits) have the potential to be inundated by debris flows, which are watery slurries of mud, sand, gravel, and plant debris. Debris flows could potentially occur anywhere in unit Qfy, but would likely be confined to channels in unit Qfo (Rowley et al., 2003).	Avoid building structures on the 100-year floodplain if possible, and especially avoid building them on or near unit Qfy or channels in unit Qfo. Campgrounds should not be located in any of these places, either. Parks staff might consider posting warning signs and emergency evacuation instructions in these areas. It is also wise to avoid removing vegetation or altering drainage patterns in the drainage basins of flood hazard areas, and to realize that a wildfire will bring an increased risk of debris flows.	pg. 10-12	Hazard areas include units Qt_1, Qfy, and Qfo.
Expanding, Collapsing and Heaving Soils	Kp Kn Kcgg Qsw Qfy Qlsr Qsw Qfy Qc Qsw Qfy	Expandable Soils: The Cretaceous shales (units Kp, Kn, Kcgg) have expandable clays that swell when wet (Noe, 2007). When these units are steeply tilted so that their edges appear at the ground surface, some of the layers swell more than others, causing the soil to heave (Noe, 1997). Settling Soils: Units Qsw, Qfy, Qlsr, and Qls, are prone to settling because they were deposited too rapidly to compact adequately (Rowley et al., 2003). Collapsing Soils: Units Qsw, Qfy, and Qc are prone to collapsing when exposed to water. Soil Piping: and units Qsw and Qfy are prone to soil piping (White and Greenman, 2008).	Conduct soil studies before building on these units, and to do the recommended mitigations.	pg. 12-13	Hazard areas include the following units: Kp Kn Kcgg Qsw Qfy Qslr Qsw Qfy Qc Qsw Qfy
Radon	Yqm PPf Kcgg Xgd Kdp Kn Kp Qg_{2u} Qt_1	Average radon levels greater than 10 pCi/L in Colorado. Average radon levels of 4-10 pCi/L in Colorado.	Mitigation is recommended when buildings are constructed on these formations (Colorado Geological Survey, 1991). Test buildings built on these units, and to remediate as needed.	pg. 13	Areas of High Hazard include the following units: Yqm PPf Kcgg Areas of Moderate Hazard include the following units: Xgq Kdp Kn Kp Qgw Qt1

* Houck, K. 2001. Geologic Hazards in Cheyenne Mountain State Park.

Note: Landslide and rockfall hazard areas do not include runout areas. It would be interesting to model these and include.