Lone Mesa State Park

Mineral and Water

Resource Assessment

Prepared for Colorado State Parks

(Contract # C170594)

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I. INTRODUCTION

Colorado State Parks requested the assistance of the Colorado Geological Survey (CGS) to complete an evaluation of the geological and hydrogeological resources (mineral, mineral fuels, water) on the 11,760 acres of the Lone Mesa State Park in Dolores County, Colorado (Figure 1). The following report documents the occurrence of these resources within the park and estimates the probability for their development. The evaluation includes narratives, a resource rating and reference maps. The evaluation includes a brief introduction to the geology of the Lone Mesa State Park. The report includes diagrams, geologic and topographic maps to help the user visualize the geologic concepts presented.

Five categories of resources are included in the evaluation:

1. oil and gas
2. coal
3. metallic minerals
4. industrial minerals and construction materials
5. water (groundwater and surface water).

II. GEOLOGIC OVERVIEW

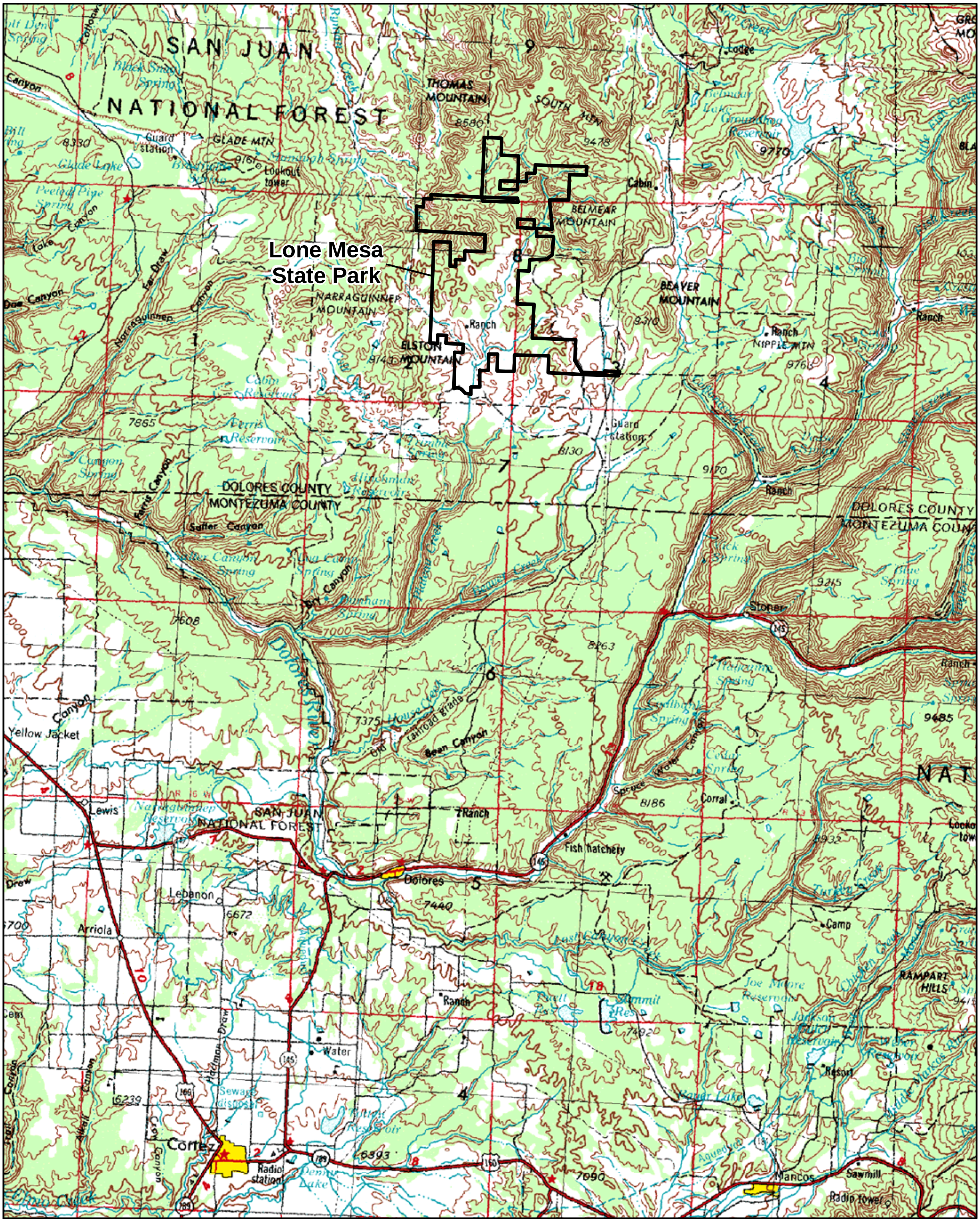
The area occupied by the Lone Mesa State Park lies in the Paradox Basin (Figure 2) in the western portion of the Four Corners Platform. Two sets of lineaments, northeast-southwest and northwest-southeast, affected the sedimentologic and tectonic patterns in the Four Corners region.

The topography of the area comprises mesas and incised canyons developed in primarily Jurassic and Cretaceous sandstone and shale. Quaternary surficial deposits, such as stream alluvium and eolian sand, are widespread in the area. A generalized stratigraphic chart of the major geologic formations present within the Paradox Basin is shown in Figure 3.

II.1. Paradox Basin

The Paradox fold and fault belt developed in response to subsurface movement and flow of Pennsylvanian evaporite deposits that created linear salt-cored anticlines (Baars and Stevenson, 1981; Doelling, 1983). Lone Mesa State Park lies within this fold and fault belt (Figure 2).

During basin subsidence in the Pennsylvanian and Permian periods, up to 20,000 feet of clastic (mud, sand, and gravel) sediments and evaporite deposits accumulated in the Paradox Basin. The evaporite deposits, primarily salt, may have reached a thickness of up to 8,000feet. As the evaporates were buried under the rapidly accumulating clastics, the weight of the clastic sediments caused the evaporates to flow and form elongate salt anticlines. Pre-existing northwest-trending basement faults that may have originated in Late Precambrian along with the main boundary faults of the ancestral Uncompahgre highland (Stone, 1977) probably controlled alignment of the salt anticlines. Stratigraphic evidence suggests that upward salt flowage was rapid from Pennsylvanian through early Permian and continued into the Jurassic (Baars and Stevenson, 1981). Flowage generally ceased as the source salt beds were depleted; uplift and erosion exposed the salt anticlines to meteoric groundwater flow. Surface dissolution then led to collapse of the anticline crests to form grabens within the anticlines.



Topographic map base at 1:250,000 from USGS.
Projection: UTM Zone 13, NAD 1983.

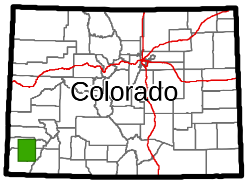


FIGURE 1
Location Map
Lone Mesa State Park
Natural Resources Assessment

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0 1 2 3 4 Miles

Scale = 1:250,000

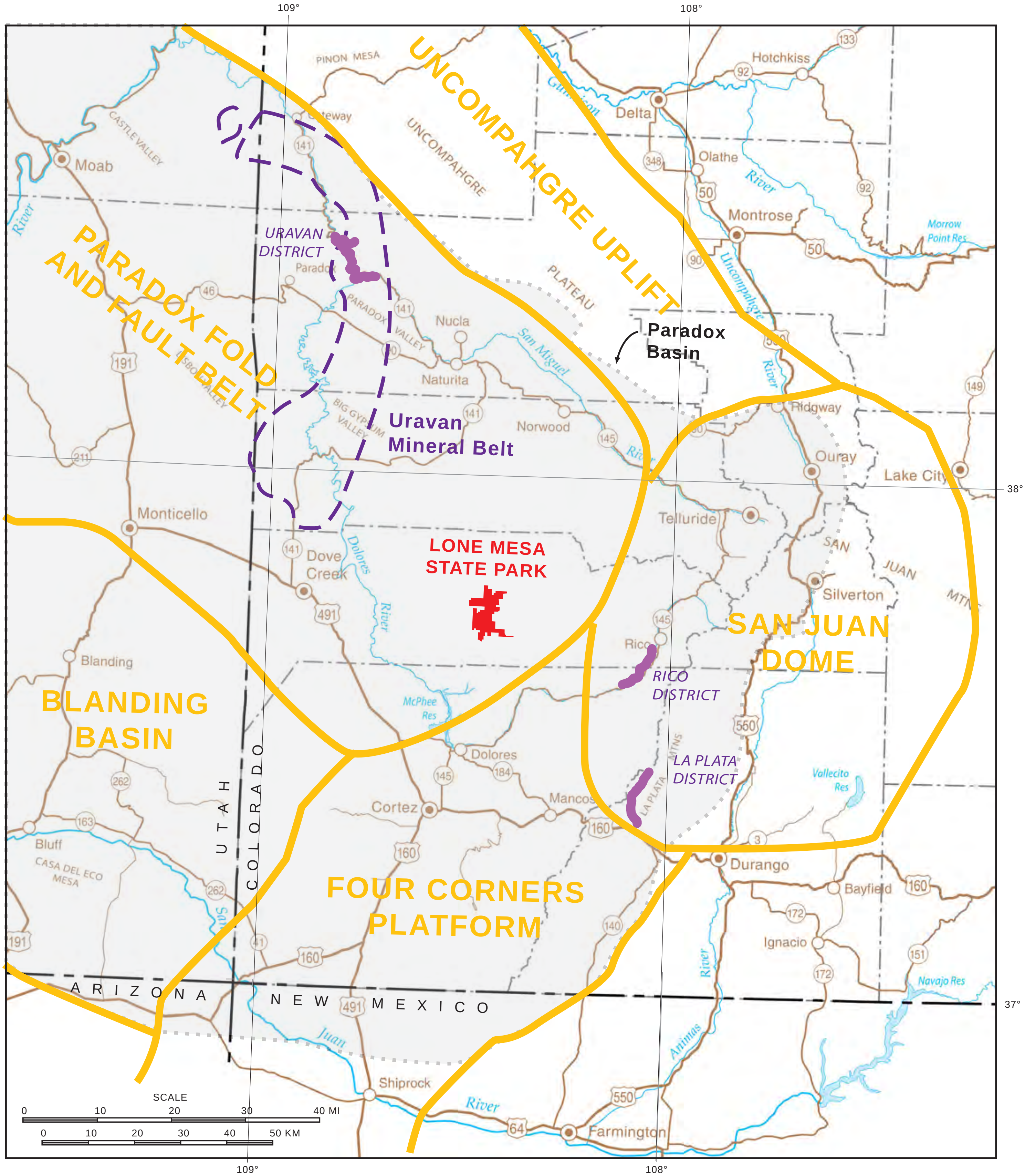
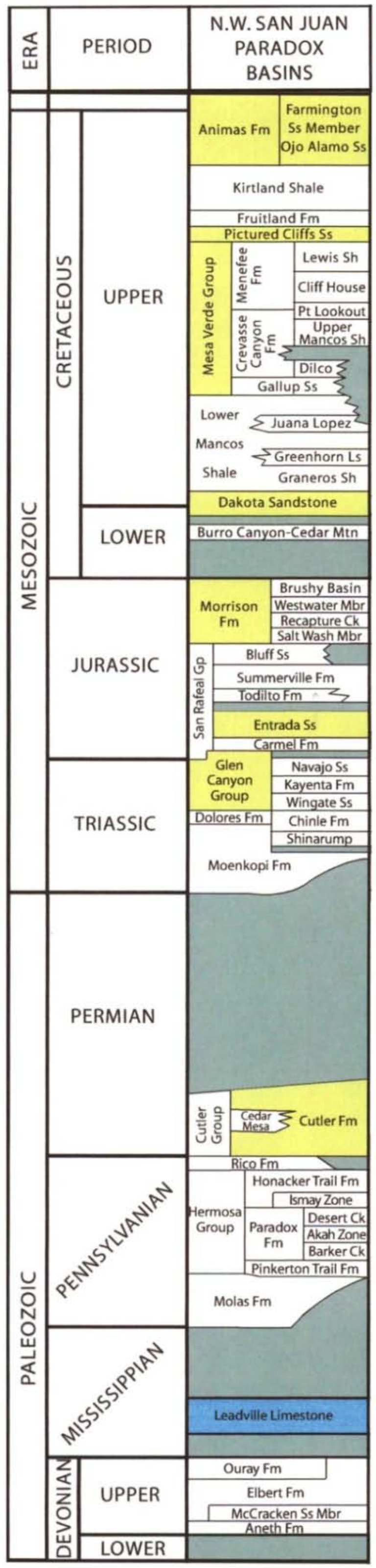


FIGURE 2
Regional Context of
Lone Mesa State Park
Natural Resources Assessment

Figure 3. Stratigraphic Chart of the Paradox Basin (compiled by CGS)

Occurring at or near the surface in the Park



Blank zones indicate rocks not present in the Paradox Basin

II.2. Geologic Units

The geologic map of the Lone Mesa State Park area (Figure 4) is derived from the map of Haynes, et al., 1972, which shows geology at a scale of 1:250,000**.** Rocks within and adjacent to the Lone Mesa State Park are sedimentary deposits of Cretaceous age – formed from sediments deposited between 145 and 65 million years ago. These sediments accumulated at a time when the Cretaceous mid-continent seaway was encroaching on the area from the east, and continued until the seaway receded again. Left behind are sediments deposited on a coastal plain, shoreline and beaches, and quiet-water muddy offshore environments.

II.2.1 Dakota Sandstone

The Dakota Sandstone is a widespread unit that appears in the Lone Mesa State Park area mainly as a yellowish brown to gray, quartzitic sandstone and conglomeratic sandstone in thick beds. Within the park, the Dakota Sandstone conformably overlies the Burro Canyon Formation (Steven and Hail, 1989; Morgan et al 2008). The Dakota grades laterally from fluvial (river deposit) sandstones into conglomerates and carbonaceous mudstones and shales with thin, impure coals. The carbonaceous units contain numerous plant fossils while the sandstones show cross-bedding, bioturbation and channel fills. The Dakota Sandstone contains coal beds that are mined in the Nucla area.

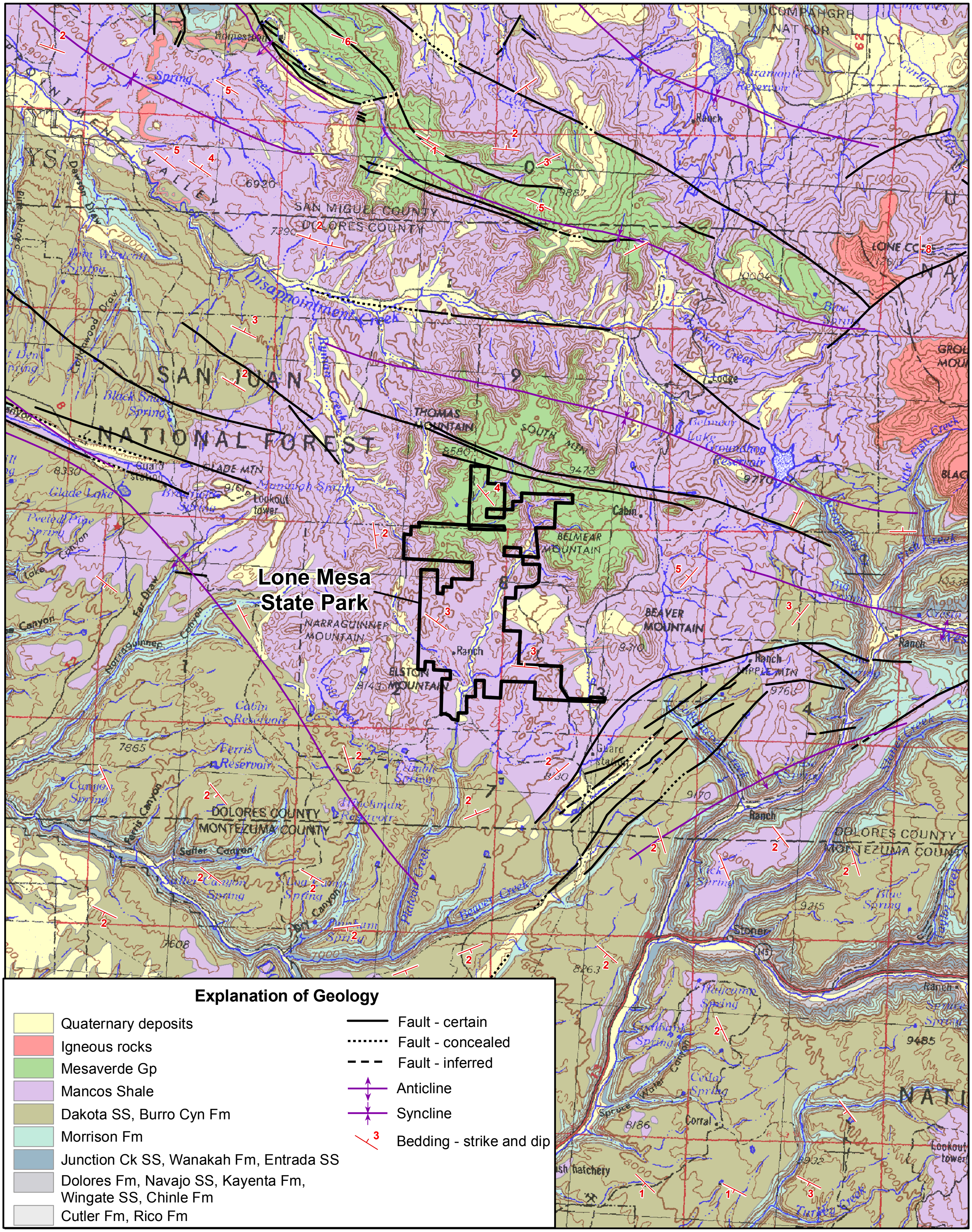
The Dakota Sandstone was formed as the Cretaceous Interior Seaway encroached from the east, leading to the formation of delta, bar, swamp, and shoreline facies (Blakey and Ranney, 2008). Dolson and Muller (1994) interpret the Dakota as a stack of strata comprising four separate sequences, reflecting tectonic and eustatic sea level fluctuations along the western edge of the interior sea.

The Dakota Sandstone in many locations forms a very hard, resistant "quartzite." It breaks into angular blocks and shows some potential as building stone. In some locations in Colorado, it is quarried for crushed rock aggregate.

II.2.2 Mancos Shale

The Mancos Shale is a sequence dominated by rocks deposited in the Cretaceous Interior Seaway. The unit reaches a thickness 3000 feet in places. The shale grades upward and intertongues with the overlying Mesaverde Formation. In the Dolores Peak Quadrangle, east of the Lone Mesa State Park area, the Mancos Shale is generally a gray to black fissile shale with a few thin fossiliferous limestone beds near the base (Bush and Bromfield, 1966). There it is 2,000 to 3,000 feet thick, thinning to the southwest.

Topographically, the Mancos Shale forms gentle slopes broken by calcareous sandstone ledges and occasional white bentonite layers. The complex unit is interpreted depositionally as changing offshore environments, from distal turbidites to near-shore muds, silts and sandstones.



N

0 1 2 3 4 Miles

Scale = 1:250,000

1:250,000-scale geology data from Haynes et al. (1972).
Topographic map base at 1:250,000 from USGS.
Projection: UTM Zone 13, NAD 1983.

FIGURE 4
Geologic Map
Lone Mesa State Park
Natural Resources Assessment

II.2.3 Mesaverde Group

The Mesaverde Group records shoreline deposition as the Cretaceous Seaway retreats across the area toward the east. In the park this unit generally overlies, but sometimes interfingers with the Mancos shale. Three Mesaverde formations are recognized in the area: (1) The Cliff House Sandstone is a yellowish-orange to yellowish-brown, fine to medium-grained cross-bedded marine sandstone and gray shale, approximately 400 feet thick. (2) Above that is the Menefee Formation, a non-marine sequence of rocks consisting of lenticular beds of yellowish-gray and brown cross-bedded sandstone, gray and brown claystone and shale, coal seams, and ironstone and limestone concretions. The thickness of the Menefee Formation ranges from 350 to 850 feet, thinning northeastward. (3) The Point Lookout Sandstone is about 400 feet thick. The upper portion is a prominent yellowish-gray to brown cliff-forming massive, cross-bedded marine sandstone. The lower portion consists of alternating thin beds of yellowish-gray sandstone and gray shale.

II.2.4 Igneous Intrusive Rocks

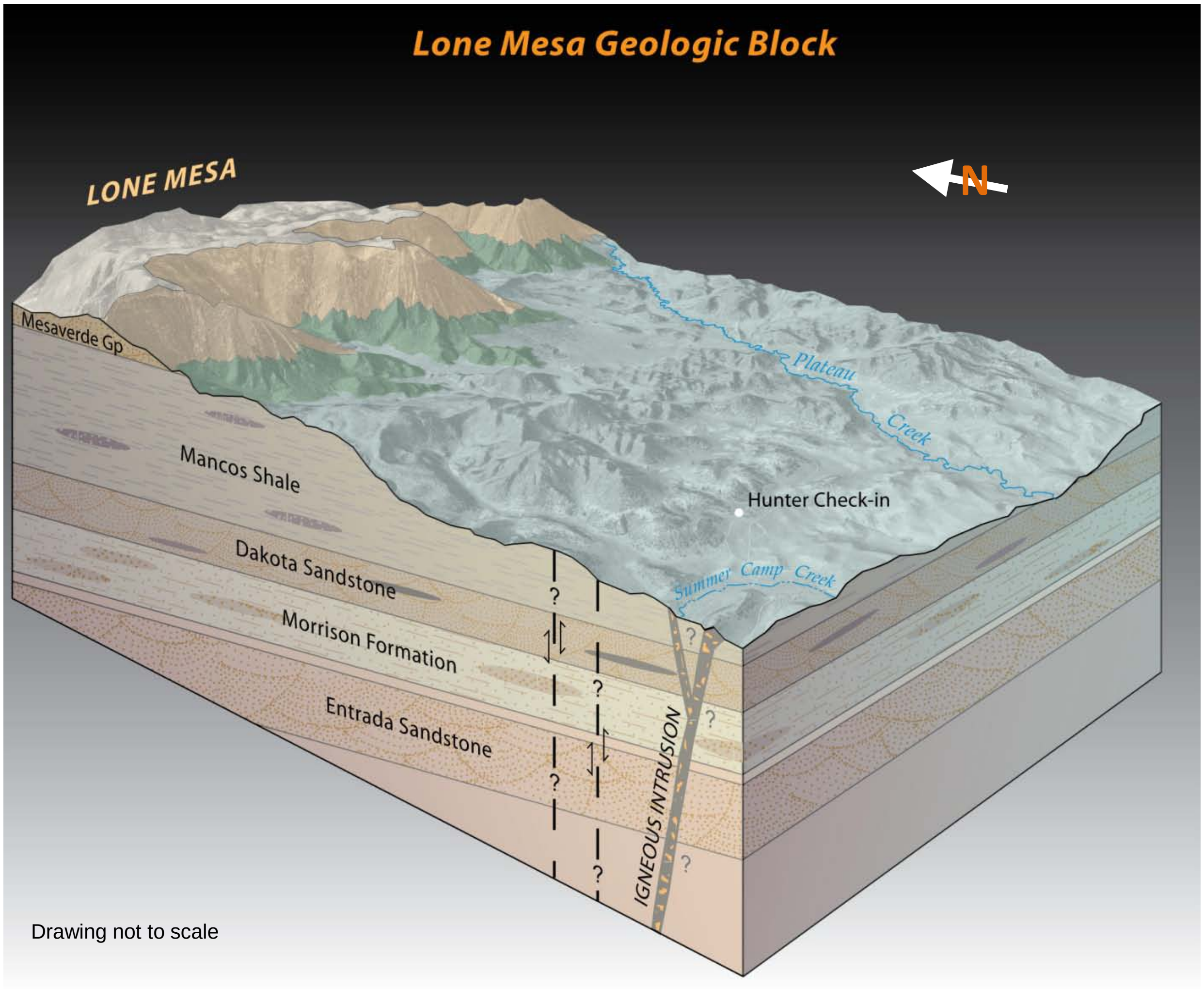
The knobs and ridges between the south entrance to the Park and Lone Mesa itself are underlain (and held up by) hypabyssal (near-surface) intrusive rocks of igneous origin. Commonly, igneous rocks are more resistant than the sedimentary rocks and form erosion-resistant features. The rock types noted in the field are dacitic to rhyolitic in composition. Small intrusions of the same type are seen as far away as Rico (Pratt et al., 1969) and have been mapped and described in the Dolores Peak Quadrangle (Bush and Bromfield, 1966) and the Little Cone Quadrangle (Bush et al., 1959). There, where detailed geologic mapping was conducted, the intrusions are described as ranging in composition from granogabbro to rhyolite, forming dikes, sills, laccoliths, and stocks within the Dakota and Mancos Formations.

II.3 Geologic Structure

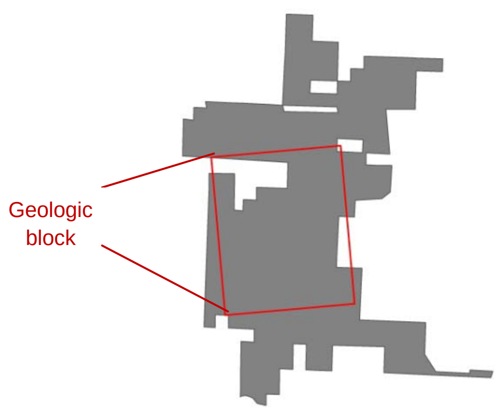
The geologic structure within the Lone Mesa State Park area consists of sedimentary rocks that dip to the north at 2 to 4 degrees. These gently dipping strata are intruded by intermediate to felsic igneous rocks. In the general area surrounding the Park, the sedimentary rocks have been deformed into a series of broad folds trending east-west, that display a “wavy” structure, with dips that vary from a few degrees north to a few degrees south. Anticlines frame the southern side of the Park. Strata dip to the north toward a syncline adjacent to the park (Figures 4 and 5). The top of the Dakota Sandstone crops out at the surface at the far south end of the Park at an elevation of approximately 7,500 feet. At the base of Lone Mesa in the center of the Park - approximately 4 miles to the north - the top of the Dakota Sandstone is at an elevation of about 6,000 feet and is some 3,000 feet below the mesa top.

No faults have been mapped in the Lone Mesa State Park but faulting is inferred. Although faults have not been documented in the Park by previous mapping, several lines of evidence suggest that they might exist. Detailed mapping in nearby quadrangles has identified faults with northeast trends that extend toward the Park. Notable linear topographic features within the Park parallel nearby faults, indicating the possibility of faults or fracture sets (Figure 6). In the other three quadrangles noted above – 20 to 25 miles to the east and northeast of the Park – bedrock faulting has been mapped. In the Dolores Peak Quadrangle (Bush and Bromfield, 1966) specifically, numerous faults are identified with a dominant orientation of N 30-45^{o} East. The ridges in the Lone Mesa State Park, interpreted to be underlain by dikes of igneous rock, show that general orientation, ranging from east-west to N45^{o}E. We infer that igneous intrusion followed faults or zones of weakness and that the ridges seen on the surface are the tops of planar dikes into the subsurface.

Figure 5. Schematic Block Diagram of the Geology of Lone Mesa State Park



Geologic block in relationship to the Lone Mesa State Park boundary



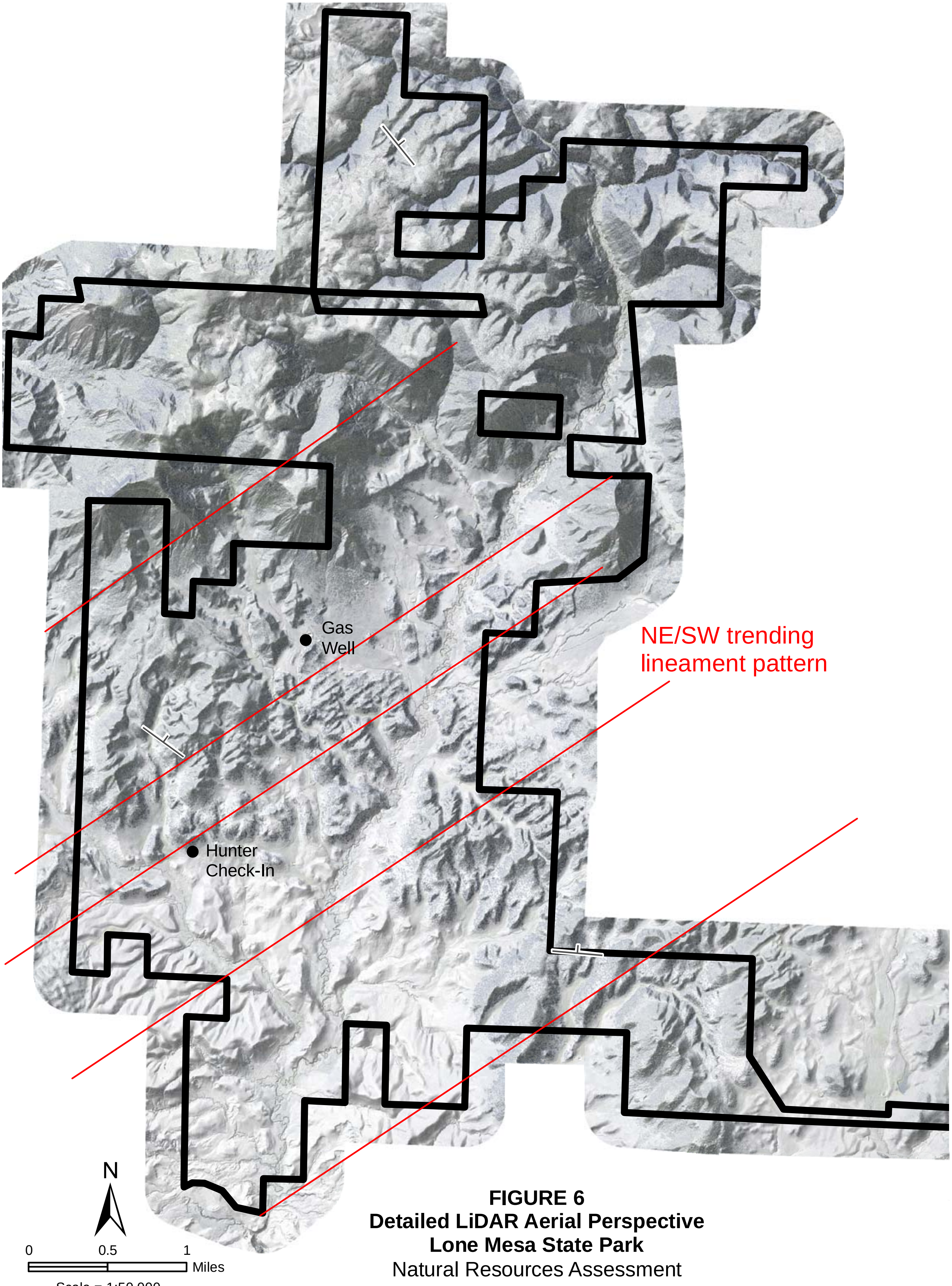


FIGURE 6
Detailed LiDAR Aerial Perspective
Lone Mesa State Park
Natural Resources Assessment

1-meter resolution LiDAR imagery and digital elevation model data from Colorado State Parks
Projection: UTM Zone 13, NAD 1983.

III. EVALUATION OF RESOURCE POTENTIAL

III.1. Mineral Potential Rating Classification

The following section reviews the potential for development of resources at the Lone Mesa State Park. Individual reviews are conducted of oil and gas, coal, metallic minerals, and industrial minerals along with a detailed evaluation of both surface and groundwater resources. Table 1 outlines the rating system used for the evaluation.

Table 1. Mineral Potential Rating System

RATING	Oil & Gas	Coal	Metallic Minerals	Industrial Minerals
0.1 Little or no potential	Lacks all the essential elements of hydrocarbon accumulation*.	Lacks strata that may contain coal; not in a coal basin.	Lacks rock types or structures that may contain metallic minerals.	Lacks rock types or structures that may contain industrial minerals or construction materials.
1 Poor	Sedimentary rocks in the tract lack one or more of the essential elements.*	Tract contains strata that may contain coal; in a coal basin; no coal occurrences within 5 miles.	Tract contains permissive rock types and structures to host metallic mineral deposits. No mineral occurrences known within 5 miles.	
2 Fair	All essential elements* exist in tract; however, existing geological control is insufficient to determine presence or a local trap or reservoir. Some production nearby.	Tract contains strata that may contain coal; in a coal basin. No coal occurrences within 1 mile.	Tract contains permissive rock types and structures to host metallic mineral deposits. No mineral occurrences within 1 mile.	Tract contains permissive rock types and structures to host industrial minerals or construction material deposits.
3 Moderate	All essential elements* in immediate area. Production within 1-2 miles or tract is on trend with existing production. Geological control is insufficient to determine presence of a local trap or reservoir.	Tract is in a known coal basin, contains known coal-bearing strata. A <u>hypothetical resource</u> could be estimated.	Tract contains permissive rock types and structures to host metallic mineral deposits. May contain mineralization. <u>Undiscovered resources</u> could be estimated.	
4 Good	Geologic control strongly suggests all essential elements* exist. Production or strong show within a mile or along a geologic trend.	Tract contains coal beds that can be classified as an identified resource.	Tract contains metallic minerals that can be classed as an identified resource.	Tract contains industrial minerals or construction materials that can be classed as an identified resource.
5 Proven	Tract contains <u>proven developed</u> or <u>proven undeveloped</u> reserves.	Tract contains <u>demonstrated reserves</u> and is producing coal.	Tract contains <u>demonstrated reserves</u> and is producing metallic minerals.	Tract contains <u>demonstrated reserves</u> and is producing industrial minerals.

III.2. Oil, Gas, and Carbon Dioxide

Geologic History, Stratigraphy and Hydrocarbon Production of Dolores County

Dolores County lies within the Paradox Basin which is a Pennsylvanian-aged, northwest trending, oval-shaped basin located mostly in southwestern Colorado and southeastern Utah (Figure 2). A broad, stable shallow marine shelf extended over much of the western United States before the Paradox Basin formed on which Cambrian, Devonian and Mississippian sands and carbonates were deposited.. . Hydrocarbon and carbon dioxide production occurs from the Mississippian Leadville Limestone, the uppermost Mississippian formation. The Leadville is a source of natural gas and condensate in the Lisbon Southeast field in San Miguel County. It is also a source of carbon dioxide in McElmo Field in Montezuma County and in the Doe Canyon area in Dolores County, which is twelve miles to the west of Lone Mesa State Park. Doe Canyon carbon dioxide resources are undeveloped.

The Paradox Basin began forming during the Pennsylvanian Period approximately 300 million years ago. The basin is asymmetric in cross section, with the thickest sediments along the northeastern margin where it is bounded by the Uncompahgre Uplift. The southwestern edge was a stable shelf. The Hermosa Group was deposited during the main phase of the Paradox Basin development; it consists of three formations: the Pinkerton Trail, Paradox, and Honaker Trail. The primary oil and gas producing formation is the Middle Pennsylvanian Paradox Formation which consists of cyclic carbonates, clastics and evaporites that were deposited in response to sea level fluctuations caused by glacial cycles. Rasmussen and Rasmussen (2009) recognize 80 of these glacial cycles during the Pennsylvanian and Early Permian periods. During times of high sea level in interglacial cycles, the basin was connected to the open ocean on the northwest and southeast; normal marine conditions existed within the basin and algal mounds grew on the shallow southwestern shelf. When sea level was lower during glacial cycles, the basin's connection with the open ocean was restricted or severed and salt was deposited in the deep northeastern portion of the basin. During rising sea level, black shales were deposited across the basin in oxygen-poor environments (Grammer et al, 1996). As subsidence decreased, evaporite deposition ceased and clastic sediments shed off the Ancestral Uncompahgre Uplift filled the basin. These sandy sediments were interbedded with marine carbonates, shales, and siltstones farther south, forming the Honacker Trail Formation. As the basin continued to fill in the early Permian Period, the Cutler Formation was deposited as coarse-grained, alluvial fans in the northeast, grading to finer-grained fluvial sandstones and shales to the southwest, all shed from the eroding Ancenstral Uncompahgre Uplift. Sediment loading caused the buried salt to move, forming NW-SE trending anticlines. Salt movement began during the Pennsylvanian and continued through the Jurassic (Caiter and Craig, 1970).

Structurally, the basin can be divided into the stable shelf area of the southwestern portion of the basin (also called the Blanding Basin) and the salt anticline area in the northeast. Lone Mesa lies astride this boundary. In the Blanding Basin oil and associated gas is trapped stratigraphically in the porous algal mounds; there is very little structural relief. Papoose Canyon Field in southwestern Dolores County in the extreme northeastern extent of the Blanding Basin is an example of one of these fields. In contrast, the salt anticline area in the northeastern portion of the basin was too deep for algal mounds to form and is now structurally complex. Production is mainly in the form of natural gas trapped in anticlines or in beds on the flanks and are truncated and sealed by the salt anticlines.

In addition to the oil fields of the Blanding Basin and the gas fields of the salt anticline area, a shale gas play has developed during the last few years. Bill Barrett Corporation drilled a number of horizontal wells in the Gothic Shale, a black shale in the Paradox Formation that is found between the Lower Ismay and the Desert Creek zones (these are names given to deposits from individual cycles of the Paradox Formation)(Figure 3). Drilling has been confined to an area within Dolores and Montezuma counties to the west and southwest of Lone Mesa State Park where the Gothic Shale is unusually thick. Wellbores are drilled vertically down to just above the Gothic Shale and then are turned and drilled horizontally within the Gothic Shale nearly a mile to the north or south of the surface location.

In 2009 Dolores County produced 33,238 barrels of oil (BO) and 814,867 million cubic feet (MCF) gas from four fields. Most of this production is from Papoose Canyon Field (20 wells about 25 miles WSW of Lone Mesa State Park) in the extreme southwestern portion of the county, which produces from the Ismay and Desert Creek algal mound zones of the Paradox Formation. Stone Pony Field is a one-well field about 30 miles SW of the Park that produces from the Desert Creek zone of the Paradox Formation. Also, oil and gas was produced from an unnamed field about 16 miles SW of the Park in the new Gothic Shale play, which will be discussed in more detail later in this report. In addition to the oil and gas, carbon dioxide has been tested in the county but not produced from the Doe Canyon area about 13 miles west of the Park. Table 2 summarizes cumulative production from fields in Dolores County. Figure 7 shows the location and status of oil and gas wells in the vicinity of the Park.

Table 2. Cumulative Oil, Gas, and Carbon Dioxide Production in Dolores County, compiled from COGCC records.

Field	**Location**	**Status (MCF)**	**Disc.**	**Abd.**	**Producing Formation(s)**	**Cum. through 2009**	
						Oil (Barrels)	**Gas (MCF)**
Papoose Canyon	T38-39N R19-20W	Prod.	1967		Desert Creek & Ismay	6,649,535	39,453,937
Squaw Creek	T39N R20W	Abd.	1981	1986	Desert Creek	11,189	24,332
Stone Pony	T38N R20W	Prod.	1991		Ismay & Desert Creek	9,304	925,689
Lone Mesa	T40N R15W	Abd.	1981	?	Tested CO2 in Leadville		Not produced
Doe Canyon	T40N R17-18 W	?			Leadville CO2		Not produced
Unnamed (Bill Barrett Corp.)	T39N R17-18W	Prod.	2007		Gothic Shale	804	295,043

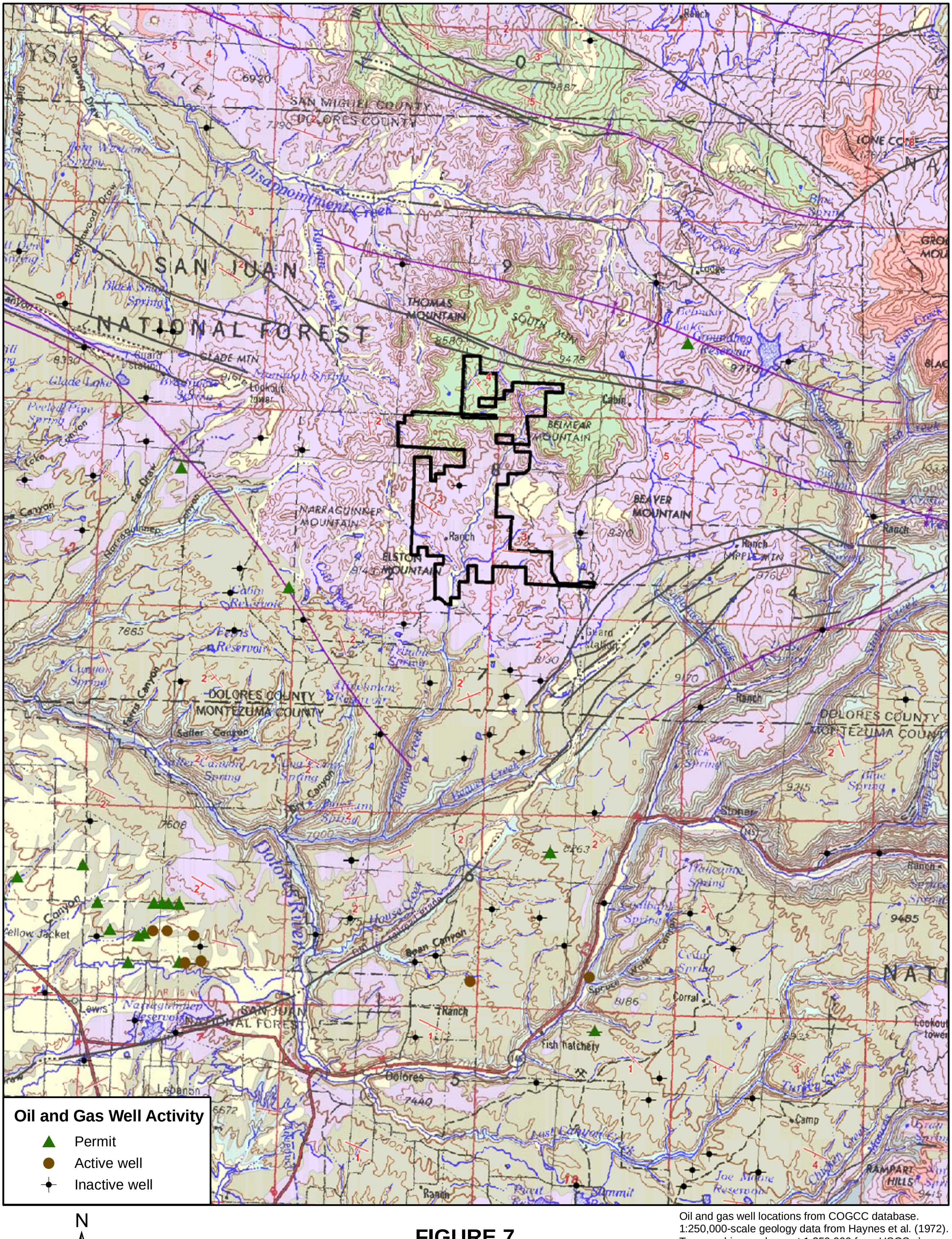


FIGURE 7
Oil and Gas Well Locations
Lone Mesa State Park
Natural Resources Assessment

Oil and gas well locations from COGCC database.
1:250,000-scale geology data from Haynes et al. (1972).
Topographic map base at 1:250,000 from USGS. \
Projection: UTM Zone 13, NAD 1983.

Potential for Oil and Gas Production in Lone Mesa State Park

III.2.1. Paradox Formation Oil Production from Algal Mounds

Lone Mesa State Park lies outside of the area with potential for oil and gas fields developed in the algal mound facies of the Paradox Formation; it overlies a portion of the Paradox Basin that was too deep under water for the algal mounds to develop.

Rating for potential hydrocarbon production from Paradox Formation algal mounds: 0.1—little or no potential. Algal mounds did not develop in this portion of the basin.

III.2.2. Honaker Trail and Cutler Production

In the salt anticline portion of the basin, gas has been produced from the Cutler and Honaker Trail formations and from clastics identified as belonging to the Hermosa Group where the formations cannot be differentiated. Several small fields occur around Lone Mesa State Park. The nearest gas fields are House Creek and Anasazi, each of which are one-well fields in Montezuma County about 12 miles south of the Park. House Creek Field was discovered in 1961 and produced 25,383 MCF gas from the Permian Cutler Formation before being abandoned in 1967. Anasazi Field was discovered in 1990 and produced 215 BO and 35,773 MCF gas from the Ismay zone of the Paradox Formation; it has been shut in since August, 1990.

Thirteen miles to the north of the Park in San Miguel County, Cocklebur Draw Field has produced 3,457,054 MCF gas from one well that was completed in the Pennsylvanian Hermosa Group. Two larger fields lie to the north. About 18 miles from the Park, Andy's Mesa Field has produced 115,834 BO and 120,653,429 MCF gas from the Cutler, Honaker Trail, and Paradox Formations. Twenty-two miles to the north of the Park, the Hamilton Creek Field has produced 16,761 BO and 50,393,544 MCF gas from the same formations.

Rating for potential hydrocarbon production from Honaker Trail and Cutler Formations: 2--Fair. The formations underlie the Park, but it is unknown whether a trap exists.

III.2.3. Gothic Shale Potential

Bill Barrett Corporation has conducted a very active drilling program since 2006 to test the Gothic Shale in Dolores and Montezuma Counties where the shale thickens considerably. Improved drilling and completion techniques allow extending horizontal laterals nearly a mile through the Gothic Shale. Because this activity is so recent, records are incomplete and it is difficult to determine the exact status of wells. However, the company has drilled several wells to the southwest, west, and northwest of the Park and is actively developing two of those areas.

Bill Barrett Corp. is actively developing an unnamed Gothic Shale field in Dolores County about 16 miles to the southwest of the Park in Township 39 North, Ranges 17 and 18 West that has produced 804 BO and 295,043 MCF gas since its discovery in 2007. Colorado Oil and Gas Conservation Commission (COGCC) records show that four wells with single laterals have been drilled with 18 additional laterals permitted. In Montezuma County Bill Barrett Corp. is developing a second area named Pedro Field in Township 38 North, Range 16 West about 13 miles southwest of the Park. It has produced 4,924 BO and 448,336 MCF gas from three wells since 2006. It appears that 14 more horizontal laterals are permitted. However, with the low natural gas prices of the last two years, it is uncertain whether these permitted wells will be drilled and, in fact, whether the Gothic Shale drilling program will continue.

In October, 2008, Bill Barrett Corp. drilled its Federal East Doe Canyon No. 1 in SW SE Sec. 9, T40 N, R16W, seven miles west of Lone Mesa State Park. COGCC records show it as a vertical hole with two laterals permitted. No production records exist and it is unknown if the either of the laterals was drilled.

In 2007 the Narraguinnep State #1 well was drilled about four miles southwest of Lone Mesa State Park in SE NE Sec. 36, T40N, R16W. It appears to be a Gothic Shale test drilled by Davis Petroleum. The well was shut in and subsequently taken over by Williams Production Company in 2009. A sundry notice was filed in August, 2009, to test the Gothic Shale to determine whether to perform a fracture treatment. There is no information to indicate whether the well was actually completed.

Another Gothic Shale test was drilled eleven miles northwest of the Park in 2006 by Bill Barrett Corp. in NE SE Sec. 22, T42N, R16W; it was plugged and abandoned in 2008.

Rating for potential hydrocarbon production from the Gothic Shale: 3--Moderate. The Gothic Shale is thick underlying the Park, but because the play is new, it is unknown what other elements are necessary for production.

III.2.4. Lone Mesa CO_2 Production Potential

Carbon dioxide occurs naturally in the Mississippian Leadville and Ouray Limestone formations (collectively known as the "Lone Mesa Unit") at depths of approximately 8275 to 8450 ft. The reservoir occurs in naturally fractured carbonates. Fault-related structural traps in conjunction with Pennsylvanian-aged salts of the Paradox formation provide the mechanism for trapping CO_2 in this area.

The only exploratory well drilled within the boundaries of the Park was completed in 1981 to a depth of 8700 ft. Initial CO_2 production levels were 11 MCF/day from the Leadville Formation and 8 MCF/day from the Ouray Formation (Colorado Oil and Gas Commission (COGCC) well database). Natural gas, however, was never produced commercially and the well was eventually plugged and abandoned in 1991.

CO_2 production from the Leadville and Ouray formations will be dependent on the market for CO_2. In 2008, Arkanova Acquisition Corp. (the current operator) acting through Gustavson Associates, LLC, expressed interest in an exploration program using two small pads within the park boundary to assess their mineral estate (Elder, 2008; COGCC, 2008). Any future CO_2 production scheme would likely involve construction of a 26 mile pipeline to tie into the primary Kinder Morgan Cortex pipeline. The current likelihood of commercial production from the Lone Mesa Unit is low due to CO_2 pricing and logistics of transport.

Rating for potential CO_2 production from Mississippian limestone formations: 5. Proven production but economics for commercial production are currently inadequate. During COGCC Hearing in 1983 it was estimated that the Lone Mesa Unit could produce a sustained 8 MCF/day flow for two years and then decline at a rate of 10% per year subsequently.

III.2.5. Lone Mesa CO_2 Sequestration Potential

CO_2 sequestration or storage is also a possible resource. Over-pressuring the reservoir could be a limiting factor at present however. Alternatively, CO_2 could first be produced and then CO_2 later injected into the depleted reservoir. Reservoir properties would need to be well characterized before any injection scenario was implemented. The same structural trapping mechanisms and overlying impermeable salts would provide the reservoir seal for CO_2 capture.

Rating for potential CO_2 storage in Mississippian limestone formations: 3. While there will be some capacity for CO_2 injection and storage currently, the reservoir is not likely to be near depletion, and consequently is not an ideal gas repository.

III.2.6. Regulatory Environment for Oil, Gas, and CO_2 Production

Subsurface extraction activities are subject to COGCC rules as prescribed by the Oil and Gas Conservation Act of Colorado. While the Colorado State Parks (CSP) has no special standing with regards to the permitting process and cannot unreasonably interfere with the rights of the mineral owner, there are specific COGCC regulations in place that provide surface owners with an avenue for input:

Rule 305 – Notice, Comment, and Approval

Notice of intent must be given to the surface owner 30 days prior to commencement of any operations of heavy equipment for drilling a well. A comment period of 20 days is mandated that allows the surface owner, public, local government designee (LGD) to provide input regarding the location of proposed drilling activities. These comments will be posted on the COGCC website. The LGD may request that the comment period be extended to 30 days or that the Colorado Department of Health and Environment comment on the application. Upon completion of the comment period, the COGCC director "may attach technically feasible and economically practicable conditions of approval . . . as the Director deems necessary to implement the provisions of the Act or these rules pursuant to Commission staff analysis or to respond to legitimate concerns expressed during the comment period." Regarding arguments that the imposed conditions are not technically feasible or economic, the burden of proof lies with the applicant. There is also an opportunity for a "party of standing", which includes the surface owner, the LGD and the operator, to object to the Director's issuance of an approval decision within 10 days. This objection will set the basis for a hearing to be held on an expedited schedule. A decision from this adjudicatory hearing will be the final one by COGCC subject to judicial appeal.

Rule 306 – Consultation

The operator must make a good faith effort to have consultation with the surface owner for locating roads, production facilities, well sites, and to discuss all reclamation or abandonment activities. Impacts regarding locations of new roads or other facilities with respect to Lone Mesa State Park development plans would be a key topic for consultation. Habitat disturbance and fragmentation might also be critical areas for discussion, as would be any activities that might affect visitor experience in the Park. The operator is required to furnish a description or diagram of the proposed drilling location and other relevant aspects of the proposed activity. In addition to the surface owner, consultations are required with the local government (or designee), CDOW, and in some cases CDPHE. A large portion of Lone Mesa is in sensitive wildlife habitat and the Colorado Division of Wildlife should provide valuable input to the operator. Consultations must occur prior to commencement of operations with heavy equipment and within

40 days concurrent with the start of the public comment period. As a result of consultation, CDOW may make written recommendations to COGCC on "conditions of approval necessary to minimize adverse impacts to wildlife resources." Further, CDOW may submit recommendations regarding the conditions and acceptability of variance requests.

Drilling permits cannot be denied under most circumstances by COGCC. Safety issues, however, can cause delays or a denial of permit. CSP can assume the support of other state agencies, especially with regards to Rule 306, the requirement for meaningful consultation. To prepare for consultations, it would be prudent to ensure a comprehensive wildlife management plan (WMP) is in place for Lone Mesa State Park. The WMP should be designed in collaboration of with CDOW and any potential operators when feasible. If the lands are not leased then CDOW would need to work with the mineral owner instead on this plan. Also, should oil and gas development become more imminent in the future, a reasonable spacing for production wells should be discussed and established for areas inside the Park.

III.2.7. Regulatory Regime for CO_2 Injection

As Colorado law currently stands, the surface owner (i.e. CSP) has control over any injection activities into the subsurface. Regulation of pore space, however, is still unclear, as are rules governing liability and ownership of injected CO_2 for storage activities. Until laws governing CO_2 sequestration have been more thoroughly addressed in Colorado it is difficult to speculate on what control CSP may have over injection activities beneath Lone Mesa State Park, especially if the point of injection lies outside Park boundaries.

III.3. Coal

Occurrence

Coal resources in the area are found within the Upper Cretaceous Dakota Sandstone and the Menefee Formation of the Mesaverde Group. The Lone Mesa State Park area lies within the Nucla-Naturita coal field and just north of the San Juan Basin coal field. While coal mining has taken place in the general area, no mines are known within the area of the Park. Several small mining operations were active in the late 1800s and early 1900s, with a total production for Dolores County estimated at 74,481 tons (Borek and Murray, 1979).

The most likely source of coal in and around the Lone Mesa State Park is the Dakota Sandstone. Rocks of the Mesaverde Group occur in only a few isolated locations in the area of the Park and no coal is known in the basal section of the Mesaverde. Eakins (1986) documents all the known drilling in the Dakota Sandstone. Three drillholes are listed in the Willow Springs 7.5-minute quadrangle, within section 35, T 4 North, Range 15 West, either within or at the very edge of the extreme southwest corner of the Park property (center of the SE ¼, section 35). These drillholes, emplaced by the U.S. Bureau of Reclamation, found 0.9 feet of coal within 25 feet of the surface. Although coal is known to exist in the vicinity, and probably occurs within the Park; it is not likely to be present in economic quantities. The coal bed is too thin to support a commercial coal mining operation.

Potential

Even though it is non-economic, because a coal occurrence is confirmed, the potential is rated as a **2 –** Fair.

Regulatory Regime

Coal development is regulated in Colorado by the Division of Reclamation, Mining and Safety, operating under the direction of the Mined Land Reclamation Board. All applications for coal exploration and coal development are submitted to this agency, whose regulatory framework is based on the Colorado Surface Coal Mining Reclamation Act, Title 34 Mineral Resources, Article 33. A key section of the Act bears directly on the Lone Mesa State Park and the potential for coal development therein. In section 2.07.6 of the Rules, as a condition of permit approval or denial, "the proposed operations will not adversely affect any publicly owned park or place listed on or those places eligible for listing, as determined by the SHPO (State Historic Preservation Office, http://www.coloradohistory-oahp.org/), on the National Register of Historic Places, unless approved jointly by the Board and the Federal, State or local agency with jurisdiction over the park or place" (Rule 2.07.6(2)(e)(i). In other words, specific approval by the head of State Parks would be required to permit a mine in (or probably even near) the Park. This would effectively nullify the possibility of coal development at Lone Mesa State Park.

III.4. Metallic Minerals

History

Currently no metal mining is occurring near the Lone Mesa State Park. Resources such as uranium, silver, gold, copper, lead, and zinc have been mined in the past but the mining has taken place at least ten miles from the Park.

The **Uravan Mineral** Belt is a narrow zone of mineralization adjacent to the Dolores River Valley from Gateway in Montrose County to Egnar in San Miguel County (Figure 2). Mineralization occurs in a similar geologic setting as far south as the town of Dove Creek. Near Dove Creek, approximately 16 miles northwest of the Lone Mesa State Park, several mines produced uranium and vanadium as recently as 1971 (Nelson-Moore, et al, 1976). The Arrowhead, the Broken Thumb, and the Rainy Day Mines lie along the Dolores River northeast of Dove Creek. All three mines produced from the lower zone of the Jurassic Morrison Formation. The Morrison Formation, host of most of the uranium and vanadium deposits in southwest Colorado, occurs at depth beneath the Lone Mesa State Park. However, no mineralization has been identified closer than the mines near Dove Creek.

The **Rico District,** approximately 20 miles east of the Lone Mesa State Park, was a significant mining area, producing gold, silver, lead, zinc, copper and other commodities into the 1980s. The mineral deposits occur in veins in which they were deposited by circulating waters probably associated with intrusive igneous activity (Vanderwilt, 1947).

Similar deposits occur in the **La Plata District**, some 22 miles southeast of the Lone Mesa State Park. Gold, silver, copper, lead and zinc were mined in the La Plata District mostly prior to World War II (Vanderwilt, 1947).

One mine produced near the Lone Cone, giving rise to the **Lone Cone District**. According to Vanderwilt (1947), the mine produced gold, silver and lead until 1944. No details are available on the nature of the deposit that yielded the minerals, although the Lone Cone is mapped as a Tertiary-age igneous intrusion (Haynes, et al, 1972.)

Occurrence

No metallic minerals have been mined in the vicinity of the Lone Mesa State Park. Resources such as uranium, silver, gold, copper, lead and zinc have been mined in the region in the past, but the mines were far removed from the Park. The most favorable geologic environment for metallic minerals in the Lone Mesa State Park area is the Morrison Formation. This sedimentary formation is host to uranium – vanadium deposits in the Uravan Mineral Belt which extends into Dolores County northwest of the Park. The nearest documented uranium mining took place approximately twenty miles northwest of Lone Mesa State Park (Nelson-Moore, et al, 1978). Morrison Formation rocks occur beneath the Park, but there has been no indication of mineralization in the immediate vicinity. Mining claims have been staked with the Bureau of Land Management (BLM) in areas around the Park (Figure 8). The claims nearest the park are old claims which have been closed. While BLM records generally do not specify the commodity for which a claim was staked, it appears that these claims were staked where the Morrison Formation is on or near the surface, so were probably staked for uranium. The nearest open or active claim lies more than six miles from the Park.

The intrusive igneous rocks that underlie the knobs and ridges in the Park south of the Lone Mesa, could well be related to the Tertiary intrusions that occur in the Lone Cone, LaPlata, and Rico Districts to which the mineral deposits in those areas are attributed. There have been no traces of mineralization reported in the Park or closer than Lone Cone. While some mineralization may occur associated with those igneous rocks in the Park, it appears that the processes that led to the formation of ore deposits at those are locations were not active in the park area.

Potential

Rating is **1 – Poor.** The park contains permissive rock types that could host uranium deposits, but no occurrences are known within five miles.

III.5. Industrial Minerals and Construction Materials

Occurrence

The category of industrial minerals includes a wide variety of commodities, including limestone, mica, phosphate, clay, and others. Of these, only sand, gravel, and crushed stone are likely to be found within the Park. This commodity is widely used for roads and in the building industry. In any given location, the probability for extraction of sand, gravel and crushed stone depends upon the quality of the resource and the proximity of markets.

One quarry is permitted just at the edge of the Park, utilizing Dakota Sandstone mainly as road base. A reconnaissance survey of the remainder of the Park indicates that there are no promising gravel deposits. Commonly occurring as alluvial deposits in stream bottoms, valuable deposits generally require hard,

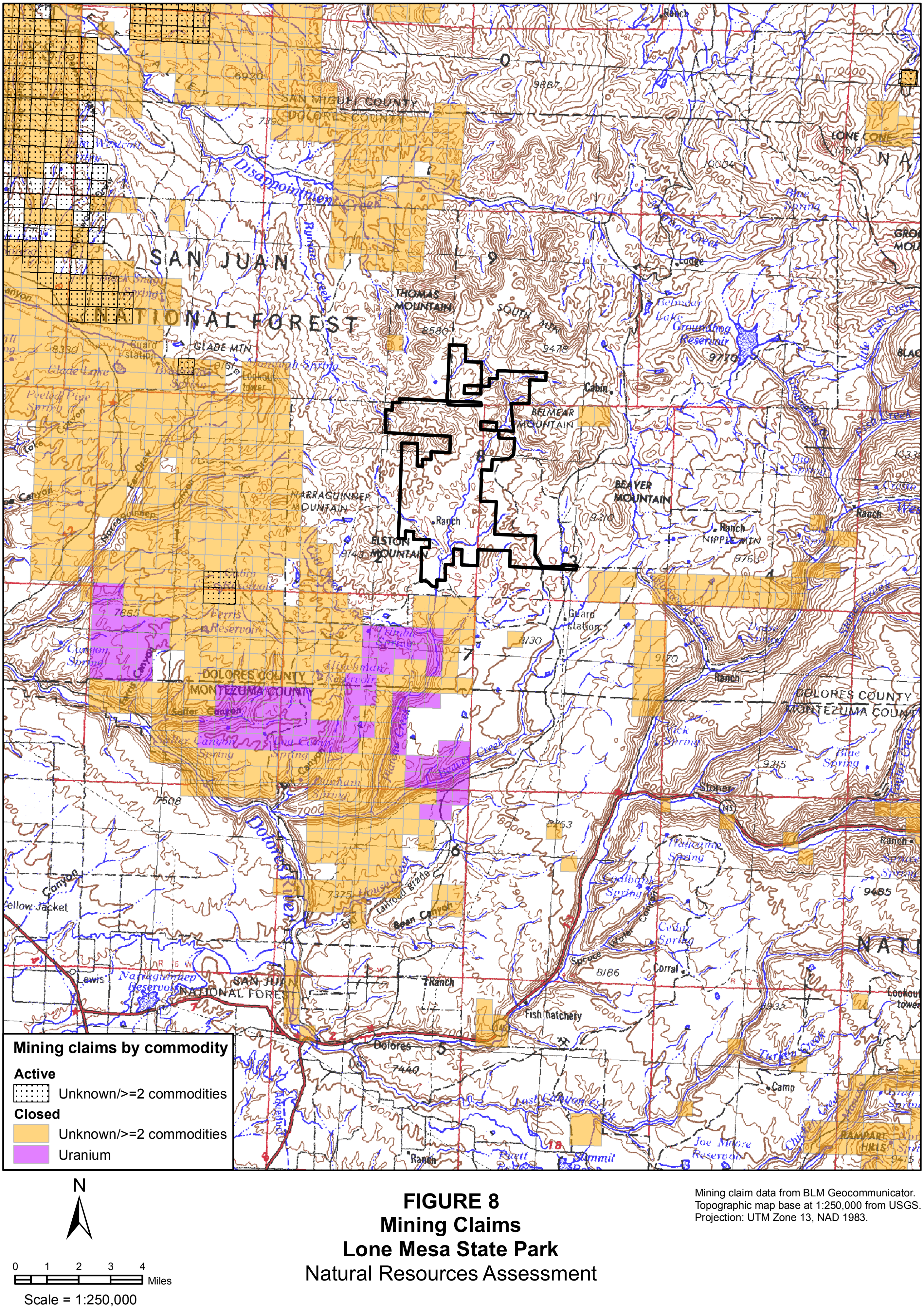


FIGURE 8
Mining Claims
Lone Mesa State Park
Natural Resources Assessment

Mining claim data from BLM Geocommunicator.
Topographic map base at 1:250,000 from USGS.
Projection: UTM Zone 13, NAD 1983.

durable gravel as a high proportion of the alluvial fill. Alluvial deposits in the Park consist mainly of fine, reworked Mancos shale with sporadic cobbles and boulders of the igneous rocks that underlie the hills and ridges precluding its usability and value.

The Paradox Formation, estimated to lie 5000 feet below the surface at the Park, is known to contain potash deposits in some places. Potash, a valuable fertilizer, is obtained from evaporite deposits– beds of minerals deposited in restricted basins as the water evaporates. Potash is extracted from the mineral sylvite – potassium chloride – which commonly accompanies halite (table salt), gypsum (calcium sulfate) and other materials in these evaporite deposits. While the deposits are deep, they can be extracted through solution mining – pumping hot water into the formation at depth, dissolving the minerals, and pumping them back to the surface. Several companies either mine or are developing solution mines in Utah and exploration is occurring in Colorado, west of the Park.

Potential

The one identified resource is the Dakota Sandstone, which occurs throughout the Park. It lies near the surface on the south of the property, with its depth increasing down-dip to the north. The presence of this unit requires that the mineral potential be classified as **4 – Good.** ." The potential for potash is considered "Fair," as the Paradox Formation is known to occur beneath the park but no information is available on the potential for sylvite occurrence.

Regulatory Regime

Mineral development is regulated in Colorado by the Division of Reclamation, Mining and Safety, operating under the direction of the Mined Land Reclamation Board. All applications for mineral exploration and development are submitted to this agency, whose regulatory framework is based on the Colorado Surface Coal Mining Reclamation Act, Title 34 Mineral Resources, Article 32. Depending upon certain conditions in 34-32-115 (f), permitting a mine or quarry within a state park would be difficult without concurrence from the Colorado Department of Natural Resources.

III.6. Water Resources

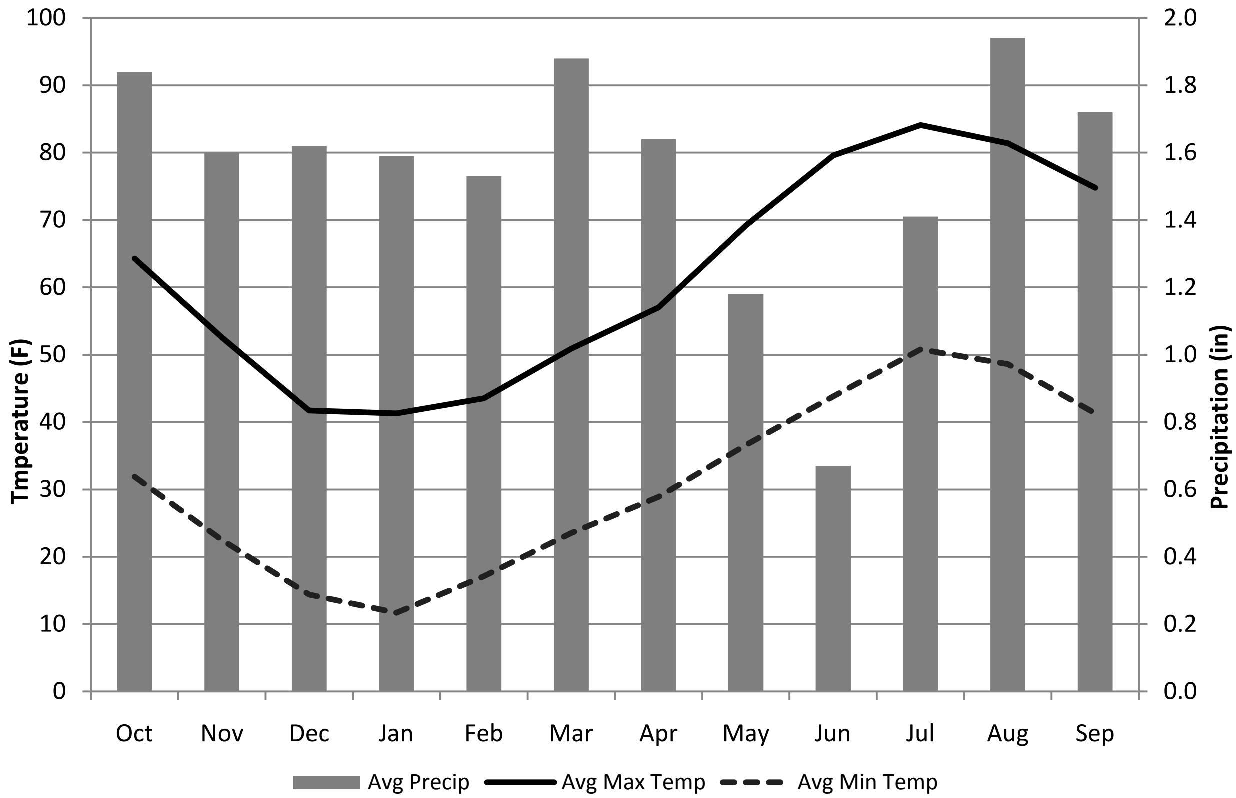
Physiographic Setting

Elevations in the Park range from approximately 7,500 feet in the southern portion of the Park along Plateau Creek to its highest point above 9,200 feet on top of Lone Mesa. The climate is characterized as transitional between high desert and mountainous climates with warm to hot summers and cool to cold winters. Temperatures in the town of Dolores (measured at the Dolores Station [052326] located 14 miles to the south) range from average daily maximum temperatures above 80 degrees Fahrenheit in July and August to average daily maximum temperatures of 41 degrees Fahrenheit in December and January (Western Regional Climate Center, 2010)(Table 3, Figure 9). Annual precipitation in the Park ranges between 18 and 20 inches in the south and between 24 and 26 inches in the north at higher elevations (NRCS/USDA, 2000). From data recorded at the Dolores climate station, precipitation is relatively evenly distributed throughout the year with monthly totals averaging 1.5 to 2 inches from August through April; May and July have precipitation totals averaging 1.1 to 1.4 inches while June is the driest month averaging less than 0.7 inches. Precipitation occurs primarily as snowfall during the period of December through March and as rain during the remainder of the year (Table 3, Figure 9).Table 3: Monthly Climate Summary (1908-2004), Dolores Station (52326)

	MONTH												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Average Max. Temp. (F)	64.3	52.6	41.7	41.3	43.5	50.9	57	69.2	79.6	84.1	81.4	74.8	61.7
Average Min. Temp. (F)	31.9	22.5	14.4	11.7	17.1	23.5	28.9	36.6	43.8	50.8	48.6	41.3	30.9
Average Total Precip. (in.)	1.84	1.6	1.62	1.59	1.53	1.88	1.64	1.18	0.67	1.41	1.94	1.72	18.62
Average Total Snowfall (in.)	1.5	7.2	11.9	15.4	13.2	10.6	4.6	0.8	0	0	0	0	65.2
Average Snow Dep. (in.)	0	1	4	8	7	3	0	0	0	0	0	0	2

Data from Western Regional Climate Center

Figure 9. Historical Climate (1908-2004), Dolores Station (52326)



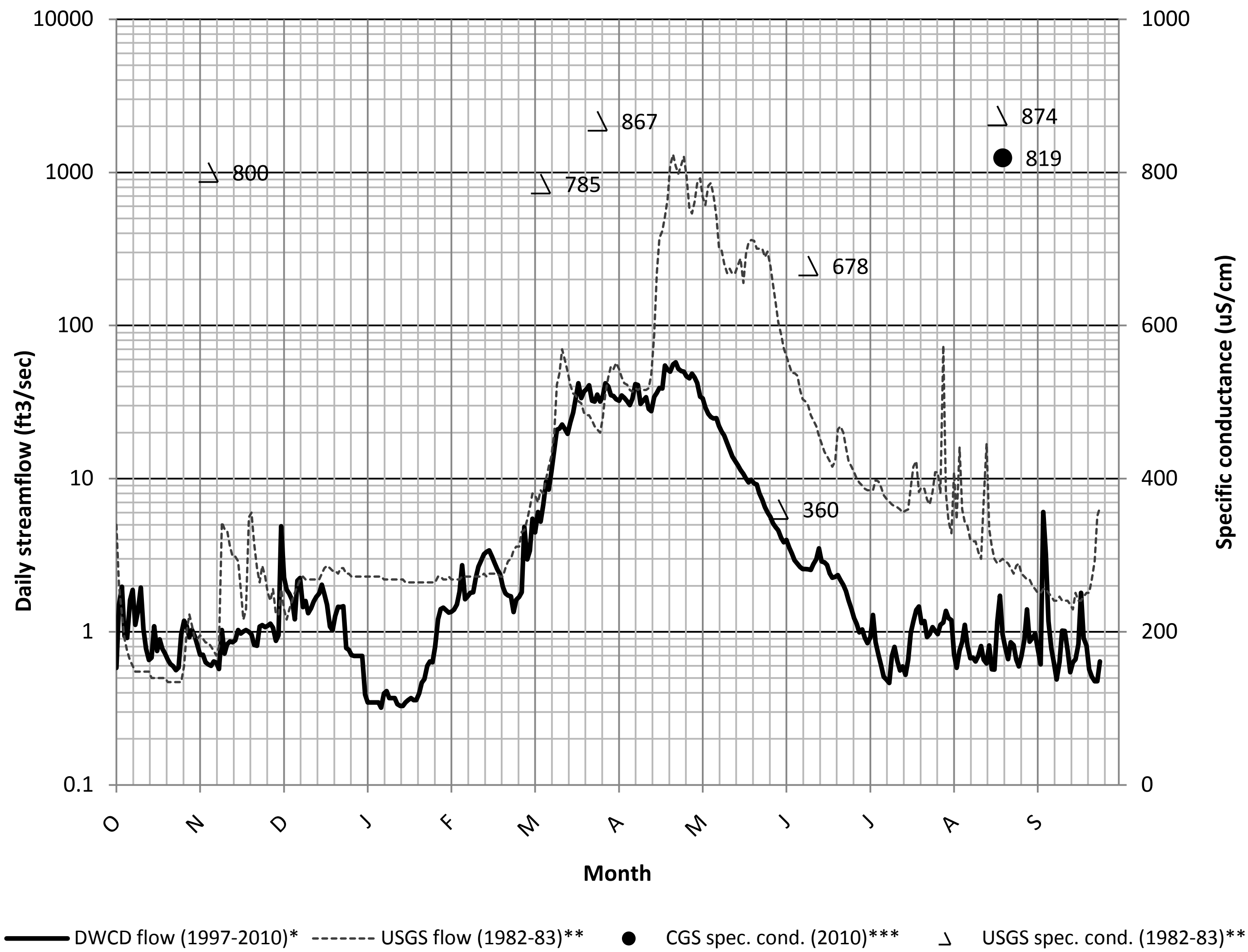
III.6.1. Surface water resources

Plateau Creek is the primary surface water drainage in the Park, originating on top of Lone Mesa and flowing in a general southeasterly direction exiting the Park at its southernmost point (Figure 1). Plateau Creek streamflow records between 1997 and 2010 from the Dolores Water Conservancy District (DWCD) indicate a flow regime characterized by spring snowmelt runoff between March and June and typically peaking in April with average daily flows of approximately 60 cubic feet per second (cfs). Flows decline through the months of May and June and reach low flow conditions in July, with baseflow likely sustained by groundwater draining out of rocks that received snowmelt recharge during the spring (Figure 10). Late Summer, Fall, and Winter streamflows are generally minimal with baseflows on average between 0.5 and 0.7 cfs from July to November with short-duration higher flows occurring in response to rainfall storm events. Streamflow gage records from the US Geological Survey (USGS) during the period of October 1982 through September 1983 at a location on Plateau Creek approximately six miles downstream of the Park and the Dolores Water Conservancy District gage, show a similar flow regime with high flows peaking in April in response to spring snowmelt runoff with sustained baseflow conditions during the summer and fall months (USGS, 2010). Summer Camp Creek is the only named tributary to Plateau Creek in the Park; however, it does not consistently flow through the summer months and is classified on the USGS 7.5-minute quadrangle topographic map as an intermittent stream, likely only carrying water seasonally and in response to storm events.

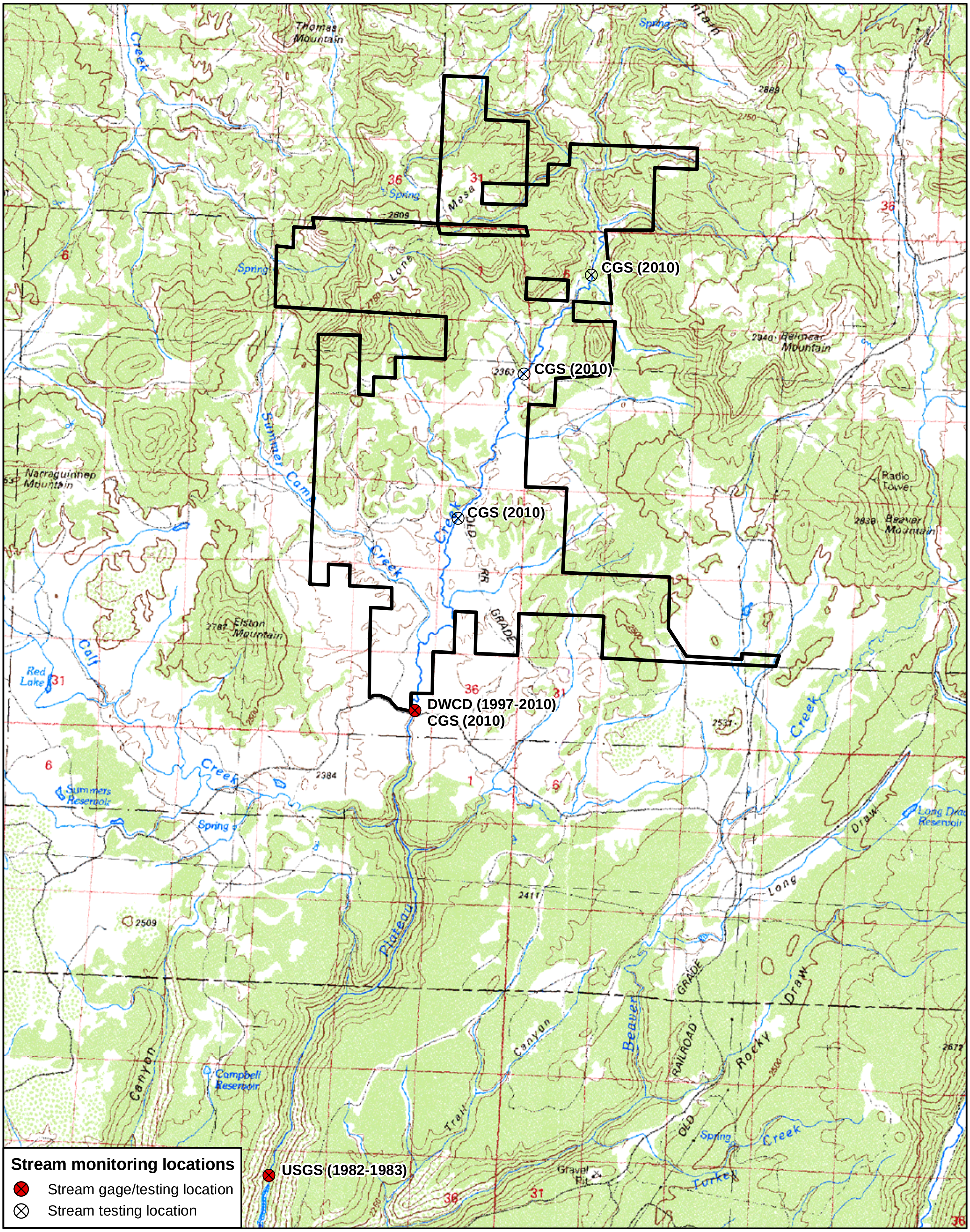
In late August 2010, the Colorado Geological Survey (CGS) performed some limited field reconnaissance and testing of the basic water quality in Plateau Creek at the Park. At that time, CGS measured the water quality parameters of specific conductance, pH, and temperature at four locations along Plateau Creek (Figure 11) using field testing equipment. Specific conductance measurements in Plateau Creek were between 782 and 846 microSiemens per centimeter (µS/cm), pH values ranged from 8.15 to 8.37, and temperature measurements were between 66 and 80 degrees Fahrenheit (19-27 degrees Celcius). USGS field testing further downstream in Plateau Creek (Figure 11) in 1982 and 1983 reflected similar water characteristics for specific conductance (785-874 µS/cm) during the Fall, Winter, and Summer under baseflow conditions. In late Spring 1983 on the "falling limb" of the streamflow hydrograph, water in Plateau Creek had considerably lower specific conductivities (360-678 µS/cm) probably reflective of the chemistry of fresher snowmelt runoff (Figure 10).

Although stream flows in Plateau Creek were not directly measured by CGS in August 2010, a substantial decrease in flow was evident in the downstream direction suggesting that it was a "losing" reach within the Park at that time. Flows in Plateau Creek on August 25, 2010 were estimated to be approximately 15 gallons per minute (gpm) (~0.03 cfs) at the most upstream observation point and decreased to approximately 1 gpm (~0.002 cfs) at the most downstream observation point (Figure 11). A "losing" reach suggests that water in the stream is infiltrating into the ground or is evaporating at a faster rate than incoming flow contributions from springs or tributaries. It also indicates that static groundwater levels adjacent to the stream are below the stream surface and may be altogether disconnected from the stream.

Figure 10. Plateau Creek Streamflow Below Lone Mesa State Park



*DWCD data is average daily streamflow for 1997-2010 at gage located directly below Lone Mesa State Park (LMSP).
**USGS data is from measurements during Oct 1982- Sept 1983 at gage located ~6 miles downstream of DWCD gage.
***CGS data is average of 4 conductivity measurements (782-846 uS/cm) taken on August 25, 2010 within LMSP.



Topographic map base at 1:100,000 from USGS.
Projection: UTM Zone 13, NAD 1983.

N

0 1 2 Miles

Scale = 1:100,000

FIGURE 11
Stream Monitoring Locations
Lone Mesa State Park
Natural Resources Assessment

III.6.2. Groundwater - Overview of Hydrogeology in the Lone Mesa State Park Vicinity

Geologic mapping by Haynes et al. (1972) and a hydrogeologic investigation by Weir et al. (1983) were used as the foundation for understanding the geology and occurrence of groundwater in the area around Lone Mesa State Park. Additional hydrogeologic data was derived from water well permit records maintained by Colorado Division of Water Resources (DWR) and from oil and gas well data available from the COGCC.

Rocks of the lower section of the Mesaverde Group and Mancos Shale exist at the surface within the Park. The Dakota Sandstone and Burro Canyon Formation, Brushy Basin and Salt Wash members of the Morrison Formation, and rocks of the Junction Creek Sandstone and Entrada Sandstone exist below the Mancos. It is these lower Cretaceous and Jurassic-aged rocks (Dakota and Burro Canyon sandstones, Salt Wash Member of the Morrison Formation, and Junction Creek and Entrada sandstones) that are the primary potential sources for potable groundwater beneath the Park. The physical hydrologic characteristics, geochemistry, relatively shallow depth, and hydrostratigraphic positioning of these rock units make them potential aquifers within the Park, worthy of consideration for groundwater development. Underlying these units is a sequence of impermeable fine-grained mudstone, siltstone, and shale layers of the Dolores Formation. Because of their physical hydrologic properties, water quality, and depth, layers of the Dolores Formation and below are not considered viable sources for drinking water in the area (Weir et al., 1983; Table 4).

CGS reviewed water well permit records for wells in the vicinity of Lone Mesa State Park to characterize groundwater production. To quantify production by hydrogeologic unit, a select number of wells near the Park were classified according to the hydrogeologic unit in which they were constructed. The hydrogeologic unit was identified based on the well location relative to mapped geology, well depth, construction details, and drillers' lithologic logs. Well specific capacities were calculated from available pumping test data to quantify and compare well yields. Specific capacity is a measure of the well yield in terms of discharge (pumping) rate per unit of drawdown in the water level inside the well. In this study, specific capacity is measured in terms of gallons per minute (gpm) per foot of water level drawdown per hour of pumping (gpm/ft/hr). For example, a specific capacity value of 1 means that for every gpm of pumping the water level in the well will drop 1 foot every hour; a specific capacity value of 10 means that for every 10 gpm of pumping the water level in the well will drop 1 foot every hour. Higher specific capacities typically mean that an aquifer is capable of transmitting water into the well more readily and generally equates with more permeable aquifers and higher overall water yields. Using instantaneous pumping rate value as a basis for comparing well and aquifer properties can be deceiving because it gives little indication whether the pumping rate is sustainable over time. The locations of wells in close proximity to the Park, and which were evaluated for production, are shown on Figure 12, symbolized according to specific capacity and hydrogeologic unit in which they are constructed.

III.6.2.1. Quaternary deposits

The extent of young Quaternary unconsolidated deposits is limited primarily to alluvium mapped along Plateau Creek within the Park although isolated colluvial and eolian deposits are also present. The eolian and colluvial deposits generally occur on slopes where it is drained of water and consist of poorly sorted material, giving it a lower permeability. Consequently, these units are unlikely to contain much developable groundwater. The thickness of the alluvium along Plateau Creek is unknown; however, the mapped extent is limited. During field reconnaissance, it was noted that Plateau Creek has a stream channel cut into bedrock in several locations within the Park and stream underflow is probably low. Any groundwater present within the alluvium will likely exhibit similar seasonal hydrologic fluctuations as Plateau Creek surface flows (Figure 10).

Wells constructed in the Quaternary deposits in the Park vicinity are shallow and generally located in the alluvium along waterways. Three alluvial wells are located along the Dolores River to the south and east of the Park and two are north and west of the Park along tributaries to Disappointment Creek. Wells in the Quaternary deposits have reported discharge rates of between 1 and 20 gpm. In total, the five alluvial wells in the area have estimated specific capacities ranging from 0.06 to 20 gpm/ft/hr with an average of 5.02 gpm/ft/hr and median of 1.17 gpm/ft/hr (Table 4). However, the mapped geology shows that these wells are located along waterways with more extensive alluvium and with more perennial flows. (Figure 12). Given that baseflow in Plateau Creek is low and the extent of alluvium along the creek is limited, Quaternary deposits within the Park are not considered a viable water supply for development.

III.6.2.2. Mesaverde Group

Lone Mesa and other smaller mesas present in and around the Park are capped by resistant rocks of the Point Lookout Sandstone member of the Mesaverde Group (Lecke et al., 1997). Over time these more competent sandstone caps have resisted erosion and protected the underlying and highly erodible Mancos Shale leaving towering cliffs of Point Lookout Sandstone above more gentle topography of the Mancos Shale below. Mesaverde Group sandstone layers may have porosities and permeabilities capable of storing and transmitting water. However, only the lower section of the Mesaverde Group is present in the Park and it is present only on isolated mesa tops within the Park. Consequently, the Mesaverde Group is unlikely to provide a sustainable groundwater resource suitable for development within the Park. Furthermore, although very little data for wells or springs in the Mesaverde Group in the vicinity of the Park are available, the water quality indicators for a single spring in the area (Weir et al., 1983) suggest that groundwater in the Mesaverde Group may exceed the National Secondary Drinking Water Standards recommended Maximum Contaminant Level (MCL) for total dissolved solids (TDS) and sulfate, potentially making it unsuitable for use as a potable water supply (Table 5). Secondary MCLs are aesthetic water quality standards and are not enforceable limits; water exceeding secondary MCLs could be used as a drinking water source if access to groundwater of better quality is not available.

The only available well production data in the area for the Mesaverde Group is from a well located approximately 13 miles northwest of the Park. This well had a reported pumping rate of 20 gpm with a specific capacity of 1.91 gpm/ft/hr (Table 4). However, despite the existence of permeable rocks of the Mesaverde Group at higher elevations in the Park on the top of Lone Mesa, as previously discussed these rocks are relatively hydrologically isolated and unlikely to support a sustainable water supply.

III.6.2.3. Mancos Shale

Most of the surface of the Park is composed of Mancos Shale, a thick (2,000-3,000 feet) marine shale sequence of low permeability containing few sandy layers and other zones of higher permeability. The Juana Lopez Member, located approximately 500 feet above the underlying Dakota Sandstone, is a sandy fossiliferous limestone or calcarenite zone known to have higher permeability and yield water (Weir et al., 1983; Lecke et al., 1997). Groundwater may flow through more permeable sandy layers and through fractured zones within the Mancos Shale, but the Mancos Shale typically serves as a confining unit to the underlying Dakota Sandstone with very little capability to transmit water. Because of its large areal coverage in and around the Park, the Mancos Shale likely receives a considerable fraction of the direct groundwater recharge from precipitation falling on the Park. However, wells and springs in the Mancos Shale commonly have high concentrations of dissolved solids above the recommended drinking water standards. Springs in the Mancos Shale within the Park exhibit lower specific conductance values than the average for springs and wells reported in Weir et al. (1983), but are still high relative to drinking water MCLs (Table 5).

The average depth of 18 nearby wells in the Mancos Shale, located mainly to the north and east of the Park (Figure 12), is 266 feet with depths ranging from 102 to 902 feet. The reported pumping rates for wells in the Mancos Shale range from 0 to 15 gpm. These wells have specific capacities ranging from 0 to 2.89 gpm/ft/hr with average and median specific capacities of 0.23 and 0.03 gpm/ft/hr, respectively (Table 4). Of the 18 wells evaluated in the Mancos Shale, 4 were dry at the time of drilling, including a dry well drilled to 267 feet located about three miles west of the Park and a dry well drilled to 902 feet about 6 miles northeast of the Park. Overall, the specific capacity of wells in the Mancos Shale is low and production from these wells tends to be minimal. Water production from wells in the Mancos Shale is highly variable and groundwater availability in the Mancos Shale can be localized with little predictability in water production (Figure 12).

III.6.2.4. Dakota Sandstone and Burro Canyon Formation

The Dakota Sandstone is primarily a sandstone and conglomerate unit which directly underlies the Mancos Shale and is at relatively shallow depth in areas of the Park. Throughout much of the vicinity, Dakota Sandstone and Burro Canyon Formation are mapped together as a single sandstone and conglomerate unit with some interbedded mudstones and shales (Haynes et al., 1972). In this study, the Dakota Sandstone and the Burro Canyon Formation are evaluated as a single water-bearing unit called the Dakota/Burro Canyon aquifer. The Dakota/Burro Canyon aquifer is a potential source for groundwater of suitable quantity and quality for use as a potable water supply in the Park. The combined thickness of the Dakota/Burro Canyon aquifer is estimated to be 100 feet in the area based on the geologic mapping and description in Haynes et al. (1972). Springs discharging from the Dakota Sandstone 5 to 15 miles to the west and northwest of the Park had measured flow rates ranging from 0.1 to 5 gpm between 1978 and 1980 (Weir et al., 1983). These springs are located at elevations between 7,900 and 8,250 feet and exhibited low specific conductance at the time they were measured, indicative of low dissolved solids concentrations (Table 5). Only one well in the Dakota Sandstone had much higher TDS and other basic water quality parameters, but its proximity to the Park and other construction details are not known.

Many of the wells located near the Park tap the Dakota Sandstone or Burro Canyon Formations. Records for 7 wells in the Dakota/Burro Canyon aquifer show a depth range of 80 to 1,196 feet and pumping rates between 5 and 20 gpm. These wells have a wide and heavily skewed range of specific capacities between 0.06 and 9 gpm/ft/hr with an average specific capacity of 1.5 gpm/ft/hr and median of 0.28 gpm/ft/hr (Table 4). Wells in the Dakota/Burro Canyon aquifer have an average hourly specific capacity over six times higher than calculated for wells in the Mancos Shale. Additionally, measured flow rates from nine nearby springs in the Dakota/Burro Canyon aquifer illustrate an even greater contrast with the hydrology of the Mancos Shale. Weir et al. (1983) reported Dakota/Burro Canyon spring flow rates of between 0.1 and 10 gpm with an average of 2.1 gpm. These spring flows represent groundwater discharge without any drawdown; if springs are assumed to be shallow or zero-depth wells and a minimal drawdown of 1 foot and test duration of 1 hour are assumed for spring flows, the corresponding estimated specific capacities are on average 2.1 gpm/ft/hr with a median of 0.5 gpm/ft/hr. When springs and wells are statistically grouped together, the overall estimated specific capacity for the Dakota/Burro Canyon aquifer averages 1.84 gpm/ft/hr and the median is 0.45 gpm/ft/hr (Table 4), roughly 8 to 15 times that for the Mancos Shale. Considering its generally good water quality and hydraulic properties in the Park vicinity, the Dakota/Burro Canyon aquifer should be considered a potential resource for potable groundwater development in the Park.

III.6.2.5. Morrison Formation

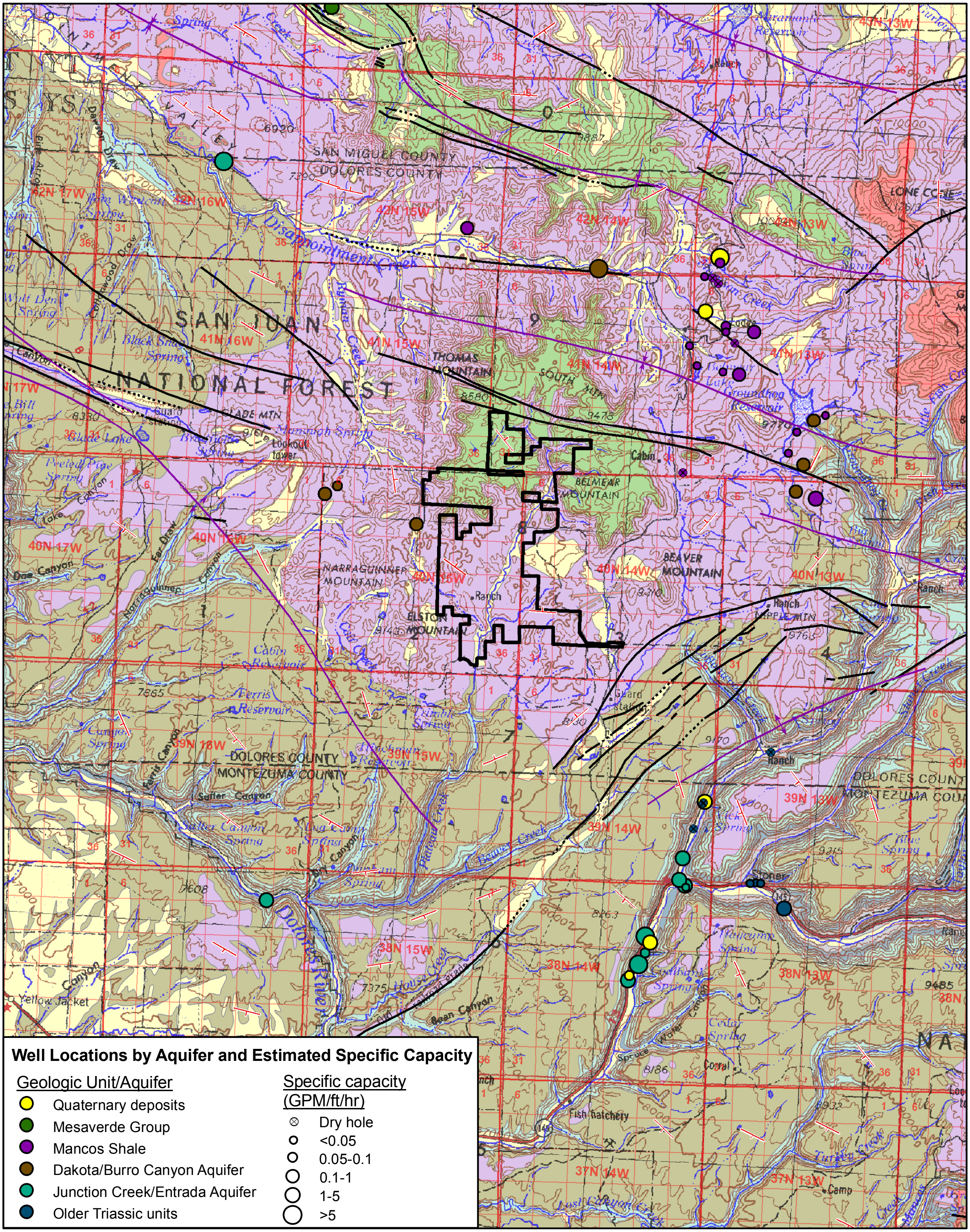
The Morrison Formation consists of the Brushy Basin and Salt Wash members in the vicinity of the Park and is between 400 and 800 feet thick based on oil and gas well logs. The Brushy Basin Member is a bentonitic mudstone unit with very limited water-bearing capacity while the underlying Salt Wash Member is composed of thick discontinuous beds of fine- to medium-grained sandstone with some interbedded mudstones (Haynes et al., 1972). The Salt Wash Member does yield groundwater (Weir et al., 1983) and reported water quality testing suggests that groundwater in the Salt Wash Member may be suitable for use as a drinking water supply (Table 5). Water quality data reported in Weir et al. (1983) from one well in the Salt Wash Member indicates that the TDS, chloride, and sulfate parameters are all within the recommended MCLs for drinking water. Water testing results from two wells in the Brushy Basin Member show dissolved solids concentrations well above recommended drinking water standards for both TDS and sulfate. There are no available well production data for the Morrison Formation; however, Weir et al. (1983) report that the Salt Wash Member yields small quantities of freshwater.

Uranium was not analyzed by Weir et al. (1983), but the Salt Wash member is known to contain significant concentrations of the element in southwest Colorado. If a drinking water source is developed in this sandstone unit, it should be tested to ensure uranium and radioactivity are below drinking water standards. The potential for developing groundwater of suitable quality and quantity from the Salt Wash Member of the Morrison Formation in the area is not well known; however, given its discontinuous nature and potential to contain radioactive sediments, the Salt Wash Member should be not be considered as a high-potential unit for groundwater development in the Park.

III.6.2.6. Junction Creek Sandstone and Entrada Sandstone

The Junction Creek Sandstone, Wanakah Formation, and Entrada Sandstone are mapped together as a single unit by Haynes et al. (1972) in the vicinity of the Park. The Junction Creek Sandstone is a fine- to coarse-grained sandstone approximately 275 feet thick (Haynes et al., 1972) which yields groundwater to springs and wells (Weir et al., 1983). The underlying Wanakah Formation is the lateral equivalent to the Summerville Formation and consists of siltstone, shale, and fine-grained sandstone with thicknesses ranging from 0 to 100 feet based on oil and gas well logs in the area. The Entrada Sandstone is a fine- to medium-grained sandstone that yields groundwater of a quality and quantity potentially suitable for development as a drinking water supply (Tables 4 and 5). In this study the Junction Creek Sandstone, Wanakah Formation, and Entrada Sandstone are considered as a single hydraulically-connected water-bearing unit called the Junction Creek/Entrada aquifer with an estimated thickness of approximately 300 feet based on oil and gas well logs. Like the Dakota/Burro Canyon aquifer, groundwater from springs and wells in the Junction Creek/Entrada aquifer exhibit low overall concentrations of dissolved solids. Where the confining Wanakah Formation is not present, the Salt Wash Member of the Morrison Formation and the Junction Creek and Entrada sandstones may be hydrologically connected and function as a single aquifer.

There are no data for wells in the Junction Creek/Entrada aquifer directly adjacent to the Park; these wells tend to be concentrated along the Dolores River approximately 7 to 10 miles to the south and east of the Park (Figure 12). Wells in the Junction Creek/Entrada aquifer vary greatly in depth (55-950 feet) with reported yields between 4 and 50 gpm. Pumping test data for a total of 10 wells in the aquifer show widely ranging specific capacities from 0.04 to 30 gpm/ft/hr but with average and median specific capacity values of 6.85 and 2.8 gpm/ft/hr, respectively. Overall, wells in the Junction Creek/Entrada aquifer exhibit considerably greater specific capacities than any other geologic units in the area. The average and median specific capacities for wells in these two units are roughly 4 to 10 times greater than for wells in the other major aquifer, the Dakota/Burro Canyon aquifer. Available data on aquifer characteristics and water quality in the Junction Creek/Entrada aquifer indicate that this unit has strong potential for development as a supply of potable groundwater in the Park.



N

0 1 2 3 4 Miles

Scale = 1:250,000

FIGURE 12
Water Well Production
Lone Mesa State Park
Natural Resources Assessment

1:250,000-scale geology data from Haynes et al. (1972).
Topographic map base at 1:250,000 from USGS.
Projection: UTM Zone 13, NAD 1983.

Table 4. Groundwater Production in the Lone Mesa Vicinity

Geologic Unit	Number of sites evaluated	Well depth (feet) range & average	Discharge average (gpm)	Drawdown average (feet)	Pumping test average duration (hours)	Specific capacity average (gpm/ft/hr)	Specific capacity median (gpm/ft/hr)	Specific capacity range (gpm/ft/hr)
Quaternary deposits	5 wells	38-147, 82	12.6	36.6	3.4	5.02	1.17	0.06-20
Mesaverde Group	1 well	75, 75	20.0	7.0	0.7	1.91	1.91	1.91
Mancos Shale	18 wells (4 dry)	102-902, 266	4.9	144.2	3.0	0.23	0.03	0-2.89
Dakota Sandstone & Burro Canyon Formation	7 wells 9 springs All springs & wells	80-1196, 504 0, 0 0-1196, 216	11.3 2.1 6.1	190.1 0, flowing 83.2	3.5 --- ---	1.50 † 2.10 † 1.84 †	0.28 † 0.50 † 0.45 †	0.06-9 † 0.10-10 † 0.06-10 †
Entrada Sandstone & Junction Creek Sandstone	10 wells	55-950, 188	16.1	24.0	2.5	6.85 †	2.80 †	0.04-30 †
Older formations	8 wells	100-837, 329	2.0	114.4	1.6	0.47	0.002	0-3.75

† For springs and wells with drawdown values of zero, the specific capacity is reported as the discharge rate.

Table 5. Groundwater Quality in the Lone Mesa Vicinity

Geologic Unit and Location (PLSS)	Name	Elevation (ft, msl)	Sample description	Discharge rate (gpm)	pH	Temperature (F)	Specific conductance (µS/cm)	°TDS (mg/L) ×MCL=500	Chloride (mg/L) ×MCL=250	Sulfate (mg/L) ×MCL=250	Test date	Location relative to LMSP	Data source
Mesaverde Group													
-----	-----	-	Spring	-	7.7	-	3,600	**3,760**	130	**2,300**	-	-	Weir et al., 1983
Mancos Shale													
T43N/R16W - 26bba	Bassnet Homestead	6,319	Well	0.1	-	-	3,900	**2,613** †	-	-	-	13 miles NW	Weir et al., 1983
-----	-----	-	Avg of 4 springs	-	6.8	-	10,500	**6,270**	**3,170**	130	-	-	Weir et al., 1983
T40N/R15W - 23bcc	Upper Hunter Check-In Spring	7,684	Spring	-	7.4	56	1,218	**816** †	-	-	8/25/10	Within Park	CGS, field data
T40N/R15W - 23cba	Lower Hunter Check-In Spring	7,670	Spring	-	8.1	58	3,090	**2,070** †	-	-	8/25/10	Within Park	CGS, field data
T40N/R15W - 11dbd	Gas Well Draw Spring	8,023	Spring	-	7.5	61	3,400	**2,278** †	-	-	8/25/10	Within Park	CGS, field data
Dakota Sandstone & Burro Canyon Formation													
T40N/R16W - 14ada	Narraquinnep Spring	8,025	Spring	0.3	7.3	52	380	255 †	-	-	7/17/80	5 miles W	Weir et al., 1983
T41N/R16W - 7bdb	Cottonwood Spring	8,081	Spring	5	-	-	-	-	-	-	9/18/78	8 miles NW	Weir et al., 1983
T41N/R16W - 7dba	White Sands Spring	8,087	Spring	0.5	7.4	65	220	147 †	-	-	7/17/80	8 miles NW	Weir et al., 1983
T41N/R16W - 16dda	Black Snag Spring	7,900	Spring	0.5	7.3	52	380	255 †	-	-	7/17/80	8 miles NW	Weir et al., 1983
T41N/R16W - 17aaa	Evans Spring	7,995	Spring	0.1	7.4	57	340	228 †	-	-	7/17/80	8 miles NW	Weir et al., 1983
T41N/R16W - 30bbb	Garbareno Spring	8,179	Spring	1	7.4	53	440	295 †	-	-	7/17/80	8 miles NW	Weir et al., 1983
T41N/R17W - 1dcc	Pot Spring	8,104	Spring	1	-	-	-	-	-	-	7/17/80	12 miles NW	Weir et al., 1983
T41N/R17W - 5dda	Big Water Spring	8,241	Spring	10	7.4	53	520	348 †	-	-	7/17/80	15 miles NW	Weir et al., 1983
T41N/R17W - 12bcb	Wolf Den Spring	8,117	Spring	0.5	7.4	55	190	127 †	-	-	7/17/80	12 miles NW	Weir et al., 1983
-----	-----	-	Well	-	7.0	-	3,720	**2,570**	180	**620**	-	-	Weir et al., 1983
Morrison Formation													
Brushy Basin Member													
-----	-----	-	Avg of 2 wells	-	7.2	-	4,180	**2,940**	107	**840**	-	-	Weir et al., 1983
Salt Wash Member													
-----	-----	-	Well	-	7.8	-	515	297	14	55	-	-	Weir et al., 1983
Undivided													
-----	-----	-	Avg of 3 springs	-	6.7	-	1,780	**1,300**	6.6	**330**	-	-	Weir et al., 1983
Entrada Sandstone & Junction Creek Sandstone													
T38N/R16W - 2ddc	Metaska #5	6,670	Well	13	7.4	-	-	320	<10	-	8/21/90	9 miles SW	DWR, well permit
-----	-----	-	Spring	-	8.3	-	315	190	3.0	16	-	-	Weir et al., 1983

°TDS=Total dissolved solids

×MCL=National Secondary Drinking Water Standards recommended Maximum Contaminant Level

†TDS values derived from specific conductance using conversion factor of 0.67.

Bolded text indicates values exceeding National Secondary Drinking Water Standards recommended MCL

III.6.2.7. Hydrogeologic Setting and Groundwater Development Potential

There is very little available data characterizing the occurrence, chemistry, and configuration of groundwater resources in the vicinity of Lone Mesa State Park. However, based on the available water quality and production data, the Dakota/Burro Canyon and Junction Creek/Entrada aquifer units appear to have the greatest potential for yielding water of suitable quality and quantity for a drinking water supply in the Park.

Geologic beds in the area tend to dip at shallow angles (2-4 degrees) and generally “funnel” into the Park in a northward direction (Figure 4; Haynes et al., 1972). From an elevation contour map of the bottom of the Dakota Sandstone from Haynes et al. (1972), CGS digitized elevation contours. The estimated surface of the top of the Dakota Sandstone was then calculated assuming a uniform Dakota Sandstone thickness of 100 feet based on the geologic description in Haynes et al. (1972). Contours representing the calculated elevation of the top of the Dakota/Burro Canyon aquifer are shown in Figure 13. The same procedure was performed to estimate the surface of the top of the Junction Creek/Entrada aquifer. The depth to the top of the Junction Creek/Entrada aquifer was determined using the average formation thicknesses based on lithologic picks on oil and gas well logs in the area. From these well logs, an average value of 583 feet was subtracted from the bottom of the Dakota/Burro Canyon aquifer (top of the Morrison Formation) to generate an estimated surface of the top of the Junction Creek/Entrada aquifer. Contours representing the calculated elevation of the top of the Junction Creek/Entrada aquifer are shown in Figure 14.

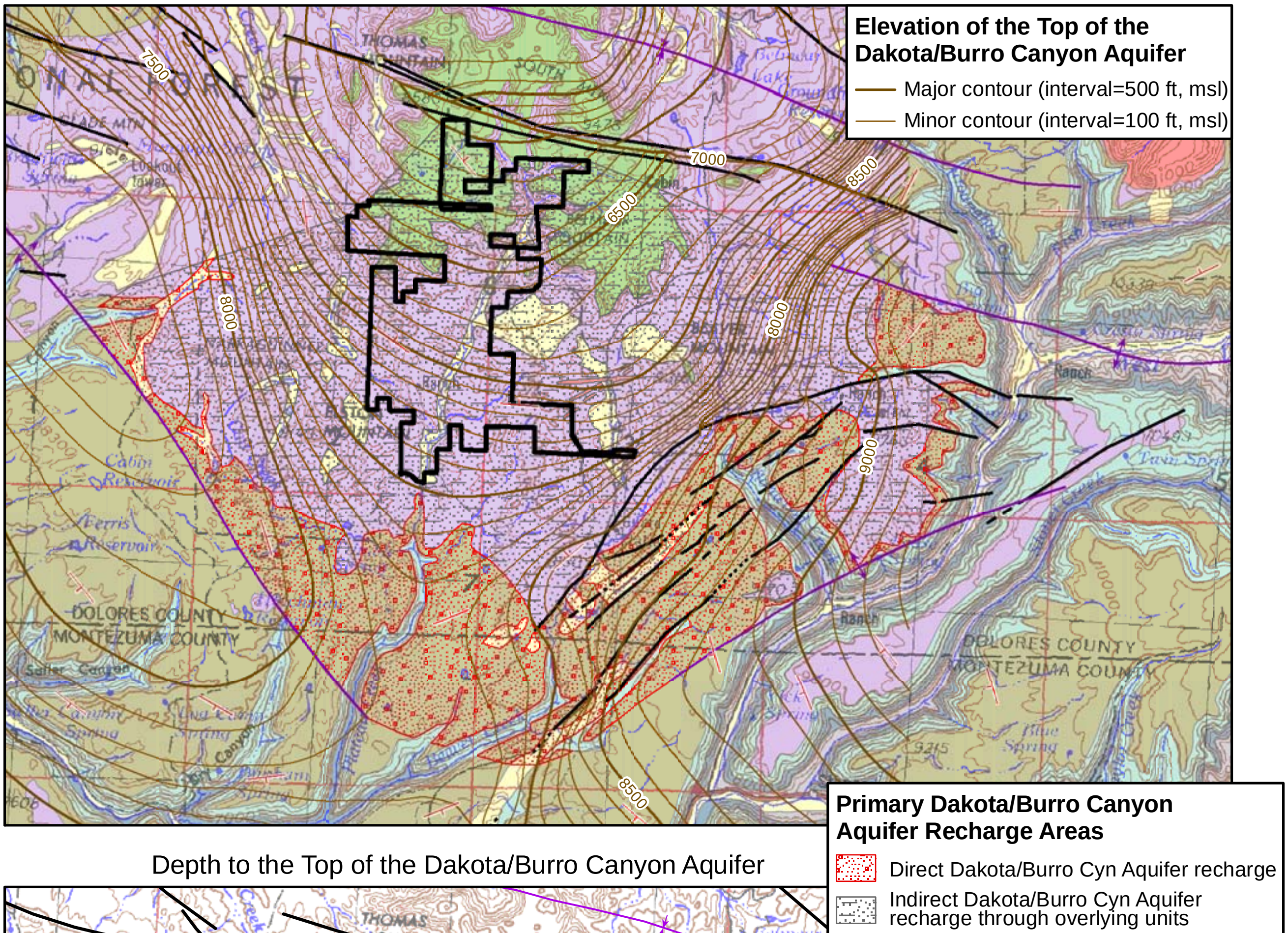
Groundwater originates from infiltrating precipitation or water in streams and rivers within a recharge area. Direct recharge into an aquifer occurs where rocks comprising the aquifer are present at the surface. Additional water can infiltrate vertically through overlying units away from the direct recharge area. Groundwater can migrate vertically through permeable material and also through fractures. Once underground, groundwater tends to follow flowpaths in the down gradient direction through zones of highest permeability. Vertical fractures or faults can function as conduits or barriers for water movement and their impact on the behavior of groundwater in the area is not well known. There are a number of mapped faults in the vicinity of the Park (Figures 13 and 14). At the northern edge of the Park there are east-west trending faults and a network of mapped faults trending in a northeast-southwest direction are present to the south and east of the Park. Furthermore, LiDAR (Light Detection And Ranging) mapping of the ground surface illuminates northeast-southwest trending linear features (lineaments) within the Park that are interpreted to be a faulting or fracture network (Figure 6). The presence of igneous boulders found within the Park and mapped igneous intrusions adjacent to the Park could indicate that igneous intrusions are also present within the Park, potentially occurring along fault or fracture planes. Such igneous intrusions could have additional affects on the movement of groundwater in the area. Because of the limited available water well data, the potentiometric groundwater surface in the area is not well understood. However, with greater amounts of precipitation falling at higher elevations in the Park and the highly fractured nature of rocks in the area, it is likely that precipitation falling on the Park infiltrates vertically through fractured material and into deeper aquifer units like the Dakota/Burro Canyon aquifer and Junction Creek/Entrada aquifer.

Figures 13 and 14 illustrate some basic components available for evaluating the most prospective locations for groundwater resources in the Park: potential recharge areas and depth ranges for both the

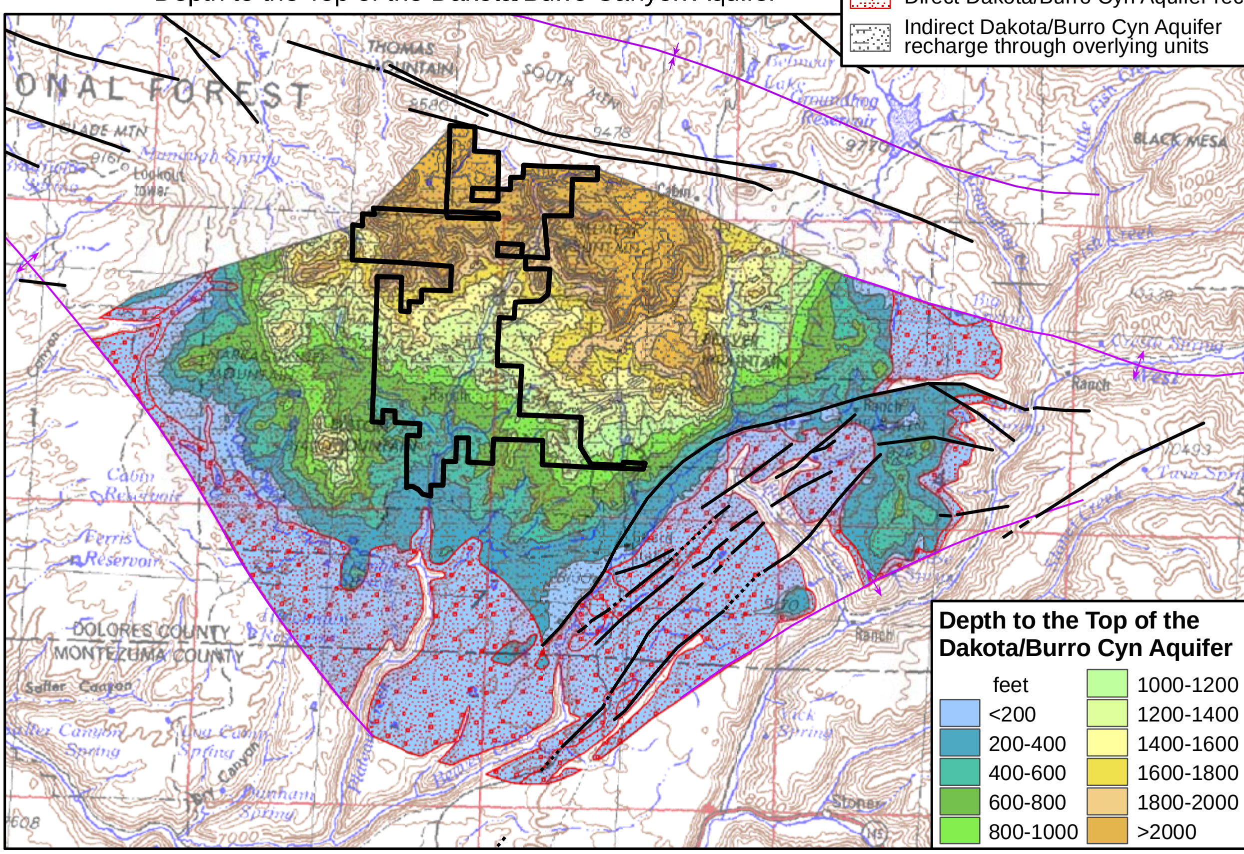
Dakota/Burro Canyon aquifer and the Junction Creek/Entrada aquifer. From the available information on groundwater resources in the area, the locations of greatest potential for cost-effective groundwater development within the Lone Mesa State Park will most likely be low elevation areas downgradient from potential recharge areas and where the Dakota/Burro Canyon and Junction Creek/Entrada aquifer units are at shallower depths. In accordance with these criteria, the locations with greatest potential for groundwater development for use as a drinking water supply are in the southern portions of the Park where the Dakota/Burro Canyon and Junction Creek/Entrada aquifers are at not too deep and where sustainable groundwater is most likely to occur because of proximity and flow paths from recharge areas. The Dakota/Burro Canyon aquifer is at a depth of less than 1000 feet in much of the southern part of the Park, particularly in the vicinity of Plateau Creek (Figure 13) at elevations below 7,800 feet where it is generally within 600 feet of the surface. Likewise, the Junction Creek/Entrada aquifer is closest to the surface in this area with an estimated depth of 1400 feet or less in many areas along Plateau Creek in the southern portion of the Park (Figure 14). Both aquifers are at the surface nearby and there appears to be less evidence of northeast-southwest trending faults and fractures in this area, which have the potential to act as impediments to lateral movement of groundwater from higher elevation recharge areas.

If significant groundwater resource development is desired within the Park, a detailed site-specific groundwater investigation of the Dakota/Burro Canyon and Junction Creek/Entrada aquifers is recommended. This work should include testhole drilling, pump tests and/or slug test analyses, and water quality sampling to further characterize the quantity and quality of the groundwater resources in the Park. A study of this kind will optimize the productivity and cost-effectiveness of the water supply wells drilled.

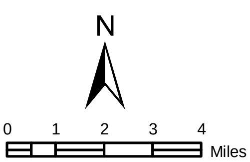
Hydrogeologic Configuration of the Dakota/Burro Canyon Aquifer



Depth to the Top of the Dakota/Burro Canyon Aquifer



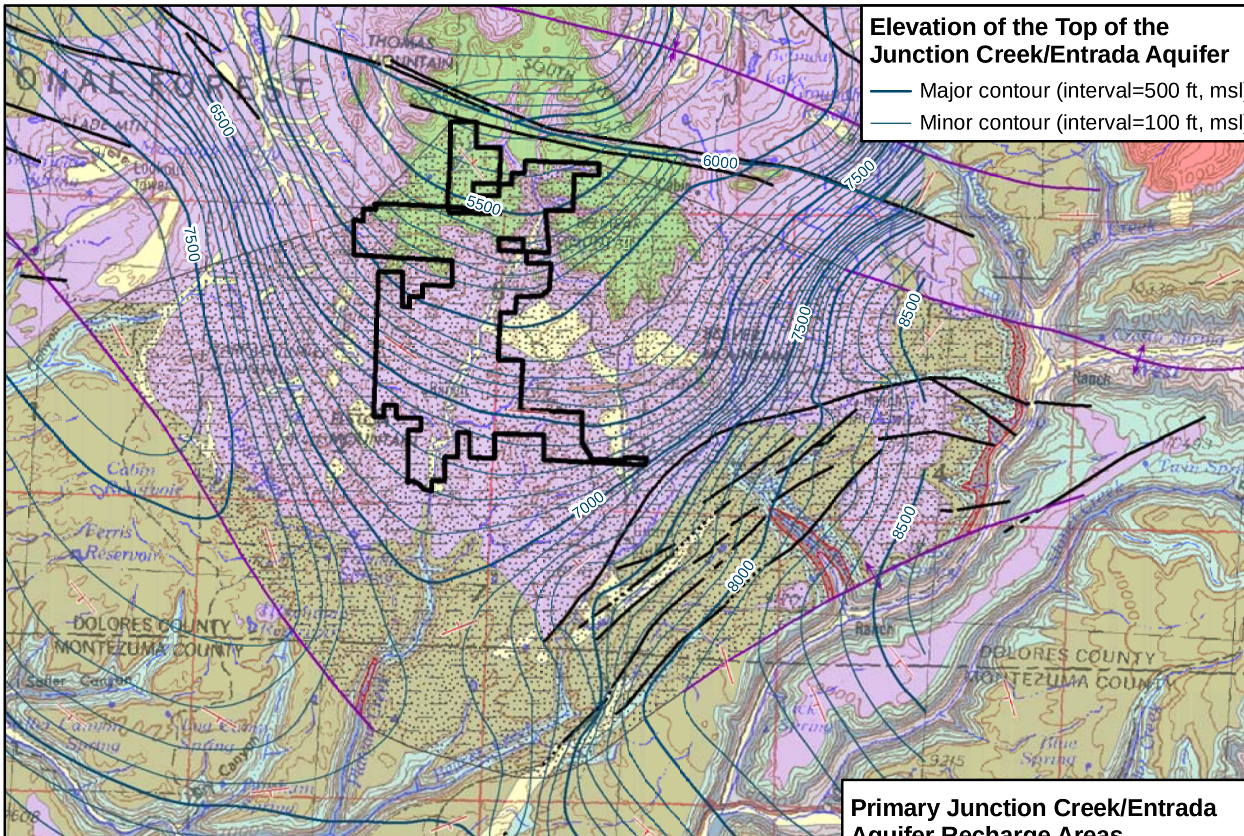
Hydrogeology and depth calculations are based on 1:250,000-scale geology data from Haynes et al. (1972). Projection: UTM Zone 13, NAD 1983.



Scale = 1:250,000

FIGURE 13
Hydrogeology of the Dakota/Burro Canyon Aquifer
Lone Mesa State Park
Natural Resources Assessment

Hydrogeologic Configuration of the Junction Creek/Entrada Aquifer

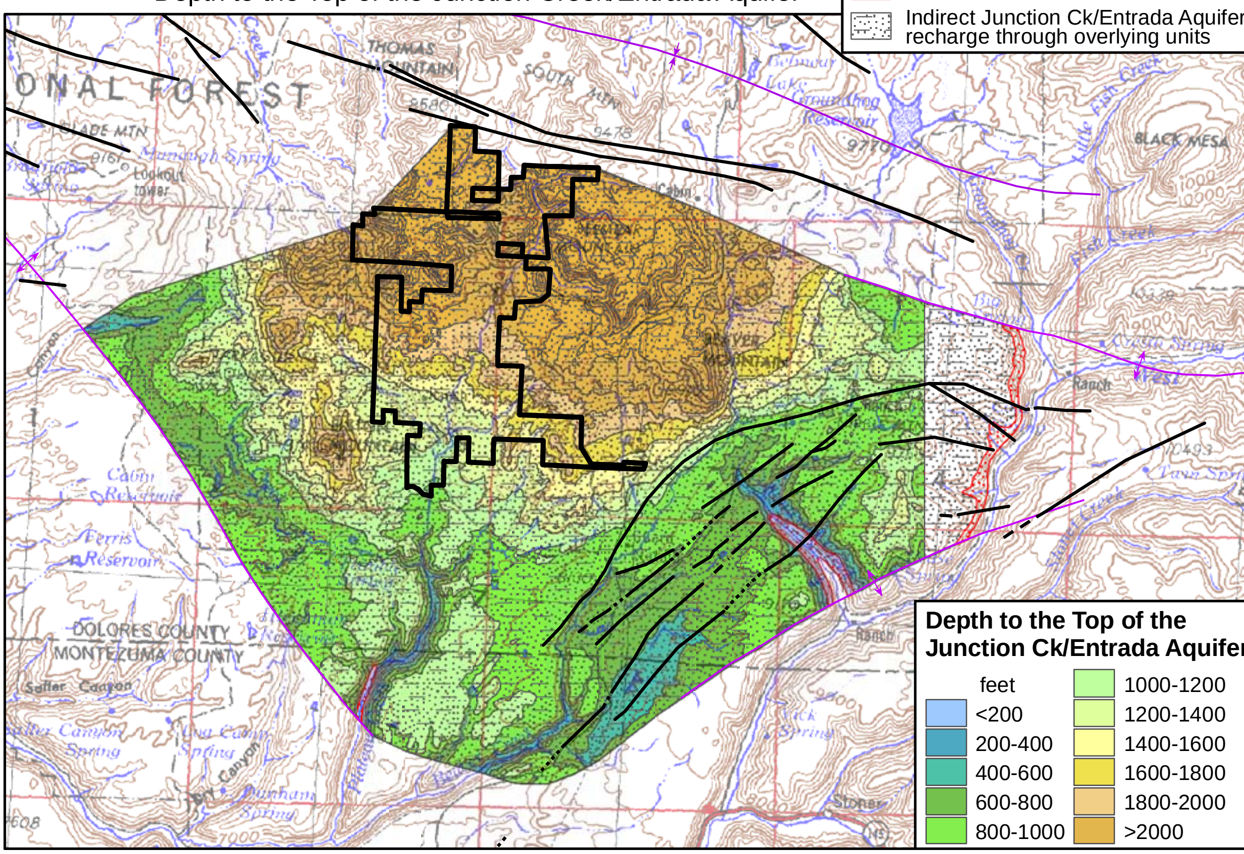


Primary Junction Creek/Entrada Aquifer Recharge Areas

Direct Junction Ck/Entrada Aquifer recharge

Indirect Junction Ck/Entrada Aquifer recharge through overlying units

Depth to the Top of the Junction Creek/Entrada Aquifer



Hydrogeology and depth calculations are based on 1:250,000-scale geology data from Haynes et al. (1972).
Projection: UTM Zone 13, NAD 1983

N

0 1 2 3 4 Miles

Scale = 1:250,000

FIGURE 14
Hydrogeology of the Junction Creek/Entrada Aquifer
Lone Mesa State Park
Natural Resources Assessment

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