OIL AND GAS RESOURCES
OF
THUNDER BASIN NATIONAL GRASSLAND, WYOMING

U.S.D.A. FOREST SERVICE
ROCKY MOUNTAIN REGION

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PREFACE

Implementing regulations of the 1987 Federal Onshore Oil and Gas Leasing Reform Act require the Forest Service to analyze the environmental effects from activities that might result from implementation of a proposed oil and gas leasing program (36 CFR 228 Subpart E). Such activities are presented as a scenario, commonly referred to as a "Reasonably Foreseeable Development Scenario", or "RFD". This report constitutes the formal presentation of the RFD for Thunder Basin National Grassland (the grassland), in support of analysis of and decision on a leasing program to be carried out under a revised land management plan. Technical information in this report has been supplied to the interdisciplinary team throughout the analysis process for the revised plan.

Thunder Basin National Grassland lies in the Powder River Basin, a very prolific oil and gas producing basin with a long history of development of conventional oil and gas resources. In the mid- to late-1990's, natural gas from coal beds (coalbed methane) became a significant target for exploration and development. Development of the resource has been occurring in the western part of the grassland throughout the preparation of this report and analysis for the plan revision. The early preliminary draft RFD (Holm, 1999) for the grassland addressed coalbed methane in some detail. However, while analysis for the grassland plan revision was in progress, the Bureau of Land Management initiated analysis of the greater coalbed methane area, including that part of the grassland with coalbed methane potential. The decision was made to address coalbed methane under that analysis. Consequently, this final RFD report provides only a general discussion of coalbed methane and future development of that resource.

Acknowledgements

The author acknowledges the following individuals for their support, productive and enlightening discussions of Powder River Basin geology and resource development, and comments on the preliminary draft RFD: Fred Crockett, Bureau of Land Management Reservoir Management Group in Casper, Wyoming, and Ron Baugh and Jimmy Goolsby, Associated Energy Consultants in Casper, Wyoming. The author also acknowledges the following members of the plan revision interdisciplinary team for thoughtful discussion on resource management, helpful hints on information about oil and gas that the team needed for analysis purposes, and assistance with determining acreage figures and map elements: Terry Dilts and Jeff Ulrich, Nebraska National Forest in Chadron, Nebraska, and Joe Reddick, Thunder Basin National Grassland in Douglas, Wyoming.

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Summary

Thunder Basin National Grassland occupies a substantial portion of the south-central and eastern Powder River Basin in northeastern Wyoming. The basin ranks among the most prolific oil and gas producing basins in the United States. It contains a nearly complete geologic section with proven oil and gas reservoirs in fields of various sizes and high potential for future exploration and development activity. A moderate, continuous level of exploration and production activity has occurred through the last ten years, subsequent to several periods of intense drilling and significant discoveries since the early 1900's. Moderate levels of exploration and development activity associate with conventional[1] oil and gas resources are expected to continue through 2010. In addition, high levels of exploration and development activity for unconventional[2] methane gas resources from coal beds are expected in the extreme western part of the grassland through 2010 and beyond. Under an unrestricted access scenario, approximately 405 acres of new long-term disturbance (20+ years) will accompany up to 150 conventional producing wells, with 80 additional exploratory dry holes (296 acres of short-term disturbance) drilled, plugged, abandoned and reclaimed. An estimated 360 acres of disturbance associated with old abandoned wells will be reclaimed. New disturbance will be offset by old disturbance reclaimed, with a net 15 acres of long-term disturbance above that which currently exists.

Activity associated with development of coalbed methane gas resources is rapidly increasing in the grassland. Earlier investigation (Holm, 1999) of coalbed methane activity resulted in an estimate of up to 540 new coalbed methane wells in the grassland, 486 of which would be completed as producing. More recent activities and knowledge of the resource, however, indicate that coalbed methane activity very likely will occur at levels higher than that. Bureau of Land Management is developing scenarios of future coalbed methane development activity.

Introduction

Implementing regulations of the 1987 Federal Onshore Oil and Gas Leasing Reform Act require the Forest Service to analyze the environmental effects from activities that might result from implementation of a proposed leasing program (36 CFR 228 Subpart E). A scenario of the type and amount of post leasing activity that is reasonably foreseeable as a consequence of leasing under specified conditions is the basis for analysis of effects. This report provides an activity scenario based on resource occurrence, with development unconstrained by restrictions beyond those provided under standard lease terms. Information in this report provides a context in which activity scenarios under different levels of management constraints can be developed.

Oil and Gas Resource Potential: Geologic criteria defined in Appendix 1 are the basis for

[1] The term "conventional resources" references discrete deposit(s)...from which oil, gas, or NGL (natural gas liquids) can be extracted using traditional development practices, including production at the surface from a well as a consequence of natural pressure within the subsurface reservoir, artificial lifting of oil from the reservoir to the surface where applicable, and the maintenance of reservoir pressure by means of water or gas injection. (U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995)

[2] The term "unconventional resources" include a broad class of hydrocarbon deposits of a type...that historically has not been produced using traditional development practices. (U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995)

determining potential for occurrence of oil and gas resources. Areas of defined potential include lands adjacent to the analysis area, where geology and exploration and development activity provide useful information for describing potential inside the analysis area. The "Oil and Gas Resource Potential" section of this report summarizes previous studies, provides descriptions of stratigraphy and structure, and describes past and current oil and gas drilling and production activities with emphasis on potential reservoir rocks, source rocks, and stratigraphic and structural traps.

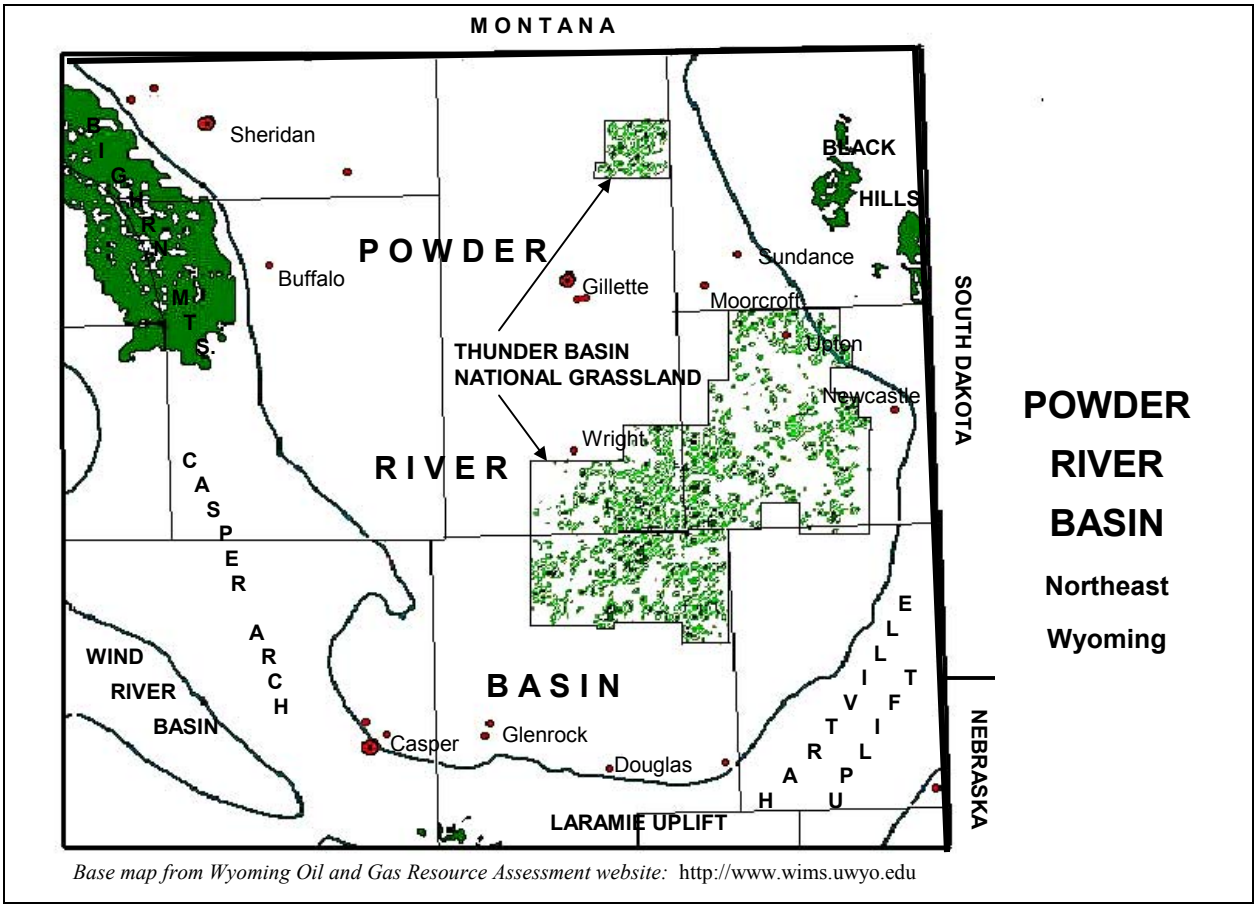
Scenario for Future Oil and Gas Exploration and Development Activity: Regulations require a reasonable scenario of possible future oil and gas activity in areas for which oil and gas leasing decisions are to be made. Such a scenario is the basis for assessing potential effects of leasing National Forest System lands and federal minerals for oil and gas exploration and development. The "Scenario for Future Oil and Gas Exploration and Development Activity" section of this report presents the type and level of anticipated activity principally based on geology and past and present activity. This section also introduces other factors that may influence the type and level of future activity, such as economics, technology, physiography, and availability of processing facilities and transportation.

Relationship of Potential for Resource Occurrence to Potential for Activity: Projected oil and gas activity may not always equate with geologic potential for the occurrence of hydrocarbons. In some areas, all geologic factors may indicate high potential for occurrence of oil and gas resources, but other factors (I.e., inaccessibility, risk, high exploration expenses, and/or low product prices) may limit options for exploration and development activity. Conversely, increases in product prices, advances in technology, new ideas about the geologic setting of an area, supply shortages, and even international events could lead to drilling activity in an area that may be interpreted to have low potential for resource occurrence. In any case, scenarios of future activity can only be based on currently known conditions and reasonable expectations of changes in variable factors, such as changing technology and price forecasts.

Land ownership in national grasslands: "Thunder Basin National Grassland" (the grassland) refers to the greater grassland area as defined by the boundaries shown on the map in Figure 1. The grassland is a checkerboard of federal, state, and private lands, with a fairly high level of "split estate" **(**a little over 146,000 acres**)**, or lands with mineral ownership different from that of the overlying surface. The nature of land ownership within the defined area of the grassland sets up a unique and challenging situation in which to project future oil and gas activity with respect to federal lands and minerals. The federal government owns about 1.16 million acres of minerals of the slightly more than 1.8 million acres within the boundaries of the grassland. The Forest Service administers the surface, much of it as relatively small isolated tracts, of slightly more than 532,000 acres of federal minerals and about 20,000 acres of privately owned minerals. The Bureau of Land Management (BLM) administers the remainder of the federal minerals (about 626,400 acres) underlying private surface within the boundaries of the grassland. A little over 657,700 acres of surface together with minerals are private or state-owned. Estimating future oil and gas exploration and production activity for these varied mineral ownerships and surface jurisdictions with respect to specific locations, isolated tracts, and even areas of less than a township in size is unreasonable.[3] Consequently, projections of future oil and gas oil and gas

[3] Individual oil and gas fields in the Powder River Basin, depending on the reservoir, range in geographic extent from approximately 640 acres (one section) to over 23,000 acres (a township).

exploration and production activity are based primarily on historical drilling trends and are applied to broad areas that consist of mixtures of land ownership.



Base map from Wyoming Oil and Gas Resource Assessment website: http://www.wims.uwyo.edu

Figure 1. Powder River Basin and Thunder Basin National Grassland, northeast Wyoming, with physiographic features. (Grassland boundaries approximate.)

Oil and Gas Resource Potential

Geology

Physiographic and geologic setting

Thunder Basin National Grassland (the grassland) covers a portion of the broad, shallow west-dipping east flank of the northeastern Wyoming Powder River Basin (the basin), which is a both a geologic basin and a physiographic basin (Figure 1). Present basin configuration resulted from Laramide orogenic events (Late Cretaceous to Early Tertiary, 50-75 mya). The basin is surrounded by uplifts: the Bighorn Mountains and Casper Arch to the west, the Laramie and Hartville uplifts to the south, the Black Hills uplift to the east, and the Miles City Arch to the north in Montana. The basin is about 125 miles long in a north-south direction and about 100

miles wide, with a deep structural axis close to its western margin, directly east of and parallel to the Bighorn Mountains. A thick, almost continuous, sequence of Cambrian- to Quaternary-age sediments fills the basin. Continental sediments (sandstone, siltstone, mudstone, and shale) of Late Jurassic to Early Tertiary age crop out in the northeastern part of the grassland on the west flank of the Black Hills uplift. Succeedingly younger (Cretaceous-Tertiary) sedimentary units of marine and continental origin (conglomerate, sandstone, siltstone, mudstone, shale, and coal) crop out from northeast to southwest across the grassland. Some of the Cretaceous units in this sequence serve as source and/or reservoirs for hydrocarbons in the subsurface.

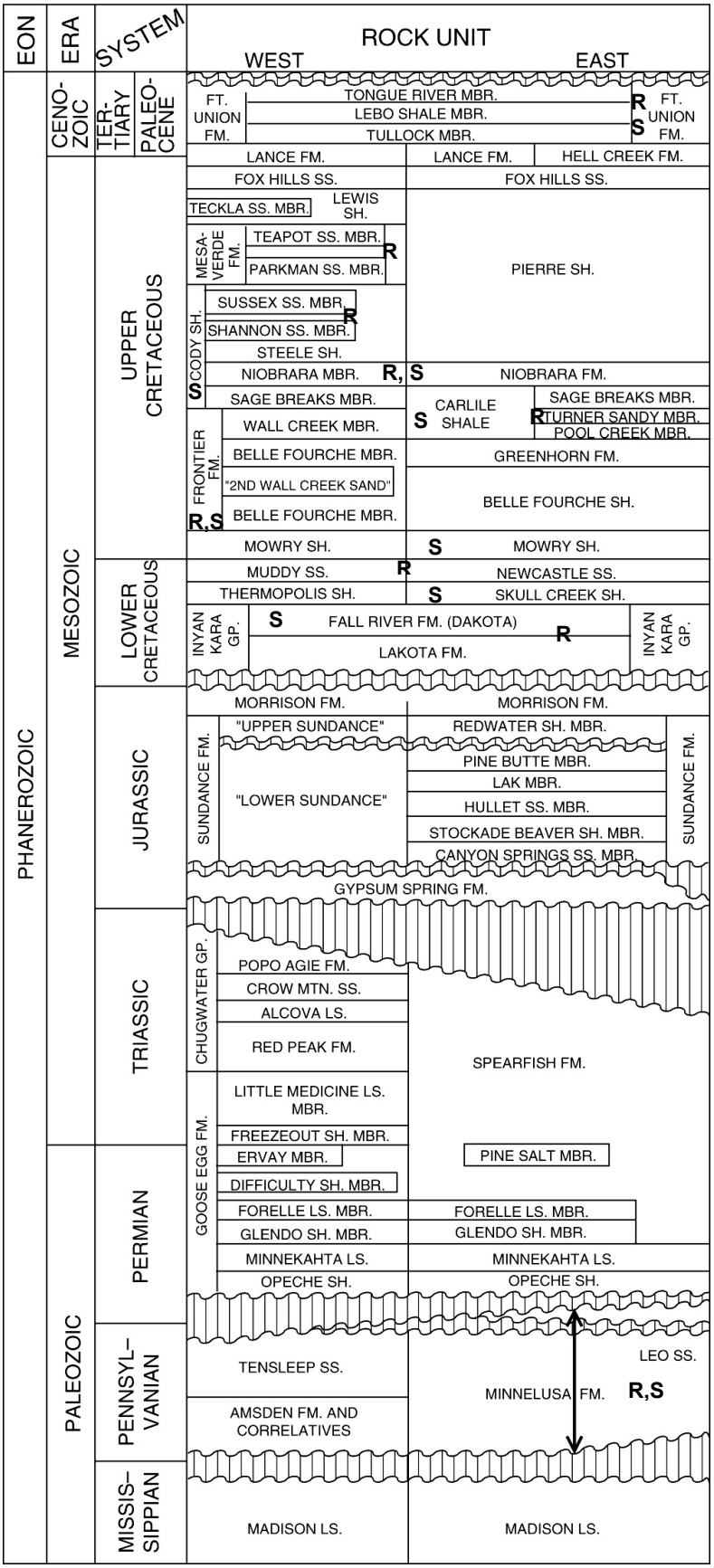
The geologic structural grain controls drainage development, particularly in the northeastern part of the grassland where drainages are aligned along the strike of the sedimentary units. A regional fracture system, generally comprising two fractures sets exert local control on surface drainage and topography (Choate, Johnson, and McCord, 1984). Differential erosion of soft Tertiary sandstones and shales and more resistant clinker (baked shales resulting from burning of coals seams) create an irregular topography of rolling to steep hills and badlands. Local variations in geology and soils affect ecosystem character, though the semi-arid climate with pronounced seasonal variation in temperature and precipitation have the greatest influence on vegetation types.

Stratigraphy (reservoirs, seals, source rocks, and stratigraphic traps)

Stratigraphic framework. The Powder River Basin contains a nearly complete sedimentary section ranging in geologic age from Cambrian at depth through Cretaceous and Tertiary to Recent exposed at the surface. Figure 2 illustrates the geologic sequence, stratigraphic relationships, and significant oil and gas producing horizons in the basin. The Paleozoic section (Cambrian through Permian) consists predominantly of carbonates (limestone and dolomite), with some interbedded shales and sandstones. The sequence is primarily of marine or marginal marine origin and rarely exceeds 2,200 feet in thickness (Dolton and Fox, 1996). The Mesozoic and Cenozoic section (Triassic through Tertiary/Eocene) records continental environments, followed by marine environments resulting from encroachment of the Western Interior Seaway, and culminating in continental environments. Formation of the present-day physiographic basin began in Late Cretaceous time by basin-bounding regional and local uplifts that shed sediments into the basin. The Mesozoic-Cenozoic section consists of about 16,000 feet of interbedded sandstone, siltstone, and shale, with lesser amounts of conglomerate, limestone, and coal.

Exposed at the surface throughout most of the grassland are young, soft sediments of the Tertiary Ft. Union and Wasatch formations. Successively older units from Upper Cretaceous Lance to Jurassic Morrison crop out from southwest to northeast over the eastern third of the grassland. Jurassic sediments are present at the surface only in the northeast part of the grassland.

Reservoirs, seals, and source rocks. Primary reservoir rocks in the subsurface of the Powder River Basin are sandstones of Cretaceous age (Figure 2). Sandstones and carbonates of Pennsylvanian age, sandstones of Tertiary age, and Tertiary coals also serve as reservoirs. The Cretaceous sandstone reservoirs are variable in character and quality, ranging from fine-grained, relatively "clean" sandstones to poorly sorted, even conglomeratic, and often have high clay content. Porosity and permeability can range from very low to 25% porosity and 1,000



STRATIGRAPHY
of the
POWDER RIVER BASIN

Mississippian through Tertiary

Emphasis on Oil and Gas Reservoirs and Source Rocks

R Reservoir rocks

S Source rocks

Stratigraphic column from U.S. Geological Survey, 1995 National Assessment of United States Oil and Gas Resources, DDS 36.

Figure 2

millidarcies permeability. Pennsylvanian age reservoirs are primarily sandstone with porosities ranging from 12% to 24%. Vuggy dolomite is a secondary reservoir in the Pennsylvanian section. Tertiary sandstones of variable composition and porosity serve as reservoirs for natural gas. Coals of Tertiary age are "unconventional" reservoirs and are discussed under "Coalbed Gas", below.

Impermeable shale layers overlying sandstone units inhibit the migration of oil and gas out of the more porous sandstone reservoirs. Some shale units of Cretaceous age are also proven source rocks of regional significance. Organic material in the shales is the source of oil and gas that are generated when the organic-rich rocks are deeply buried and subjected to high temperatures and pressures. As generation occurs, the oil and gas are forced out of the shales and migrate into the more porous sandstone units where hydrocarbons accumulate under certain kinds of reservoir and sealing conditions.

Tertiary formations in the basin contain thick coals – the richest source of coal in the nation. Wyoming leads all states in coal production, largely from the Powder River Basin, with seven mines, including the largest open pit mine in the U.S., on Thunder Basin National Grassland. The coals are not only mined, but also serve as source of and reservoir for methane gas, a clean-burning fuel for which demand is increasing.

Stratigraphic traps. Primary reservoirs in the Powder River Basin have depositional characteristics favorable for the occurrence of stratigraphic traps. Stratigraphic traps generally are porosity "pinch-outs", such as restricted bodies of sandstone encased in shale by sequential depositional events. Stratigraphic traps are not necessarily directly associated with any kind of structural deformation, though a combination of structural-stratigraphic trapping mechanisms controls some oil and/or gas accumulations. Most of the fields in the basin are stratigraphic in nature, and future discoveries are also expected to be in stratigraphic traps.

Geologic structure

The regional structure of the area in which the grassland lies is that of a gentle homoclinal slope dipping 1-2^{o} or less west. Small-scale folds and faults occurring in the sedimentary section on this slope are interpreted to be compaction structures that formed in response to facies changes associated with the marine, fluvial, and lacustrine environments characteristic of the Cretaceous and Tertiary sections. In the Cretaceous and older section, pre-existing deep basement structures may, in part, control deposition patterns and synsedimentary structural features. Such control becomes less influential in succeedingly younger sediments. In the Tertiary section, structural irregularities on shallow coal beds, including small domes and depressions, reflect uneven surfaces of deposition and differential compaction of coal and adjacent sediments. (Larsen, 1989, and Kent, 1978a).

Coalbed gas

Extensive coal beds in various U.S. basins, including the Powder River Basin, are proven reservoirs for methane gas. The gas can occur as free gas, as gas adsorbed on pore and micropore surfaces within the coal matrix, and as gas dissolved in water that commonly occurs in coals. Pumping off the water and reducing the hydrostatic pressure results in release of the gas adsorbed (trapped) on coal surfaces and dissolved in the water.

Coals in the Tongue River member of the Tertiary Fort Union Formation are significant reservoirs of methane gas in the central basin, including the westernmost part of the grassland. The primary producing coal is the Wyodak-Anderson seam, generally 60-70 feet thick, but up to 100 feet thick in local areas. The seam is most productive west of the outcrop at depths of 200-1,000 feet below the surface. Depths increase westward from the outcrop. Factors controlling the occurrence and productivity of coalbed gas include thickness, heterogeneity, depth, composition and maturity of the coal; seals; gas content and permeability of the coal reservoir; gas composition; pressure regime; structural setting (folds, faults, joints, cleats); and hydrology. (Rice, 1995). The Tongue River coals are low rank coals (low maturity; lignite to subbituminous B), and the coal gas is biogenic (of biologic origin) rather than thermogenic (originating from "cooking" or thermal alteration of the coals). Gas content of the coals appears to be variable, ranging from 20 standard cubic feet per ton to 90 standard cubic feet per ton in deeper coals (Finley and Goolsby, 2000). The very large resource of coal in the Tongue River member in the basin (about 1.2 trillion tons in seams greater than two feet thick to depths of 3,000 feet) provide for a very large gas-in-place resource. Recent studies to determine recoverable gas have determined that about 25 trillion cubic feet of gas based on a weighted average gas content of 65 standard cubic feet per ton of coal may be recoverable from coal beds in the Powder River Basin (Finley and Goolsby, 2000).

Active mining of the Anderson-Wyodak coal seam occurs on the grassland west of the coal outcrop along a generally north-south trend in Ranges 70-71W. In the grassland, the Anderson-Wyodak is most prospective as a methane gas reservoir in an area covering approximately 13 townships, or 468 square miles, west of the area mined for coal in T40-43N, R70-71W. Areas of structural relief resulting from differential compaction (discussed under "Structure", above) increase the prospectiveness of the coalbed gas resource. Such areas generally have a more extensive fracture system that enhances accumulation of free gas and allows for greater release of adsorbed gas.

USGS oil and gas plays

In its 1995 National Assessment of United States Oil and Gas Resources, the U.S. Geological Survey (USGS) identified 12 "conventional" oil and gas plays and four "unconventional" oil and gas plays in the Powder River Basin. Conventional accumulations of oil and gas include those "discrete deposit(s)...from which oil, gas, or NGL (natural gas liquids) can be extracted using traditional development practices, including production at the surface from a well as a consequence of natural pressure within the subsurface reservoir, artificial lifting of oil from the reservoir to the surface where applicable, and the maintenance of reservoir pressure by means of water or gas injection." Unconventional oil and gas accumulations are those that fall into "a broad class of hydrocarbon deposits of a type...that historically has not been produced using traditional development practices..." The "unconventional" class of oil and gas resources includes gas from coal beds, more commonly called coalbed methane. (Definitions from U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995.)

Portions of nine conventional oil and gas plays identified by the USGS occur on the grassland (Table 1). Three of the nine are quite extensive and occur over almost all of the area of the grassland and beyond. The other seven occur on only portions of the grassland (Figure 3). Portions of four unconventional plays also occur on the grassland. Two continuous-type plays are in fractured shales that serve as both source and reservoir for oil and gas. Portions of two

unconventional coalbed gas plays (PRB Central Basin and PRB Shallow Mining Related plays, as defined in the 1995 USGS assessment) occur in the western part of the grassland. Exploration and development activity associated with the coalbed methane plays contributed to some of the highest levels of activity in the onshore U.S. in 1998-2000, with high levels of activity expected to continue well into the 21st century.

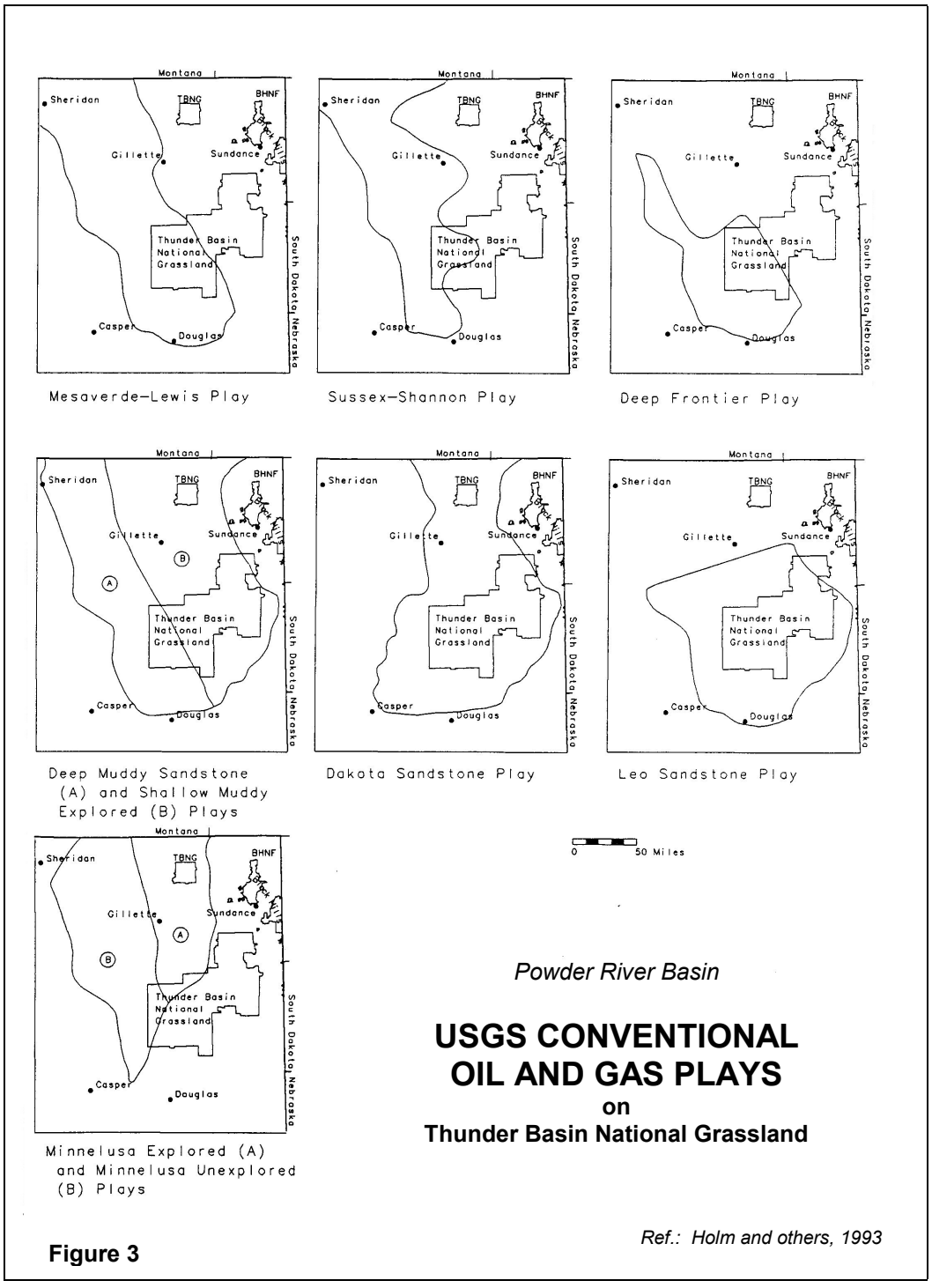


Figure 3

Table 1. Characteristics of USGS oil and gas plays that occur at least in part on Thunder Basin National Grassland. Specific proven reservoirs identify each of the conventional plays. The unconventional fractured shale plays are hypothetical with insufficient data to permit assessment to the extent of the proven plays (*USGS, 1995).* Plays that occur on over 90% of the grassland are in boldface. Abbreviations: Penn. = Pennsylvanian; Strat = stratigraphic; combo = combination structural-stratigraphic; sh = shale.

USGS OIL AND GAS PLAYS – POWDER RIVER BASIN							
	Formation	**Reservoir**	**Porosity**	**Source**	**Trap**	**°API/GOR**	**Status & Potential**
CONVENTIONAL RESERVOIRS	Mesaverde-Lewis Sst.	Sandstone	12-18%	Kn, Kc, Kf, Ks	Stratigraphic	35-47°/ 100-10,000	Oil, gas Numerous fields, mod-high potential, sm-med accumulations
	Sussex-Shannon Sst.	Sandstone	10-15%	Kn, Kc, Kf, Ks	Stratigraphic	35-39°/ 300-2,100	Oil Few fields, mod-high potential, sm-med accumulations
	Turner	Sandstone	12-15%	Km, UK sh.	Stratigraphic	39-43°/ 500-2,400	Oil Few fields, mod. potential, small accum.
	Deep Frontier Sst.	Sandstone	10-15%	Kc, Kn, Kf, Km	Stratigraphic	34-47°/ 1,000-13,000	Oil, gas Few fields, mod. potential, small accum.
	Muddy Sst.	**Sandstone**	**9-22%**	**Km, Ksc, Kfr shale**	**Stratigraphic**	**35-50°/ 1,000-3,000**	**Oil** **Numerous fields w/ signif. reserves, mod. potential, sm-med accumulations**
	Fall River Sst.	**Sandstone**	**8-23%**	**Km, Ksc, Kfr shale**	**Strat, combo**	**28-46°/ 400-2,000**	**Oil** **Numerous fields w/ signif. reserves, mod. potential, med. accumulations**
	Lakota Sst.	Sandstone	To 25%	Km, Ksc, Kfr shale	Strat, combo	26-45°	Oil Few fields, moderate potential, small accum.
	Upper Minnelusa Sst.	Sandstone, dolomite	To 28%	Penn. shale	Stratigraphic	18-40°/ 60	Oil Numerous fields, good potential, med-lg accumulations
	Leo Sst	**Sandstone**	**To 25%**	**Penn. shale**	**Stratigraphic**	**20-35°/ non-gas**	**Oil** **Few fields, good potential, small accumulations**
UNCONVENTIONAL RESERVOIRS	PRB Central Basin	Coal		Self-sourced	Continuous, structure enhanced		Gas (coalbed methane) Developing, high potential, large reserves
	PRB Shallow Mining Related	Coal		Self-sourced	Continuous, structure enhanced		Gas (coalbed methane) Developing, high potential, large reserves
	Niobrara Fractured Shale	Fractured shale		Self-sourced	Continuous		Unproven; speculative
	Mowry Fractured Shale	Fractured Shale		Self-sourced	Continuous		Unproven; speculative

Historical activity

The Powder River Basin is one of the richest petroleum provinces in the Rocky Mountains with more than 2.7 billion barrels of recoverable oil and over 2.3 trillion cubic feet of gas discovered in about 700 fields between 1908 and 1995 (Dolton and Fox, 1996). All or parts of approximately 74 fields occur within the boundaries Thunder Basin National Grassland (Figure 4). Reservoirs in the area produce mostly oil with associated gas. The oil is sweet, with gravities ranging from about 20° API to 50° API. Lower gravity oils occur in the eastern or shallower reservoirs, with increasing gravities west at greater depths. Coalbed methane (sweet gas) reservoirs are being developed in the western part of the grassland at shallow depths.

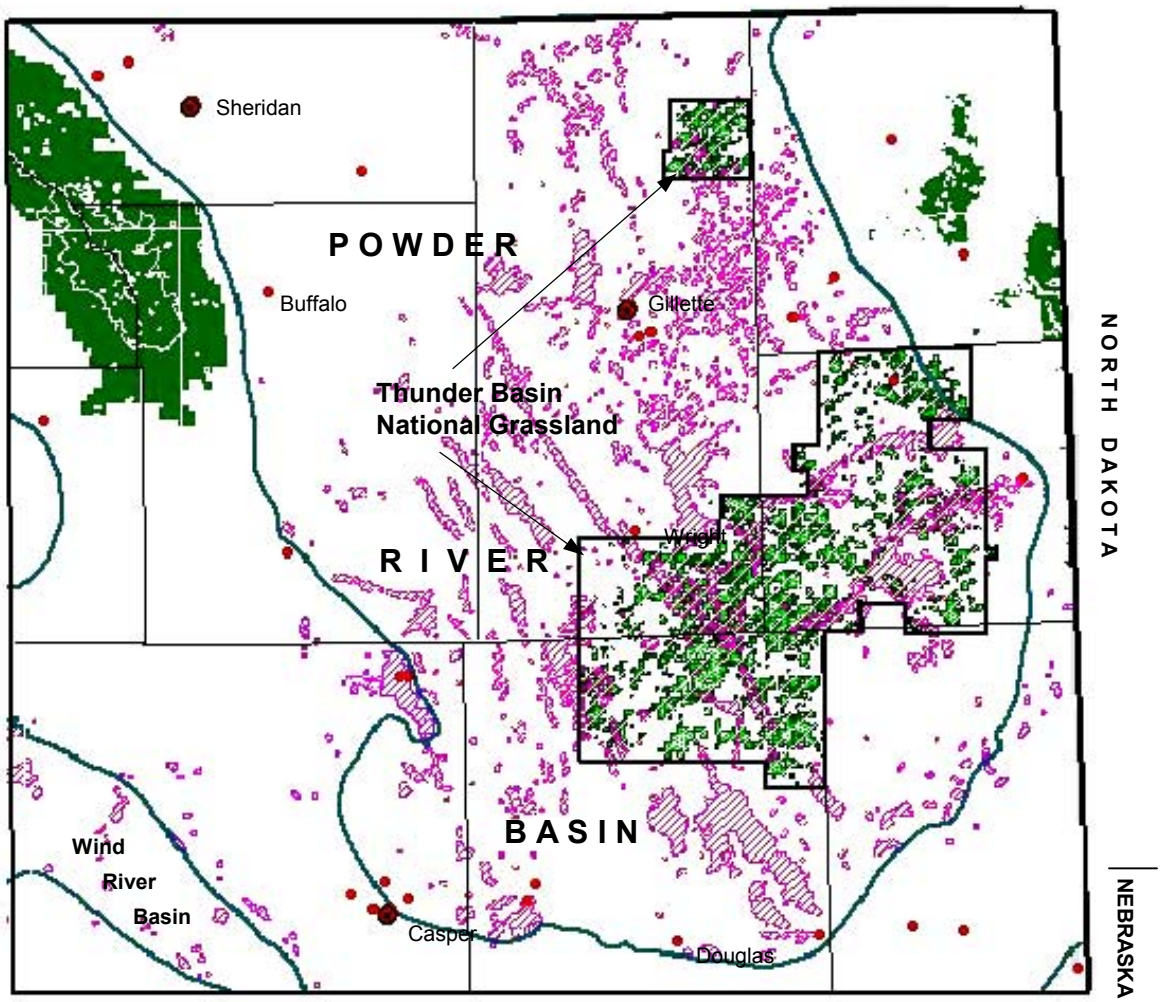


Figure 4

Base map from Wyoming Oil and Gas Resource Assessment website: http://www.wims.uwyo.edu

Recent exploration and production trends

Exploration and development of shallow oil resources occurred during the early 1900's in the eastern part of the basin near Newcastle and in the western part of the basin with the discovery of the giant Salt Creek field. Most of the activity in and near the grassland through the 1940's occurred in reservoirs that are relatively shallow near the eastern margin of the basin. Evolving concepts in stratigraphy, particularly with respect to trapping mechanisms, along with improved drilling technology, contributed to a surge in drilling activity during the 1960's and 1970's. Many of the major fields in the deeper parts of the basin were discovered during this time period. A later surge of exploration, discovery, and development occurred again in the early 1980's with a significant increase in oil prices. Even though prices have reached historic lows since the mid-1980's, low risk, coupled with new affordable technology, has contributed to ongoing drilling programs, further development of older fields, and a few new discoveries. Figure 5 illustrates the continuous nature of drilling and success rate trends through the 1990's.

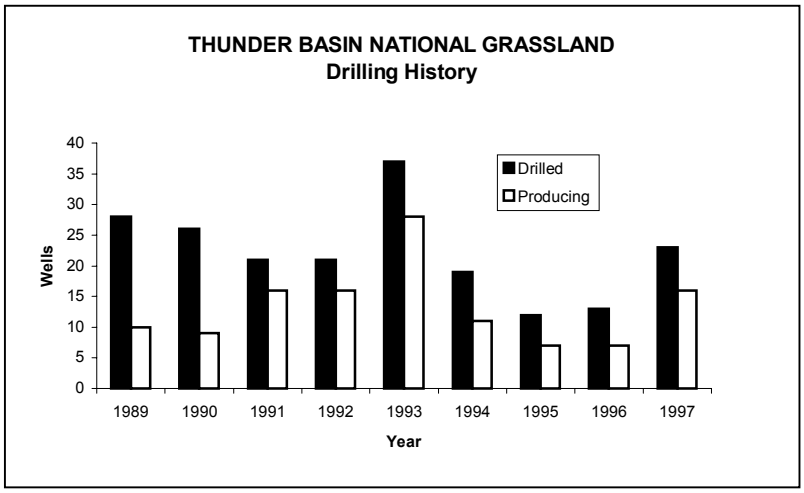


Figure 5. Number of wells drilled and completed in Thunder Basin National Grassland, 1989-1997.

For purposes of analysis, four different oil and gas areas can be defined in the grassland based on slightly different characteristics of oil and gas occurrence (Figure 6). Differences in structural setting, depositional character, erosional history, and depth and extent of reservoirs among the four areas account for somewhat different development and production characteristics from area to area. Each area can be characterized by a major producing trend: North Area – Muddy and Minnelusa trends, Northeast Area – Fiddler Creek trend, Southeast Area – Clareton trend, and West Area – multiple trends and reservoirs.

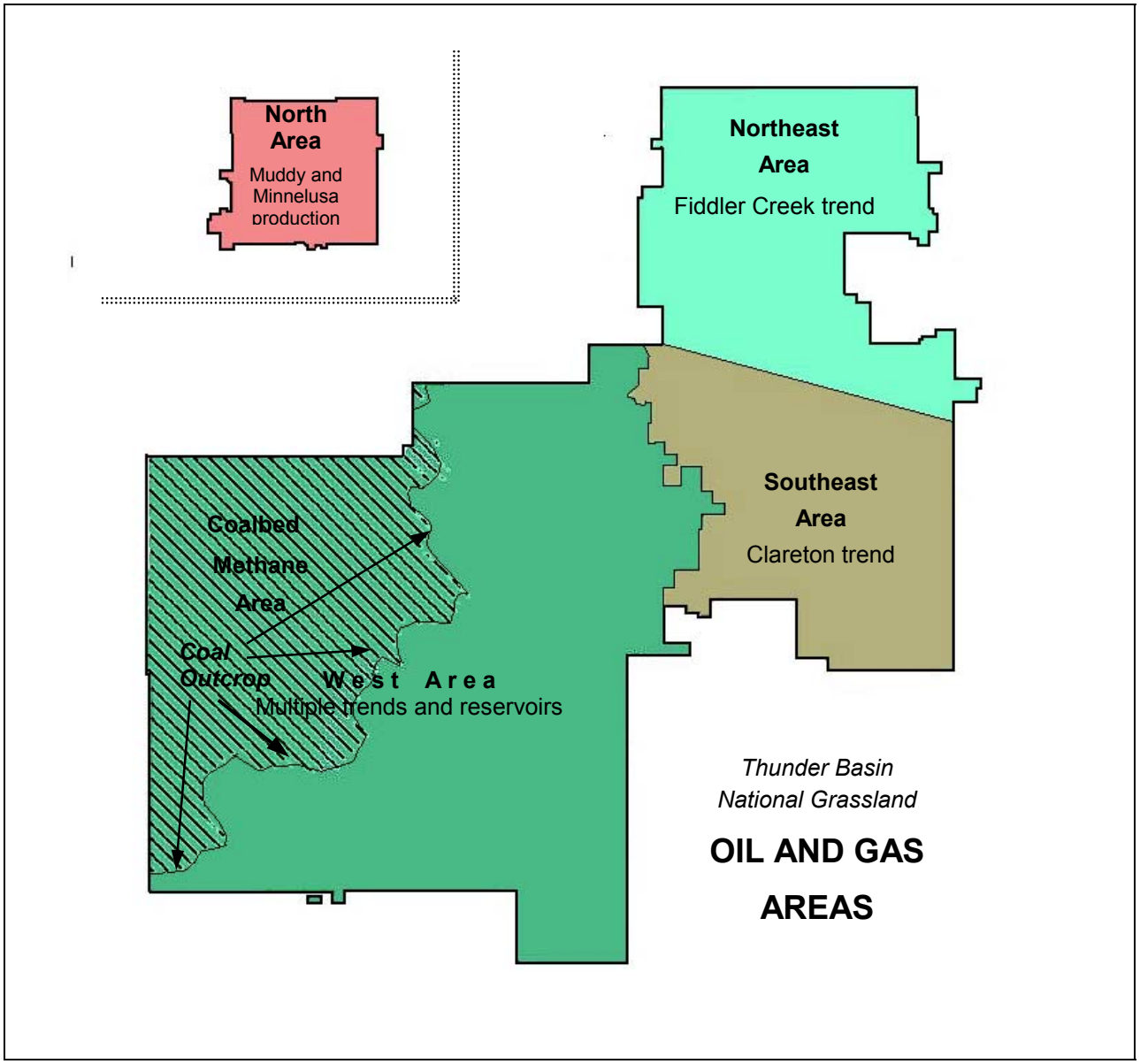


Figure 6. Thunder Basin National Grassland oil and gas areas characterized by producing trends. North Area: Muddy and Minnelusa production. Northeast Area: Fiddler Creek trend. Southeast Area: Clareton trend. West area: Multiple trends and reservoirs, including Muddy, Frontier-Turner, and Sussex-Shannon. Major coal producing horizons not present east of outcrop ("burn line").

North Oil and Gas Area. *Muddy and Minnelusa oil and gas trend. Spring Creek Geographic Area.*

The entire potentially productive geologic section from Tertiary and Upper Cretaceous down through Pennsylvanian age rocks occurs in the North Area (Muddy/Minnelusa trend; Spring Creek Geographic Area). Production in the area is from two reservoirs, Cretaceous Muddy and Pennsylvanian Minnelusa, at depths ranging from about 5,000 ft to 8,000 ft. It is the only part of the grassland in which the Minnelusa produces. Production from both Minnelusa and Muddy

reservoirs occurs only in the southwest half of the North Oil and Gas Area. A low and variable rate of drilling occurred continuously through the 1990's (Figure 7), with averages of four wells drilled per year and less than one new producer completed per year. Success rate over the 1989-1997 time period has been about 20%.

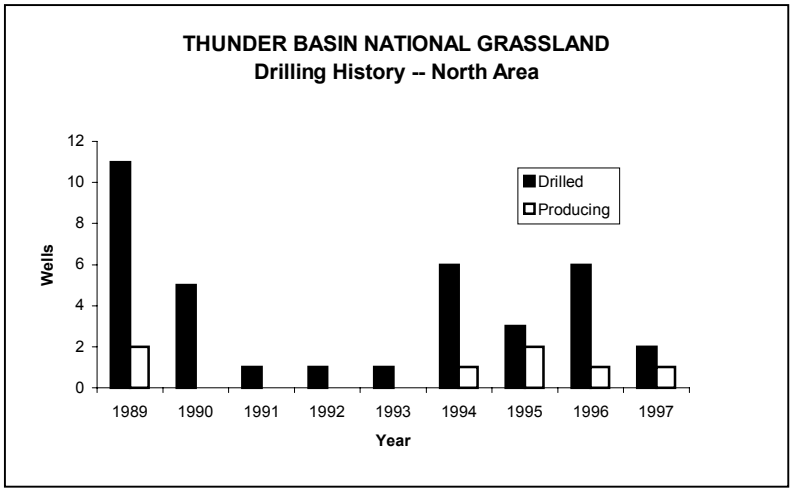


Figure 7. Number of wells drilled and completed in the north oil and gas area of Thunder Basin National Grassland, 1989-1997.

Northeast Oil and Gas Area. *Fiddler Creek oil and gas trend. All of Upton-Osage and northern half of the Fairview-Clareton Geographic Areas.*

With respect to geology and the occurrence of oil and gas resources, the Northeast Oil and Gas Area has relatively limited and shallow reservoirs (200-5,000 ft east half; 4,000-13,000 ft west half). Erosion has removed much of the younger stratigraphic section and reservoirs (mid-Cretaceous and younger) from the eastern half of the area. Only one major producing trend, Fiddler Creek, occurs in the Northeast area and has produced oil from Cretaceous Newcastle (Muddy) since 1919, predominantly at shallow depths. The area has had sporadic, widespread exploration activity, but no major discoveries other than in the Fiddler Creek trend. Very little drilling occurred 1989-1997 (Figure 8), averaging 3-4 wells per year (1 per year 1993-1997) with an average of only 1 new producing well per year Success rate 1989-1997 was 27%.

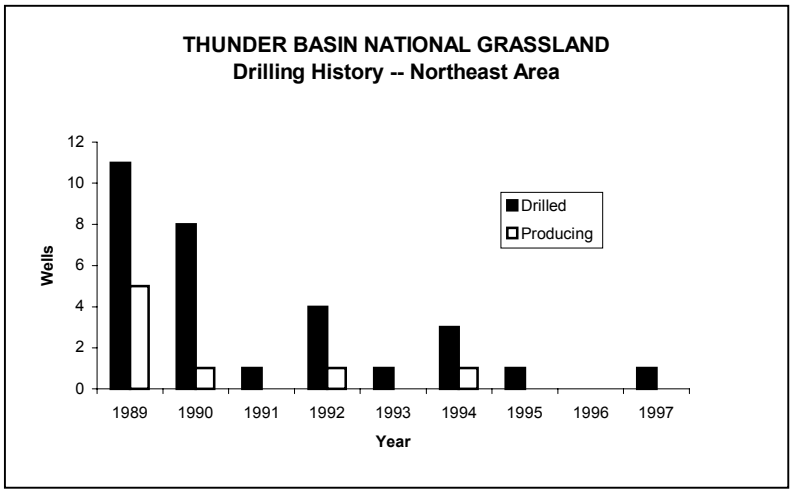


Figure 8. Number of wells drilled and completed in the northeast oil and gas area of Thunder Basin National Grassland, 1989-1997.

Southeast Oil and Gas Area. *Clareton oil and gas trend. Southern half of the Fairview-Clareton Geographic Area.*

The Southeast Oil and Gas Area also has relatively limited and shallow reservoirs, with Cretaceous Lance at the surface throughout most of the area and older reservoir rocks preserved in the subsurface. Much of the area has been heavily developed and includes Clareton, Mush Creek, Skull Creek, Black Thunder, Hampshire, and Finn-Shurley fields. Production is mostly from Newcastle (Muddy), with a few older (Dakota-Lakota) and younger (Turner) Cretaceous horizons also contributing to production. Discovery of the Clareton trend occurred in 1944, with development continuing to the present. Continuous, though sporadic, drilling occurred in the area through the 1990's (Figure 9). An average of slightly over 7 wells per year were drilled 1989-1997, with an average of 6-7 new producers per year. Success rate 1989-1997 was 91%.

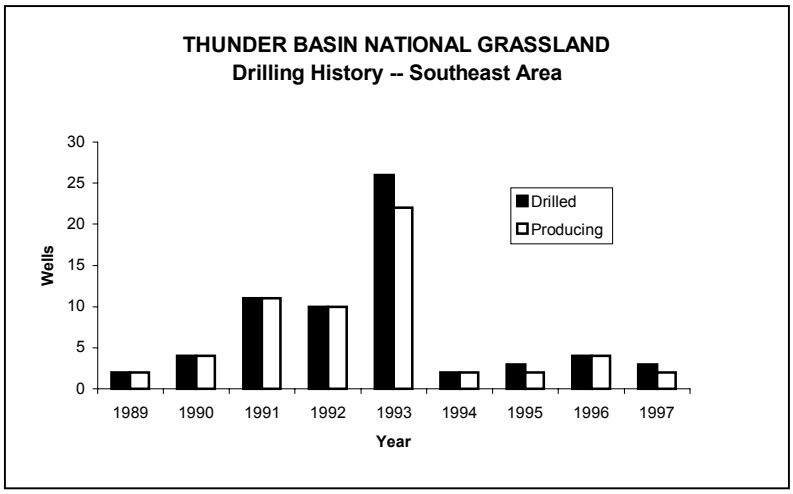


Figure 9. Number of wells drilled and completed in the southeast oil and gas area of Thunder Basin National Grassland, 1989-1997.

West Oil and Gas Area. *Multiple oil and gas trends. Cellar-Rosecrans, Broken Hills, and Hilight-Bill Geographic Areas.*

The West Oil and Gas Area is the most complex or variable of the grassland, with a large number of fields ranging in depth from about 5,000 ft to 13,000 ft and producing from a number of different Cretaceous age reservoirs. Two fields in the area (Box Creek and Sherwin) were developed prior to the mid 1960's. A flurry of activity occurred during the late 1960's through mid 1970's, with the discovery of 27 of the 47 fields that occur in the West Area of the grassland. Another 19 fields have been developed in the West Area since the late 1970's/early 1980's. Excluding coalbed methane, which occurs in the very westernmost part of the grassland, the area has had continuous drilling activity through the 1990's (Figure 10) with an average of about nine wells per year drilled during 1989-1998 and a little over five completions per year. Success rate 1989-1997 was 58.5%.

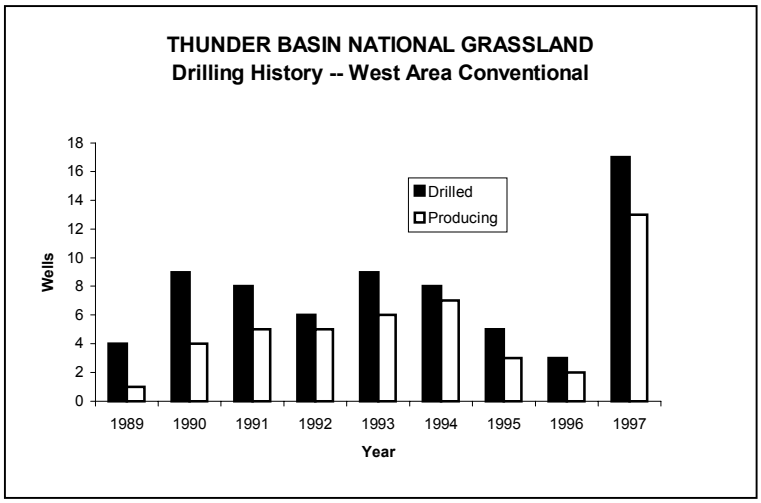


Figure 10. Number of wells drilled and completed in the west oil and gas area of Thunder Basin National Grassland, 1989-1997.

Coalbed methane area. *Westernmost part of West Oil and Gas Are. Hilight-Bill Geographic Area.*

A large number of Tertiary coal beds also occur in the westernmost part of the West Oil and Gas Area. During the late 1990's, industry began focusing intense efforts on developing the methane gas resource from these coal beds. Growing markets for gas as a clean-burning fuel, higher product prices, evolving geologic concepts, and increased knowledge about the technology needed to produce this resource efficiently and economically have contributed to high levels of activity within the area. The number of producing coalbed methane wells in Wyoming, most in the Powder River Basin, increased by a factor of 10 between 1996 and 1999. Production increased by almost 600% in that time period, and continues to increase. Within the area of the grassland at the end of 2000, approximately 700 wells were drilled or proposed to be drilled. Future coalbed methane activity in a major portion of the basin, including the coalbed methane area of Thunder Basin National Grassland, is being considered in an environmental analysis being conducted by BLM.

Potential for oil and gas resource occurrence

Based on geology and a long history of successful oil and gas exploration and development, all but a small portion of the Thunder Basin National Grassland has high potential for the occurrence of oil and gas resources (Figure 11*).* A small area in the extreme northeast corner of the grassland has medium potential for the occurrence of oil and gas resources due to reservoir rock of Cretaceous and younger age having been eroded from the area. The boundary between the high potential area and medium potential area coincides roughly with the contact between Cretaceous and Jurassic age sediments at the surface, with only Jurassic and older rocks present in the area of medium potential. The area of high potential has demonstrated existence of source rock, thermal maturation, reservoir strata possessing permeability and porosity, and traps. Appendix 1 provides criteria by which potential for oil and gas resource occurrence is determined. Table 2 summarizes characteristics of geology and production in each of the areas of occurrence potential in the grassland.

The small part of the northeast area designated with medium potential has indications that source rock, thermal maturation, reservoir strata possessing permeability and porosity, and traps may be present. However, without the Cretaceous strata that have proven to include the primary productive reservoirs throughout the basin, the area lacks demonstrated existence of the necessary geologic elements for the occurrence of oil and gas. Table 2 summarizes potential for occurrence of oil and gas resources in Thunder Basin National Grassland.

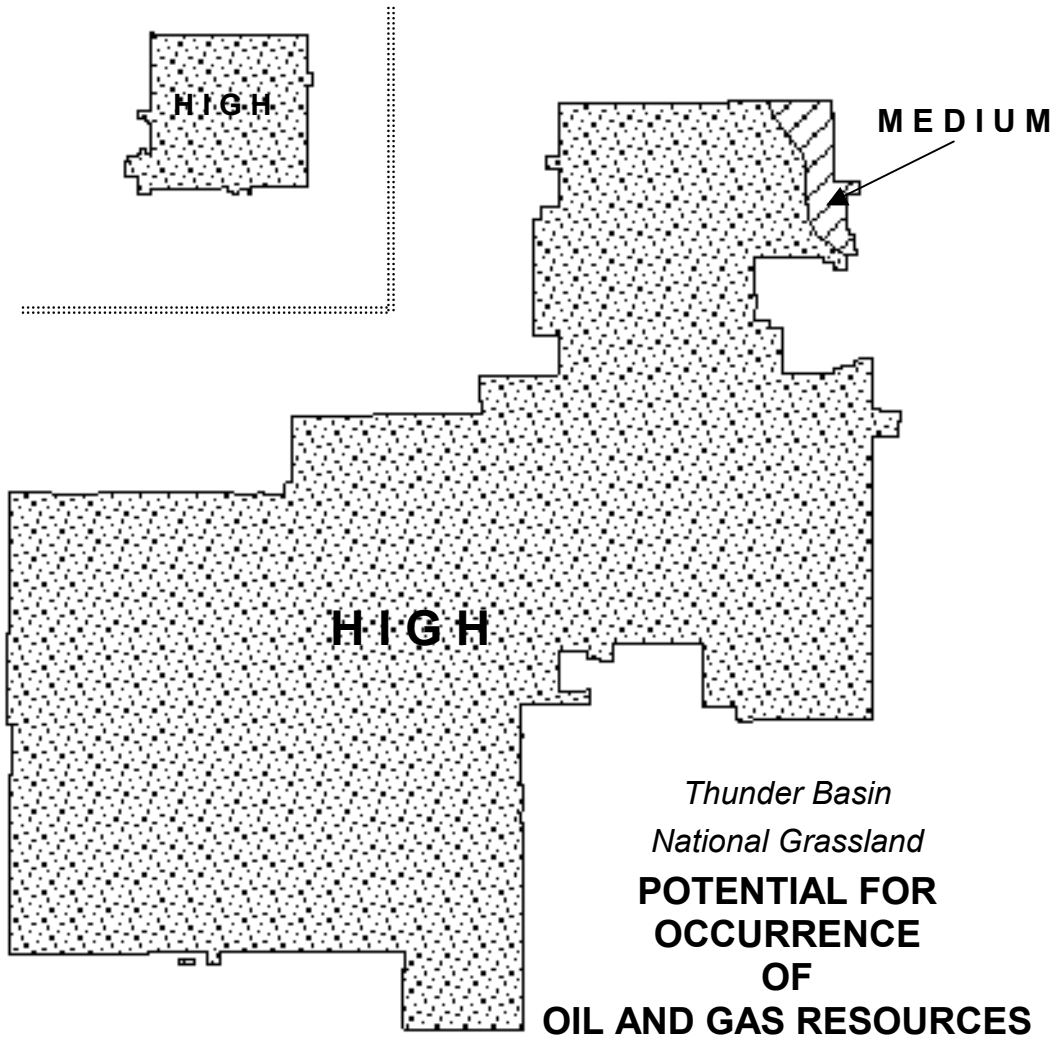


Figure 11

Table 2. Summary of potential for occurrence of oil and gas resources within geographic boundaries of Thunder Basin National Grassland.

Thunder Basin National Grassland Area of High Potential for Oil and Gas Resources	
Area	All of grassland south and west of SE-NW line in NE of T46N, R63W through T47-48N, R63W and NE of T48N, R64W
Potential reservoirs	Tertiary coals (Fort Union); Cretaceous sandstones (Mesaverde, Sussex, Turner-Frontier, Muddy-Newcastle, Dakota); Pennsylvanian sandstones and minor dolomites (Minnelusa, Leo)
Possible geographic extent of new fields	Conventional oil and gas: 160-9,600 Ac Coalbed methane: Up to 300,000 Ac
Expected reservoir depths	500-6,000 ft in eastern half of grassland (conventional reservoirs) 3,000-10,000 ft in western half of grassland (conventional reservoirs) 5,000-13,000 ft in western half of grassland (conventional reservoirs) 300-1,500 ft in west-western part of grassland (coalbed methane)
Expected hydrocarbon types	Oil, sweet Gas, sweet (associated with produced oil) Gas, sweet (coalbed methane)
Expected produced water	Minor to moderate amounts with oil production High amounts with coalbed methane production.

Thunder Basin National Grassland Area of Medium Potential for Oil and Gas Resources	
Area	Small part of grassland north and east of SE-NW line in NE of T46N, R63W through T47-48N, R63W and NE of T48N, R64W
Potential reservoirs	Pennsylvanian sandstones and minor dolomites (Minnelusa, Leo)
Possible geographic extent of new fields	160-640 Ac
Expected reservoir depths	500-1,500 ft
Expected hydrocarbon types	Oil, sweet
Expected produced water	Minor to moderate amounts with oil production

Scenario for Future Oil and Gas Exploration and Development Activity

Summary of geology and potential for resource occurrence

All but a very small part of Thunder Basin National Grassland has high potential for the occurrence of oil and gas resources. A nearly complete geologic section with numerous proven oil and gas reservoirs, primarily of Cretaceous age, is present throughout the grassland except in a small area in the extreme northeast. The small northeast area has moderate potential for the occurrence of oil and gas resources due to absence by erosion of the primary producing section of Cretaceous age rocks section (Figure 11 and Table 2).

History of exploration and development activity

Oil and gas exploration and development in the Powder River Basin in and near the area of the grassland commenced in the early 1900's. Some of the earliest oil and gas development (1915-1920) occurred along the eastern margins of the basin where reservoirs are shallow and were easily accessible by simple drilling techniques. After the early period of development, activity was very limited, with a period of 30 years in which no new discoveries were made. Renewed efforts in the 1940's resulted in some new discoveries, with activity continuing and peaking in the late 1970's and early 1980's.

Discovery and early development of Thornton field (T48N, R66W; 1915) and the Fiddler Creek trend, including Osage field (T46-47N, R63-64W; 1919) preceded the designation of Thunder Basin National Grassland (Bankhead-Jones Act, 1937). Some of the early wells in the Thornton and Fiddler Creek producing trends came under federal administration under Bankhead-Jones and continue to produce under Forest Service and BLM administration to the present. Primary reservoirs in these two trends are Cretaceous Newcastle (Muddy) in Fiddler Creek and Cretaceous Turner in Thornton.

After Thornton and Fiddler Creek, no new major discoveries occurred in the area of the grassland until the 1940's. In 1944, production from Newcastle sandstone was established in a similar trend, Clareton, to the south of Fiddler Creek. The Clareton trend includes Clareton, Skull Creek, and Mush Creek fields. In 1949, the discovery of Hampshire field extended the Fiddler Creek Newcastle production to the west at greater depths. Extension of production from Newcastle and Muddy sandstones in the Fiddler Creek and Clareton trends continued through the 1950's.

With improved drilling techniques and evolving geological concepts, production from Minnelusa reservoirs was established in the North Area in the 1960's. Production from Muddy reservoirs was established in that area at about the same time.

During the late 1960's and through the mid-1970's, a high level of exploration activity throughout the grassland resulted in the discovery of 29 new fields. Production was established at greater depths in the central and more western areas of the grassland from both known reservoirs (Newcastle and Muddy) and newly discovered reservoirs, including Upper Cretaceous Sussex and Parkman sandstones. Relatively high levels of exploration and development activity

continued through the late 1970's and early 1980's with ongoing development of known reserves and the discovery of an additional 21 fields, mostly in the West Oil and Gas Area of the grassland. Activity tapered off in the late 1980's with a significant fall in oil prices, and only one new field was established in the grassland in the 1990's in the North Area (Trout Pond, Minnelusa reservoir).

Influences on oil and gas exploration and development

Economics

Oil

Average annual crude oil prices have vacillated in the low to medium range since historical highs in 1981 (Figure 12). Prices in 1998 plummeted with the average annual price at $10.88 per barrel (1998 dollars). Prices for Wyoming sweet oil (Powder River Basin/Thunder Basin National Grassland) generally are slightly higher than the national average, but follow the same trend. In the context of a global market, U.S. prices are expected to increase gradually as demand increases. Predicted stability and a strengthening market will support continued exploration and development activity in the Powder River Basin and grassland. Price projections for Wyoming crude oil are generally conservative compared to those made by Energy Information Agency and other sources of projections.

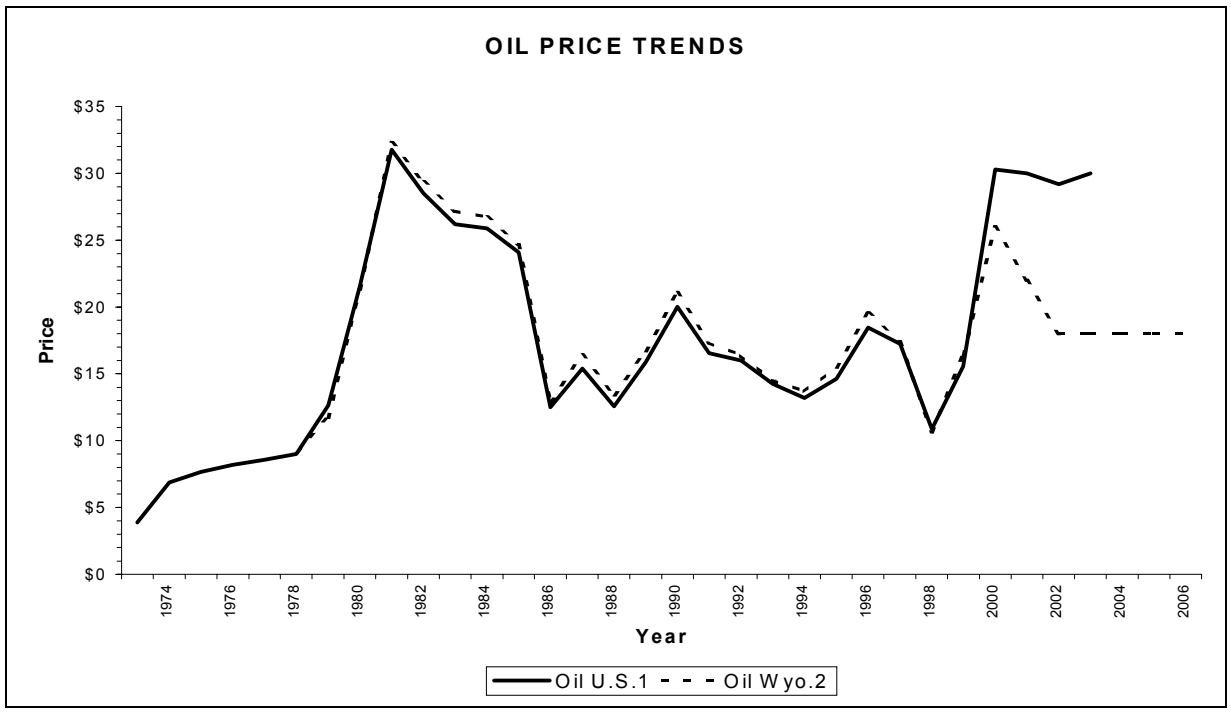


Figure 12. Trends in price of oil. *Source: Energy Information Administration, 1999, Annual Energy Review, and 2001, Short-Term Energy Outlook; Wyoming State Geological Survey, December, 2000, Wyoming Geo-Notes.*

Gas

Average annual gas prices were relatively stable at $1.50-$2.00 per million cubic feet through the 1990's following a high in the $2.50-$3.00 range during the mid-1980's (Figure 13.) However, prices rose dramatically in 2000 due generally to supply being unable to keep up with rapidly increasing demand. Nationally, demand for gas is expected to continue to grow. Economic growth, seasonal weather variations, and environmental factors (I.e., advantages of clean-burning fuels) have influenced the demand for natural gas. Increasing demand is behind higher prices and demand for development of coalbed methane resources in the Powder River Basin, including on Thunder Basin National Grassland. Persistent high demand for natural gas will continue to drive high levels of coalbed methane development, but will probably not have much effect on conventional exploration and development activities as the potential for occurrence of conventional gas resources in the Powder River Basin is relatively low.

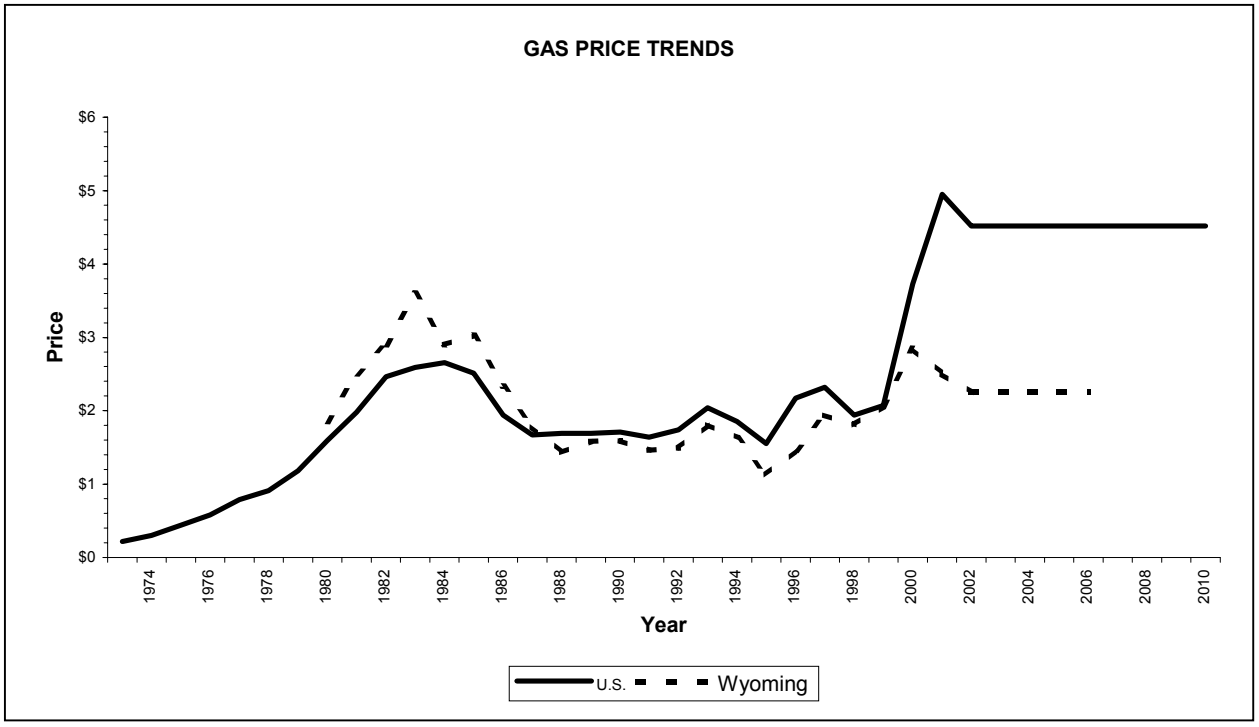


Figure 13. Trends in price of gas. *Source: Energy Information Administration, 1999, Annual Energy Review, and 2001, Short-Term Energy Outlook; Wyoming State Geological Survey, December, 2000, Wyoming Geo-Notes.*

Technology and geologic science

Improved techniques and equipment used in exploration, drilling, and production are being developed continuously and consequently become more effective and economic over time. Advanced geophysical exploration methods and improved drilling and completion techniques have potential to contribute to higher levels of activity. For the purposes of this report, advanced technology will be considered to have a positive, though non-quantified, effect on future drilling activity on the grassland.

Evolving concepts in geologic science also contribute to ongoing and renewed exploration and development. The development of coalbed methane is a example of how new ideas about geologic environments, coupled with innovations in production technology, contribute to significant new discoveries.

Physiography

Most of Thunder Basin National Grassland is easily accessible with several paved roads traversing the area and numerous gravel roads and two-tracks. Physiographically, the area is one of rolling terrain, with isolated steep-sided hills and gullies. Areas with physical characteristics that may not allow easy accessibility to vehicular traffic include river valleys and associated riparian areas (such as Cheyenne River) and topographically distinct areas (such as Rochelle Hills and Cow Creek Buttes). For the most part, physical factors will not significantly affect accessibility to oil and gas resources, though they may play a role in limiting some activities in localized areas.

Pipelines and transportation

Because of the high level of oil and gas development in the Powder River Basin, a large number of pipelines (both oil and gas), processing facilities, compressor stations, and refineries exist within relatively close distances throughout the area of the grassland. Some of the oil produced in the basin is stored on or near producing sites and periodically trucked to nearby processing facilities. Availability of pipelines, transportation, and processing facilities is not expected to limit anticipated moderate levels of ongoing and future exploration and development activities for conventional oil and associated gas resources. The high rate of development of natural gas resources in the form of coalbed methane, however, will be dependent on new infrastructure, particularly pipelines. Recent and ongoing construction of new pipelines (Wyoming State Geological Survey, 2000) will serve to support increasing levels of gas production, particularly coalbed methane, associated with expanding drilling programs.

Other factors affecting oil and gas exploration and development

In addition to geology, historical drilling rates, economic trends, indications of industry interest, and physiography, other factors also can affect the type and level of future activity. State and federal regulations and lease terms are difficult-to-quantify factors that affect the type and level of exploration and development activities. Management decisions within the context of state and federal laws and regulations and public expectations ultimately can be expected to limit the type and extent of oil and gas activities that development based on resource occurrence alone would require. Such decisions must consider physical factors (I.e., slopes, soils, water), biological factors (I.e., habitat and presence of threatened and endangered species and other wildlife considerations), historic factors (I.e., Native American heritage sites), and other land uses (I.e., recreation sites, mining, special interest areas). The degree of limitation of exploration and development activity is dependent upon management decisions that are made based on extensive environmental analysis. This report provides projections of activity based on potential for resource occurrence and historical trends. Projections of activity under specific management direction are made in the analysis that provides details of the types of limitations that might occur under a certain management decision.

Industry interest

During 2000, high levels of exploration and production activity in the Powder River Basin and Thunder Basin National Grassland were centered on coalbed methane. Conventional resources, however, also continue to be targeted by industry. Although conventional oil and gas activity levels may not be as high as they have been at other times during the past, the area continues to experience some ongoing activity due to relatively high prospectiveness, relatively low risk, and prices that are somewhat higher and more stable than they have been in recent years. Applications for Permit to Drill (APDs) filed with the BLM are a sure indication that drilling and development activities will continue at a steady rate. In late 2000, almost 800,000 acres of the 1.2 million acres of federal minerals in the grassland were under lease, with continuous requests for new leases on unleased lands. About 280,000 acres of leased federal minerals are held by production.

Most recent geophysical exploration projects were in 1998: two conventional 2D projects and two unconventional 3D projects. The two conventional lines were shot northeast of Bill, Wyoming and the southern edge of the Spring Creek Unit (Sec. 32, T54N, R69W and Sec 05, T53N, R69W). One of the 3D projects also was shot in the Spring Creek area and the other in Sixmile Basin (T44-45N, R62-63W).

Reasonable foreseeable development (RFD) of oil and gas resources

The potential for oil and gas occurrence is high for almost all of Thunder Basin National Grassland. Geological factors necessary for oil and gas occurrence exist throughout the area, as documented by information and data obtained through drilling and production that has occurred since the early 1900's. Development and production have proved the existence of a large number of reservoirs and fields throughout the Powder River Basin, including on Thunder Basin National Grassland. The potential for future exploration and development continues to remain high, with reasonable expectations of expanded development of existing fields and new discoveries occurring with the use of new technology and innovative geological concepts.

Activity associated with exploration for and development of conventional resources on the grassland is expected to increase through 2012 based on geologic factors, trends in exploration and development, and higher product prices accompanying increasing demand for energy resources. Activity associated with development of coalbed methane resources is expected to remain at very high levels. Concurrent with increasing exploration and development activity, reclamation of older disturbed sites associated with abandonment of depleted wells and reservoirs is expected to proceed at moderate rates.

This report provides a basic scenario of activity that assumes minimally restricted access to all areas of the grassland. Projections are made based on 1989-1997 drilling and development trends for conventional oil and gas resources and recent indications of interest. A total of 140-230 conventional oil and gas wells are expected to be drilled through 2010 over the entire area of the grassland, with 100-150 of those wells being developed as production wells. Preliminary estimates for development of coalbed methane resources (Holm, 1999) indicate up to 540 wells to be drilled in the next 10 years, with up to 486 being developed as production wells. More recent activities and knowledge of the resource, however, indicates that coalbed methane activity

very likely will occur at levels higher than that. BLM is developing more definitive scenarios of future coalbed methane activity. Table 3 provides details of this basic scenario of development.

Table 3. Thunder Basin National Grassland projected exploration and development activity for conventional oil and gas resources.

AREA INFORMATION			WELLS AND DISTURBANCE					
Oil & Gas Area	**Oil & Gas Area Acres**	**Geographic Area**	**Wells Total**	**Wells P&A (Short-term)**	**Wells Prod. (Long-term)**	**Old wellsites reclaimed**	**Short-term acres disturbed**	**Long-term acres disturbed**
North	96,204	Spring Creek	40	30	10	5 sites 15 Ac	111	12
Northeast	328,578	N 1/3 Fairview-Clareton, Upton-Osage	30	20	10	10 sites 30 Ac	74	-3
Southeast	314,173	S 2/3 Fairview-Clareton	70	10	60	100 sites 300 Ac	37	-138
West	1,077,595	Highlight-Bill, Broken Hills, Cellar-Rosecrans	90	20	70	5 sites 15 Ac	74	144
Total	**1,816,550**		**230**	**80**	**150**	**120 sites 360 Ac**	**296**	**15**
West CBM	371,597	Activity scenario, analysis, and leasing decision deferred to BLM Powder River analysis						

Definitions
Short-term disturbance: 3 years for dirt-moving, operations, reclamation (pads, and roads associated with dry holes)
Long-term disturbance: 20+ years for producing sites

Assumptions
ROADS: 0.35 miles with 40' right-of-way = 73,920 ft^2 = 1.7 Ac road/well
SHORT-TERM DISTURBANCE: 2 Ac avg pad/drilling well + 1.7 Ac road = 3.7 Ac/wellsite
RECLAMATION of old wellsites: Estimate 3 Ac/site (1.5 Ac road + 1.5 Ac pad)
LONG-TERM DISTURBANCE (producing sites): 1 Ac avg pad/well + 1.7 Ac road = 2.7 Ac/well – Ac reclamation

Conclusions

Thunder Basin National Grassland is situated in a geologic basin that has proven oil and gas potential with a long history of development of significant oil and gas resources. Geologic potential for occurrence of oil and gas resources is high throughout the grassland except for a small area in the northeast part of the grassland. The potential for development of oil and gas resources is also high throughout the grassland. Moderate levels of conventional oil and gas exploration and development activity are expected to continue through the next 10 years, with projected drilling of up to 230 conventional oil and gas wells, as many as 150 of which are expected to be completed as producing wells. High levels of exploration and development activity are also expected for unconventional coalbed methane in western portions of the grassland.

Appendix 1. Classification of Oil and Gas Potential

U.S. Forest Service Rocky Mountain Region Revision, December 19, 1994, of Classification in BLM Handbook H-1624-1, May 7, 1990

HIGH	Demonstrated existence of source rock, thermal maturation, reservoir strata possessing permeability and porosity, and traps. Demonstrated existence is defined by physical evidence or documentation in the literature.
MEDIUM	Geophysical or geological indications that the following may be present: source rock, thermal maturation, reservoir strata possessing permeability and porosity, and traps. Geologic indication is defined by geological inference based on indirect evidence.
LOW	Specific indications that one or more of the following may not be present: source rock, thermal maturation, or reservoir strata possessing permeability and porosity, and traps.
NO CURRENTLY RECOGNIZABLE POTENTIAL	Demonstrated absence of source rock, thermal maturation, reservoir rock, and traps. Demonstrated absence is defined by physical evidence or documentation in the literature.

Note: Inclusion of an area in a USGS oil and gas play defined in the national assessment should be considered in determining potential for oil and gas resources. However, because the USGS assesses speculative plays, play definition alone should not be the only criterion for determining potential.

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