Mineral Potential Report
Bureau of Land Management Lands and Minerals
Selected
Proposed Chaco Area Withdrawal
McKinley, Sandoval, and San Juan Counties, New Mexico

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1 Executive Summary

In January 2022, the Bureau of Land Management Farmington Field Office published a Federal Register Notice detailing the proposed withdrawal of approximately 336,400 record acres of public lands from location and entry under the General Mining Act of 1872 and from leasing under the Mineral Leasing Act of 1920 within approximately 10 miles of Chaco Culture National Historical Park in northwest New Mexico for up to 20 years. This report was prepared to determine the mineral potential of land designated for withdrawal by providing a description of geologic background information, known mineral deposits, and historical production and estimating future potential mineral development.

The proposed withdrawal lands, and lands outside of the proposed withdrawal boundary, are part of the Greater Chaco region which holds significant cultural and spiritual value for Indigenous communities across northwest New Mexico. The withdrawal lands also lie within the San Juan Basin, a major oil and natural gas basin, and the main structural feature of the Navajo physiographic section of the Colorado Plateau Province, part of the Intermontane Plateaus region of the Western United States. The Colorado Plateau Province covers the Four Corners region, where New Mexico, Arizona, Utah, and Colorado meet. Within the San Juan Basin lies a sedimentary rock sequence over 14,000 feet thick that ranges in age from Devonian to Tertiary containing a variety of minerals that have been commercially developed. Historical mineral development in the region, dating back to the mid-19th and early 20th centuries, includes extensive oil and natural gas production focused north of Chaco Culture National Historical Park, helium development on structural highs near the Four Corners area, significant uranium mining in the Grants Uranium District south of the park near Crownpoint, NM, and a number of coal mines used to feed power.
generating stations across the region.

The current mineral development trends are primarily focused on oil and gas within the northern portion of the withdrawal boundary, where active hydrocarbon exploration and production activity is on-going on both Federal and non-Federal fluid mineral leases. The withdrawal area contains nearly 260,000 acres of unleased Federal fluid mineral estate along with approximately 71,700 acres of leased Federal fluid mineral estate. There are zero active or proposed Federal coal leases or coal-related applications within the proposed withdrawal boundary. There are no operating uranium mines within the entire Grants uranium district, or within the withdrawal boundary. Some abandoned uranium mines are undergoing reclamation through the Abandoned Mine Lands programs outside of the withdrawal boundary. There are 129 recorded, prospective unpatented uranium mining claims located within the withdrawal boundary covering over 2,600 acres of land.

Future potential mineral development within the withdrawal boundary is most likely to be focused on horizontal drilling for oil and natural gas resources. High-grade, low-cost uranium deposits exist elsewhere in the world making domestic production unlikely, and coal production in New Mexico is dwarfed domestically by other states such as Wyoming. It is projected that no new uranium or coal mines would be proposed within the withdrawal boundary regardless of a mineral withdrawal. The proposed withdrawal would affect oil and natural gas development on Federal mineral estate, it is projected that 47 oil and gas wells would not be drilled over the next 20 years if the withdrawal is approved, with foregone production estimated to be over 4 million barrels of oil and 75,188,327 thousand cubic feet (MCF) of natural gas that would not be produced. Due to the "checkerboard" nature of both surface and mineral ownership within the proposed withdrawal boundary, and the need for
relatively large blocks of leases for horizontal well development, the removal of Federal fluid minerals within the withdrawal boundary could also affect future development potential of lands under other mineral ownership.
2 Introduction and Lands Involved

2.1 Introduction

The purpose of this report is to inform the proposed petition/application for withdrawal of public lands surrounding Chaco Culture National Historical Park (CCNHP) in Northwest New Mexico, application Serial Number NMNM-144042, that was submitted by the Bureau of Land Management (BLM) New Mexico State Office (NMSO) located in Santa Fe, New Mexico on behalf of the Secretary of the Interior. The BLM NMSO on behalf of the Secretary of the Interior requests the withdrawal of 336,424.38 record acres of public lands (Figure 1), from location and entry under the General Mining Act of 1872 (30 U.S.C. 22-42) and from leasing under the Mineral Leasing Act of 1920 (30 U.S.C. 181 et seq.), subject to valid and existing rights. Affected mineral resources are described in Chapter 3 of this report. Disposal of minerals under the Materials Act of 1947 would not be affected under the withdrawal proposal; this includes minerals such as common varieties of sand, stone, gravel, pumice and pumicite, cinders, clay and humate. These mineral materials will not be discussed in this report since they would remain available for disposal under the withdrawal proposal.

The objective of this report is to determine the mineral potential of land designated for withdrawal by providing general geologic background, a description of known mineral deposits, past and present mineral production information, and data on mining claims and mineral leases, and finally an overview of future mineral potential. This report will evaluate the entire withdrawal area as it is geologically similar, however the withdrawal will affect only those parcels in the boundary which have BLM mineral ownership. Conclusions made in this report are not intended for any other purpose.

The report is written in accordance with 43 CFR 2310.3-2 “Development and processing
of casefile for submission to the Secretary”, along with the standards for FPLMA Section 204 Withdrawals of Lands, and the guidelines in BLM Manuals 3031 on Energy and Mineral Resources Assessments (BLM, 1985) and 3060 on Mineral Reports (BLM, 1994). United States Geological Survey (USGS) Open File Report 84-787 “Guide to Preparation of Mineral Survey Reports on Public Lands” was also used as a reference as it provides a well-accepted approach to determining mineral resource potential and certainty of that potential (Goudarzi, 1984). The criterion for determining mineral potential is described in Section 4 of this report. Data sources, listed the References Cited section of this report, include published literature along with information from databases maintained by the United States Geological Survey, the New Mexico Bureau of Geology and Mineral Resources, and the Bureau of Land Management.

2.2 Lands Involved

The lands requested for withdrawal encompass 336,424.38 acres of public land managed by the BLM Farmington Field Office in northwest New Mexico surrounding Chaco Culture National Historical Park (Figure 1). The total surface acreage of the withdrawal boundary is approximately 958,824.80 acres. The affected Federal lands lie within an aliquoted approximation of a boundary proposed under HR 2181 and S 1079 titled “Chaco Cultural Heritage Protection Act of 2019” during the 116th Congress. The boundary is generally a 10-mile proximity of CCNHP to include the outliers of 1) Pueblo Pintado to the east, south of the tri-county intersection of San Juan, McKinley, and Sandoval Counties, 2) Kin Bineola to the west, and south of the community of Lake Valley east of San Juan County Road 7750 at the San Juan and McKinley county boundary, and 3) Kin Y’a’a to the southwest, east of Crownpoint and New Mexico Highway 371. Additional acreage encumbers the space between 10-mile proximity attributable to the main park and Kin Bineola and the Bisti/De-Na-Zin Wilderness to include the
Fossil Forest Research Natural Area (RNA).

The full legal land description of the withdrawal area is contained in the associated Federal Register Notices. The Federal lands proposed to be withdrawn overlap two existing withdrawals totaling 8,560.49 acres: the 7,045.07-acre Ah-Shi-Sle-Pah Wilderness and a 1,515.41-acre portion of the Bisti/De-Na-Zin Wilderness.

The Federal lands within the proposed withdrawal area are primarily used for mineral resource development, livestock grazing, and dispersed recreation. Areas of non-Federal land are used for similar purposes, as well as for residential housing. The entire withdrawal area, and areas outside of the proposed withdrawal, are part of the Greater Chaco region which holds significant cultural and spiritual value for Indigenous communities across northwest New Mexico. The Chacoan culture was present in this area for 400 years, from approximately 850 to 1250 AD. Chaco Culture National Historical Park was designated as a UNESCO World Heritage Site in 1987. The withdrawal area lies within the San Juan Basin, a prolific oil and natural gas basin that has been developed over the last 100 years. There are also significant coal and uranium resources within the San Juan Basin. Recently, areas within the San Juan Basin have been proposed for use in renewable energy production as well, mainly for solar energy installations and associated electrical transmission lines.

3 Description of Geology
3.1 Physiography

The proposed withdrawal lands lie within the Navajo physiographic section of the Colorado Plateau Province, part of the Intermontane Plateaus region of the Western United States (Fassett, 2000). The Colorado Plateau Province covers the Four Corners region, where New Mexico, Arizona, Utah, and Colorado meet. The Colorado Plateau is a geologically stable
crustal block, meaning that relatively little rock deformation in the form of faulting and folding has occurred there when compared to other areas such as the Rocky Mountains or the Basin and Range Province. Within the Colorado Plateau, the San Juan Basin is the main structural feature, a depression with a circular, asymmetric or “oyster shell” shape which covers an area roughly 140 miles wide and 200 miles long, or approximately 22,000 square miles, in northwest New Mexico and southwest Colorado (Figure 2) (Craigg, 2001). The low-lying San Juan Basin is bound on all sides by mountain ranges or other structural highs – Sleeping Ute Mountain and the La Plata Mountains to the north, the Nacimiento Mountains to the east, the Zuni Uplift and Ignacio Monocline to the south, and the Carrizo and Chuska Mountains to the west (Figure 2). The southeast portion of the basin does not have a defining structural feature. Faulting is common around the boundaries of the structural basin (Craigg, 2001). Key features of the basin include the Four Corners Platform, Hogback Monocline, Central Basin, and the Chaco Slope. The Four Corners Platform hosts three prominent intrusive volcanic features (laccoliths) that form structural highs in the area – the Carrizo Mountains, Sleeping Ute Mountain and the La Plata Mountains. Tertiary intrusions are also present on the west side of the basin just outside the Hogback Monocline – Shiprock and the Chuska Mountains.

The proposed withdrawal lands are located in the Central Basin and Chaco Slope portions of the larger San Juan structural basin (Figure 2). The central basin is delineated from the rest of the structural basin by the Hogback monocline on the west, north and east sides, visible as you drive west from Farmington, NM to Shiprock, NM on Highway 64. The Chaco slope forms the southern boundary of the central basin, consisting of a gently northward-dipping platform from the Zuni Uplift near Grants and Gallup, NM to the central basin, near the McKinley County/San Juan County line (Figure 2). The Four Corners Platform sits to the northwest of the Hogback and
extends into southwest Colorado.

The area is characterized by gently rolling tableland and mesas dissected by a multitude of ephemeral washes, most of which drain to the north in a northwest-southeast trend in a south towards the intermittent Chaco River drainage, which eventually drains to the San Juan River which flows northwestward until it meets the Colorado River in Utah (Fassett, 2000). Areas within the withdrawal boundary have been eroded by ephemeral washes to form badland topography, notably within the previously withdrawn Bisti/De-Na-Zin and Ah-Shi-Sle-Pah Wilderness Areas.

Climate in the basin is arid to semiarid with rainfall averaging less than 15 inches per year, concentrated in the late summer/early fall “monsoon” season generally (Fassett, 2000). Chaco Cultural National Historical Park receives an average of just under 9 inches of precipitation per year. Temperatures within the study area range below 0° F in the winter to over 100° F in the summer. Vegetation types are variable, from sparsely vegetated badlands areas to sagebrush plateaus to relatively thick stands of pinon-juniper with the occasional ponderosa pine and finally stream valleys filled with cottonwoods, tamarisk, and willows.

3.2 Rock Units – Lithology and Stratigraphy

A sedimentary rock sequence up to 14,400 feet thick overlying basement crystalline rock that ranges from Devonian to Tertiary in age was deposited within and on top of the San Juan Basin structural depression (Figure 3) (Craigg, 2001). The sedimentary sequence dips inwards from the higher elevation surrounding margins to a trough-like or oyster shell shaped center, the deepest portion is within the Central Basin which underlies part of the study area. Younger sediments sit on top of and within the older sediments like a layer cake placed into the structural basin San Juan Basin.
Surface geology within the proposed withdrawal area consists of Quaternary-age sediments within the ephemeral washes and Cretaceous-age rocks outside of the ephemeral washes. On the north side of the withdrawal boundary, the Nacimiento is exposed on the surface. Moving south across the study area, progressively older rock formations are exposed as you move up the Chaco Slope where the younger, overlying rocks have been eroded. On the south side of the study area, the lower part of the Cretaceous Mancos Shale is exposed on the surface.

The regional geologic map for the study area (Figure 4) shows that the surface exposures are almost entirely Cretaceous strata, with some Tertiary deposits exposed as well. and Cretaceous periods with minor amounts of Quaternary deposits filling the valleys. Outcrops of the Tertiary period are predominately representative of fluvial type environments while Cretaceous age deposits are predominately representative of cyclic marine and nonmarine environments that coincide with the presence of the Cretaceous Western Interior Seaway in this area and repeated transgression and regression of the paleo-shoreline. Structural dip is to the northeast within the withdrawal area, meaning formations are buried deeper the further northeast you move into the basin off the Chaco Slope and into the Central Basin (Figure 5).

3.2.1 Precambrian and Paleozoic

There are no exposures of rocks deposited during the Precambrian or Paleozoic Eras within the main portion of the San Juan Basin or within the study area. Precambrian rocks in the area consist of the crystalline basement rocks of the basin that underlie all younger sedimentary rocks in the structural lows. Precambrian rocks are exposed outside the study area in the uplifts at the basin margins such as the Nacimiento Mountains, Zuni Uplift, and San Juan Uplift. Precambrian rocks in these areas, mainly granites and quartzites, have been aged at 1.5 to 1.75 billion years old (Brister and Hoffman, 2002).
Paleozoic sedimentary rocks unconformably overlie the Precambrian crystalline basement at great depth beneath the San Juan Basin and the study area, likely over 10,000 feet or more. Most Paleozoic age formations are sedimentary and were deposited from Pennsylvanian time (320 Ma) through the end of Permian time (252 Ma). Paleozoic sedimentary rock consists of interbedded sandstones, shales, and limestones of marine origin that have been studied further west and north where they can be found in outcrop in places such as the Zuni Uplift (Stevenson, 1983). Paleozoic strata are important oil and gas-bearing reservoirs west of the San Juan Basin in the Paradox Basin of southeast Utah. Paleozoic strata have also been targeted for their helium content on structural highs on the western side of the San Juan Basin along the Four Corners Platform.

Pre-Carboniferous rock units present in the study area include the Late Cambrian Ignacio Quartzite and the Late Devonian Aneth, Elbert, and Ouray formations. The Aneth formation, disconformably overlying the Ignacio Quartzite, is a marine shale sequence deposited in the early Devonian (Stevenson, 1983). The overlying Aneth formation exists at depth but has not been well studied in outcrop within the San Juan Basin area. The Devonian Elbert formation consists of the basal McCracken marine sandstone and an upper shale member interbedded with thin dolomite beds, indicating a tidal flat depositional environment (Stevenson, 1983). Overlying the Elbert is the Ouray limestone, a limestone and dolomite sequence deposited in the late Devonian.

Mississippian stratigraphy in the basin includes the Leadville Limestone, a marine sedimentary deposit that includes an upper and lower member, an oolitic and crinoidal limestone and a sucrosic dolomite to micritic limestone, respectively (Stevenson, 1983). Further south in the basin, the Arroyo Penasco Group consists of Esperitu Santo Formation, a quartz
conglomerate, and the Tererro Formation, a shallow marine dolomite, that correlate to the same depositional time as the Leadville Limestone to the north (Stevenson, 1983).

Following the Mississippian, Pennsylvanian formations in the area include the Molas Formation, a paleosol, and the Hermosa Group which consists of the Pinkerton Trail Formation, the Paradox Formation, and the Honaker Trail Formation (Stevenson, 1983). The Pinkerton Trail and Honaker Trail Formations both consist of interbedded marine sandstones, shales, and thin limestones. The Paradox Formation in between the two is a thick evaporite carbonate deposit, consisting of halite, anhydrite, dolomite, and black shales from a restricted shelf marine environment (Stevenson, 1983). The majority of the hydrocarbon production in the San Juan Basin from Paleozoic strata is from the Paradox Formation, where low energy algal mound complexes developed into stratigraphic traps (Stevenson, 1983).

The earliest Permian rocks in the San Juan Basin area consist of the arkosic, reddish-brown sandstones of the Cutler-Abo Formation, which use different nomenclature depending on geographic location in the basin – Cutler in the Four Corners area and Abo in the southeast part of the basin; the source of this sediment was the Uncompahgre Uplift (Stevenson, 1983). Depending on location within the basin, the Cutler-Abo is overlain by the Bursum Formation, a marine limestone (eastern Zuni Mountains and Albuquerque), or the eolian De Chelly Sandstone (western Zuni mountains and Defiance Uplift area). Moving northwestward, sedimentary deposits thin throughout Permian time as fluvial and evaporative lacustrine environments became prevalent forming the Yeso Formation, Glorieta Sandstone, and San Andres Limestone (Stevenson, 1983). The Yeso Formation consists of redbeds of marine origin, the Glorieta Sandstone is a cross-stratified marine sandstone, and the San Andres Formation is a near-shore marine carbonate deposit.
3.2.2 Mesozoic – Triassic, Jurassic and Cretaceous

Mesozoic strata, deposited during the Triassic, Jurassic, and Cretaceous periods, in the San Juan Basin and the study area are again buried at great depths beneath the study area – over 9,700 feet for the oldest Triassic strata in the Central Basin, but are found in outcrop at the basin margins (Craigg, 2001).

**Triassic**

Triassic deposition in the study area and San Juan Basin, occurring from approximately 252 Ma to 201 Ma, was mainly in a nonmarine fluvial environment as rivers and streams drained structural highs on the southeast portion of the basin (Brister and Hoffman, 2002). Triassic rocks generally disconformably overlie Permian rocks in the basin, but disconformably overlie Pennsylvanian or Precambrian rocks along the eastern and northern edges (O’Sullivan, 1977).

Triassic rocks contained within the San Juan Basin structural are the lower Triassic Moenkopi shale, upper Triassic Agua Zarca sandstone (east) or Shinarump sandstone (west), and the upper Triassic Salitral shale, Poleo sandstone, Chinle shale, and Correo sandstone (Wengerd 1950). These formations are characterized by nonmarine (stream channel, flood plain, eolian, and lacustrine) depositional environments, and have a total thickness of roughly 1650 to 2000 feet near the San Juan/McKinley County line (Wengerd, 1950 and Craigg, 2001). Much of the Triassic strata information comes from outcrops in areas outside the San Juan Basin, as drilling into Triassic strata within the basin has been minimal.

On the North flank of the Zuni Uplift near Gallup and Grants, NM, the lower Triassic Moenkopi, upper Triassic Shinarump sandstone, and upper Triassic Chinle shale and Correo sandstone are present. In both locations, Triassic sediments are located at great depth. The Moenkopi consists of interbedded reddish-brown sandstone and shale that is up to 500 feet thick. The Agua Zarca sandstone is a reddish buff to light gray conglomeratic sandstone with minor
siltstone and silty shale, up to 380 feet thick. The Shinarump sandstone is a conglomeratic sandstone, gray to buff in color with abundant petrified wood in outcrop, up to 200 feet thick. The Salitral shale, a member of the Chinle shale up to 105 feet thick, is varicolored and contains limestone concretions. The Poleo sandstone, another member of the Chinle shale, is a gray to buff massive sandstone up to 115 feet thick. The Chinle formation consists of multi-colored shale, sandy shale, shaly sandstone and limestone conglomerate lenses with abundant fossils and petrified wood up to 1400 feet thick. The Correo sandstone, a member of the Chinle formation, is a dark brown to reddish-buff massive and cross-bedded sandstone up to 120 feet thick.

In the late Triassic, Chinle shale and sandstone beds were deposited over broad, westward sloping swampy alluvial plans by streams that drained into the California sea in Nevada. A bentonite is found in the Chinle that is likely from volcanic activity far to the northwest. Chinle strata are extremely thick and relatively fine grained, indicating slow continuous subsidence of the subaerial alluvial plain throughout the late Triassic in the Four Corners area.

Triassic sedimentary rocks found at depth beneath the study area mainly consist of the early and middle Triassic Moenkopi Formation, late Triassic Chinle Group and laterally equivalent Late Triassic Dolores Formation, formed by fluvial deposition, which is disconformably overlain by the middle Jurassic Wingate or Entrada sandstones (Craigg, 2001).

Jurassic

Jurassic strata, lying over 9300 feet beneath the study area, were deposited between 201 Ma and 145 Ma, and have been studied in outcrops located in surrounding highlands (Craigg, 2001). A period of non-deposition and erosion occurred in the early Jurassic, followed by deposition in mainly non-marine environments (fluvial, lacustrine, eolian) in the early to middle Jurassic forming the Wingate sandstone, San Rafael Group (Entrada, Wanakah and Cow Springs
members), Junction Creek sandstone, and finally the Morrison formation. Other authors have defined Jurassic strata across New Mexico differently (see Lucas and Anderson, 1998), but the interpretation from Craigg (2001) more specifically applies to the proposed withdrawal area. In the Grants Uranium District, Jurassic strata have been intensively studied as they have high economic value and outcrop at Red Rock State Park, Thoreau, Ambrosia Lake, and Mesa Gigante (Lucas and Anderson, 1998).

The eolian Wingate sandstone is the only early Jurassic unit, it is present along the northwest margin of the San Juan Basin, along a rough line intersecting Fort Defiance, AZ, Shiprock, NM and Cortez, CO (Craigg, 2001). The Wingate consists of reddish-brown, very fine to medium-grained, well-sorted sandstones with high angle crossbedding (Craigg, 2001). Overlying the Wingate is the Entrada, the basal member of the San Rafael Group that extends well outside the San Juan Basin boundaries. The Entrada is formed of a red and white to light brown silty sandstone and well-sorted quartz sandstone interbedded with siltstones; crossbedding is common as the Entrada was mainly eolian with interdune deposition creating the siltstones (Craigg, 2001). In the Grants Region, the middle Jurassic Entrada sandstone consists of the Dewey Bridge member and the Slick Rock member, the Todilto formation consists of the Luciano Mesa member and the Tonque Arroyo member; then the Summerville formation, Bluff sandstone, and finally the Morrison Formation consists of the Salt Wash member, Brushy Basin member, and Jackpile member (Craigg, 2001). The Dewey Bridge member is a medial silty interval, and the Slick Rock is an upper sandy section. The Todilto Luciano Mesa member is a dark gray limestone, the Tonque Arroyo is a gypsum and anhydrite section up to 120 feet thick indicating long-standing evaporite conditions.
In the northern area of the proposed withdrawal, the basal portion of the Wanakah Formation is the Todilto Limestone Member, a gray limestone with an upper gypsum and anhydrite unit with siltstone and sandstone (Craigg, 2001). The Beclabito Member (previously the Summerville Formation) was deposited in a marginal marine or sabkha environment as a massive or planer to crossbedded siltstone and fine-grained sandstone (Craigg, 2001) that conformably overlies the Todilto. The Horse Mesa Member (previously the Bluff Sandstone) of the Wanakah was deposited in eolian, interdune, fluvial and sabkha environments and conformably overlies the Beclabito. The Horse Mesa is a cliff-forming planar to cross-bedded quartzose sandstone that ranges from red to orange to white in color. Above the Horse Mesa Member of the Wanakah Formation is the last formation of the San Rafael Group – the Cow Springs Sandstone. Outcrops in the southwest portion of the San Juan Basin, just outside the study area, forms prominent cliffs of cross-bedded greenish-gray to yellow-gray to light-brown well sorted quartzose and arkosic sandstone, with common color banding (Craigg, 2001). The depositional environment was mainly eolian and interdune. The Junction Creek sandstone is only present in the northern part of the San Juan Basin, having been mapped in southwest Colorado and interpreted to extend at least a few miles into New Mexico (Craigg, 2001).

The Morrison Formation is present throughout the San Juan Basin and beneath the study area at depth, consisting of tan to pink, locally conglomeratic fine- to coarse-grained sandstone with interbedded siltstone, shale, clay, and limestone (Craigg, 2001). The Morrison, consisting of 5 members, was deposited in various fluvial environments (channel and flood plain) as well as lacustrine environments. The members, from oldest to youngest, are the Salt Wash, Recapture, Westwater Canyon, Brushy Basin and Jackpile. The Salt Wash member is sandstone and conglomerate with mudstone interbeds up to 440 feet thick, the Brushy Basin member contains
variegated smectitic claystones up to 350 feet thick, and the Jackpile member is a nearly 100-foot-thick section of kaolinitic sandstone. The Morrison Formation, especially the Westwater Canyon Member, is a prolific water-bearing formation throughout the San Juan Basin, with the fine-grained shales and clays acting as confining units for the coarser grained sandstones (Craigg, 2001). The Jackpile Member has been interpreted to extend well into the proposed withdrawal area (Owen 1984 after Craigg 2001 page 33 of PDF). Overall, the Morrison formation is present across the entire study area, with its thickness ranging from 200 feet near Grants, NM to over 1100 feet within the Central Basin. The top of the Morrison formation is a key marker unit across the San Juan Basin and has been extensively mapped throughout the area (Craigg, 2001). Vertebrate fossils have been recovered from the late Jurassic Morrison Formation, specifically the Brushy Basin member – Allosaurus, Camarasaurus, Diplodocus, Seismosaurus and Stegosaurus (Lucas and Anderson, 1998).

**Cretaceous**

In the late Cretaceous (95 Ma), following non-deposition and erosion during the late Jurassic and early Cretaceous, the region and study area were covered by the Western Interior Seaway. The seaway was oriented northwest-southeast, following basement-level structural features of the region, with the shoreline migrating back and forth in a northeast-southwest direction over approximately 30 million years. This resulted in over 6,500 feet of marine, coastal plain, and non-marine sediment deposits within the Central Basin consisting of interbedded mudstones, sandstones, limestones, coals, and conglomerates (Brister and Hoffman, 2002).

The upper Cretaceous rocks in and near the subject withdrawal lands include, from oldest to youngest: the Dakota sandstone; the Mancos shale, including the Gallup and Crevasse Canyon sandstones; the Mesaverde Group, which includes the Point Lookout sandstone, the coal-bearing Menefee Formation, and the upper Cliff House sandstone, the Lewis shale, the Pictured Cliffs
sandstone, the Fruitland Formation, which is the most important coal-bearing formation in the basin, the Kirtland shale. These upper Cretaceous rocks consist of inter-tonguing marine and nonmarine sedimentary layers that were deposited on the western margin of a vast inland sea during basin wide transgressive-regressive cycles (Bielski, 1983 and Fassett and Hinds, 1971).

The Dakota sandstone was deposited in the earliest Late Cretaceous, sometime around 100 Ma, on a regional erosion surface in a continental alluvial-plain to marine shoreface environment (Craig, 2001). The Dakota has five formal subdivisions – the Envinal Canyon Member, Oak Canyon Member, Cubero Tongue, Paguate Tongue, and Twowells Tongue in ascending order. It generally is a buff to brown, crossbedded conglomeratic sandstone to a medium-grained sandstone in the lower part to a dark-gray carbonaceous shale with siltstone and lenticular sandstone beds in the middle to a fine-grained sandstone interbedded with gray shale in the upper part (Craig, 2001). Average thickness is somewhere between 200 to 300 feet. The Dakota sandstone is a marine transgressive sequence of mainly shallow-marine sandstone which intertongues with Mancos shale in its upper part (Molenaar, 1977).

The Mancos Shale, with a maximum thickness of over 2300 feet, conformably overlies and intertongues with the Dakota. The Mancos Shale was deposited in a shallow offshore marine environment (±400-foot water depth) and consists of gray to black shale and claystone with calcareous siltstone and sandstone and occasional bentonite beds in addition to offshore sandstone bar deposits (Craig, 2001). The Mancos is thought to contain more sandstone in the southern and western portions of the San Juan Basin, and more limestone and calcareous shale in the northern and eastern portions of the basin (Craig, 2001). Various members and tongues are connected to the Mancos – the Graneros, Bridge Creek (or Greenhorn) Limestone, Semilla

The Gallup Sandstone has a multitude of lithologies to include conglomerate, sandstone, shale, carbonaceous shale, and coal that was deposited during the first major regression of the Late Cretaceous Western Interior Seaway in the San Juan Basin area (Craig, 2001). Depositional environments include marine shoreface, offshore, coal swamp and continental fluvial and eolian dune environments. The Gallup is found only in the southwest portion of the San Juan Basin, partially underlying the proposed withdrawal area, as a northwest-trending truncation line exists that was formed by an erosional surface in the Cretaceous (Craig, 2001).

The oil and gas industry has commonly referred to the sandier target intervals within the Mancos Shale northeast of the true Gallup truncation line as the “Gallup zone”, where they are targeting the members and tongues of the Mancos shale (generally the Tocito Sandstone Lentil) which are not depositionally related to the Gallup Sandstone (Molenaar, 1973). Sandstones within the Gallup are pink to light gray, fine- to medium-grained and moderately well sorted. Maximum thickness of the Gallup is about 300 feet.

The Crevasse Canyon Formation, another spatially limited formation due to presence of a truncation surface, overlies the Gallup and consists of the Dilco Coal, Dalton Sandstone and Gibson Coal Members (Craig, 2001). The Dilco Coal contains gray shale and claystone, carbonaceous shale, coal, siltstone and sandstone deposited in continental stream channel, floodplain and swamp environments. The Dalton Sandstone is a regressive marine shoreface deposit of fine to medium-grained quartzose sandstone to coarse-grained or conglomeratic sandstone. The Gibson Coal is lithologically and depositionally similar to the Dilco Coal.
The Mesaverde Group, so-named for the outcrops of these formations found near Mesaverde National Park in southwest Colorado, consists of the lower Point Lookout Sandstone, the coal-bearing Menefee Formation, and the upper Cliff House Sandstone. The Point Lookout sandstone consists of regressive, littoral marine sandstones that are the most laterally extensive in the basin and are generally thickly bedded, light gray, locally cross-bedded sandstones with interbedded dark marine shale (Craig, 2001). In the southern part of the basin, the Satan Tongue of the Mancos Shale splits the Point Lookout into an upper body and the lower Hosta Tongue, which outcrops near Crownpoint, NM (Craig, 2001). Overlying the Point Lookout is the non-marine Menefee Formation, consisting of interbedded, repetitive sequences of sandstone, siltstone, shale, carbonaceous shale, claystone and coal beds deposited in fluvial (channel and floodplain), lagoon and coal swamp type environments (Craig, 2001). In the southern part of the basin, the Menefee can be divided into the Cleary Coal Member and the Allison Member. The Allison Member of the Menefee, a stacked channel sandstone with siltstone, gray shale, claystone and an upper coal, has produced important Cretaceous vertebrate fossils west of CCNHP. Overlying the Menefee is the upper Cliff House Sandstone, a marine shoreface deposit of thickly bedded, fine-grained, well-sorted and locally cross-bedded sandstone, was deposited during the last major regression of the Cretaceous Western Interior Seaway in the San Juan Basin (Fassett, 1977 and Craig, 2001). The Cliff House stratigraphy is complicated by various historical interpretations and terminology used by the oil and gas industry that does not reflect the actual stratigraphy. Fassett (1977) describes the Cliff House as having basal sandstone lenses that pinch out to the northeast, the thick La Ventana Tongue in the middle, and an upper unnamed tongue. Northwest of Farmington, NM, an outcrop of the Beechatuda Tongue of the Cliff House is managed as a type-section for this basal sandstone.
The Lewis Shale is a thick, sandy, light to dark gray colored offshore marine shale with sandy limestone, siltstone and fine-grained sandstone interbeds that was deposited during the last major transgression of the Western Interior Seaway and is the highest marine shale in the basin (Silver, 1951 and Craigg, 2001). The Lewis also contains the Huerfanito Bentonite bed, a key time-marker bed formed from the weathering of volcanic ash in seawater (Fassett and Hinds, 1971). Overlying the Lewis is the regressive marine Pictured Cliffs Sandstone, an upwards coarsening, thickly bedded, bioturbated and locally cross-bedded sandstone with interbeds of thin marine shales (Fassett and Hinds, 1971).

The Fruitland Formation overlies the Pictured Cliffs and is subsequently overlain by the Kirtland Shale. The Fruitland and Kirtland both contain interbedded, cyclic nonmarine channel sandstones, siltstones, claystones and shale formed in fluvial and swamp environments. The most important distinction between the two formations is that the Fruitland Formation contains several coal beds and carbonaceous shales, while the Kirtland does not. The Kirtland consists of a lower shale, middle Farmington Sandstone Member, and an upper shale (Craigg, 2001). The Kirtland Shale is the last Cretaceous-age formation within the study area as there is a disconformable contact with the overlying Tertiary Ojo Alamo. In certain areas just northeast of Farmington and in the Colorado portion of the San Juan Basin, the McDermott Member of the Animas Formation is Late Cretaceous in age, but the study area does not contain these units.

3.2.3 Cenozoic – Tertiary and Quaternary

Formations younger than the Late Cretaceous, described below, are only present in the northeastern portion of the study area, as they have been eroded or pinch out as you move southwestward from the intersection of San Juan, Sandoval, and McKinley County towards Crownpoint, NM. Tertiary (or Paleogene and Neogene) units within the San Juan Basin and
study area range in age from 66 Ma to 2.58 Ma and consist of the Ojo Alamo Sandstone, Nacimiento Formation, and San Jose Formation. The Paleocene Ojo Alamo consists primarily of stacked channel sandstone and conglomeratic sandstone deposits that often cut into the underlying formations, but interbedded floodplain deposits in the form of shale lenses are also present (Craigg, 2001). Petrified/silicified wood is commonly present within the Ojo Alamo, a prime example of this can be seen in an area known as the Log Jam just north of the study area in the Bisti/De-Na-Zin Wilderness. The Nacimiento Formation overlies the Ojo Alamo, described as an interbedded dark colored shale with discontinuous, medium- to coarse- grained arkosic sandstone that is often poorly consolidated (Craigg, 2001). The San Jose Formation is Eocene in age and is the youngest formation in the San Juan basin and in the study area. It was deposited in fluvial environments and is described as an interbedded sequence of sandstone with cross-beding and petrified/silicified wood, siltstone and variegated shale (Craigg, 2001). Rocks younger than the San Jose Formation in the study area generally consist of Quaternary (2.58 Ma and younger) deposits within ephemeral stream channels.

Shallow groundwater aquifers occur primarily in the Tertiary aged Ojo Alamo but can also be present in other less extensive and more localized sands of the Fruitland and Pictured Cliffs formations. Although many San Juan Basin aquifers are known to yield water to wells, the yields are low (less than 20 gpm) (BLM 1987). The quality of groundwater in the San Juan Basin generally ranges from fair to poor. In most places the total dissolved solids TDS content exceeds 1,000 mg/L and can range from 500 to 4,000 mg/L (BLM 1987 and USGS 2001).

3.3 Structural Geology and Tectonics

Tectonism in the San Juan Basin began sometime during late Paleozoic time, as there is no geologic evidence to support the presence of a structural depression in the area during
Precambrian time (Kelley, 1951). Precambrian geologic history of the region has been erased by metamorphism, deformation, erosion and subsequent burial by Paleozoic rocks (Craigg, 2001). The San Juan Basin has been affected by tectonism since the late Paleozoic, but late Cretaceous to early Tertiary time is when the main features of the basin took shape. Four major structural elements exist within the San Juan Basin – uplifts, structural platforms, monoclines and the Central Basin (Kelley, 1951). The major uplifts on the boundaries of the basin – the Defiance, Zuni, Lucero, San Juan and Nacimiento – were active during Paleozoic and Mesozoic time (Kelley, 1951). The structural platforms of the San Juan structural basin include the Chaco slope and the Four Corners, Chama, Puerco, Acoma, and Zuni platforms. The monoclines are the most striking features of the basin and include the Nutria monocline near the Zuni Uplift, the Defiance monocline near the Defiance Uplift, the Nacimiento monocline near the Nacimiento Uplift, and the Hogback monocline that defines the central basin (Kelley, 1951).

The Central Basin, delineated by the Hogback monocline and the Chaco slope, is a basin within the larger structural basin (Kelley, 1951). The Central Basin is what is most often referred to when the San Juan Basin is discussed. The major structural features of the San Juan Basin formed as a result of the Laramide orogeny, which is responsible for forming the modern-day Rocky Mountains, that began approximately 70-80 million years ago (Ma) and ended 35 to 55 Ma. The Laramide orogeny was the result of flat-slab subduction along a convergent margin, where the oceanic crust of the Farallon and Kula plates were sliding beneath the far western margin of the continental crust of the North American plate in an eastward direction. The result of this subduction was buckling of the overlying continental crust, creating structural highs (mountain ranges) and intermontane lows (basins) across what is now the Rocky Mountain
region. The San Juan Basin is one of these intermontane lows, as are many other basins across the west such as the Powder River and Bighorn basins in Wyoming.

The Colorado Plateau structural fabric, established by late Precambrian time, consists of orthogonal fault sets with the primary set aligned northwest-southeast and the antithetic set aligned northeast-southwest, were created by regional strike-slip type stress (Stevenson, 1983). The main northwest trending fractures control the San Luis Uplift, the Four Corners lineament, the Tocito horst and the Zuni Uplift (see Figure 1 in Stevenson, 1983). The Four Corners platform is bound by the House Creek fault and the Hogback monocline which are part of the antithetic set of northeast trending faults in the basin (Stevenson, 1983). The Hogback fault is a high-angle reverse fault that shows slip within the Paleozoic strata, with Mesozoic and younger rocks draped over the fault by the mainly eastward Laramide-age compression (Stevenson 1983). Structural relief from the Four Corners platform across the monocline is over 4000 feet, which is a primary reason that Paleozoic reservoirs have not been explored in the main Central Basin of the greater San Juan Basin (Stevenson, 1983). In the southern portion of the study area, the Zuni uplift was a structural high throughout the Pennsylvanian, until Permian rocks were deposited overtop (Stevenson, 1983). Along the Chaco Slope, Pennsylvanian strata nonconformably overlie the Precambrian basement. The Chaco Slope is a homoclinal feature north of the Zuni Uplift that is bound on the northeast by basement fault-blocks near the Tocito Dome and Hospah fields.

The Four Corners lineament, a northwest-southeast trending fracture system, has controlled depositional patterns throughout the San Juan Basin and the Paradox Basin. This feature separates the Central Basin from the Four Corners Platform, with the Hogback monocline
separating them and left-laterally offsetting the Four Corners lineament to the southwest (Stevenson, 1983).

4 Description of Energy and Mineral Resources

As mentioned in Section 1.1, the proposed withdrawal does not affect “salable” minerals managed under the Materials Act of 1947 (30 U.S.C. 601 et seq.); this includes minerals such as common varieties of sand, stone, gravel, pumice and pumicite, cinders, clay and humate. The withdrawal does apply to “locatable” minerals that are managed under the General Mining Act of 1872 (30 U.S.C. 22-42) and “leasable” minerals that are managed under the Mineral Leasing Act of 1920 (30 U.S.C. 181 et seq.). Leasable and locatable minerals that would be affected by the proposed withdrawal are described below. Energy and mineral resources that are not described below are not known to exist within the proposed project area.

4.1 Coal (Leasable)

4.1.1 Geologic Setting, Known Deposits and Mineralized Areas

There are 3 coal-bearing Cretaceous-age formations present within the San Juan Basin and the study area that have been or could be mined at the surface or in the shallow subsurface – from oldest to youngest the Crevasse Canyon, Menefee, and Fruitland Formations. Late Cretaceous coal-bearing rocks with coals thick enough to be mined formed in coastal peat swamp environments where sediment and organic material accumulated slowly as the Western Interior Seaway regressed northeastward. The Crevasse Canyon Formation contains the Dilco Coal Member and the Gibson Coal Member, which outcrop near the southern end of the San Juan Basin and proposed withdrawal area near Crownpoint, NM (generally within Township 16 and 17 North) (Figure 4). The Menefee Formation, of the Mesaverde Group, has two coal-
bearing members, the Cleary Coal Member and the upper coal member, both of which are thin with seams averaging 3-5 feet thick (Brister and Hoffman, 2002). The Cleary Coal Member outcrops in the southern portion of the proposed withdrawal area just north of Crownpoint, NM (within Township 18 North), and the upper coal member outcrops near Chaco Culture National Historic Park (within Township 21 and 22 North) (Figure 4). The Menefee Formation contains an estimated 1.1 billion short tons of surface-minable, low-ash content, sub-bituminous coal with relatively high sulfur content (Brister and Hoffman, 2002). It is estimated that 106 million short tons of Menefee coal within the San Juan Basin would meet Clean Air Act standards for sulfur content (Brister and Hoffman, 2002).

The Fruitland Formation is the youngest coal-bearing formation in the study area, with coal seams up to 30 feet thick but averaging 5-10 feet thick. The coals in the Fruitland Formation are generally sub-bituminous, 18-22% ash by weight, with variable sulfur content (Brister and Hoffman, 2002). The Fruitland is estimated to contain more than 200 billion tons of coal (Fassett 2000). It is estimated that 883 million short tons of Fruitland coal that meet Clean Air Act standards for sulfur are in reserve within the San Juan Basin (Brister and Hoffman, 2002). Coal fields within the study area and San Juan Basin in general have been mapped based on the near-surface presence of these coal-bearing rock formation, the coal fields that overlap the study area include the Bisti, Star Lake, Chaco Canyon, Chacra Mesa, Standing Rock, Crownpoint, Ambrosia Lake, and the San Mateo Coal Fields (Figure 7).

4.1.2 Historic Development

Coal has been produced in New Mexico since at least the early- to mid-1800s according to written records (Nickelson, 1988) and has likely been used since well before then. Coal in the San Juan Basin is produced from a multitude of fields, all of which mine into Late Cretaceous-
age sedimentary rocks – the Fruitland Formation, the Menefee Formation, and the Crevasse Canyon Formation. Coal mines are located where these formations either outcrop or are located in the relatively shallow subsurface along the northern, western, and southern portions of the basin (Figure 5). The first true mine in the state was likely opened in 1863 during the Civil War (Nickelson, 1988). Coal deposits in the San Juan Basin were recorded as early as 1868. The development of railroads in the 1880’s and 1890’s through northwest New Mexico opened markets for coal out of the San Juan Basin. In McKinley County, many coal mines operated near Gallup, NM in the late 1800s and early 1900s with railroads to the Albuquerque, NM area used to transport coal to outside markets. Records from 1882 to 1986 indicate that coal produced from the San Juan Basin across McKinley, Sandoval, Rio Arriba, and San Juan Counties totaled over 268 million tons (Nickelson 1988).

According to data from the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), within the study area there are 8 recorded abandoned and reclaimed coal mines or coal prospects listed below. No other recorded coal mines, active or abandoned, exist within the proposed study area.

- The Smouse Prospect which targeted the Crevasse Canyon Formation in the early 1900s.
- The Tiejen Prospect which targeted the Dilco Coal of the Crevasse Canyon Formation in the early 1900s.
- The Reid Prospect which targeted the Gibson Coal of the Crevasse Canyon Formation and stopped operation in the mid-1940s.
- The Blake Mine which produced from the Menefee Formation
- The Crownpoint Mine which produced from the Gibson Coal of the Crevasse Canyon formation from 1918 – 1951.
• The George Mine which produced from the Gibson Coal of the Crevasse Canyon Formation sometime before 1939
• The Dalton-Hannah Mine which produced from the Gibson Coal of the Crevasse Canyon Formation from 1952 – 1963.
• The De-Na-Zin Mine which produced from the Fruitland Coal from 1980 - 1989.

Of the 3 coal-bearing formations within the San Juan Basin, the Fruitland is the most prolific producer of coal for energy generation. Major mines targeting the Fruitland Coal within the San Juan Basin that have produced coal from Federal leases since 1978 are the Navajo, San Juan, La Plata, Gateway, De-Na-Zin and Burnham mines. Of these mines, only the abandoned and fully reclaimed De-Na-Zin Mine is located within the withdrawal area. These six mines have produced a cumulative total of 492,818,602 short tons of coal as of 2019. Of the six, only the Navajo Mine, a surface mine owned by Navajo Transitional Energy Company, and the San Juan Underground Mine, owned by Westmoreland Mining, are still active today. Both mines are located west of Farmington, NM, well north of the proposed withdrawal area. These two mines are used exclusively to supply coal to the Four Corners Power Plant and San Juan Generating Station, respectively. The Navajo Mine is expected to continue operation until at least 2033. At the date of this report, the San Juan Generating Station has shut down and the San Juan Mine has ceased mining coal and is undergoing closure operations. Other major coal mines within the San Juan Basin, but also outside the study area, include the inactive McKinley Mine just north of Gallup, NM which produced from the Cleary Coal Member of the Crevasse Canyon Formation and is undergoing reclamation, and the inactive Lee Ranch Mine northeast of Grants, NM which also targeted the Cleary Coal Member. The El Segundo Coal Mine, west of Crownpoint, NM, is located just outside of the proposed withdrawal boundary and produces from non-Federal coal
leases within the Crevasse Canyon Formation. The withdrawal would not affect any operating coal mine in the San Juan Basin as they are all outside of the withdrawal boundary.

4.1.3 Known Leases and Prospects

There are no active or proposed Federal coal leases or other coal encumbrances within the withdrawal area. There were twenty-two Preference Right Lease Applications (PRLAs) for coal within or partially within the proposed withdrawal area that covered 51,277.91 acres of BLM-managed mineral estate, 46,663.4 acres of which overlap the proposed withdrawal (Figure 8). The PRLAs are closed and are no longer considered valid, existing rights. Eleven of the PRLAs, originally submitted by Ark Land Co., were exchanged for other bidding credits in Wyoming under the Dingell Act. Three PRLAs, originally submitted by Thermal Energy Co., were deemed non-economic by the BLM which rejected the applications. BLM’s decision was appealed and upheld by the Interior Board of Land Appeals in Case # IBLA 2011-187. A fourth, also submitted by Thermal Energy Co, was similarly rejected by BLM and upheld by the Interior Board of Land Appeals in Case # IBLA 89-647. Four others submitted by Ark Land Co were eventually relinquished. One each submitted by Chaco Energy Co and Thermal Energy Co were denied but remained pending for several decades. Lastly, one, NMNM 010931 submitted by Sunbelt Mining Co, was issued a lease and transferred to BIA for administrative management because the mineral estate was patented to Trust when they were selected by Navajo Nation under the Navajo Hopi Land Exchange Act. Within the proposed withdrawal, only 38,255.18 once encumbered by these PRLAs remains Federal mineral estate, with the rest having been transferred to Trust under either Public Land Order 2198 or the Navajo Hopi Land Exchange Act or patented to Navajo Allotted with supplemental mineral patents under the Mescal Settlement Agreement.
In addition to the leased PRLA, four other federal coal leases were issued within or partially within the analysis area, comprising 12594.67 acres with 7,737.67 acres (leased PRLA inclusive) lying within the proposed withdrawal. All of the Federal Coal Leases have been since closed and are no longer considered a valid existing right. Competitive lease NMNM 002457 was eventually relinquished by the Chaco Energy Co. Rincon Resources Co and Sunbelt Mining Co, each with 50% interest, were awarded competitive leases NMNM 0186612, NMNM 0186615, and NM 045183 which were eventually transferred to BIA for administrative management. Part of NMNM 0186612 remained administered by BLM. Of these only the 2,569.51 acres of the relinquished lease remain Federal mineral estate. For the leases transferred to BIA, the acreage for NMNM 0186612 is Navajo Allotted with the issuance of supplemental mineral patents under the Mescal Settlement Agreement. The acreage for NMNM 0186615 and 045183 were patented to Trust when they were selected by Navajo Nation under the Navajo Hopi Land Exchange Act.

Lastly, there were thirteen State of New Mexico Coal Leases comprising 6,445.38 acres with 6,039.53 lying within the analysis area. Because of past land exchanges, 1,200.05 of the previously leased State coal are now Federal mineral estate and part of the proposed withdrawal. The details of these State coal leases are not known other than they have been since closed.

4.1.4 Mineral Economics and Future Potential

Future potential for coal development within the withdrawal area is negligible. There are just 3 active or recently active coal mines in the state of New Mexico, the San Juan Mine which is undergoing closure processes at the time of this report, the Navajo Mine and the El Segundo Mine. Coal production in New Mexico is dwarfed by domestic production from other states such as Wyoming. For example, according to information from the Energy Information
Administration (EIA), aggregate coal production for the state of Wyoming in 2020 was 218,555,844 short tons, compared to 10,129,124 short tons produced in 2020 from New Mexico (EIA, 2022). Coal reserves from the 3 mines in New Mexico are calculated to be 65 million recoverable short tons, with a total of 6,719 million short tons of estimated recoverable reserves in the state. Wyoming producing mines have 4,907 million short tons of recoverable reserves, with an estimated reserve of 34,747 million short tons in the state (EIA, 2022).

Additionally, two of the three existing coal mines in New Mexico, the Navajo Mine and San Juan Mine, exist only to provide coal to adjacent power generating stations and do not ship coal elsewhere. El Segundo continues to provide coal to customers for uses other than power generation. The San Juan Mine and adjacent San Juan Generating Station located near Farmington, NM northwest of the withdrawal area are both inactive and undergoing closure as the power plant owners Public Service Company of New Mexico (PNM) increasingly looks towards renewables for power generation. The Navajo Mine and adjacent APS Four Corners Power Plant, located on the Navajo Nation near Fruitland, NM, are planning to operate for at least another decade. As the national power grid shifts towards other forms of energy generation, mainly renewables and natural gas, the demand for coal as part of electric generation is dropping. In 2010 the electric power sector utilized 975.1 million short tons of coal, in 2020 the electric power sector utilized only 435.8 million short tons of coal (EIA, 2022).

Overall, nationwide coal demand is down – in 2010 the United States produced 1,084,368,148 short tons of coal, and in 2020 produced about half at 535,434,354 short tons of coal. With local and nationwide demand for coal dropping and existing coal mines in the general area, it is unlikely that coal from within the proposed withdrawal area would be a target for economic development. Most of the coal within the withdrawal area is located near CCNHP as
well, where the Fruitland formation is at or near the surface, which would make permitting a mine challenging if not impossible due to land use conflicts. Additional coal reserves have already been withdrawn within the Bisti/De-Na-Zin and Ah-Shi-Sle-Pah Wilderness Areas as well, creating a lack of cohesive, mineable coal reserves under current price environments.

### 4.2 Oil, Natural Gas, and Helium (Leasable)

#### 4.2.1 Geologic Setting, Known Deposits and Mineralized Areas

During the late Cretaceous the region known as the San Juan Basin sat along the western shoreline of the Western Interior Seaway which covered areas from Texas to North Dakota along a roughly northwest – southeast trendline. The migration of the paleoshoreline back and forth over geologic time, and the sedimentation that occurred during this time, resulted in deposition of layered nonmarine and marine sedimentary rocks across the region. The marine rocks often preserved organic matter which was converted to oil and natural gas from burial and resulting temperature and pressure increases. The oil and gas were then trapped in both the nonmarine reservoir rocks and the marine source rocks. The sedimentary rock sequence that underlies the study area contains many sequences of source rocks, reservoir rocks, and various trapping mechanisms that contain oil and natural gas. Similar generation and trapping of oil and gas occurs in sedimentary rocks of other ages within the San Juan Basin as well, but the Cretaceous strata are the most prolific producers.

The study area overlaps portions of the Central Basin and Chaco Slope features of the San Juan Basin (Figure 2), which is the second largest gas-producing basin in the United States and ranks second in total estimated reserves behind the Hugoton field that covers portions of Texas, Oklahoma, and Kansas (Fassett, 2010). Oil and natural gas have been produced from over 300 fields in the basin, from strata as old as the Devonian and as young as the Tertiary (Fassett,
Natural gas production from the New Mexico portion of the basin in 2021 was 5.11 billion cubic feet (BCF), down from a high of over 1 TCF (trillion cubic feet) in each year from 2004-2006 according to data from the New Mexico Oil Conservation Division. Oil production from the New Mexico portion of the basin in 2021 was 7.76 million barrels of oil (MMBO). The San Juan Basin contains over 300 individual oil and gas fields (Figure 9), most being relatively small. Sedimentary strata from the Paleozoic to the Tertiary have been explored for oil and gas potential in the basin. Paleozoic formations have been drilled for oil and gas (including helium) on the edges of the San Juan Basin, most notably on the Four Corners platform, in the Rattlesnake, Tocito Dome, and Table Mesa fields all located south of Shiprock, NM and north-northwest of the study area (Figure 2). Production from Paleozoic reservoirs in northwest New Mexico has yielded 14 MMBO and 54 BCF of natural gas from 14 oil and gas fields (Stevenson, 1983). In general, Paleozoic strata has not been tested for oil and natural gas in the Central Basin as the shallower, Cretaceous strata are highly productive and deposited at depths that are easier to reach. All Paleozoic oil and gas production in northwest New Mexico occurs where basement lineaments intersect (Stevenson, 1983). Oil and gas shows have been reported in Paleozoic strata, Mississippian and Pennsylvanian carbonates, in deep portions of the Central Basin (Stevenson, 1983), although the trap is likely stratigraphic.

Triassic strata in the San Juan Basin are entirely nonmarine and have only produced minor hydrocarbon shows as they lack thick marine source rocks (Wengerd, 1950). Minor quantities of oil and gas may be present in the Triassic strata of the San Juan Basin due to certain timing, fracturing, and sealing events in the subsurface creating pathways for Pennsylvanian hydrocarbon movement upwards (Wengerd, 1950). Carbon dioxide has been produced from Triassic formations in Montezuma County, CO (MacIntosh #1 Sec 25, T36N, R18W) at a rate of...
150 to 500 MCF/day from the Shinarump conglomerate. Jurassic rocks are nonmarine in origin and have economic significance for their gypsum, uranium ore, building stone and aquifer potential in other portions of New Mexico, but are not known to contain productive quantities of oil and natural gas are not valuable for mineral potential in the study area (Lucas and Anderson, 1998).

Cretaceous strata are the most prolific oil and gas reservoirs within the San Juan Basin (and the proposed withdrawal area), producing 93% of the total oil and 99% of the total gas from the basin (Fassett, 2010). Since 2009 drilling has taken place almost exclusively in Cretaceous rocks within the San Juan Basin. Historically, natural gas production came primarily from conventional reservoirs such as the Dakota Sandstone, Mesaverde Group, Pictured Cliffs Sandstone, and Fruitland Coal (Fassett, 2010). Historic oil production in the basin has come from the Tocito Sandstone Lentil and other fractured Mancos Shale reservoirs, along with the Dakota sandstone (Fassett, 2010). In 2011 and 2012, following the coal-bed methane boom, the basin was revitalized with the increased use of horizontal drilling and multi-stage hydraulic fracturing targeting unconventional reservoirs within the Mancos Shale, collectively referred to as the “Gallup” zone by industry or Mancos-Gallup, which includes the Tocito Sandstone Lentil and the El Vado Member of the Mancos Shale along with other coarser-grained intervals. The main oil window for the Mancos/Gallup zone within the basin has been delineated in the area near Nageezi and Counselor, NM just on the northern edge of the proposed withdrawal boundary (BLM, 2018). Horizontal wells targeting the Mancos have also produced large amounts of natural gas in the Middle Mesa and Rosa areas near Navajo Reservoir towards the Colorado-New Mexico border where natural gas and natural gas liquids are concentrated. Since 2012, applications for permit to drill processed by the Farmington Field Office have been almost
exclusively horizontal wells targeting the Mancos Shale and associated “Gallup zone” of the Mancos, with most vertical wells and a limited number of horizontal wells targeting coal-bed methane within the Fruitland Coal in northern townships. The Mesaverde Group was the target of natural gas production within the withdrawal area south of CCNHP before the 1970s, but the wells were clustered on isolated structural traps and development was not widespread. Some production is still ongoing in that area, but new wells are infrequent. Horizontal wells in the Mancos Shale/Gallup zone are expected to be the main focus of development within the San Juan Basin moving forward.

The most well-known deposit of natural gas within the withdrawal area is within the Fruitland Coal, which contains thick coal seams and associated coal-bed methane gas (Fassett and Boyce, 2005). Coal beds act as source rock, reservoir, and trap all in one for coal-bed methane (CBM) deposits. The gas is held within the carbon molecules of the coal by adsorption, rather than being held in pore space as oil or natural gas is in other sedimentary rock types. The Fruitland coal beds are highly fractured in parts of the basin and not fractured at all in other parts of the basin. It is these fractures that provide the permeability in Fruitland coal-bed methane reservoirs. In areas where the Fruitland coals are not fractured, even though gas content is high, the Fruitland produces little to no gas. For the most part, individual coal beds are separate coal-bed methane reservoirs, each encased in impermeable mudstones. The fractures in Fruitland coals are normally water saturated and it is necessary to initially pump water from the coals to lower the pressure in the system which in turn allows the adsorbed gas to migrate from the micro pores of the coals to the well bore. The usual pattern for Fruitland coal-gas wells is for them to initially produce large amounts of water and little gas and until the water is unloaded and gas begins flowing more effectively (Fassett and Boyce, 2005).
The Fruitland coal reservoir is not a single, continuous coal bed; rather, it is composed of several discrete coal beds. Usually, the number of beds per well ranges from 6 to 9 with as many as 16 beds present. Net thickness is highly variable, ranging from 0 (due to erosional truncation) to 110 feet, but averages about 33 feet. Matrix permeability is variable, but generally very low. Production is possible due to the presence of extensive networks of coal cleats (fractures); fracturing of the coal is attributed to Laramide tectonic activity. The cleat network is typically water bearing. Dewatering has been an important factor in CBM production. The organic components of the Fruitland coal contain adsorbed gas. As water is produced from the cleat network, pressure is reduced, and adsorbed gas is desorbed from the matrix to the cleats and becomes producible (Engler, 2001). The Fruitland Formation in the southern part of the basin has potential for additional gas production, but because of lower thermal maturity and general lower gas content for the coals in this area, and because the Fruitland coalbeds are much thinner, the potential is less than for areas in the northern part of the basin.

Natural gas has been produced from the Fruitland Coal in the San Juan Basin and study are since the late 1980’s, with a majority of CBM wells being drilled in the early 2000’s when natural gas prices were high. The Fruitland Formation is one of the youngest Cretaceous-age formations in the withdrawal area and basin, so it is found at depths less than 1000 feet making wells easier and cheaper to drill than deeper formations, allowing for generally lower production rates from the wells (less than 100 MCF/day). The lower gas production rates can be partly related to the lower thermal maturity and general thinner coals in the southern portion of the basin compared to the thicker, more deeply buried and more thermally mature coals in the northern and coal fairway regions of the basin (Fassett, 2005). Thermal maturity studies by (Pawlewicz, 1991) and (Fassett, 1991) conclude that vitrinite reflectance of coal decrease from
the structural axis of the basin outward. Estimates of ultimate gas production from the San Juan Basin prior to the discovery of Fruitland coal-bed methane in the basin were on the order of 25 TCF. To date, the fractured-sandstone reservoirs of the basin have produced about 22 TCFG and have a relatively long productive life ahead of them (Fassett, 2005). Fruitland coals are estimated to have from 50-85 TCFG resources and have produced about 11.4 TCFG. The Fruitland Coal is the largest conventional gas reservoir in the San Juan Basin in terms of resources and ultimate production potential (Fassett, 2005).

The proposed withdrawal area overlaps nearly all of the potentially productive strata within the Central Basin and Chaco Slope portions of the San Juan Basin. The Fruitland Formation outcrops along a roughly NW-SE trend line just north of CCNHP, limiting the Fruitland potential to areas north of the outcrop. Across the withdrawal area potential Cretaceous reservoir rocks exist from the Fruitland Coal down through the Dakota, comprising the entire Cretaceous section, with potential for Jurassic and older reservoir rocks to exist as well. It has been shown that water content increases in some of the common reservoir rocks as you move southwest along the Chaco Slope. The USGS published Total Petroleum System (TPS) analyses for undiscovered resources within the Fruitland TPS, Lewis Shale TPS, and Mancos-Menefee Composite and underlying Todilto TPS in 2002 and updated them in 2020 (USGS, 2013 and Marra et al., 2020). In 2020, total undiscovered gas resources within the Fruitland TPS, which partially overlaps the northeastern withdrawal area before the Fruitland formation outcrops, were estimated at 12,467 BCF and 13 million barrels of natural gas liquids (MMBNGL) (Marra et al., 2020). The 2020 assessment of the Lewis Shale TPS indicated that 882 BCF of natural gas and 2 MMBNGL were undiscovered, with only a small portion of the TPS overlying the proposed withdrawal area. The Mancos-Menefee composite TPS was estimated to contain 4 MMB of oil,
11,539 BCF of natural gas, and 56 MMBNGL in the 2020 report, with the Menefee coal bed gas and Mesaverde conventional oil reservoirs being the main contributors for portions of the TPS that overlap the withdrawal area (Marra et al., 2020). The 2018 RFD also indicates that there is occurrence potential for oil and gas throughout the withdrawal area (Figure 10) (BLM, 2018). However, the development potential of areas south of CCNHP is classified as low to negligible (Figure 10). The withdrawal area south of Chaco Park also known as the Chaco Slope has been explored extensively over the last hundred years with the first oil discovery at Seven Lakes while drilling for water in 1911. Since then, several fields have been discovered based on surface structural mapping and later seismic acquisition in the 1970s. The most notable field south of CCNHP is the Hospah, discovered in 1927 based on the mapped surface geologic structure. It produces from the Dakota and Hospah sands. The field is still active and has produced over 22 million barrels of oil. Other small fields in the area have produced from structural and combination structural/stratigraphic traps in the Entrada, Mesaverde, and the Gallup formations.

Helium was trapped in the San Juan Basin via the same trapping mechanisms for oil and natural gas, but likely originated through radiogenic decay of uranium and thorium in granitic Precambrian basement rocks that underlie the study area (Broadhead, 2005). After generation, the helium migrated upwards into Paleozoic reservoir rocks along high-angle, strike-slip faults on the Four Corners Platform along the northwest edge of the San Juan Basin, where helium concentrations of up to 7.5% have been documented and production totals reached nearly 1 BCF (billion cubic feet) (Broadhead, 2005). The faults that the helium migrated along exist across much of the San Juan Basin, following the northwest-southeast trend of the paleo-shoreline from the Western Interior Seaway, and granitic basement rocks underlie the entire basin as well. However, no helium wells have been drilled off the Four Corners Platform in either the Central
Basin or Chaco Slope, so it is unknown if commercial volumes of helium exist in Paleozoic strata off the structural high. Triassic strata within the Basin may also contain commercial concentrations of helium, but no wells have been drilled to begin delineating fields or production potential. Helium production and exploration has slowed since the mid-2000s, but there has been renewed interest in the helium potential of the Four Corners Platform over the past several years as the global helium supply is low.

4.2.2 Historic Development

The first documented oil discovery in New Mexico was in the San Juan Basin in 1911 at what is known as the Seven Lakes Field on the south-central Chaco Slope, where a well drilled for water found oil in the Menefee formation around 330 feet deep (Fassett, 2010). Ten years later, in 1921, the first gas discovery in the San Juan Basin was documented just south of Aztec, NM in a well drilled almost 1000 feet deep into the Farmington Sandstone Member of the Kirtland Shale (Fassett, 2010). Today, very little oil or natural gas production occurs within the Menefee and Farmington Sandstone Member of the Kirtland. In 1922, a well in the Hogback Field west of Farmington, NM was drilled to a depth of 800 feet into the Dakota Formation struck oil, setting off a fevered exploration period through the 1920s (Fassett, 2010). Surface structures on the Four Corners platform were targeted and found to be productive in both Cretaceous and Paleozoic strata. During this time gas was also found in the Pictured Cliffs sandstone and the Mesaverde Group. Pipelines to Albuquerque and Santa Fe were built around 1930 to expand the market for the gas. From 1930 to 1950, two large Pennsylvanian gas field discoveries were made on anticlinal structures in the Four Corners platform – the Barker dome and Ute dome fields (Fassett, 2010). In 1951 a 24-inch pipeline was built to California, providing an outlet for large volumes of gas, and spurring a drilling boom in the 1950s. The first three
major gas-producing sandstone units in the Central Basin were delineated at this time – the Dakota sandstone, Mesaverde Group, and Pictured Cliffs sandstone. Two oil fields producing from the Tocito sandstone lentil of the Mancos shale were also discovered at this time – the Bisti and Horseshoe fields. Helium has been produced in New Mexico since 1943, all from Paleozoic strata on the Four Corners Platform on the northwest edge of the basin (Broadhead, 2005). Helium production ceased between 1990 and 2001 (Broadhead, 2005), and recently there have been new attempts to produce helium from Paleozoic reservoirs on the Four Corners Platform.

Early oil and gas exploration just north of the withdrawal area started in the mid 1950’s with Shell Oil Company drilling its first successful oil well in May of 1956 in what later became the Bisti Gallup Oil Fields. The Bisti Lower Gallup Field located just north of the Bisti/De-Na-Zin and the separate but parallel trending Bisti Carson Unit, produce from a complex of offshore marine bar sandstones (Sabins, 1963). The Bisti Lower Gallup field trends southeast and extends right up to the wilderness boundary with the Devon Neilson #1 well located outside but drilled directionally under the wilderness lands. The primary producing formation is the lower Gallup sandstone bar deposit, which is interbedded within a thick Cretaceous, Mancos shale section. The Gallup Fields produces mainly oil from stratigraphic reservoir traps that are roughly 30 miles long but particularly narrow ranging from only 1 to 3 miles wide. The long linear northwest-southeast trending fields represent the marine offshore bar deposition that occurred parallel to the Cretaceous shoreline (Sabins, 1963). The trapping mechanisms for the Bisti Lower Gallup, like most of the San Juan Basin’s large oil and gas fields, are stratigraphic with a few smaller fields located outside the central basin being formed by structural closure. Because of these anatomically narrow reservoirs there is still the potential to discover new oil fields southwest of the above-mentioned producing trends or fields.
From the 1960s to the 1980s, drilling fluctuated with demand and changes in regulation, with most drilling in the withdrawal area taking place in Mesaverde gas pools and Gallup oil pools south of CCNHP on isolated structural traps, but no large discoveries were made until the 1980s and 1990s with discovery of the Fruitland Formation coal-bed methane resource. Fruitland formation coal beds started methane production in the late 1970’s and have increased to the point where they exceeded gas production from all of the conventional sandstone reservoirs (EMNRD, 2007). Production from the Fruitland Coal peaked in the early- to mid-2000s when natural gas prices were in a volatile state following Hurricane Katrina. Most producing wells within the withdrawal area are located near the northeastern boundary and produce from the Fruitland Coal reservoir.

4.2.3 Known Leases and Wells

The withdrawal area contains 259,852.22 acres of unleased Federal fluid mineral estate. There are 80 valid existing leases that lie within or partially within the proposed withdrawal area, encompassing 94,523.74 acres. Of that acreage, 71,746.51 acres lie within the proposed withdrawal boundary. Of the existing leases, all but 2 have existing wells on them and are in “Held By Production” status, meaning they will remain leased until the last well capable of production on the lease is plugged and abandoned. The 2 leases that are not “Held By Production”, NMNM129735 and NMNM130879, would expire March 31, 2023, and November 3, 2023, respectively, if no paying well is drilled on the leases or the leases are not included in some other type of agreement with currently producing leases. Additionally, there are 25 State of New Mexico oil and gas leases within or partially within the withdrawal analysis area comprising 7,680.47 acres. Lastly, there are 104 Navajo Allotted Leases within the withdrawal analysis area comprising 16,101.33 acres.
According to GIS data, there are a total of 1,022 wells within the proposed withdrawal area (Figure 12). Of these 1,022 wells, 333 wells are in an active status on existing leases of all ownerships. Of the 333 active wells, 326 are producing, 5 are injection or saltwater disposal wells and the remaining 2 wells are considered other well types. The saltwater disposal wells are drilled into the Mesaverde or Entrada Formations under oversight of the New Mexico Office of the State Engineer. Only 16 active wells are present south of CCNHP and the Fruitland Formation outcrop (includes active and “new” which were spud but not completed within Mesaverde Gas Pools in T20N, R9W). Producing wells in the withdrawal area are mostly completed in the Fruitland Coal, Chacra, and Gallup Formations. 135 of the remaining wells were cancelled and never drilled. The remaining 554 wells are plugged and abandoned. Many of the plugged wells south of CCNHP were targeting oil in the Gallup and Dakota or natural gas in the Mesaverde. Horizontal wells, accounting for most of the production within the withdrawal area currently, are focused on the northeast side of the withdrawal area and all target the Mancos and associated “Gallup” zone, which is a name has been applied to many coarser-grained intervals within the Mancos. The Gallup zone reaches its geologic limitation somewhere around 5-miles from CCNHP, around when the Fruitland coal outcrops. The true Gallup formation (named for outcrops near Gallup, NM) is thought to be truncated in the subsurface between the Fruitland Formation outcrop and the north-northeastern boundary of the proposed withdrawal. The majority of existing gas wells within the boundary are vertical wells producing from the Fruitland Coal. The Fruitland Coal potential ceases to exist somewhere between the withdrawal boundary and the outcrop of the formation just north of CCNHP (Figure 6), where at some point moving up-dip towards the southwest will result in the absence of economic gas. The shallowest well drilled into the Fruitland Coal has a total depth of 518’ and is located south of Farmington,
NM in Section 26 of T28N, R15W (30-045-22552). Within the study area, the shallowest Fruitland Coal well located in Section 24 of T22N, R09W (API# 30-045-31092) has a total depth of 624’. There are no drilled, producing, or plugged and abandoned helium wells within the withdrawal area.

4.2.4 Mineral Economics and Future Potential

Future development potential for oil and natural gas wells on Federal mineral estate within the withdrawal area mainly exists north and northeast of CCNHP, although the resources exist in other portions of the withdrawal area. Recent industry drilling trends and geologic data indicate that economic concentrations of oil and natural gas do not exist south of the Fruitland outcrop except on isolated geologic structure. The area south of CCNHP and the Fruitland Coal outcrop, which comprises most of the withdrawal area, is not expected to be developed further as only a handful of new wells have been drilled in the area over the last 40 years, and only 16 active wells still exist there. Although some limited potential may exist south of CCNHP from the Dakota, Gallup and Mesaverde reservoirs, with undiscovered reserves within the Menefee coal beds, there have been no new discoveries over the last 40 years through record high and record low commodity prices. The potential for future development in the region south of the CCNHP is considered low to negligible (Figure 11).

The most productive oil-bearing formation in the area, outside of the Dakota sandstone, is the Gallup and associated “Gallup zone” of the Mancos Shale northeast of the true Gallup truncation line. Since the 1950’s numerous dry holes or uneconomic wells have helped defined the boundaries of the true Gallup pools with few prospective, undeveloped spacing units left. While Gallup, or Gallup zone of the Mancos, horizontal wells exist north of CCNHP within the withdrawal boundary, no new wells have been proposed in oil reservoirs south of the park. The
2018 RFD indicates that potential for horizontal well development south of the Fruitland outcrop near CCNHP is low to negligible (BLM, 2018). Moving up-dip (south-southwest) from the Fruitland Coal outcrop (Figure 6) leads to increased water saturation within the deeper oil and gas reservoirs (Dakota, Gallup, Mesaverde and Pictured Cliffs) and the Fruitland Coal no longer exists south of the outcrop boundary. The Fruitland Coal is the most prolific historic reservoir currently developed within the withdrawal area. Activity since approximately 2012 has been focused on targeting the Mancos and Gallup unconventional reservoirs with horizontal drilling and multi-stage hydraulic fracturing near the withdrawal boundary in a line roughly parallel with Highway 550 which mimics the general reservoir offshore bar trends that were deposited along the paleo shoreline of the Western Interior Seaway. Production data from existing wells in the area show that moving south from the Nageezi and Counselor, NM area towards CCNHP leads to an increase in water production (approximately 50% water in the production stream) from wells and a decrease in oil and natural gas production, as the reservoir is becoming water-saturated which can hinder economics of well development depending on commodity prices and overall production volumes. Despite these constraints, the development potential of areas identified in the 2018 RFDS was adhered to when creating estimated well counts within the withdrawal area. That is – areas identified in Figure 11 of this report as high, medium, low or negligible potential were treated as such when creating well count estimates for consistency with the 2018 RFDS.

It is likely that there will be additional Gallup/Mancos wells drilled between the withdrawal boundary and the Fruitland formation outcrop, to test the extent and limits of the water-wet boundary of the Mancos-Gallup reservoir. Full development of the withdrawal area is unlikely based on current industry drilling patterns and reservoir data, which indicate the
reservoir potential decreases between 5 and 10 miles outside of CCNHP, creating a natural geologic barrier to development near the park. The 2018 RFD also indicates that development potential is considered low to negligible within most of the withdrawal area except the outermost portion of the 10-mile boundary on the northeast side of the park (Figure 11 of this report) (BLM, 2018). While the RFD predicts there may be wells developed south of CCNHP, it is unlikely to occur on Federal leases as there is only one active Federal lease south of the park and it is currently in a non-producing status (Figure 13). It is expected that horizontal well development will continue on active leases within the withdrawal boundary between the Fruitland Coal outcrop and the 10-mile withdrawal boundary north of the park. The withdrawal may limit development and leave stranded resources in the ground as horizontal development requires large blocks of leases to produce oil and gas economically and effectively.

There are 168 active Fruitland coalbed methane wells within the Chaco withdrawal boundary, 1 of which is horizontal with 167 verticals. The average well has produced 0.305 BCFG with a maximum of 1.4 BCFG. Coalbed methane potential exists on the northeast side of the withdrawal area from the basin toward the Fruitland Coal outcrop which lies just north of the park. Fruitland coal development will be limited by the outcrop of the Fruitland coal just north of CCNHP. Large amounts of water are generally produced from Fruitland wells along with natural gas and consequently, water disposal infrastructure is required for development which can be costly and hinder development. Currently producing Fruitland Coal wells lie at a depth no shallower that 650 feet within the withdrawal. Looking at undrilled spacing units between the withdrawal boundary and where the Fruitland Coal is deeper than 650 feet, there are approximately 259 undrilled locations available (160 acre spacing). Within the withdrawal area, the Fruitland Coal is a shallow objective and vertical wells are common since horizontal wells
are difficult to execute with such shallow depths. It is expected that additional Fruitland Coal wells could be drilled within the withdrawal boundary if the price of natural gas stays above historic levels. This area of the basin is outside of the Fruitland Coal fairway along the New Mexico-Colorado border, where reservoir pressures are higher, and wells produce more gas on average but is still a viable development target.

In the 2018 RFD, a ranking system was created to identify areas where oil and gas development was more likely to occur (BLM, 2018). In this ranking system were high (10+ horizontal wells per township), medium (6-9 horizontal wells per township), low (4-8 vertical wells per township) and negligible (< 1 wells per township) areas of development potential. In order to estimate the number of wells that may be affected by the proposed withdrawal, we used an acre-based calculation to estimate the number of wells that may be drilled within the withdrawal boundary based on the development potential from the RFD. Within the withdrawal area there are 1.25 townships classified as high development potential, 5.75 as medium, 7.5 as low, and 24 as negligible (including lands that were not classified by the RFD but are geologically similar to other negligible lands). Well reduction estimates were completed using the 2018 RFD (see Table 4 in BLM 2018), which projects 10+ horizontal wells to be drilled per township in high potential areas, up to 9 horizontal wells per township in medium potential areas, up to 8 wells in low potential areas and < 1 well per township in negligible potential areas. Using acre-based estimating method, it is projected that 93 new oil and gas wells (66 horizontal and 27 vertical or directional per the RFD expected well types) would be drilled within the withdrawal boundary over the next 20 years on leased and currently unleased Federal mineral estate. If unleased Federal lands are withdrawn within 10 miles of CCNHP it would result in an estimated reduction of 47 oil and gas wells over the next 20 years (20 horizontal and 27 vertical
or directional). Using production estimates from the 2018 RFD, this would result in the loss of 206,737 barrels of oil per year and 3,759,416 MCF of natural gas per year. If 47 wells are not drilled as a result of the withdrawal proposal, 4,134,746 barrels of oil and 75,188,327 MCF of natural gas production would be foregone and associated royalties would not be paid to the Federal Government. The same methodology applied to the 5-mile withdrawal alternative results in an estimated 16 well reduction (5 horizontal and 11 vertical), which is the total estimated wells that would be drilled within the area because all but 7% of Federal minerals are unleased within 5 miles of CCNHP. Estimated foregone production from the 16 wells is 68,318 barrels of oil and 1,242,324 mcf of natural gas per year, or 1,366,360 barrels of oil and 24,846,480 mcf of gas over the 20-year withdrawal timeframe.

As a result of input received during public comment, wells that may not be drilled on Indian Allotted (IA) mineral estate adjacent to Federal mineral estate proposed to be withdrawn were also estimated. A methodology was created to classify level of impact on IA minerals by looking at the adjacency to existing leased minerals of all ownership types, as well as adjacency to unleased Federal minerals that would be withdrawn and areas that were previously nominated for leasing. Impacts to IA minerals were classified as high, moderate, low and negligible, where negligible means the proposed withdrawal would not impact the likelihood of development on IA minerals and high means the proposed withdrawal would impact the probability of development on IA minerals. Indian Allotted mineral acreage was run through the same well estimation calculation as Federal mineral acreage for both the 10- and 5-mile withdrawal alternatives. Within the 10-mile withdrawal area, 37 wells could be drilled on IA minerals with 24 of those wells projected on currently unleased minerals. If the 10-mile withdrawal is approved, it is estimated that 8 wells would be foregone on unleased Indian Allotments due to
the unavailability of adjacent Federal mineral estate. Within the 5-mile withdrawal area, 9 wells could be drilled, all on unleased Indian Allotted minerals as no IA leases exist within 5-mile of the park. It is estimated that 3 wells would be foregone on Indian Allotted minerals if the 5-mile withdrawal is approved due to the unavailability of adjacent Federal minerals.

Helium wells and associated production have not been estimated as there have been no helium wells drilled within or near the withdrawal area. It is unlikely that helium production would occur in the withdrawal area regardless of a withdrawal unless wildcat wells are drilled to test for helium and find an economic field at reservoirs below the Cretaceous-age oil and gas-bearing strata.

4.3  Uranium (Locatable)

4.3.1  Geologic Setting, Known Deposits and Mineralized Areas

Uranium can be found in almost any rock type from sedimentary sandstones, coals and limestones to metamorphic pegmatites and veins to volcanic deposits. Early discoveries of uranium in the Morrison Formation led to designation of the Grants uranium district in Cibola, McKinley, Sandoval, and Bernalillo counties (McLemore et al., 2016). The Grants district is broken into the Church Rock, Nose Rock, Smith Lake and Ambrosia Lake deposits, all of which are underlaid by the Morrison formation. Uranium is well known to exist within the Grants uranium districts within the San Juan Basin, the Grants District overlaps the southern portion of the proposed withdrawal area (Figure 14). Jurassic-age Morrison formation sandstones host the uranium as a fluvial sandstone placer deposit in both districts.

Over 340 million pounds of “yellow cake” uranium oxide U₃O₈ were produced from these two districts from 1948 through 2001, which is over 97% of all uranium produced in New Mexico and 37.8% of all US produced uranium (Brister and Hoffman, 2002). New Mexico
uranium reserves are 2nd in the US behind Wyoming, with 15 million short tons of ore, translating to 84 million pounds of \( U_3O_8 \) present in the Morrison Formation within the San Juan Basin. The Grants uranium district has not produced since 2002, despite being one of the global leaders in uranium production and producing more uranium than any other mining district in the United States (McLemore et al., 2016). The Westwater Canyon, Brushy Basin, and Jackpile members of the Morrison are the most commonly uranium-bearing, with the Westwater Canyon Member being the most prolific (Craigg 2001). Ore bodies are typically lenticular, tabular masses of complex uranium and organic compounds, redistributed sandstone uranium deposits, or remnant sandstone uranium deposits. Minor uranium has been identified within the Cretaceous Dakota sandstone, but no commercial production has occurred. Limestone-hosted uranium has also been produced in New Mexico, with 6.7 million pounds of uranium oxide from the Todillo Member of the Wanakah Formation (Jurassic). The Todillo limestone is the most productive uranium producing limestone in the world, but production stopped after 1981. Uranium also may occur in other sedimentary rocks, or in fracture-controlled veins of igneous or metamorphic rocks but production from these deposits is minimal.

4.3.2 Historic Development

Uranium has been mined extensively in New Mexico and within the southern portion of the San Juan Basin, partially overlapping the proposed withdrawal area, since the early 1900s (McLemore, 2007). The Carrizo Mountains on the northwest flank of the San Juan Basin were first staked with mining claims for uranium sometime around 1918, and the Navajo Reservation was opened to locating mining claims in 1919 (claims on the Reservation are required to be leased, which differs from claims on Federal lands). Early vanadium mining on the Navajo Reservation in the eastern Carrizo Mountains, by Vanadium Corporation of America, shipped
ore to a mill in Monticello, UT where the uranium was recovered and used as part of the Manhattan Project from 1943 – 1945 (McLemore, 2007). The Atomic Energy Commission, established in 1947, purchased the uranium concentrate that was produced in New Mexico from 1948 – 1966, which drove the uranium boom in the Four Corners area (McLemore, 2007). In 1950, uranium was discovered near Grants, NM in the Todilto Limestone, a member of the Jurassic Wanakah Formation, which led to prospecting throughout the San Juan Basin and the eventual delineation of the Grants Uranium District.

New Mexico’s uranium reserves are estimated to be the second largest in the U.S., with 84 million pounds of U$_3$O$_8$ (McLemore, 2007). Uranium is hosted in rocks throughout the state from the Precambrian to recent. From 1951 through 1980, the Grants Uranium District, located in the southern portion of the San Juan Basin (Figure 14) produced more uranium than anywhere else in the U.S. At one time the Grants district was the 4$^{th}$ biggest uranium producer in the world, with over 340 million pounds of U$_3$O$_8$ produced, a majority of which came from the Jurassic Morrison Formation, specifically the Westwater Canyon Member (McLemore, 2007). The uranium is hosted within the Morrison sandstones either as tabular, roll-front or fault-related deposits. Redistributed uranium deposits in the early Cretaceous Dakota Formation have been mined as well and produced 501,169 pounds of U$_3$O$_8$ in the southern portion of the San Juan Basin. Peak production of uranium in New Mexico was 9,371 tons of U$_3$O$_8$ shipped to mills. Over-production in the 1970s and 1980s, along with decreasing demand from dismantling of nuclear weapons and increasing domestic coal supply to meet energy needs, along with a downtrending ore grade from most active mines, led to closures of conventional underground and open pit uranium mines by 1989 (McLemore, 2007). Mine-water recovery continued in some areas until 2002 by Quivira Mining Co., previously Kerr-McGee Corp (McLemore, 2007). The
under-regulated uranium mining and milling industries of twentieth century left a legacy of abandoned and contaminated mine and mill sites in New Mexico, including piles of windblown mining waste and mill tailings and polluted ground water. Although many sites have been reclaimed and remediated, there remains many sites that are un-reclaimed and groundwater contamination is still present.

4.3.3 Known Mining Claims

The Grants uranium mining district overlaps the southern portion of the withdrawal area (Figure 14). There are no currently operating uranium mines within the entire Grants uranium district. Some abandoned mines are undergoing reclamation through the Abandoned Mine Lands programs. There are 129 recorded unpatented uranium mining claims located within the withdrawal boundary according to the BLM Mineral Lands Records System (MLRS) database. There are zero known acres of uranium leases on mineral estate managed by the Bureau of Indian Affairs, who do not manage uranium with mining claims but instead lease the rights to uranium under different regulations. The 129 mining claims in the withdrawal boundary account for 2,665.14 acres of land. A map of the claims is shown in Figure 15, a vast majority of the claims are located near Crownpoint, NM south of CCNHP, with others located along the NE boundary of the proposed withdrawal area. While these claims currently exist, there are no pending plans of operation for the claims that would lead to any type of mining activity. There have been no validity exams performed on the claims, as of now they are considered prospective. Claims are commonly staked when uranium prices are high, prices in 2021 were $33.91/lb of U₃O₈ yellow cake, down from a high of $55.64/lb in 2011 but up from the $11.04/lb price in the year 2000 according to the Energy Information Administration website.

4.3.4 Mineral Economics and Future Potential
Future potential for uranium within the subject area is considered low overall. Since high-grade, low-cost uranium deposits in Canada, Kazakhstan, East Germany, South Africa, and Australia and the large low-grade deposits in Kazakhstan are sufficient to meet current international demands, it is unlikely that uranium development will occur in the withdrawal area. Additionally, the market for uranium is largely dependent on nuclear power, but the current shift is towards renewables with additional reliance on natural gas as coal is phasing out. There have been no successful nuclear power plants brought on-line recently in the U.S. that would lead to increased uranium demand. The Navajo Nation has declared that no uranium production will occur on tribal lands, which could preclude development in the Grants district where mineral ownership is broken into a checkerboard pattern and would require multiple mineral owners to approve mining. Most of Mt. Taylor and adjacent mesas have been designated as the Mt. Taylor Traditional Cultural Property, which would preclude development in portions of the Grants district as well. Overall, uranium demand has dropped in the U.S. from nuclear power plants over the past 5 years. In 2016, 50.6 million pounds of yellow cake were purchased at an average of $42.43 per pound by the nuclear power industry, compared to 46.7 million pounds at an average price of $33.91 per pound in 2021. With permitting hurdles, lack of contiguous mineral ownership, and a lack of interest in nuclear power reactors from the U.S., it is unlikely that uranium would be developed extensively within the withdrawal area. It is expected that international uranium sources would be sufficient to supply any increase in demand for nuclear power in markets outside of the U.S.

5 Potential for Occurrence of Mineral Resources

The potential for occurrence of mineral resources is graded with a two-part system that is laid out by BLM Manual 3031 (BLM 1985). The potential for occurrence is meant to describe
the existence of minerals within the study area but does not consider whether a mineral concentration would be economic to develop or indicate a likelihood of development. The framework from BLM Manual 3031 is as follows (refer to Figure 16):

- **Level of Potential**
  - **O** = The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.
  - **L** = The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.
  - **M** = The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.
  - **H** = The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The “known mines and deposits” do not have to be within the area that is being classified but must be within the same type of geologic environment.
  - **ND** = Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

- **Level of Certainty**
  - **A** = The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.
- B = The available data provide indirect evidence to support or refute the possible existence of mineral resources.
- C = The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources.
- D = The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

The potential for mineral occurrence is described below for certain categories of minerals. The list of minerals described below is not meant to be exhaustive of every mineral type the BLM may manage, but groups certain minerals into broad categories especially for those that may not occur. Many minerals are excluded that fall under the category of salable minerals, as they are not affected by the proposed withdrawal. Geothermal energy as a mineral resource is also not included as it is not included in the withdrawal and the study area does not contain the geothermal gradient necessary to develop these types of resources.

5.1 Locatable Minerals

5.1.1 Metallic Minerals – L/C

Metallic minerals may include gold, silver, copper, lead and zinc, among others. There are no known metallic mineral mining districts, reported occurrences or historic production in the withdrawal area. The geologic environment and inferred geologic processes of the withdrawal area are unfavorable to presence of metallic minerals as they are not commonly found in sedimentary rocks that cover the entire withdrawal area. There are no nearby source rocks for metallic minerals that would lead to presence of metallic minerals in any type of placer deposit within the study area either.
5.1.2 Non-metallic and Industrial Minerals – L/C

Many non-metallic and industrial minerals such as limestone, clays, silica sand and gravel fall under the category of salable minerals and are not affected by the proposed withdrawal. Non-metallic and industrial minerals may also include asbestos, barite, fluorspar, lithium, and potash among others. There are no known non-metallic and/or industrial minerals mining districts within the proposed withdrawal area. The geologic environment and inferred geologic processes of the withdrawal area are unfavorable to the presence of these types of minerals which are not commonly found in sedimentary rocks that are present throughout the entire withdrawal area. Silica sand of uncommon variety, such as proppant sand for hydraulic fracturing use, does not exist in the sedimentary rocks in the area. Common sources of frac sand are generally eolian dune-derived sands where the sorting and rounding of sand grains are very consistent. The sands in the study area are generally marine or fluvial in nature, not eolian thus this type of sand is unlikely to occur.

5.1.3 Uranium – H/D

The proposed withdrawal area overlaps mapped uranium mining districts with historic production and is known to contain strata that commonly host uranium (the Jurassic-age Morrison Formation), meaning the potential for uranium to occur within the area is high. This is based on direct evidence of adjacent uranium production and the presence of uranium-bearing sandstones. The geologic environment and inferred geologic processes in the southern portion of the withdrawal area near Crownpoint, NM are favorable to uranium presence and accumulation. The presence of mining claims does not mean uranium is present in economic quantities, but indicates the mineral is likely to be present in some quantity.
5.2 Leasable Minerals

5.2.1 Coal – H/D

The proposed withdrawal lands are known to contain coal within strata within the Fruitland Formation, Menefee Formation of the Mesaverde Group, and Crevasse Canyon Formation. There are known historic coal mines that produced coal economically and expired PRLA’s are also present within the withdrawal area. Multiple mapped coal fields overlap the withdrawal area as well. This conclusion is based on the direct evidence of coal presence, known geologic environments, and inferred geologic processes which were favorable to coal formation in the area.

5.2.2 Oil, Natural Gas and Helium – H/D

The proposed withdrawal lands are known to contain oil and natural gas across the entire area. The presence of Cretaceous strata that is either currently producing or historically produced is documented across the entire withdrawal area. There are hundreds of active or plugged and abandoned oil and natural gas wells present within the proposed withdrawal. Helium is known to occur in Paleozoic strata outside of the withdrawal area and is likely present at great depth within the withdrawal area. Triassic strata have also been reported to contain helium, but no wells have been drilled to test concentration and production potential. This conclusion is based on direct evidence of oil and natural gas presence, known geologic environments within the San Juan Basin, and inferred geologic processes which were favorable to oil and natural gas formation in the area.
6 List of Preparers

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Geologic Map of the CCNHP Area Withdrawal

New Mexico Bureau of Geology & Mineral Resources Geologic Map of the CCNHP Area Withdrawal

Scale 1 Inch = 6 miles @ 8.5" X 11"

Chaco Culture National Historical Park Area Withdrawal Boundary
Chaco Culture National Historical Park (CCNH-P)
Federal Forest Reserve: Natural Area
Designated Wilderness
Kanab Wash
Geologic Map Unit (NMBGMR)

Public Land Survey System (PLSS) Township
Federal Mineral Estate
Withdrawn Federal mineral estate & railroad
Deposited Federal mineral estate at the surface (NMBGMR)

Geologic Map Unit (NMBGMR)

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Increasing Certainty >>>

\(^1\) No Potential