

Reasonable Foreseeable Development Scenario for Oil and Gas Activities

National Forests and Grasslands in Texas

Prepared for the U.S. Forest Service

by

Kelsey Crocker and James F. Glover

United States Department of the Interior

Bureau of Land Management

New Mexico State Office

Final Report

Amended November 2018

National Forests and Grasslands in Texas

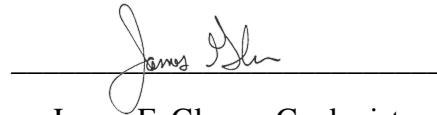


**Reasonable Foreseeable Development Scenario for Oil
and Gas Activities
National Forests and Grasslands in Texas**

Prepared By:



Kelsey Crocker, GIS Specialist



James F. Glover, Geologist

United States Department of the Interior

Bureau of Land Management

New Mexico State Office

FINAL REPORT – AMENDED NOVEMBER 2018

Contents

Introduction	1
<i>Guidance and Data Sources</i>	2
<i>Assumptions and Findings</i>	3
Historical Activity	4
<i>Recent Drilling Activity</i>	4
<i>Oil and Gas Production</i>	5
<i>Oil and Gas Prices</i>	6
<i>Pipelines and Facilities</i>	6
Occurrence Potential	7
<i>Producing Formations—East Texas Forests</i>	7
<i>Producing Formations—Lyndon B. Johnson National Grassland</i>	7
<i>Producing Formations—Caddo National Grassland</i>	7
<i>Occurrence Potential Ratings</i>	8
Oil and Gas	8
Coalbed Methane.....	8
Projections of Future Activity	9
<i>Development Potential</i>	9
Oil and Gas	9
Coalbed Methane.....	9
<i>Future Drilling and Oil and Gas Production Projections</i>	10
Estimated Surface Disturbance	15
Estimated Water Use for Hydraulic Fracturing	16
Induced Seismicity	17
Summary	18
References	19

List of Figures

Figure 1. Surface and oil and gas mineral ownership within the National Forests and Grasslands in Texas.

Figure 2. Drilling activity within the NFGT Proclaimed Boundary, 1973-2017 (IHS Energy Group, 2017). Data is complete through June, 2017.

Figure 3. Drilling activity within the Local Analysis Area, 1973-2017 (IHS Energy Group, 2017). Data is complete through June, 2017.

Figure 4. All horizontal wells drilled within the Local Analysis Area (IHS Energy Group, 2017).

Figure 5. Recent oil and gas wells drilled within the Local Analysis Area, 2008-2017 (IHS Energy Group, 2017).

Figure 6. Historical oil and natural gas production within the NFGT Proclaimed Boundary, 1973-2017 (IHS Energy Group, 2018).

Figure 7. Historical oil and natural gas production within the Local Analysis Area, 1973-2017 (IHS Energy Group, 2018).

Figure 8. Historical and projected U.S. natural gas and oil prices, 1970-2040 (Energy Information Administration, 2017).

Figure 9. Correlation between natural gas prices and drilling within the Local Analysis Area (Energy Information Administration, 2017; IHS Energy Group, 2017).

Figure 10. Natural gas pipelines and infrastructure in and around the National Forests and Grasslands in Texas (IHS Energy Group, 2018).

Figure 11. Oil and refined product pipelines and infrastructure in and around the National Forests and Grasslands in Texas (IHS Energy Group, 2018).

Figure 12. Chronostratigraphic chart of East Texas (modified from Baker, 1995).

Figure 13. Oil and gas occurrence potential within the Local Analysis Area.

Figure 14. Coalbed methane occurrence potential within the Local Analysis Area.

Figure 15. Oil and gas development potential within the Local Analysis Area, 2018-2037.

Figure 16. Oil and gas development potential for Forest Service Lands, 2018-2037.

Figure 17. Comparison of historical 20-year drilling totals within the NFGT Proclaimed Boundary with RFD projections for 2018-2037. Historical data from IHS Energy Group, 2018.

Figure 18. Comparison of historical 20-year drilling totals within the Local Analysis Area with RFD projections for 2018-2037. Historical data from IHS Energy Group, 2018.

Figure 19. Salt water disposal wells in and around the National Forests and Grasslands in Texas (IHS Energy Group, 2018).

List of Tables

Tables are presented in-line with the text. Supplemental tables are presented at the end of the document.

Table 1. Rating system for hydrocarbon occurrence potential.

Table 2. Summary of development potential classification. Acreages for each of the development potential categories are presented for Forest Service lands, for the Proclaimed Boundary, and for the Local Analysis Area.

Table 3. Cumulative projections for drilling activity and production, 2018-2037.

Table 4. Annual projected drilling activity (including horizontal and vertical well counts and water use for hydraulic fracturing) and production (oil, natural gas, and produced water) from Forest Service lands within the NFGT Proclaimed Boundary, 2018-2037.

Table 5. Annual projected drilling activity (including horizontal and vertical well counts and water use for hydraulic fracturing) and production (oil, natural gas, and produced water) from all lands within the NFGT Proclaimed Boundary, 2018-2037.

Table 6. Annual projected drilling activity (including horizontal and vertical well counts and water use for hydraulic fracturing) and production (oil, natural gas, and produced water) from the Local Analysis Area (which includes the NFGT Proclaimed Boundary plus a 1.5-mile buffer), 2018-2037.

Table 7. Estimated ultimate recoveries (EURs) for oil, gas, and produced water from horizontal and vertical wells.

Table 8. Summary of estimated surface disturbance, 2018-2037.

Table 9. Values used for estimating existing and projected surface disturbance.

Supplemental Table A. Surface and oil and gas mineral ownership within the NFGT Proclaimed Boundary. Acreages are from GIS and should be considered approximate.

Supplemental Table B. Well densities for development potential categories.

Introduction

The purpose of this reasonable foreseeable development (RFD) scenario is to analyze the known and potential oil and gas resources in and around the National Forests and Grasslands in Texas (NFGT) and project the potential future oil and gas development activity for the next twenty years (2018-2037) based on logical and technical assumptions. Historic and current activity, occurrence potential, projected development potential (including projections for vertical and horizontal wells drilled during the life of the plan), estimated future surface disturbance, estimated water use for hydraulic fracturing, and estimated oil, natural gas, and water production volumes are presented. This RFD scenario has been prepared in support of the United States Forest Service’s land use planning process.

The analysis presented herein covers the proclaimed boundaries of the Angelina, Davy Crockett, Sabine, and Sam Houston National Forests, and the Caddo and Lyndon B. Johnson National Grasslands (referenced collectively as the NFGT Proclaimed Boundary). The NFGT Proclaimed Boundary contains approximately 1.92 million total acres of all mineral ownership types. The U.S. Forest Service manages 678,000 surface acres (35%) within the NFGT Proclaimed Boundary. Underlying the Forest Service-managed surface, there are 469,000 acres of Federally-managed oil and gas minerals and 209,000 acres of non-Federal oil and gas minerals. Of the Federally-managed oil and gas minerals, 274,000 acres (58%) are currently leased (as of August 2018). Surface ownership and oil and gas mineral ownership within the NFGT Proclaimed Boundary are shown in **Figure 1**. Additional land and mineral ownership statistics for the NFGT Proclaimed Boundary are presented in **Supplemental Table A**.

The U.S. Forest Service also requested oil and gas development projections for lands within 1.5 miles of the NFGT Proclaimed Boundary. For the purposes of this RFD, we define the Local Analysis Area to include all lands within the Proclaimed Boundary in addition to lands encompassed by the 1.5-mile buffer. The Local Analysis Area contains approximately 2.77 million total acres of all mineral ownership types.

Throughout this document, separate projections are provided for Forest Service lands, lands within the Proclaimed Boundary, and lands within the Local Analysis Area.

In discussions of geology and hydrocarbon occurrence potential, the Angelina, Davy Crockett, Sabine, and Sam Houston National Forests are referenced as a group as the “East Texas Forests” because they are all located on Texas’ east coastal plain. The Lyndon B. Johnson National Grassland and the Caddo National Grassland are geologically distinct and are discussed separately.

All acreages presented herein are based on geographic information systems (GIS) calculations and should be considered approximate.

Guidance and Data Sources

The BLM derives guidance for RFD scenarios from the “Interagency Reference Guide: Reasonable Foreseeable Development Scenarios and Cumulative Effects Analysis, 2004” developed by the Rocky Mountain Leadership Forum, a consortium of federal natural resource management agencies. This document defines the RFD scenario as a reasonable projection of the most likely anticipated oil and gas activity supported by a clearly stated set of assumptions. This projection establishes a baseline scenario that is unconstrained by management imposed conditions and is based on historical and geological parameters. This baseline RFD scenario can then be used to compare the resource management plan alternatives and to analyze the long term effects that could result from oil and gas activities. The RFD scenario is not a decision document and does not establish limitations on development.

This baseline scenario assumes all potentially productive areas within the assessed areas can be open under standard lease terms and conditions, except those areas designated as closed to leasing by law, regulation, or executive order.

Minerals that are withdrawn from Federal leasing by law include:

- Federal minerals beneath incorporated areas (such as cities and towns)
- Federal minerals beneath Congressionally-designated wilderness areas

Approximately 21,443 acres of Federal oil and gas minerals within the NFGT Proclaimed Boundary were identified as withdrawn by law and were removed from subsequent RFD analysis. These areas are identified in **Figure 1** with red shading. State and fee minerals within incorporated areas and wilderness areas are not necessarily affected by Federal withdrawals and could potentially still be developed.

Information presented in this report was compiled from various sources. Historical and current well data (including production volumes) was provided by IHS Energy. Land and mineral ownership data as well as most other GIS data were provided by the BLM New Mexico State Office, the U.S. Forest Service’s National Forests and Grasslands in Texas, and the BLM Oklahoma Field Office. Geological data was sourced from reports from the Bureau of Economic Geology at the University of Texas at Austin, U.S. Geological Survey (USGS) Oil and Gas Assessments, and various professional publications. Hydraulic fracturing fluid volumes were sourced from the Bureau of Economic Geology at the University of Texas at Austin. Information regarding price trends was taken from the Energy Information Administration. All data sources are cited appropriately throughout the text.

Assumptions and Findings

For this RFD scenario, we assume that future activity will consist primarily of horizontal drilling. We also assume that oil and natural gas prices will follow Energy Information Administration projections (Annual Energy Outlook, 2017).

On Forest Service lands within the NFGT Proclaimed Boundary, the RFD baseline scenario projects 485 new oil and gas wells (324 horizontal and 161 vertical or directional) for 2018-2037. As of 2017, existing wells on Forest Service surface within the NFGT Proclaimed Boundary were associated with approximately 1,700 acres of surface disturbance. Over the life of the twenty-year plan, the maximum potential disturbance (including existing and projected disturbance) is 4,000 acres. Accounting for reclamation, we expect for 2,500 acres of surface disturbance to remain at the end of the plan in 2037. Hydraulic fracturing of the projected wells will require an estimated 1.7 billion gallons (equivalent to 40 million barrels or 5,136 acre-feet) of water. Over the life of the plan, the existing and projected wells will produce an estimated 21,769,000 barrels (bbls) of oil, 1,341,944,000 thousand cubic feet (Mcf) of gas, and 243,857,000 bbls of water.

For all lands within the NFGT Proclaimed Boundary, the RFD baseline scenario projects 1,530 new oil and gas wells (1,019 horizontal and 511 vertical or directional) for 2018-2037. As of 2017, existing wells within the NFGT Proclaimed Boundary were associated with approximately 6,800 acres of surface disturbance. Over the life of the twenty-year plan, the maximum potential disturbance (including existing and projected disturbance) is 13,900 acres. Accounting for reclamation, we expect for 8,200 acres of surface disturbance to remain at the end of the plan in 2037. Hydraulic fracturing of the projected wells will require an estimated 5.3 billion gallons (equivalent to 125 million barrels or 16,160 acre-feet) of water. Over the life of the plan, the existing and projected wells will produce an estimated 68,669,000 bbls of oil, 4,233,347,000 Mcf of gas, and 769,281,000 bbls of water.

In the Local Analysis Area (the 1.5-mile buffer around the NFGT Proclaimed Boundary), the RFD baseline scenario projects 2,340 new oil and gas wells (1,560 horizontal and 780 vertical or directional) for 2018-2037. As of 2017, existing wells in the Local Analysis Area were associated with approximately 9,700 acres of surface disturbance. Over the life of the twenty-year plan, the maximum potential disturbance (including existing and projected disturbance) is 20,800 acres. Accounting for reclamation, we expect for 16,000 acres of surface disturbance to remain at the end of the plan in 2037. Hydraulic fracturing of the projected wells will require an estimated 8 billion gallons (equivalent to 192 million barrels or 25,000 acre-feet) of water. Over the life of the plan, the existing and projected wells will produce an estimated 104,985,000 bbls of oil, 5,928,346,000 Mcf of gas, and 1,207,232,000 bbls of water.

Historical Activity

A total of 1,204 wells have been drilled with surface locations on Forest Service lands within the NFGT Proclaimed Boundary through June 2017 (IHS Energy Group, 2017). The total figure includes 185 gas wells (15%), 269 oil wells (22%), and 700 abandoned wells (58%). The remaining 50 wells (4%) consist of 10 injection wells, 9 salt water disposal wells, six wells in pre-productive statuses (start, at total depth, and treated), and 25 wells in non-productive statuses (pilot, service, observation, suspended, and temporarily abandoned).

A total of 4,694 wells have been drilled within the NFGT Proclaimed Boundary through June 2017 (IHS Energy Group, 2017). The total figure includes 1,178 gas wells (25%), 1,001 oil wells (21%), and 2,330 abandoned wells (50%). The remaining 185 wells (4%) consist of 36 injection wells, 42 salt water disposal wells, 33 wells in pre-productive statuses (start, at total depth, and treated), and 74 wells in non-productive statuses (pilot, service, observation, suspended, and temporarily abandoned).

A total of 7,091 wells have been drilled within the Local Analysis Area (the 1.5-mile buffer) through June 2017 (IHS Energy Group, 2017). The total figure includes 1,901 gas wells (27%), 1,381 oil wells (19%), and 3,539 abandoned wells (50%). The remaining 270 wells (4%) consist of 41 injection wells, 72 salt water disposal wells, 19 wells in pre-productive statuses (start, at total depth, and treated), and 138 wells in non-productive statuses (pilot, service, observation, suspended, and temporarily abandoned).

Annual drilling activity within the NFGT Proclaimed Boundary and Regional Analysis Area are shown in **Figure 2** and **Figure 3**, respectively. The first oil well in Texas was drilled in 1866 at Oil Springs, near Nacogdoches and north of what is now the Angelina National Forest, and the East Texas Oil Field was discovered in 1930 (Bureau of Economic Geology, 2005). In north central Texas, the Newark East gas field (encompassing the Lyndon B. Johnson National Grassland and producing from the Barnett Shale) was discovered in 1981, and development boomed in the late 1990s to early 2000s following improvements in horizontal drilling and well completion techniques (Martineau, 2007). The first horizontal wells in the Local Analysis Area were drilled in and near the Sabine National Forest in 1990. Nineteen ninety-five was the first year that horizontal drilling accounted for greater than half of total drilling within the Local Analysis Area and the NFGT Proclaimed Boundary. **Figure 4** shows the locations of all horizontal wells drilled within the NFGT Proclaimed Boundary and Local Analysis Area.

Recent Drilling Activity

Figure 5 shows the locations of oil and gas wells drilled in the past ten years (2008-2017) within the NFGT Proclaimed Boundary and Local Analysis Area. Since 2008, the majority of development has consisted of horizontal drilling (69% of wells drilled in the Proclaimed Boundary and 68% of wells drilled in the Local Analysis Area). Most development has been

located in and around the Lyndon B. Johnson National Grassland and in the northern portions of the Angelina and Sabine National Forests. Densely clustered vertical drilling has occurred north of the Sabine National Forest and south of the Sam Houston National Forest.

On Forest Service lands within the NFGT Proclaimed Boundary, a total of 89 wells have been drilled in the past ten years (2008-2017) (IHS Energy Group, 2017). The total figure includes 43 gas wells (48%), 23 oil wells (26%), and 11 abandoned wells (12%). The remaining 12 wells (13%) consist of 2 salt water disposal wells, 6 wells in pre-productive statuses (start, at total depth, and treated), and 4 wells in non-productive statuses (pilot, service, observation, suspended, and temporarily abandoned).

Within the NFGT Proclaimed Boundary, a total of 714 wells have been drilled in the past ten years (2008-2017) (IHS Energy Group, 2017). The total figure includes 475 gas wells (67%), 110 oil wells (15%), and 61 abandoned wells (9%). The remaining 68 wells (9%) consist of 2 injection wells, 12 salt water disposal wells, 16 wells in pre-productive statuses (start, at total depth, and treated), and 38 wells in non-productive statuses (pilot, service, observation, suspended, and temporarily abandoned).

Within the Local Analysis Area, a total of 2,246 wells have been drilled in the past ten years (2008-2017) (IHS Energy Group, 2017). The total figure includes 1,512 gas wells (67%), 307 oil wells (14%), and 181 abandoned wells (8%). The remaining 246 wells (11%) consist of 13 injection wells, 50 salt water disposal wells, 47 wells in pre-productive statuses (start, at total depth, and treated), and 136 wells in non-productive statuses (pilot, service, observation, suspended, and temporarily abandoned).

Oil and Gas Production

Figure 6 and **Figure 7** show historical oil and natural gas production since 1973 for the NFGT Proclaimed Boundary and the Local Analysis Area, respectively (IHS Energy Group, 2018). Data are shown through year-end 2017.

Within the NFGT Proclaimed Boundary, gas production trended gradually upward from 1973 to 2009, then increased sharply from 39 million Mcf in 2009 to a maximum of 124 million Mcf in 2012. Gas production fell slightly to 100 million Mcf/year from 2013 to 2016, ending at 107 million Mcf in 2017. Oil production increased sharply from 1.3 million barrels in 1993 to a maximum of 2.4 million barrels in 1995 before dropping to 670,000 barrels in 2001. Oil production trended gradually upward again until 2012 before falling to a low of 360,000 barrels in 2017.

Within the Local Analysis Area, gas production trended gradually upward from 1973 to 2009, then increased sharply from 66 million Mcf in 2009 to a maximum of 211 million Mcf in 2012.

Production fell to 149 million Mcf in 2016, ending at 157 million Mcf in 2017. Oil production increased sharply from 2.4 million barrels in 1993 to a maximum of 3.1 million barrels in 1995 before dropping to 800,000 barrels in 2001. Oil production trended gradually upward again until 2012 before falling to a low of 517,000 barrels in 2017.

Oil and Gas Prices

Historical and projected annual natural gas and oil prices are shown in **Figure 8**. Natural gas prices peaked at \$8.86/Mcf in 2008 and oil prices peaked at \$99.67/barrel in 2008. For the purposes of this RFD scenario, we assume natural gas and oil prices during the 2018-2037 planning period will align with the Energy Information Administration 2017 projections. We found that drilling activity within the Regional Analysis Area correlates reasonably well with the rise and fall of natural gas prices; this is illustrated in **Figure 9**.

Pipelines and Facilities

Figure 10 shows the existing gas pipelines and facilities in and around the NFGT Proclaimed Boundary, and **Figure 11** shows the existing oil and refined petroleum product pipelines and facilities (IHS Energy Group, 2018). The U.S. Energy Information Administration defines intrastate pipelines as pipelines that operate totally within state borders and link producers to local markets or to the interstate pipeline network. Conversely, interstate pipelines cross one or more state borders, connecting regional networks. Extensive interstate and intrastate pipeline infrastructure for transporting oil, gas, and other petroleum products already exists in and around the NFGT Proclaimed Boundary (IHS Energy Group, 2018; EIA, 2018). Additional interstate oil and gas pipeline projects through east Texas are planned in order to transport production from the Permian Basin to refineries and export markets on the Gulf Coast (Smith, 2018). An in-depth discussion of current and future pipeline capacity and demand is beyond the scope of this report; for more information on pipelines, please refer to *Natural Gas Pipelines in the Southwest Region* (EIA, 2018).

Occurrence Potential

Producing Formations—East Texas Forests

The East Texas National Forests (Angelina, Davy Crockett, Sabine, and Sam Houston) are located on the east coastal plain of Texas and lie above multiple major oil and gas plays, including the Woodbine Sand, the Eagle Ford Shale, and the Fredericksburg and Trinity Groups (all Cretaceous). Other producing formations include, but are not limited to, the Jurassic Haynesville Shale, the Jurassic Cotton Valley Group (including the Bossier Shale), the early Cretaceous Hosston (Travis Peak) Formation, the Cretaceous Buda Limestone, the Cretaceous Austin Group, and the Eocene Wilcox Group. A stratigraphic chart for east Texas (modified from Baker, 1995) is presented in **Figure 12**. The geology of east Texas has been extensively studied and documented; for more detail on the hydrocarbon potential and geological setting of east Texas, please refer to Schenk and Viger (1995 and 1996).

Producing Formations—Lyndon B. Johnson National Grassland

The Lyndon B. Johnson National Grassland is located in the Bend Arch-Fort Worth Basin province of north-central Texas. In the past ten years, over 90% of oil and gas development in and around the Lyndon B. Johnson National Grassland has targeted the Mississippian Barnett Shale (845 of the 903 wells drilled between 2008 and 2017) with horizontal drilling. Other producing formations include the Pennsylvanian Strawn Group and Bend Group (including the Marble Falls Limestone), and the Ordovician Viola and Ellenburger Groups. For more information on the Bend Arch-Fort Worth Basin province, see Ball et al. (1996); for the most recent USGS assessment of the Barnett Shale, see Marra et al. (2015); for a stratigraphic chart, see Alsalem et al. (2017).

Producing Formations—Caddo National Grassland

Although local accumulations of oil and gas may be present in the area, the Caddo National Grassland lies above a structurally complex and uplifted area immediately forward of the Ouachita Tectonic Front in northeast Texas. The structural and geologic history here precludes the development of extensive petroleum systems, and therefore the area lacks the prolific petroleum accumulations found in the nearby Fort Worth and East Texas Basins (Johnson and Luza, 2008; Wickman, 1977). The edges of two U.S. Geological Survey-defined assessment units (the Bossier and the Cotton Valley) overlap the Caddo National Grassland, but exploration in this area has been limited and unsuccessful. As of June 2017, well records indicated three shut-in wells and no active producers in or around Caddo National Grassland.

Occurrence Potential Ratings

For the purposes of this document, “occurrence potential” is defined as “the geologic likelihood for oil and gas accumulations to exist in a given area,” and does not account for economic factors or historical development trends. (See the “Projections of Future Activity” section of this document for analysis that incorporates these factors.)

The BLM has established criteria for rating the oil and gas occurrence potential of lands studied for planning area documents. This rating system is based on guidance outlined in the Bureau of Land Management Handbook H-1624-1. The USGS assessment units within the Local Analysis Area were classified using a number of geologic characteristics that qualify them as having high occurrence potential for hydrocarbon accumulation:

- presence of hydrocarbon source rocks
- presence of reservoir rocks with adequate porosity/permeability
- potential for structural/stratigraphic traps to exist
- opportunity for migration from source to trap, and
- favorable temperature, depth of burial, and subsurface pressure conditions.

The occurrence potential ratings for this RFD Scenario are described in **Table 1**, below.

Table 1. Rating system for hydrocarbon occurrence potential.

Occurrence Potential	Explanation
Very High	Within two or more overlapping USGS Assessment Units.
High	Within one USGS Assessment Unit.
Medium	Outside of USGS Assessment Units, but conditions for hydrocarbon accumulation may exist.
Low	Outside of USGS Assessment Units. One or more of the conditions for hydrocarbon accumulation is absent.

Oil and Gas

We consider the NFGT Proclaimed Boundary and Local Analysis Area to have medium to very high potential for the occurrence of oil and gas (**Figure 13**). The USGS has defined multiple assessment units with oil and gas potential that encompass the Local Analysis Area (Western Gulf Province assessment, Schenk and Viger, 1995; East Texas Basin Province assessment, Schenk and Viger, 1996; Bend Arch-Forth Worth Basin Province assessment, Ball et al., 1996).

Coalbed Methane

We consider the East Texas Forests to have a central southwest-northeast band of high potential for the occurrence of coalbed methane (**Figure 14**). This band corresponds to coal seams within the Wilcox Group. We did not identify any coal-bearing formations underlying the Lyndon B. Johnson or Caddo National Grasslands. These areas are considered to have low potential for the occurrence of coalbed methane.

Projections of Future Activity

Development Potential

Oil and Gas

Development potential was determined at a resolution of one square mile using a grid overlay, comparable to the section- or township-level resolution utilized in RFDs in regions surveyed using the Public Land Survey System. Recent drilling trends, geologic assessments, applications for permit to drill (interpreted as indications of interest from industry), and the correlation between natural gas prices and drilling rates (**Figure 9**) were incorporated to determine the likely location and quantity of future development activities. Large-scale geographic features that could impact development were also considered (for example, lakes that would necessitate elevated or floating well platforms or horizontal drilling to access the underlying minerals). Development potential classification is summarized in **Table 2** and shown spatially in **Figure 15** (all lands within the Local Analysis Area) and **Figure 16** (highlighting Forest Service lands).

Table 2. Summary of development potential classification. Acreages for each of the development potential categories are presented for Forest Service lands, for the Proclaimed Boundary, and for the Local Analysis Area.

Development Potential	Projected wells per 100 sq. mi.	Forest Service Lands	Proclaimed Boundary	Local Analysis Area
Very High	> 100	70,000 ac. (110 sq. mi.)	254,000 ac. (397 sq. mi.)	397,000 ac. (620 sq. mi.)
High	26 - 100	94,000 ac. (147 sq. mi.)	213,000 ac. (333 sq. mi.)	326,000 ac. (509 sq. mi.)
Medium	4 - 25	457,000 ac. (714 sq. mi.)	1,232,000 ac. (1,925 sq. mi.)	1,725,000 ac. (2,695 sq. mi.)
Low	< 4	35,000 ac. (55 sq. mi.)	201,000 ac. (314 sq. mi.)	302,000 ac. (471 sq. mi.)

Coalbed Methane

Development potential for coalbed methane was determined using the same methods and criteria as development potential for oil and gas (see previous section). While it is likely that coalbed methane is present and could potentially be produced, no coalbed methane development has ever occurred in or near any of the forests. Therefore, development potential for coalbed methane is rated Very Low for the entire Local Analysis Area, including all forests and grasslands. We predict no to minimal coalbed methane development over the planning period.

Future Drilling and Oil and Gas Production Projections

Table 3 summarizes our baseline estimates for drilling activity and oil, natural gas, and water production during the 2018-2037 planning period. **Tables 4 through 6** provide more detail for each of the assessed areas, including annual projections and type of drilling (vertical vs. horizontal). These projected well counts are comparable to historical rates of drilling; see **Figures 17 and 18** for rolling twenty-year totals for wells drilled in the NFGT Proclaimed Boundary and Local Analysis Area, respectively.

Table 3. Cumulative projections for drilling activity and production, 2018-2037. See **Tables 4 through 6** for detailed annual projections for each area. MMBBL = million barrels; BCF = billion cubic feet.

Area	Wells	Production			Detail Table
		Oil (MMBBL)	Gas (BCF)	Water (MMBBL)	
Forest Service Lands	485	21.8	1,342	244	4 (page 11)
NFGT Proclaimed Boundary	1,530	68.7	4,233	769	5 (page 12)
Local Analysis Area	2,340	105	6,475	1,177	6 (page 13)

RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

Table 4. Annual projected drilling activity (including horizontal and vertical well counts and water use for hydraulic fracturing) and production (oil, natural gas, and produced water) from Forest Service lands within the NFGT Proclaimed Boundary, 2018-2037.

Year	Projected wells			Water Use (bbl)	Oil Production (bbl)	Gas Production (Mcf)	Water Production (bbl)
	Horiz.	Vert.	Total				
2018	5	3	8	619,000	259,000	32,670,000	7,429,000
2019	8	4	12	984,000	387,000	36,398,000	7,560,000
2020	10	5	15	1,230,000	510,000	40,238,000	7,730,000
2021	13	6	19	1,595,000	651,000	44,745,000	8,087,000
2022	15	8	23	1,849,000	802,000	49,924,000	8,633,000
2023	17	8	25	2,087,000	932,000	54,842,000	9,328,000
2024	16	8	24	1,968,000	994,000	58,035,000	10,058,000
2025	16	8	24	1,968,000	1,014,000	60,035,000	10,686,000
2026	17	8	25	2,087,000	1,073,000	63,077,000	11,461,000
2027	17	8	25	2,087,000	1,133,000	66,362,000	12,352,000
2028	17	9	26	2,095,000	1,184,000	69,393,000	13,309,000
2029	18	9	27	2,214,000	1,242,000	72,511,000	13,999,000
2030	18	9	27	2,214,000	1,284,000	75,311,000	14,370,000
2031	19	9	28	2,333,000	1,337,000	78,502,000	14,732,000
2032	19	9	28	2,333,000	1,385,000	81,829,000	15,068,000
2033	19	10	29	2,341,000	1,432,000	85,263,000	15,361,000
2034	20	10	30	2,460,000	1,485,000	88,978,000	15,592,000
2035	20	10	30	2,460,000	1,524,000	92,222,000	15,826,000
2036	20	10	30	2,460,000	1,556,000	94,796,000	16,043,000
2037	20	10	30	2,460,000	1,585,000	96,813,000	16,233,000
Total	324	161	485	39,844,000	21,769,000	1,341,944,000	243,857,000

RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

Table 5. Annual projected drilling activity (including horizontal and vertical well counts and water use for hydraulic fracturing) and production (oil, natural gas, and produced water) from all lands within the NFGT Proclaimed Boundary, 2018-2037.

Year	Projected wells			Water Use (bbl)	Oil Production (bbl)	Gas Production (Mcf)	Water Production (bbl)
	Horiz.	Vert.	Total				
2018	17	9	26	2,095,000	816,000	103,063,000	23,436,000
2019	25	13	38	3,079,000	1,222,000	114,823,000	23,848,000
2020	32	16	48	3,936,000	1,608,000	126,938,000	24,387,000
2021	40	20	60	4,920,000	2,055,000	141,156,000	25,510,000
2022	48	24	72	5,905,000	2,529,000	157,491,000	27,234,000
2023	53	27	80	6,524,000	2,939,000	173,006,000	29,428,000
2024	51	25	76	6,270,000	3,136,000	183,080,000	31,729,000
2025	49	25	74	6,032,000	3,200,000	189,388,000	33,709,000
2026	52	26	78	6,397,000	3,384,000	198,984,000	36,157,000
2027	53	27	80	6,524,000	3,575,000	209,347,000	38,966,000
2028	55	28	83	6,770,000	3,735,000	218,910,000	41,985,000
2029	57	28	85	7,008,000	3,917,000	228,747,000	44,161,000
2030	57	29	86	7,016,000	4,049,000	237,578,000	45,331,000
2031	59	29	88	7,254,000	4,216,000	247,646,000	46,474,000
2032	60	30	90	7,381,000	4,369,000	258,141,000	47,535,000
2033	61	31	92	7,508,000	4,517,000	268,974,000	48,458,000
2034	62	31	93	7,627,000	4,684,000	280,693,000	49,187,000
2035	63	31	94	7,746,000	4,809,000	290,926,000	49,926,000
2036	63	31	94	7,746,000	4,909,000	299,047,000	50,611,000
2037	62	31	93	7,627,000	5,000,000	305,409,000	51,209,000
Total	1,019	511	1,530	125,365,000	68,669,000	4,233,347,000	769,281,000

RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

Table 6. Annual projected drilling activity (including horizontal and vertical well counts and water use for hydraulic fracturing) and production (oil, natural gas, and produced water) from the Local Analysis Area (which includes the NFGT Proclaimed Boundary plus a 1.5-mile buffer), 2018-2037.

Year	Projected wells			Water Use (bbl)	Oil Production (bbl)	Gas Production (Mcf)	Water Production (bbl)
	Horiz.	Vert.	Total				
2018	27	13	40	3,317,000	1,254,000	146,532,000	37,991,000
2019	39	20	59	4,801,000	1,887,000	161,204,000	38,646,000
2020	49	24	73	6,024,000	2,464,000	176,157,000	39,402,000
2021	61	30	91	7,500,000	3,139,000	194,837,000	41,035,000
2022	73	37	110	8,984,000	3,859,000	217,339,000	43,612,000
2023	82	41	123	10,087,000	4,524,000	240,085,000	47,105,000
2024	78	39	117	9,595,000	4,773,000	252,496,000	50,288,000
2025	75	38	113	9,230,000	4,896,000	261,309,000	53,365,000
2026	79	40	119	9,722,000	5,174,000	274,727,000	56,916,000
2027	82	41	123	10,087,000	5,456,000	289,542,000	61,046,000
2028	84	42	126	10,333,000	5,712,000	303,643,000	65,622,000
2029	87	43	130	10,698,000	5,993,000	318,360,000	68,949,000
2030	88	44	132	10,825,000	6,225,000	332,383,000	70,817,000
2031	89	45	134	10,952,000	6,438,000	346,578,000	72,320,000
2032	91	46	137	11,198,000	6,669,000	362,519,000	73,975,000
2033	93	47	140	11,444,000	6,907,000	379,387,000	75,292,000
2034	95	47	142	11,682,000	7,133,000	396,716,000	76,193,000
2035	96	48	144	11,809,000	7,339,000	412,835,000	77,250,000
2036	96	48	144	11,809,000	7,502,000	425,806,000	78,280,000
2037	96	47	143	11,801,000	7,641,000	435,891,000	79,128,000
Total	1,560	780	2,340	191,898,000	104,985,000	5,928,346,000	1,207,232,000

The Lyndon B. Johnson National Grassland and surrounding area (**Figure 14**, red box) have high to very high development potential; development is expected to consist of horizontal drilling that targets natural gas in the Barnett Shale.

In the Caddo National Grassland and surrounding area (**Figure 14**, blue box), historical trends of low levels of development are expected to continue throughout the planning period.

In the East Texas Forests and surrounding area (**Figure 14**, purple box), we expect the majority of drilling in the very high and high development potential areas in and around the northern parts of the Davy Crockett, Angelina, and Sabine National Forests to continue to target natural gas, particularly in the Haynesville Formation. Development in the central and southern portions of these forests, as well as in the Sam Houston National Forest, has historically been a mix of gas and oil. Discovery of subsurface structures that act as hydrocarbon traps (for example, salt domes) could lead to pockets of dense vertical development, such as those in and around the Sam Houston National Forest (**Figure 5**). With the exception of the northern part of Lake Sabine, little development has occurred or is expected to occur beneath the lakes and reservoirs in the East Texas Forests.

We estimated the future yearly oil and gas production values by generating decline curves for vertical and horizontal wells from historical production data in the planning area and then convolving those production curves with the forecasted well counts. These estimates account for both production from existing wells and production from predicted wells. Estimated ultimate recoveries (EURs) for individual wells can be found in **Table 7**.

Table 7. Estimated ultimate recoveries (EURs) for oil, gas, and produced water from horizontal and vertical wells.

Well Type	Total Oil (bbl)	Total Gas (Mcf)	Total Water (bbl)
Horizontal Well	70,000	3,900,000	479,000
Vertical Well	56,000	2,262,000	787,000

Estimated Surface Disturbance

As of 2017, there was approximately 1,700 acres of existing disturbance associated with oil and gas development on Forest Service-managed surface within the NFGT Proclaimed Boundary. For period 2018-2037, we estimate an additional 2,300 acres of disturbance, which includes both new wells and new disturbance on existing well pads, for a maximum potential disturbance of 4,000 acres during the planning period. Accounting for interim and final reclamation, we expect 2,500 acres of surface disturbance to remain at the end of the planning period.

As of 2017, there was approximately 6,800 acres of existing disturbance associated with oil and gas development on all lands within the NFGT Proclaimed Boundary. For period 2018-2037, we estimate an additional 7,100 acres of disturbance, which includes both new wells and new disturbance on existing well pads, for a maximum potential disturbance of 13,900 acres during the planning period. Accounting for interim and final reclamation, we expect 8,200 acres of surface disturbance to remain at the end of the planning period.

As of 2017, there was approximately 9,700 acres of existing disturbance associated with oil and gas development within the Local Analysis Area. For period 2018-2037, we estimate an additional 11,100 acres of disturbance, which includes both new wells and new disturbance on existing well pads, for a maximum potential disturbance of 20,800 acres during the planning period. Accounting for interim and final reclamation, we expect 16,000 acres of surface disturbance to remain at the end of the planning period.

Table 8 presents our estimates of total surface disturbance associated with the baseline projections for the twenty-year period (2018-2037). **Table 9** presents the detailed information used to estimate the surface disturbance associated with individual wells.

Table 8. Summary of estimated surface disturbance, 2018-2037.

Surface Disturbance Category	Acres on Forest Service Surface	Acres in Proclaimed Boundary	Acres in Local Analysis Area
Existing Disturbance, as of 2017	1,700	6,800	9,700
New Disturbance, 2018-2037	2,300	7,100	11,100
Maximum Potential Disturbance (Existing + New)	4,000	13,900	20,800
Interim and Final Reclamation, 2018 to 2037	1,500	5,700	8,800
Disturbance Remaining at End of Plan (Maximum – Reclamation)	2,500	8,200	16,000

Table 9. Values used for estimating existing and projected surface disturbance.

Parameter	Value
Well pad area during drilling and completion	5 acres
Surface disturbance per well pad due to roads and flow lines	0.6 acres
Estimated additional surface disturbance per well pad	0.25 acres
Horizontal well pad area after interim reclamation	2.2 acres
Vertical well pad area after interim reclamation	0.75 acres
Average life of horizontal well	12 years
Average life of vertical well	25 years
Vertical well configuration	1 well/pad
Horizontal well configuration	2 wells/pad

Estimated Water Use for Hydraulic Fracturing

Annual estimates for water required for hydraulic fracturing throughout the 2018-2037 planning period are included in **Tables 4 through 6**.

For these estimates, water volumes of 333,000 gallons (7,929 barrels) per vertical well and 5 million gallons (119,048 barrels) per horizontal well were used. These estimates assume that all wells will be hydraulically fractured, and do not account for re-use or recycling of hydraulic fracturing fluid. Fracturing fewer wells, using less water-intensive techniques such as nitrogen or foam fracturing, and/or re-using or recycling hydraulic fracturing fluid would reduce these volumes. The Texas Bureau of Economic Geology estimates that, as of 2011, 92% of the water used for fracturing the Barnett Shale (in and near the Lyndon B. Johnson National Grassland) is fresh, and 80% is sourced from surface water. In the East Texas Basin, approximately 95% of the water used for hydraulic fracturing is fresh, and 70% is sourced from groundwater. Water reuse/recycling was estimated at 5% for both regions (Nicot, 2012). In 2011, water used for hydraulic fracturing accounted for 0.2% of all water use in Texas (EPA, 2016).

Statistics for water volumes used for hydraulic fracturing for the East Texas Basin and for the Barnett Shale come from the Texas Bureau of Geology and Mineral Resources’ report on oil and gas water use in Texas (Nicot, 2012) and from the U.S. Environmental Protection Agency’s assessment of impacts from hydraulic fracturing on drinking water resources (U.S. Environmental Protection Agency, 2016). Average water volumes for fracturing vertical wells vary by formation and range from 100,000 gallons per well (Wilcox Group; EPA, 2016) to 1.3 million gallons per well (Barnett Shale; EPA, 2016). Average water volumes for fracturing horizontal wells vary by formation and range from 4 million gallons per well (Cotton Valley Formation; Nicot, 2012) to 7 million gallons per well (Haynesville Formation; Nicot, 2012).

Induced Seismicity

Activities related to oil and gas development frequently involve extracting or injecting large volumes of fluids out of or into the earth, which can, under certain circumstances, cause earthquakes that are strong enough to be felt by people (“felt earthquakes”). These activities are described in more detail in *A Historical Review of Induced Earthquakes in Texas* (Frohlich et al., 2016) and include:

- High-volume production from shallow depths
- Waterflood operations (injecting water for secondary recover operations)
- Wastewater disposal, especially at high rates and/or in or near basement rock

While hydraulic fracturing also involves the injection of fluid into rock layers, operations take place over shorter periods of time and involve much smaller injection volumes than wastewater disposal. As of 2015, there had been “...only three reported cases of hydraulic fracturing-induced earthquakes in the United States...Most induced earthquakes in the United States are a result of wastewater disposal” (Rubinstein & Mahani, 2015).

Wastewater (salt water) disposal involves the underground injection of waste fluids for the purpose of permanent isolation. Salt water disposal wells in and around the National Forests and Grasslands in Texas are shown in **Figure 19**. There are 42 disposal wells within the NFGT Proclaimed Boundary: One (1) in the Angelina National Forest; zero (0) in the Caddo National Grassland; fifteen (15) in the Davy Crockett National Forest; nine (9) in the Lyndon B. Johnson National Grassland; eight (8) in the Sabine National Forest; and nine (9) in Sam Houston National Forest.

Risk associated with earthquakes in north and east Texas is low. The USGS’ One-Year Seismic Hazard Forecast (published in March 2018 and includes both induced and natural earthquakes) states that the probability of “potentially minor-damage [-causing] ground shaking” in north and east Texas in 2018 is less than 1%.

The Texas Railroad Commission (RCC), which regulates fluid injection related to oil and gas development, could take regulatory steps to minimize or reduce induced seismicity. In 2013, the Oklahoma Corporation Commission (OCC) implemented a “traffic light” protocol, which requires operators to slow down (“yellow light”) or cease (“red light”) disposal operations if seismicity occurs above a certain strength and within a certain distance (OCC, 2015). The number of earthquakes in Oklahoma with a moment magnitude of 3 or greater (the approximate threshold for “felt” earthquakes) decreased from a record high of 903 in 2015 to 304 in 2017 (Oklahoma Office of the Secretary of Energy and Environment, 2018). The RCC could implement a similar protocol if Texas begins to experience more damaging and/or frequent earthquakes.

Summary

We examined the available information on the National Forests and Grasslands in Texas and adjacent lands (geologic reports, recent drilling data, and professional knowledge of the area) and used that data to prepare a map that indicates areas of potential oil and gas development for 2018-2037 (**Figure 16**). We also estimated the number of wells that could be drilled during this period, as well as the disturbance associated with projected and existing wells over the life of the plan.

We estimated that on Forest Service lands within the NFGT Proclaimed Boundary, 485 wells (324 horizontal and 161 vertical) may be reasonably assumed to be drilled, and 40 million barrels of water used to hydraulically fracture those wells. On Forest Service lands within the Proclaimed Boundary, the maximum potential surface disturbance over the life of the plan is 4,000 acres, and we project 2,500 acres of disturbance to remain by 2037.

Within the NFGT Proclaimed Boundary, 1,530 wells (1,019 horizontal and 511 vertical) may be reasonably assumed to be drilled, and 125 million barrels of water used to hydraulically fracture those wells. Within the Proclaimed Boundary, the maximum potential surface disturbance over the life of the plan is 13,900 acres, and we project 8,200 acres of disturbance to remain by 2037.

Within the Local Analysis Area (a 1.5-mile buffer around the NFGT Proclaimed Boundary), we estimated that 2,340 wells (1,560 horizontal and 780 vertical) may be reasonably assumed to be drilled, and 192 million barrels of water used to hydraulically fracture those wells. Within the Local Analysis Area, the maximum potential surface disturbance over the life of the plan is 20,800 acres, and we project 16,000 acres of disturbance to remain by 2037.

These projected drilling totals are comparable to past drilling totals over similar timeframes (**Figures 17 and 18**). However, horizontal drilling is expected to increase as a percentage of overall drilling, resulting in increased demand for water for hydraulic fracturing as well as increased production.

References

- Alsalem, O.B., Fan, M., and Xie, X., 2017, Late Paleozoic Subsidence and Burial History of the Fort Worth Basin: AAPG Bulletin vol. 101 (11): 1813-1833, available at <https://doi.org/10.1306/01251716016>
- Baker, E.T., 1995, Stratigraphic Nomenclature and Geologic Sections of the Gulf Coastal Plain of Texas: U.S. Geological Survey Open File Report 94-461, available at <https://pubs.usgs.gov/of/1994/0461/report.pdf>
- Ball, M. M., and Perry, W.J., Jr., 1996, Bend Arch-Fort Worth Basin Province (045), in Gautier, D. L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., ed., 1995 National assessment of United States oil and gas resources; results methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, Release 2, available at <http://certmapper.cr.usgs.gov/data/noga95/prov45/text/prov45.pdf>
- Bureau of Economic Geology, 2005, Oil and Gas Map of Texas and Oil and Gas Production in Texas: The University of Texas at Austin, available at <http://www.beg.utexas.edu/UTopia/images/pagesizemaps/oilgas.pdf>
- Frohlich, C., et al., 2016, A Historical Review of Induced Earthquakes in Texas: Seismological Research Letters vol. 87 (4).
- Gallegos, T.J., and Varela, B.A., 2015, Data regarding hydraulic fracturing distributions and treatment fluids, additives, proppants, and water volumes applied to wells drilled in the United States from 1947 through 2010: U.S. Geological Survey Data Series 868, 11 p., available at <https://dx.doi.org/10.3133/ds868>
- IHS Energy Group, 2017, U.S. Well Data, IHS Enerdeq Browser, v7.
- IHS Energy Group, 2018, Oil and Natural Gas Production Volumes, IHS Enerdeq Browser, v2.
- IHS Energy Group, 2018, U.S. Pipeline and Facility Data, IHS Enerdeq Browser, v2.
- Johnson, K., and Luza, K., 2008, Earth Sciences and Mineral Resources of Oklahoma, Oklahoma Geological Survey.
- Marra, K.R., Charpentier, R.R., Schenk, C.J., Lewan, M.D., Leathers-Miller, H.M., Klett, T.R., Gaswirth, S.B., Le, P.A., Mercier, T.J., Pitman, J.K., and Tennyson, M.E., 2015, Assessment of undiscovered shale gas and shale oil resources in the Mississippian Barnett Shale, Bend Arch–Fort Worth Basin Province, north-central Texas: U.S. Geological Survey Fact Sheet 2015-3078, 2 p., available at <http://dx.doi.org/10.3133/fs20153078>

RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

- Martineau, D.F., 2007, History of the Newark East Field and the Barnett Shale as a Gas Reservoir: AAPG Bulletin vol. 91 (4): 399-403, available at <https://doi.org/10.1306/intro910407>
- Nicot, J., Reedy, R., Costley, R., and Huang, Y., 2012, Oil & Gas Water Use in Texas: Update to the 2011 Mining Water Use Report: Bureau of Economic Geology, The University of Texas at Austin, available at http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/0904830939_2012Update_MiningWaterUse.pdf
- Oklahoma Corporation Commission, OCC Announces Next Step in Continuing Response to Earthquake Concerns, 7/17/2015. Press release. Available at <https://occeweb.com/News/DIRECTIVE-2.pdf>
- Oklahoma Office of the Secretary of Energy and Environment, Earthquakes in Oklahoma: What We Know, accessed October 1, 2018. <http://earthquakes.ok.gov/what-we-know/>
- Petersen, M., et al., 2018 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes: Seismological Research Letters vol. 89 (3), available at <https://doi.org/10.1785/0220180005>
- Rubinstein, J., Mahani, A.B., Myths and Facts on Waste Water Injection, Hydraulic Fracturing, Enhanced Oil Recovery, and Induced Seismicity, Seismological Research Letters Volume 86, Number 4 July/August 2015, doi: 10.1785/0220150067, available at https://scits.stanford.edu/sites/default/files/isfc_2_rubenstein_pap_srl-2015067.pdf
- Schenk, C. J., and Viger, R.J., 1995, Western Gulf Coast Province (047), *in* Gautier, D. L., Dolton, G.L., Takahashi, K.I., and Varnes, K.I., ed., 1995 National Assessment of United States Oil and Gas Resources; results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, Release 2, 110 p. Available at <http://certmapper.cr.usgs.gov/data/noga95/prov47/text/prov47.pdf>
- Schenk, C. J., and Viger, R.J., 1996, East Texas Basin Province (048) and Louisiana-Mississippi Salt Basins Provinces (049), Region 6; Gulf Coast, Geologic Framework, *in* Gautier, D. L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., ed., 1995 National assessment of United States oil and gas resources--Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, Release 2, 95 p. Available at <http://certmapper.cr.usgs.gov/data/noga95/prov49/text/prov49.pdf>
- Smith, C.E., 2018, Near-Term Pipeline Plans Nearly Double, Future Slows: Oil and Gas Journal vol. 116 (2), available at <https://www.ogj.com/articles/print/volume-116/issue-2/special->

RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

[report-worldwide-pipeline-construction/near-term-pipeline-plans-nearly-double-future-slows.html](#)

Smith, J.C., 2010 (ed. 2016), Handbook of Texas Online: East Texas Oilfield: Texas State Historical Association, available at

<http://www.tshaonline.org/handbook/online/articles/doi01>

U.S. Bureau of Land Management, Handbook H-1624-1 Planning for Fluid Mineral Resources, available at

https://www.blm.gov/sites/blm.gov/files/uploads/Media_Library_BLM_Policy_Handbook_H_1624_1.pdf

U.S. Energy Information Administration, 2017, Annual Energy Outlook with projections to 2050, available at <https://www.eia.gov/outlooks/aeo/>

U.S. Energy Information Administration, 2017, Cushing, Oklahoma WTI Spot Price, available at

<https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=A>

U.S. Energy Information Administration, 2017, Henry Hub Natural Gas Spot Price, available at

<https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm>

U.S. Energy Information Administration, 2017, U.S. Natural Gas Wellhead Price, available at

<https://www.eia.gov/dnav/ng/hist/n9190us3a.htm>

U.S. Energy Information Administration, 2018, Texas State Energy Profile Analysis, available at

<https://www.eia.gov/state/analysis.php?sid=TX>

U.S. Energy Information Administration, 2018, Natural Gas Pipelines in the Southwest Region, available at

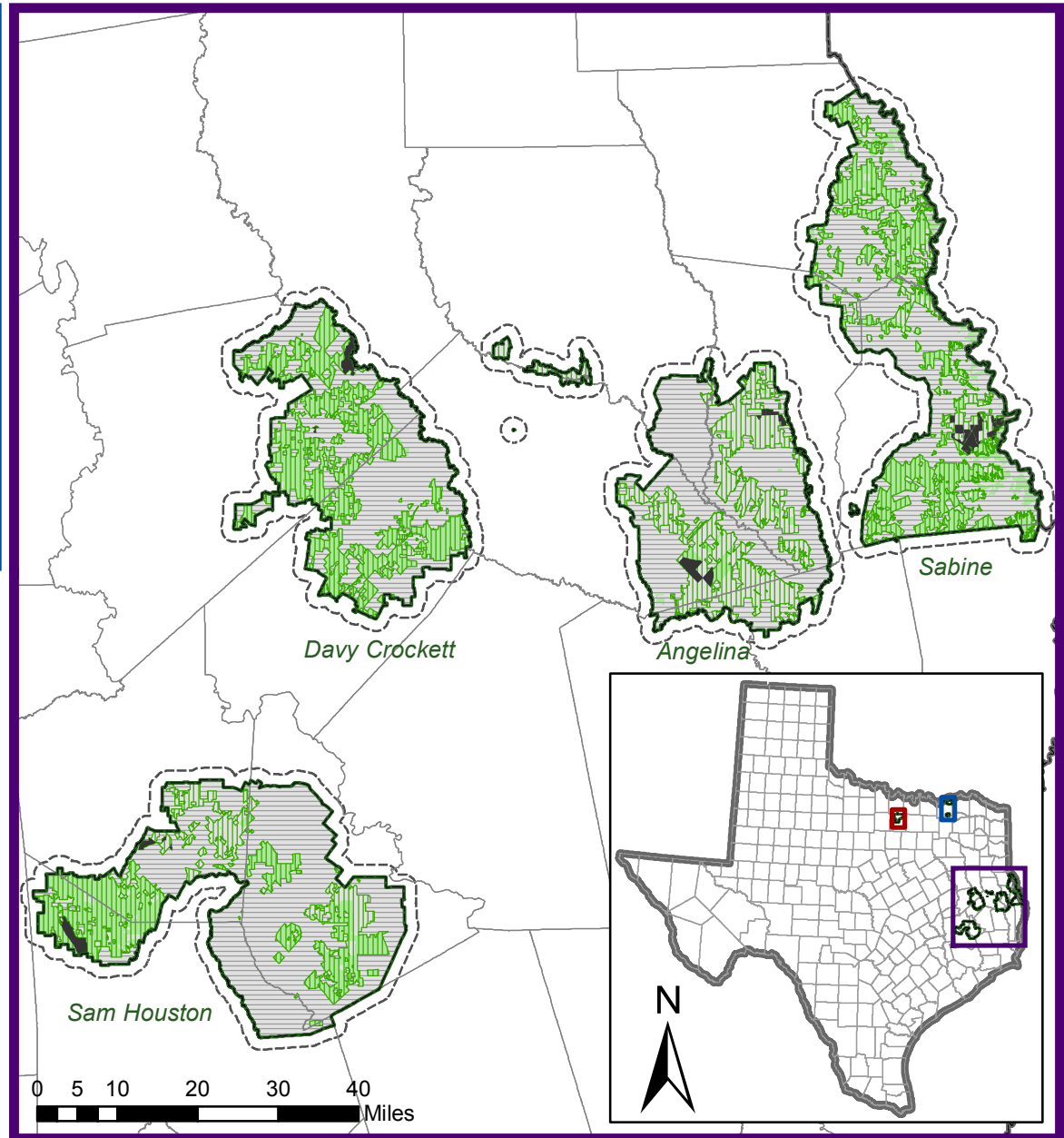
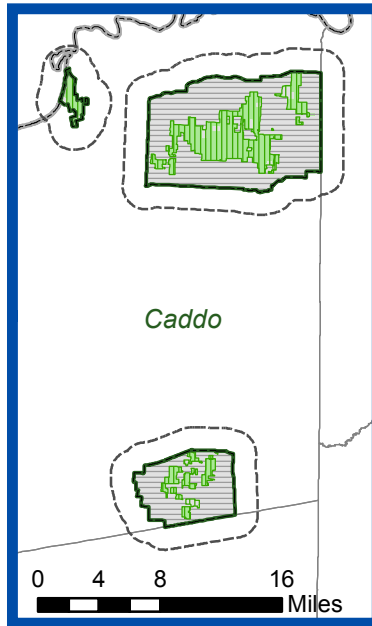
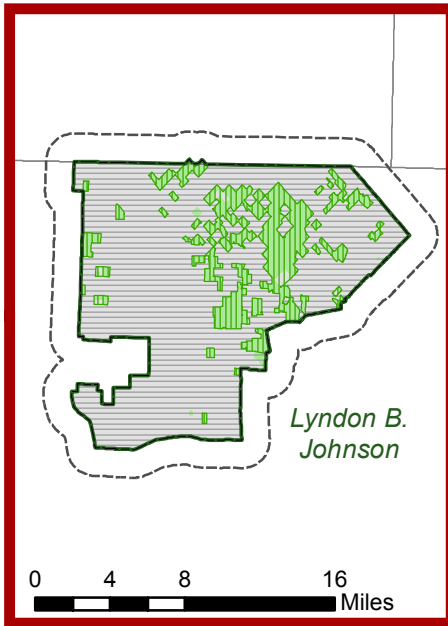
https://www.eia.gov/naturalgas/archive/analysis_publications/ngpipeline/southwest.html

U.S. Environmental Protection Agency, 2016, Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report): U.S. Environmental Protection Agency, EPA/600/R-16/236F, available at <https://www.epa.gov/hfstudy>








Wickman, John, 1977, Interpretations of the Ouachita Mountains, Oklahoma, Twenty-Ninth Annual Field Conference 1977, Wyoming Geological Association Guidebook.

Figure 1. Surface and Oil and Gas Mineral Ownership within the National Forests and Grasslands in Texas.

Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



Surface and Oil and Gas Mineral Ownership

-  Surface - Forest Service
-  Surface - Other Ownership
-  Oil and Gas - Federal Ownership
-  Oil and Gas - Non-Federal Ownership
-  Federal Minerals Closed to Leasing by Law
-  NFGT Proclaimed Boundary
-  Local Analysis Area (1.5-mile buffer around the NFGT Proclaimed Boundary)

Coordinate System: North American 1983
 Projection: North America Albers Equal Area Conic
 Datum: North American 1983
 False Easting: 0.0 False Northing: 0.0 Central Meridian: -96.0
 Standard Parallel 1: 20.0 Standard Parallel 2: 60.0 Latitude of Origin: 40.0
 Units: Meter

No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

Figure 2. Drilling activity within the NFGT Proclaimed Boundary, 1973-2017 (IHS Energy Group, 2017). Data is complete through June, 2017.

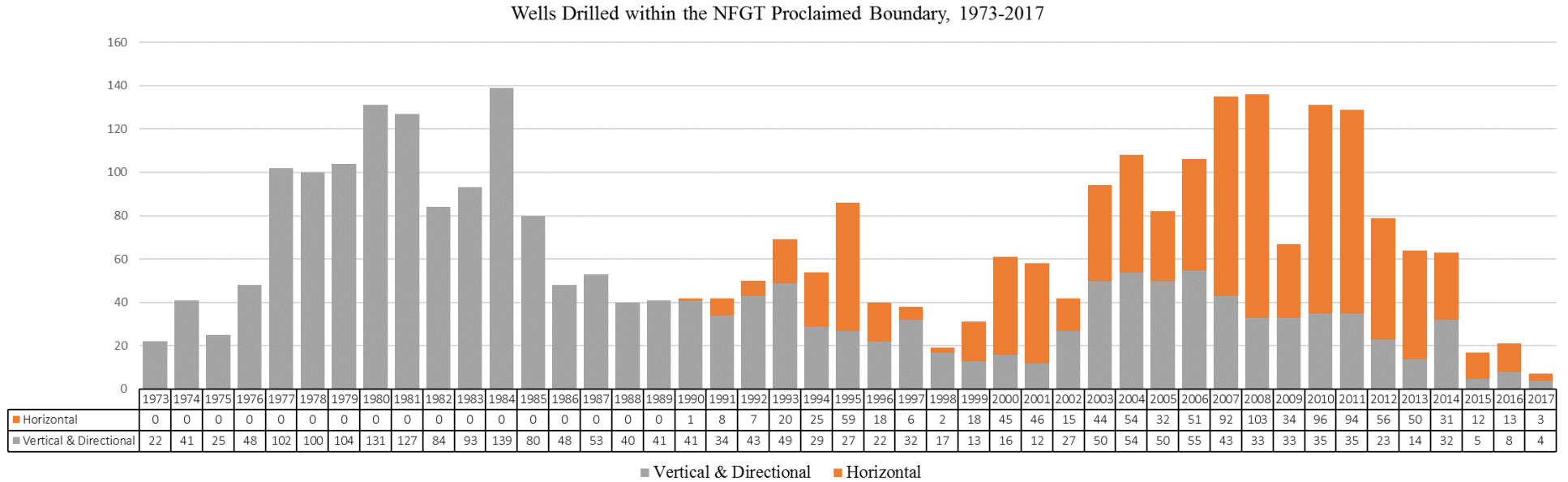


Figure 3. Drilling activity within the Local Analysis Area, 1973-2017 (IHS Energy Group, 2017). Data is complete through June, 2017.

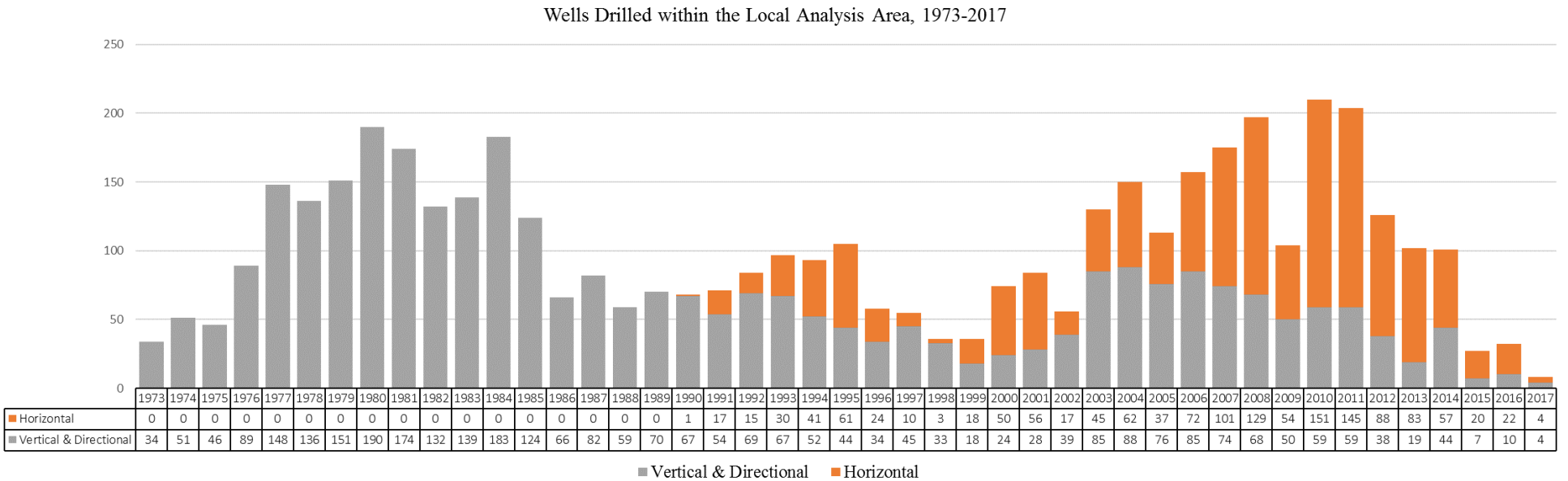
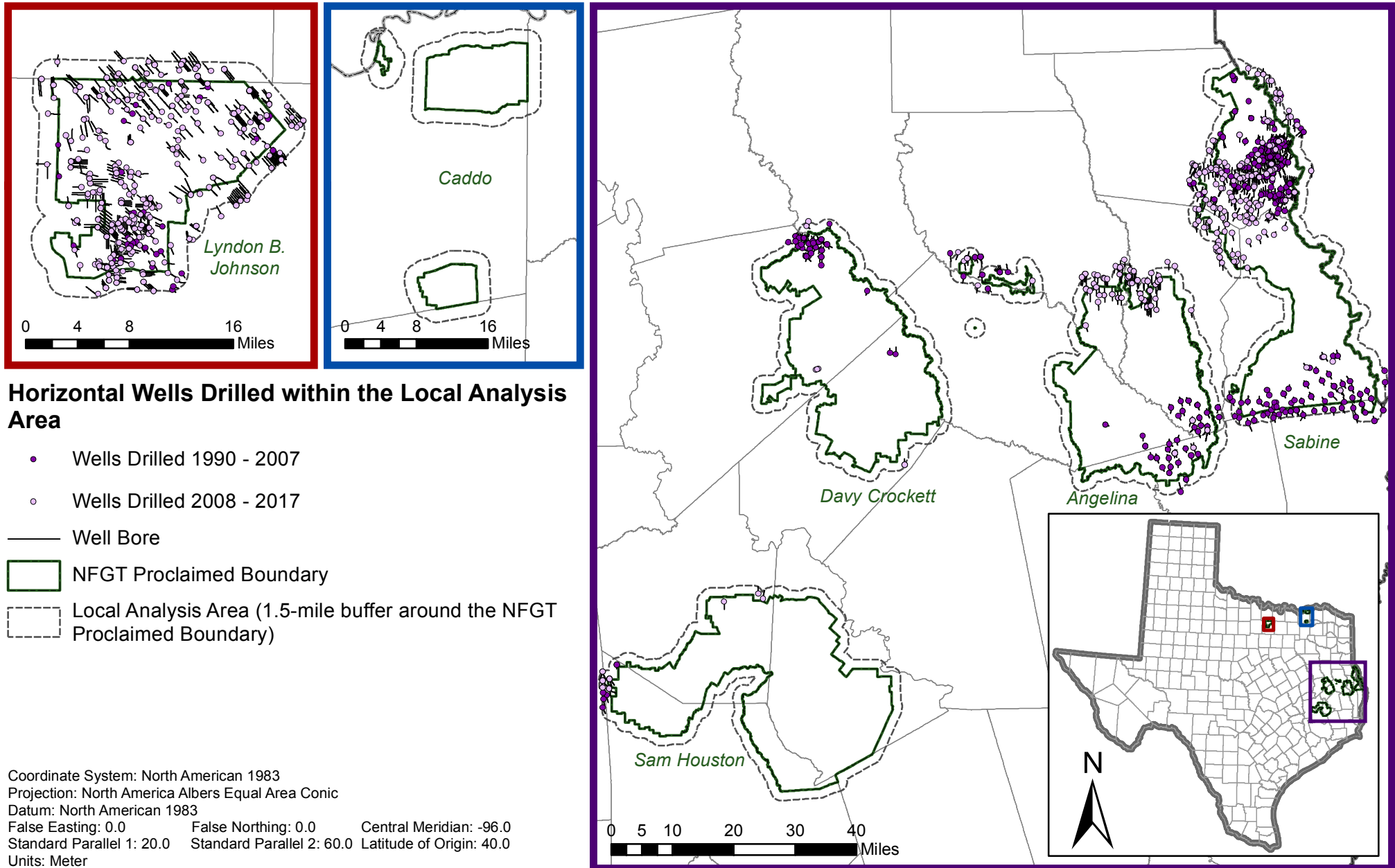


Figure 4. All Horizontal Wells Drilled Within the Local Analysis Area (IHS Energy Group, 2017).

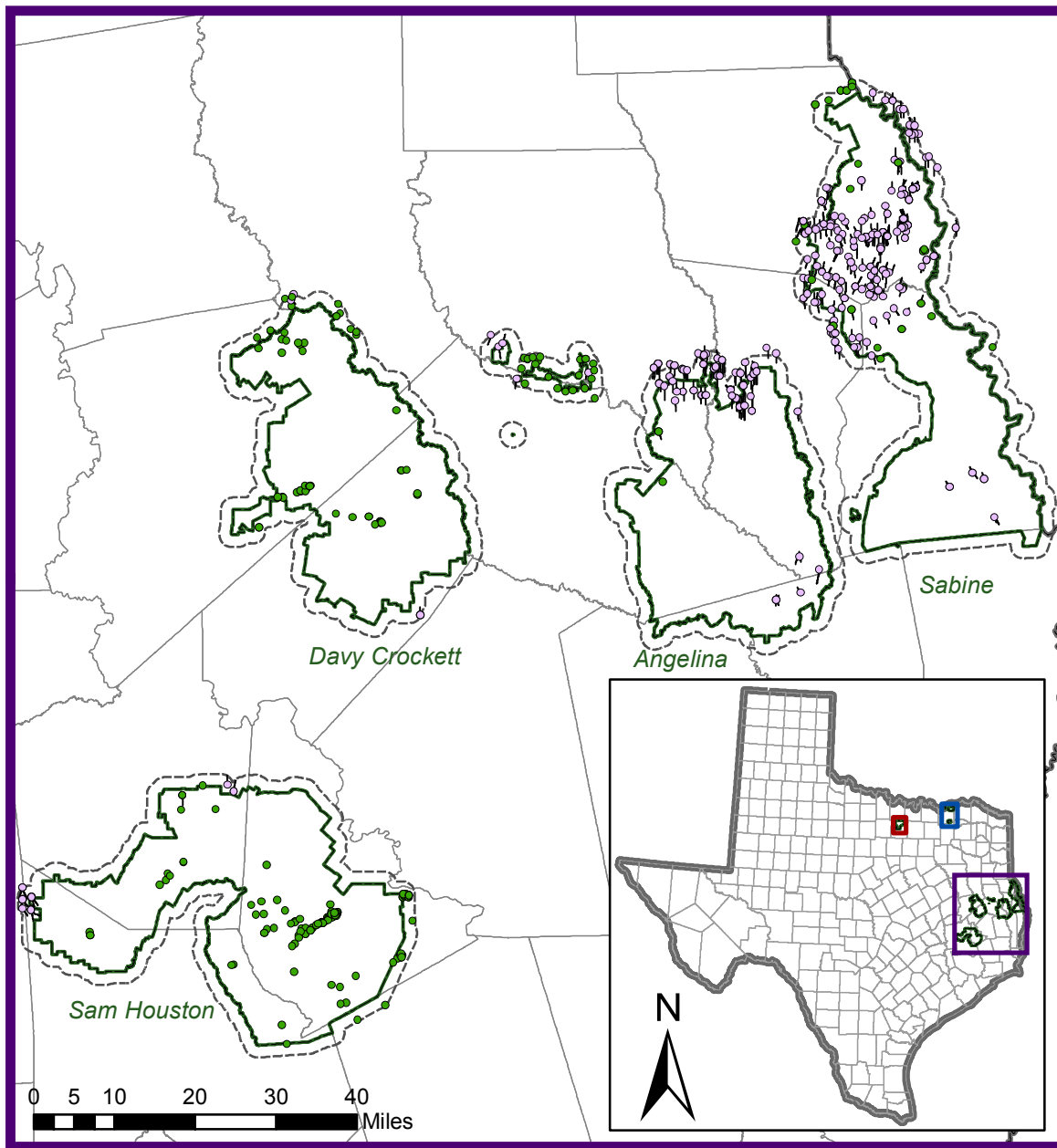
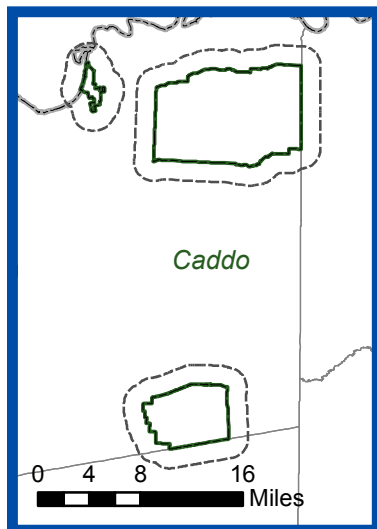
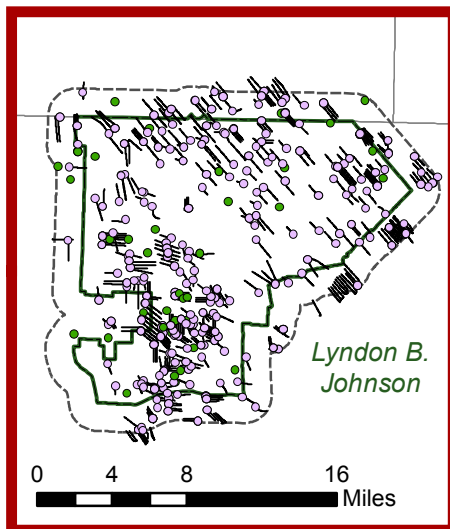
Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 5. Recent Oil and Gas Wells Drilled Within the Local Analysis Area, 2008-2017 (IHS Energy Group, 2017).

Kelsey Crocker, GIS Specialist
 James Glover, Geologist
 November 2018



Wells Drilled Since 2008

- Vertical and Directional Wells
- Horizontal Wells
- Well Bore
- ⋯ Local Analysis Area (1.5-mile buffer around the NFGT Proclaimed Boundary)
- ▭ NFGT Proclaimed Boundary

Coordinate System: North American 1983
 Projection: North America Albers Equal Area Conic
 Datum: North American 1983
 False Easting: 0.0 False Northing: 0.0 Central Meridian: -96.0
 Standard Parallel 1: 20.0 Standard Parallel 2: 60.0 Latitude of Origin: 40.0
 Units: Meter

No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 6. Historical oil and natural gas production within the NFGT Proclaimed Boundary, 1973-2017 (IHS Energy Group, 2018).

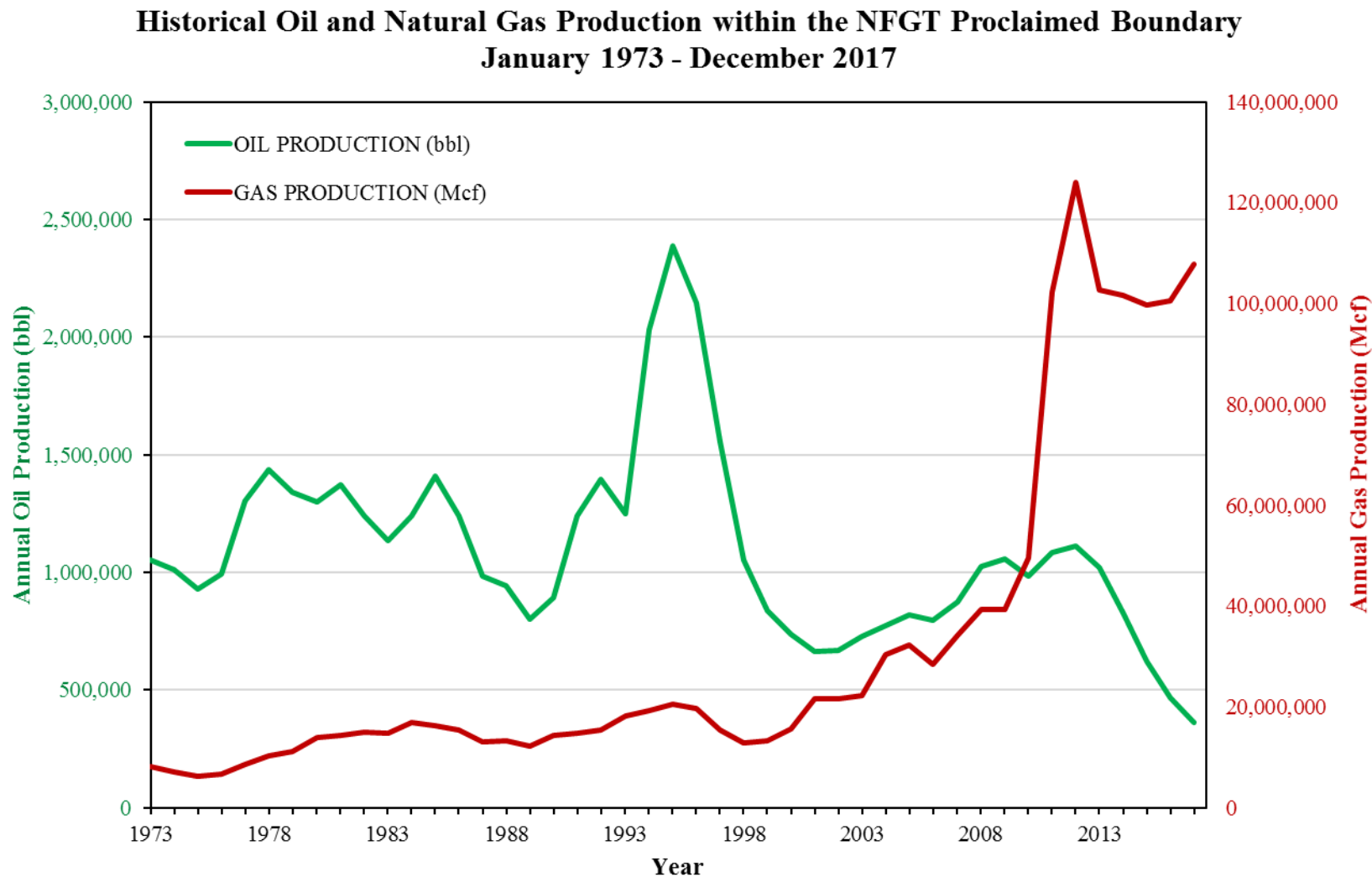


Figure 7. Historical oil and natural gas production within the Local Analysis Area, 1973-2017 (IHS Energy Group, 2018).

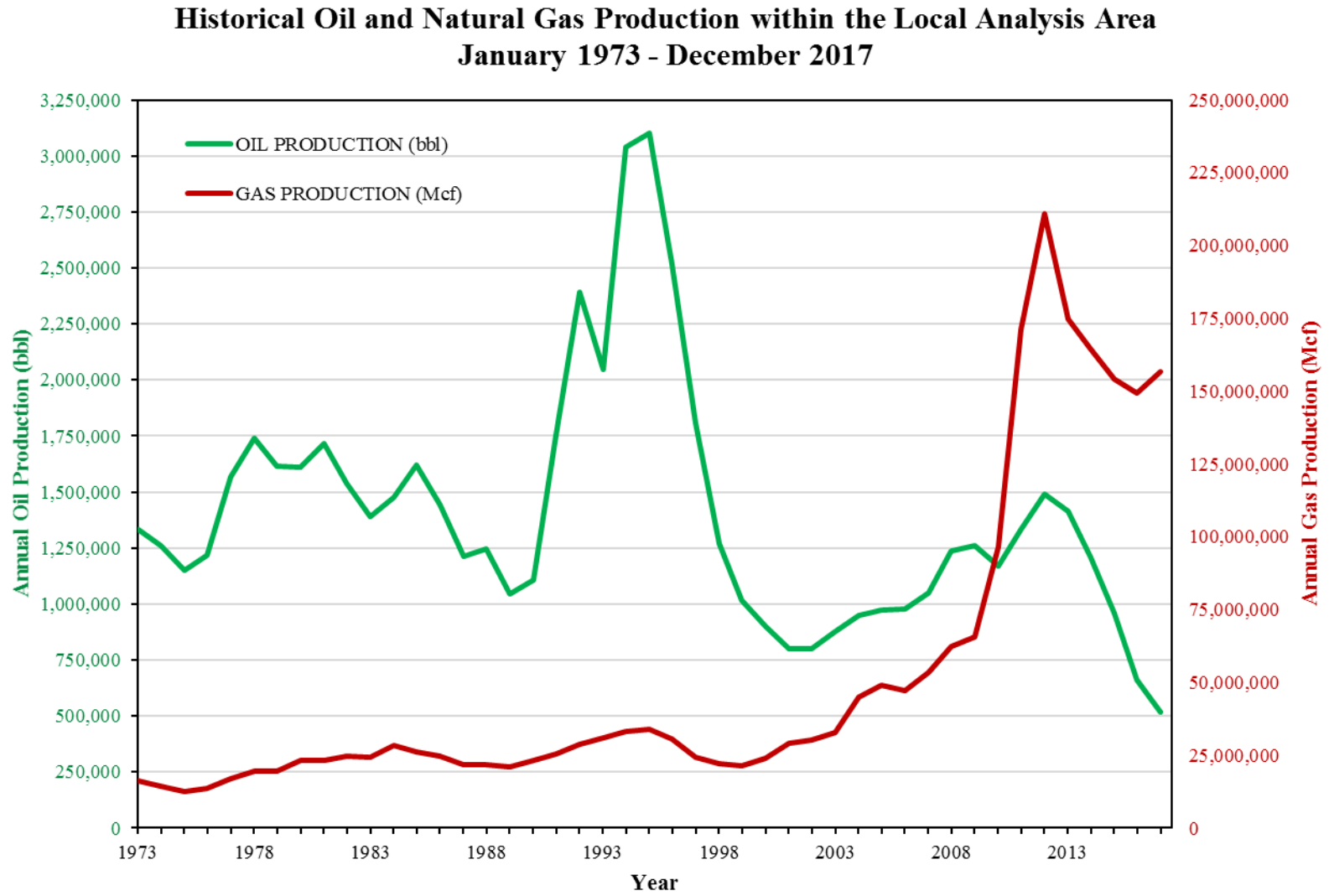
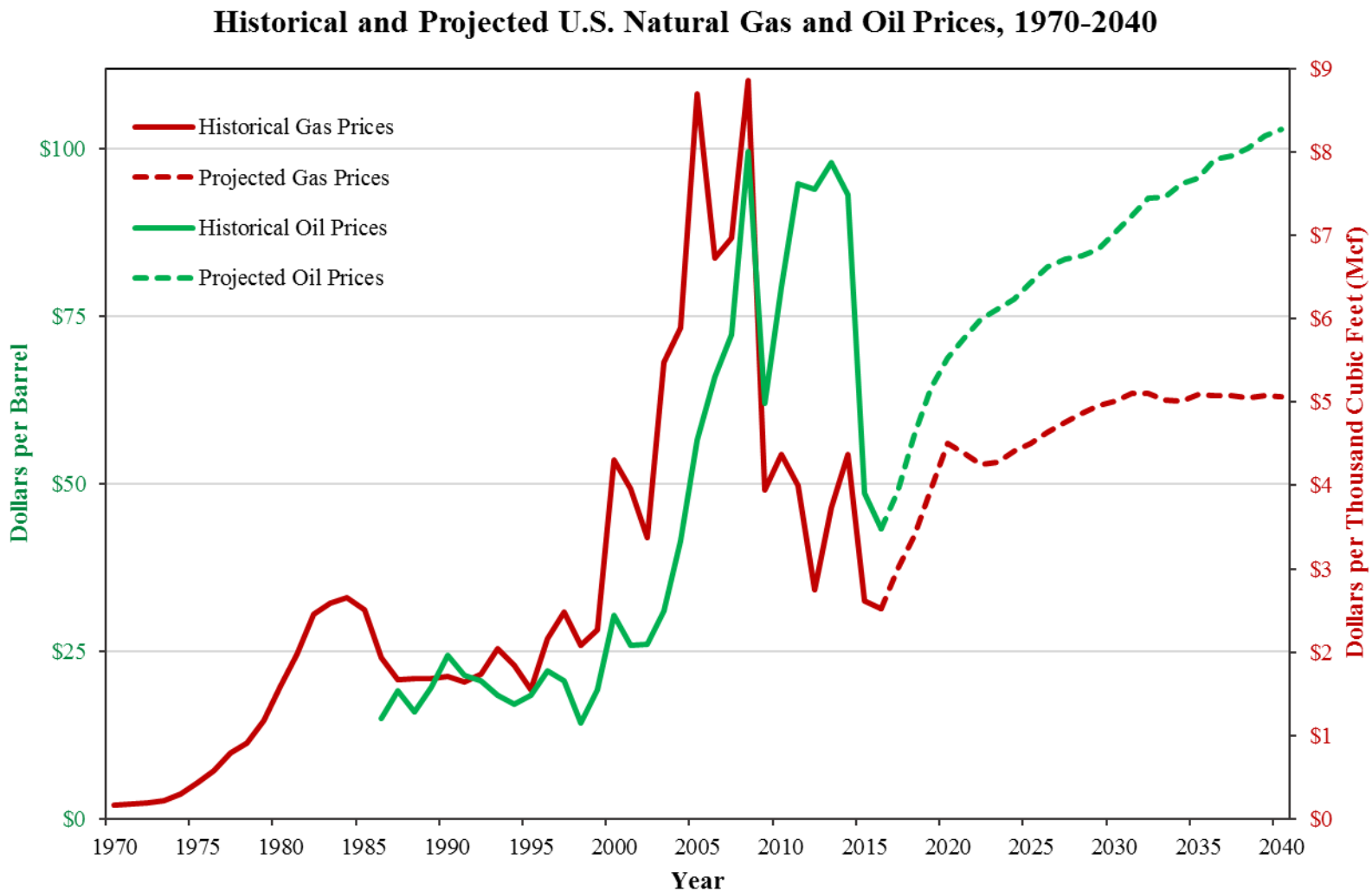


Figure 8. Historical and projected U.S. natural gas and oil prices, 1970-2040 (Energy Information Administration, 2017).



RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

Figure 9. Correlation between natural gas prices and drilling activity within the Local Analysis Area (Energy Information Administration, 2017; IHS Energy Group, 2017).

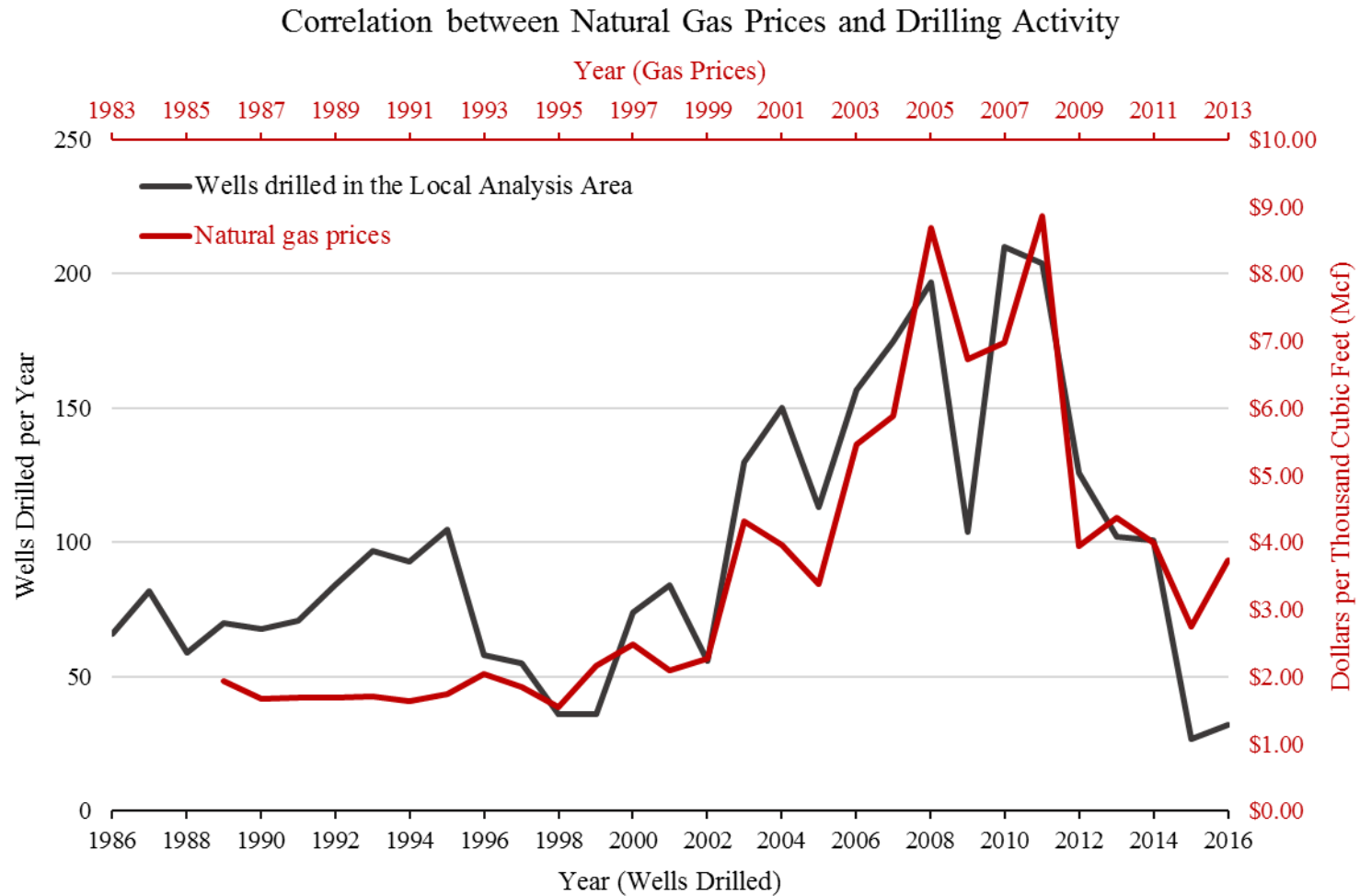
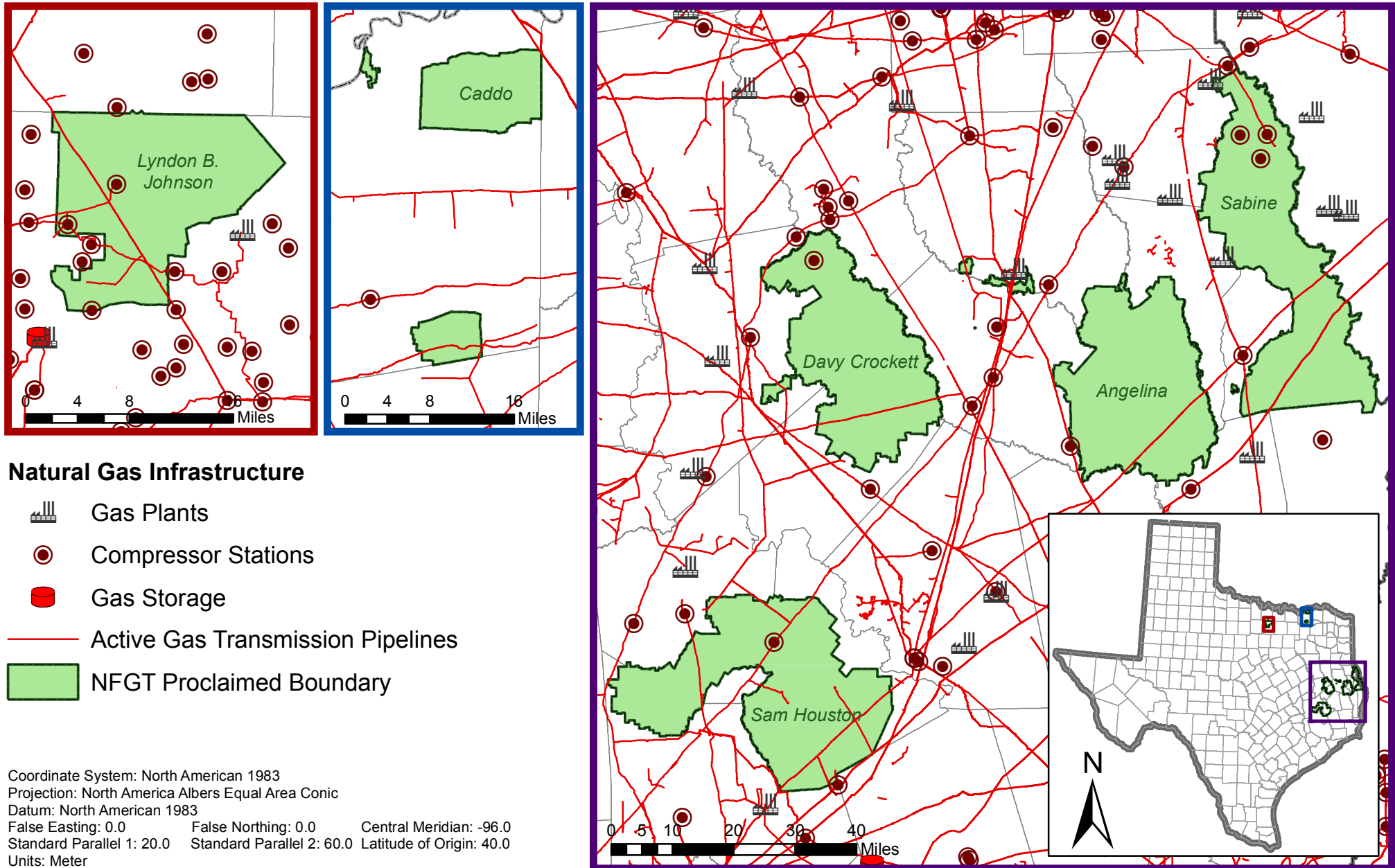


Figure 10. Natural Gas Pipelines and Infrastructure in and around the National Forests and Grasslands in Texas (IHS Energy Group, 2018).

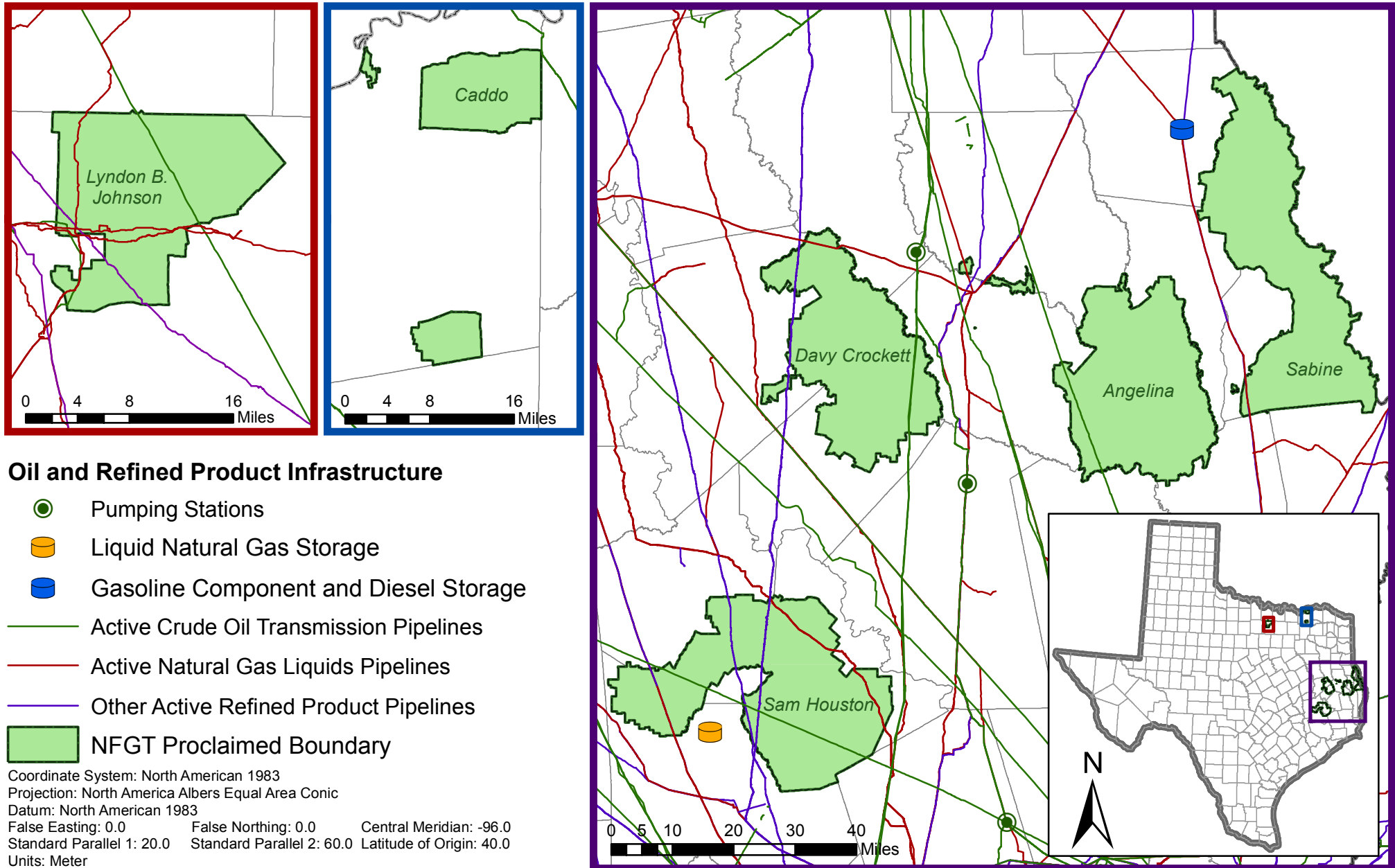
Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 11. Oil and Refined Product Pipelines and Infrastructure in and around the National Forests and Grasslands in Texas (IHS Energy Group, 2018).

Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 12. Chronostratigraphic chart of East Texas (modified from Baker, 1995).

Explanation of abbreviations: Ss., sandstone; Sd., sand; Ls., limestone.

ERA	PERIOD	EPOCH	EAST COASTAL PLAIN (NW--SE)	
CENOZOIC	Quaternary	Holocene	Alluvium	
		Pleistocene	Beaumont Formation	
			Lissie Formation	Montgomery Formation
				Bentley Formation
			Willis Sand	
	Tertiary	Pliocene	Goliad Sand	
		Miocene	Oakville Sandstone	Fleming Formation
			Catahoula Sandstone	Upper part of Catahoula Ss.
				Anahuac Formation
				Frio Formation
		Oligocene	Vicksburg Formation	
			Jackson Group	
		Eocene	Claiborne Group	Yegua Formation
				Cook Mountain Formation
				Sparta Sand
				Weches Formation
				Queen City Sand
	Reklaw Formation			
	Carrizo Sand			
	Wilcox Group			Calvert Bluff Formation
Simsboro Formation				
Hooper Formation				
Paleocene	Midway Group			
MESOZOIC	Cretaceous	Gulfian	Navarro Group	Kemp Clay
Corsicana Marl				
Nacatoch Sand				
Neylandville Marl				

Continued on following pages

Figure 12, continued.

ERA	PERIOD	EPOCH	EAST COASTAL PLAIN (NW--SE)		
MESOZOIC continued	Cretaceous continued	Gulfian continued	Taylor Marl	Upper part Taylor Marl	
				Pecan Gap Chalk	Annona Chalk
				Wolfe City Sand	
				Lower part Taylor Marl	
			Austin Group	Gober Chalk	
				Brownstown Marl	
				Blossom Sand	
				Bonham Marl	
				Ector Tongue	
			Eagle Ford Shale	Sub-Clarksville Sd.	
		Woodbine Sand			
		Comanchean	Washita Group	Maness Shale	
				Buda Limestone	
				Grayson Marl	
				Georgetown Limestone	Main Street Limestone
					Pawpaw Formation
					Weno Clay
					Denton Clay
			Fort Worth Limestone		
			Duck Creek Formation		
			Fredricksburg Group	Kiamichi Formation	
				Edwards Limestone	Goodland Limestone
				Comanche Peak Ls.	
				Keys Valley Marl member	Walnut Formation
Cedar Park member					
Bee Cave member					

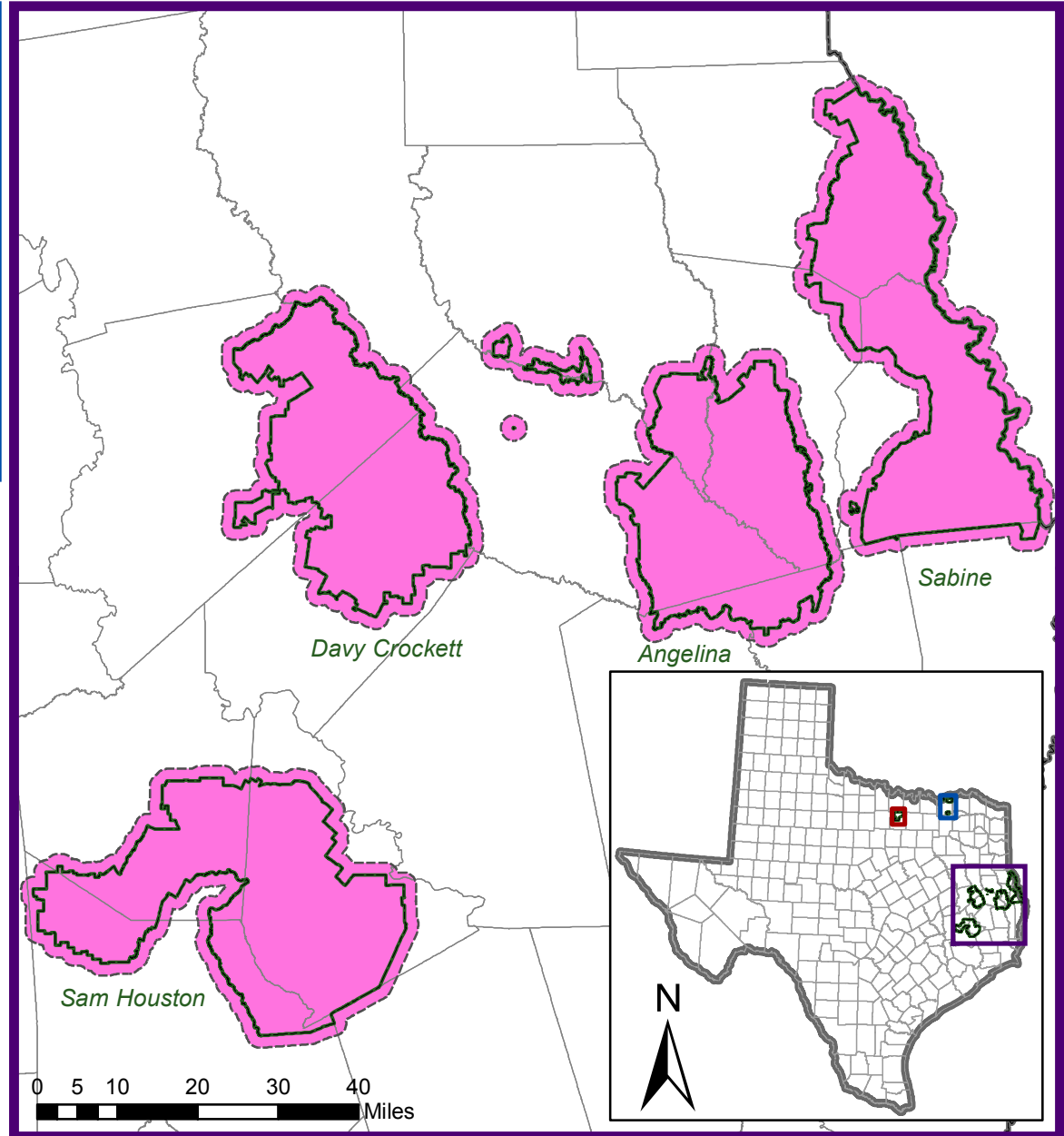
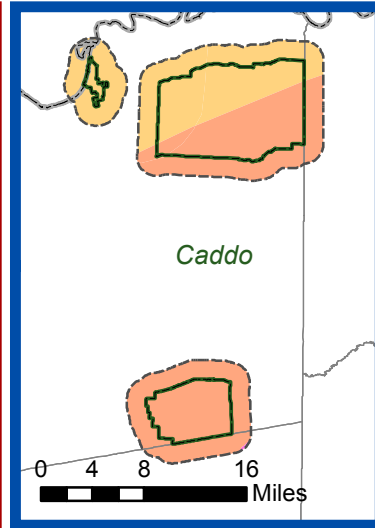
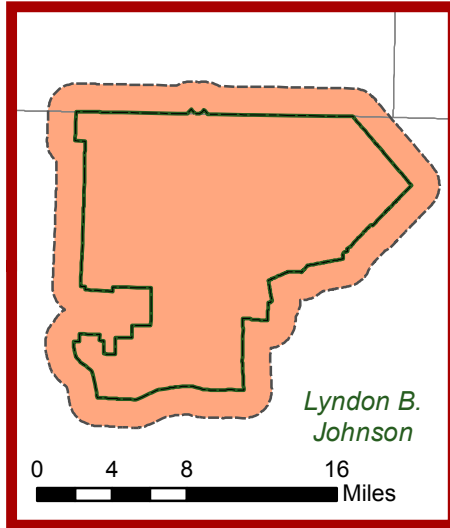
Continued on following page

Figure 12, continued.

ERA	PERIOD	EPOCH	EAST COASTAL PLAIN (NW--SE)		
MESOZOIC continued	Cretaceous continued	Comanchean continued	Trinity Group	Paluxy Sand	
				Glen Rose Limestone	Mooringsport Formation
					Ferry Lake Anhydrite
					Rodessa Formation
				Pearsall Formation	Hensell Shale member
					James Limestone member
	Pine Island Shale member				
	Jurassic	Coahuilian	Nuevo Leon Group	Sligo (Pettet) Formation	
			Durango Group	Hosston Formation	
		Upper Jurassic	Cotton Valley Group	Schuler Formation	
				Bossier Formation	
			Gilmer Limestone		
			Buckner Formation		
			Smackover Formation		
			Norphlet Formation		
		Middle Jurassic	Louann Salt		
			Werner Formation		
Triassic		Upper Triassic	Eagle Mills Formation		
PALEOZOIC			Oachita facies		

Figure 13. Oil and Gas Occurrence Potential within the Local Analysis Area.

Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



Oil and Gas Occurrence Potential

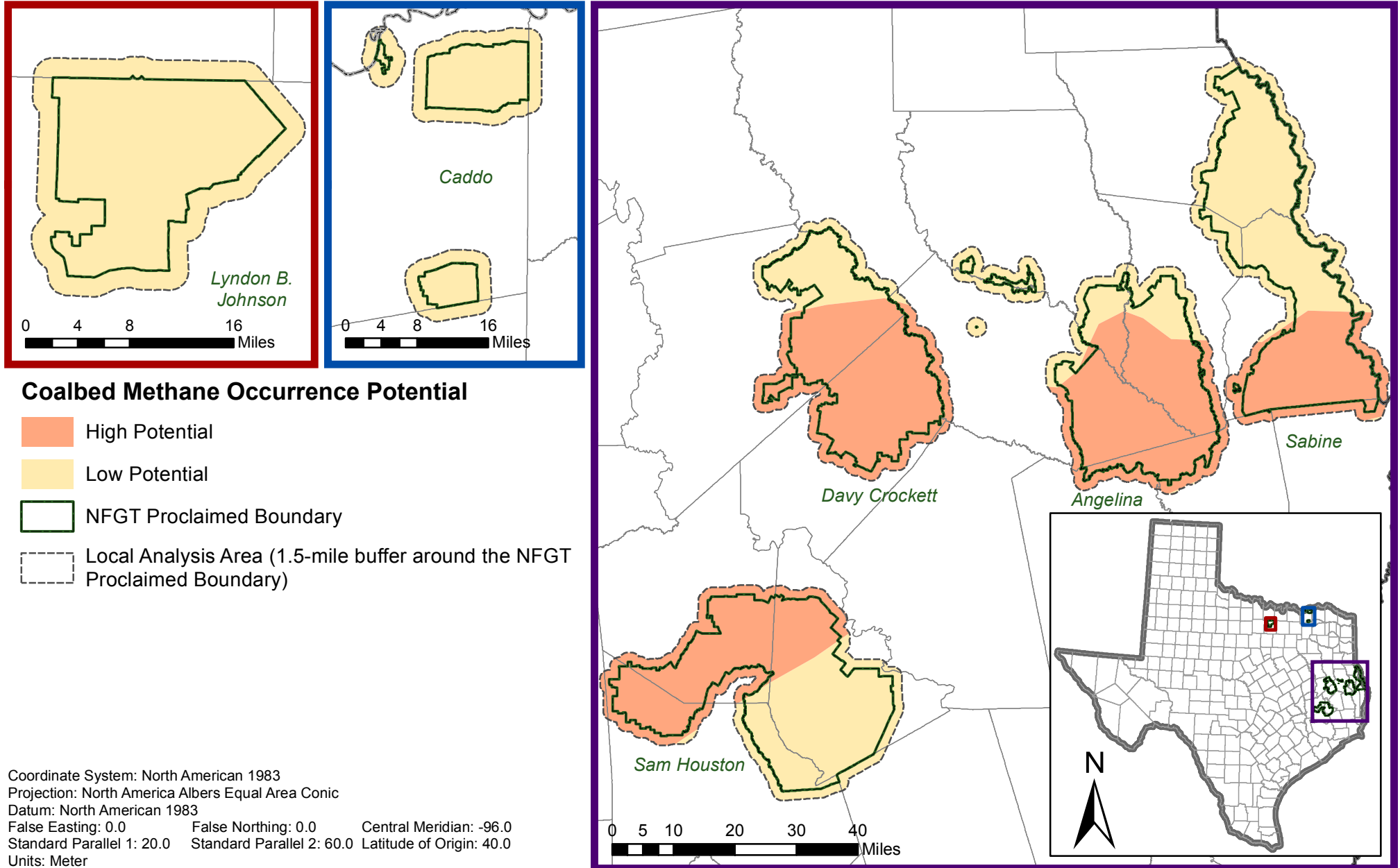
- Very High Potential
- High Potential
- Medium Potential
- NFGT Proclaimed Boundary
- Local Analysis Area (1.5-mile buffer around the NFGT Proclaimed Boundary)

Coordinate System: North American 1983
 Projection: North America Albers Equal Area Conic
 Datum: North American 1983
 False Easting: 0.0 False Northing: 0.0 Central Meridian: -96.0
 Standard Parallel 1: 20.0 Standard Parallel 2: 60.0 Latitude of Origin: 40.0
 Units: Meter

No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 14. Coalbed Methane Occurrence Potential within the Local Analysis Area.

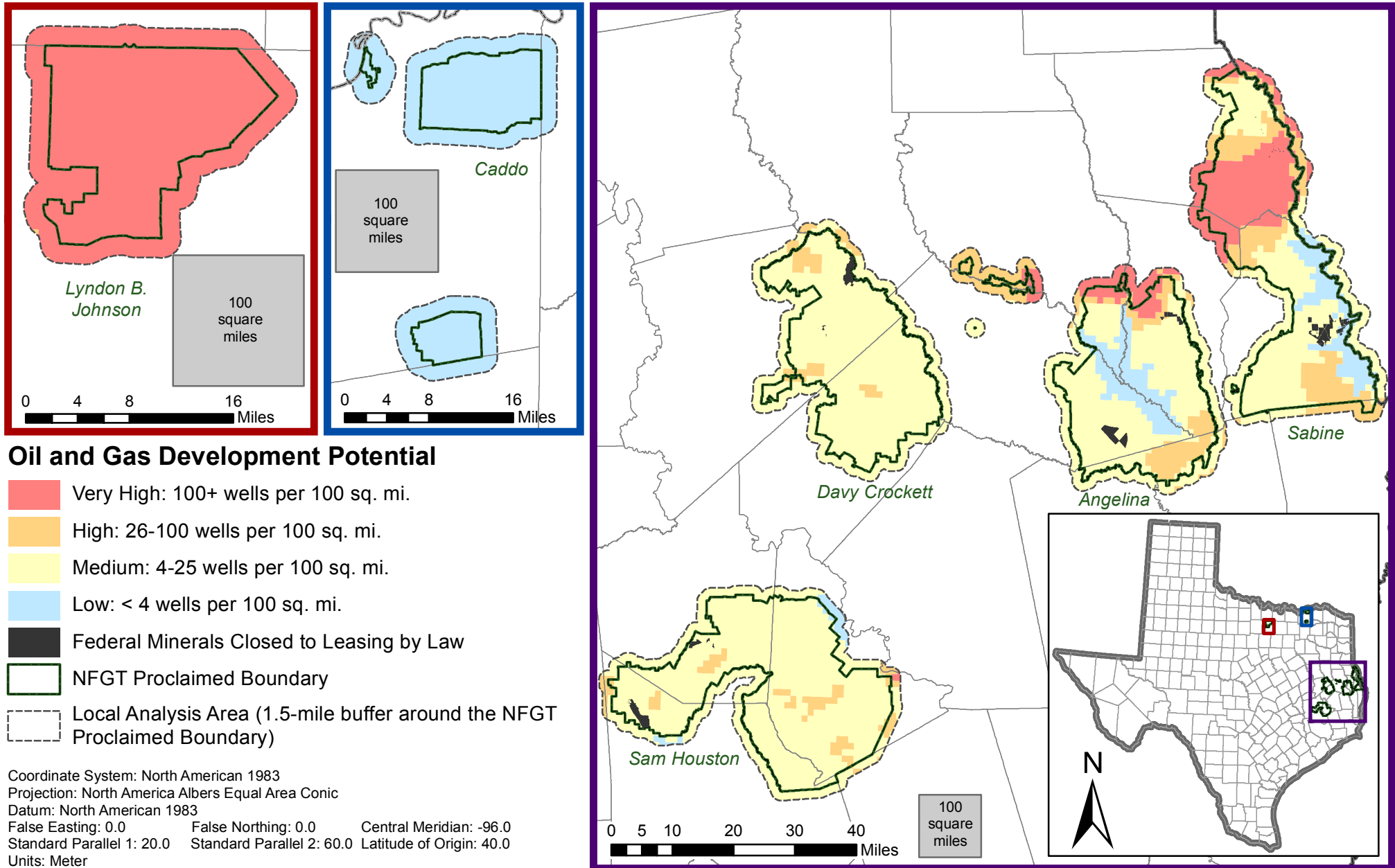
Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 15. Oil and Gas Development Potential within the Local Analysis Area, 2018-2037.

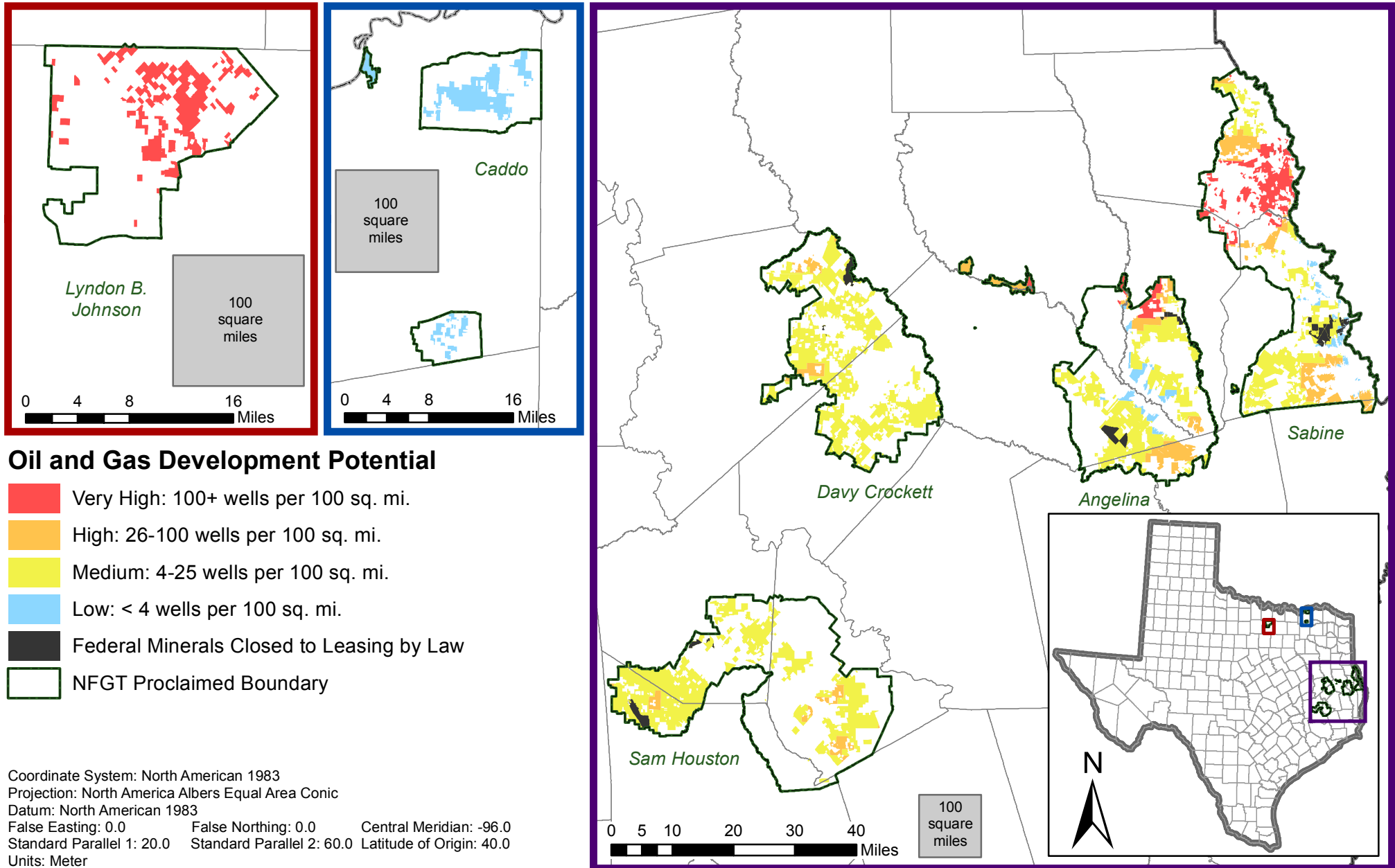
Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 16. Oil and Gas Development Potential for Forest Service Lands, 2018-2037.

Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

Figure 17. Comparison of historical 20-year drilling totals within the NFGT Proclaimed Boundary with RFD projections for 2018-2037. Historical data from IHS Energy Group, 2018.

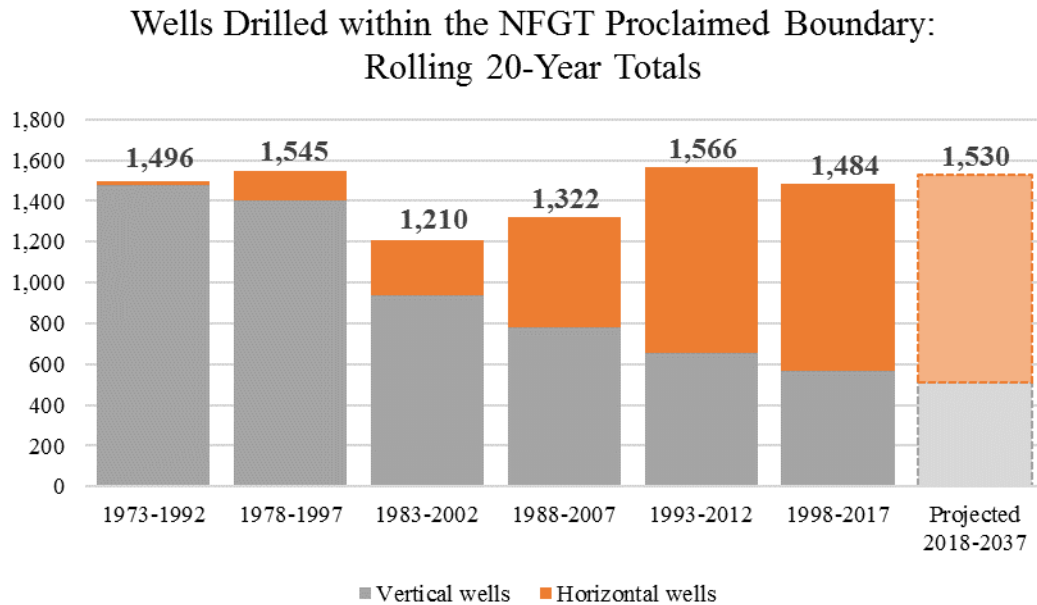


Figure 18. Comparison of historical 20-year drilling totals within the Local Analysis Area with RFD projections for 2018-2037. Historical data from IHS Energy Group, 2018.

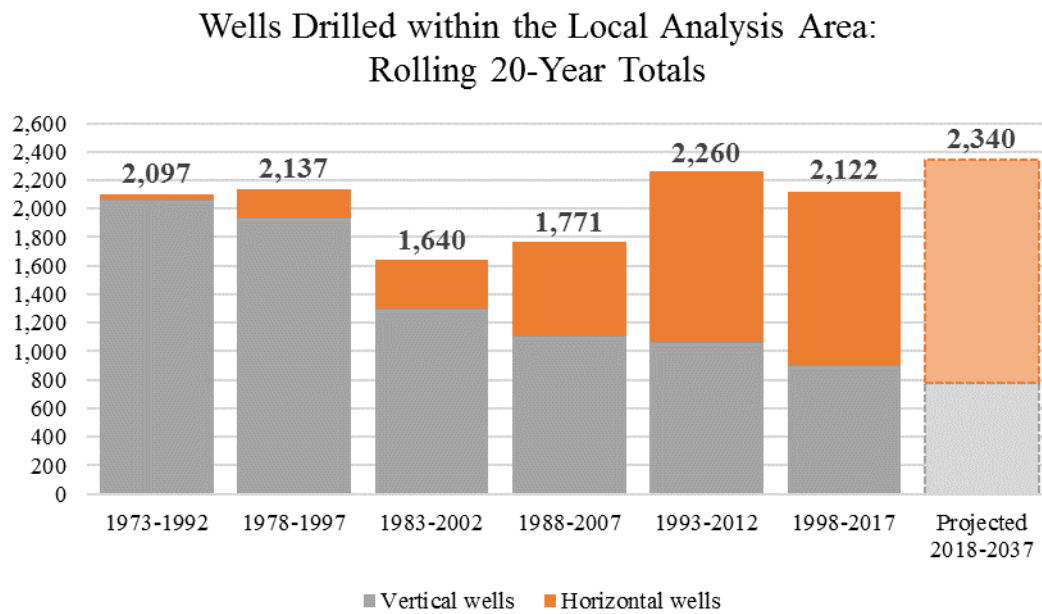
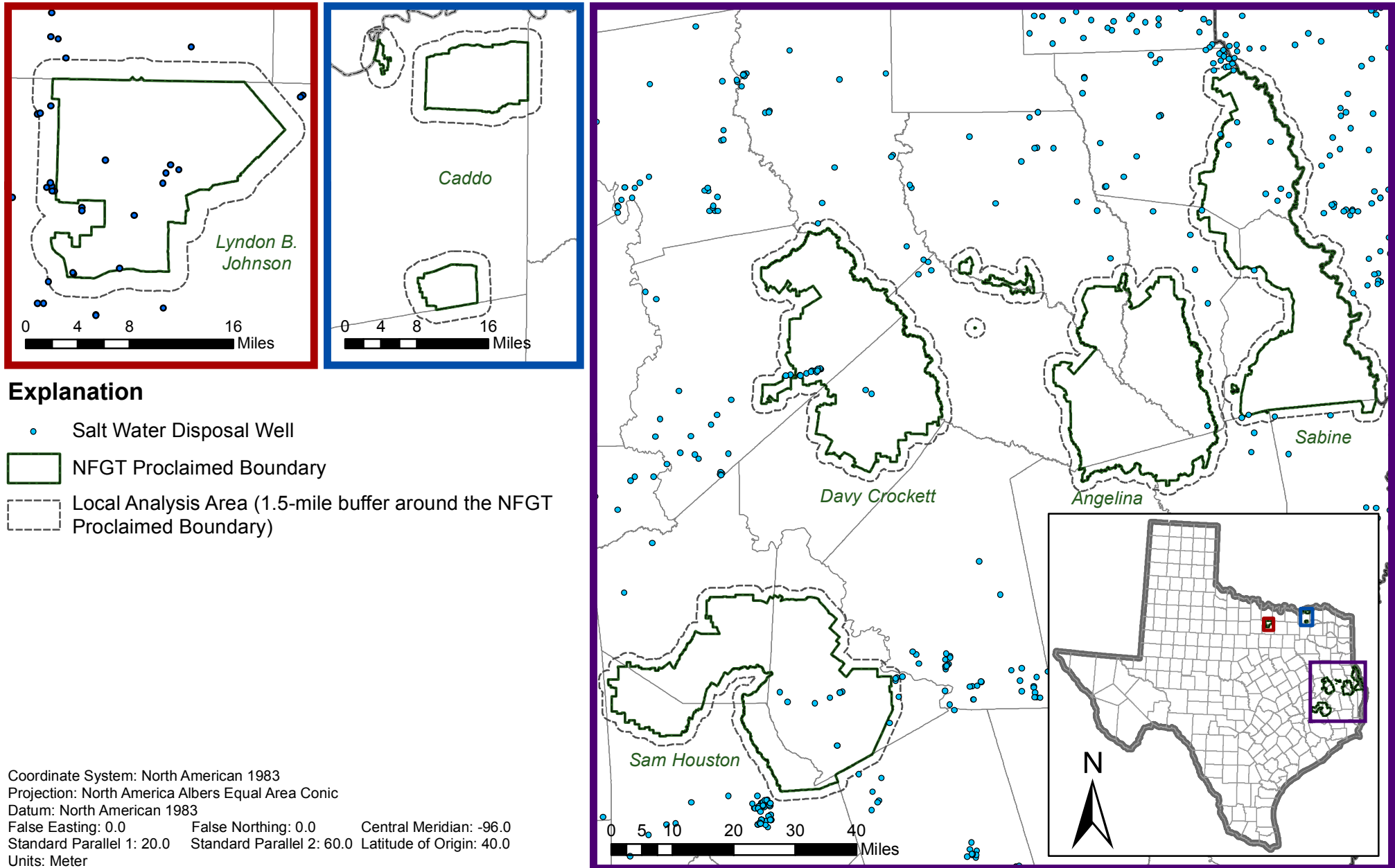


Figure 19. Salt Water Disposal Wells in and around the National Forests and Grasslands in Texas (IHS Energy Group, 2018).

Kelsey Crocker, GIS Specialist
James Glover, Geologist
November 2018



No warranty is made by the Bureau of Land Management or the U.S. Forest Service as to the accuracy, reliability, or completeness of these data for individual or aggregate use with other data. Original data was compiled from various sources. This information was developed through digital means and may be updated without notice.

RFD Scenario for Oil and Gas Activities—National Forests and Grasslands in Texas

Supplemental Table A. Surface and oil and gas mineral ownership within the NFGT Proclaimed Boundary. Acreages are from GIS and should be considered approximate.

	Forest Service Surface Acres	Non-FS Surface Acres	Total Surface Acres
Angelina National Forest	154,460	243,663	398,123
Federal Oil and Gas Minerals - Total	16,297	872	17,169
Open to Federal Leasing	10,598	872	11,470
Closed to Leasing - Wilderness Area	5,699	0	5,699
Non-Federal Oil and Gas Minerals	138,163	242,791	380,954
Caddo National Grassland	17,629	50,837	68,467
Federal Oil and Gas Minerals - Total	16,469	58	16,527
Open to Federal Leasing	16,469	58	16,527
Non-Federal Oil and Gas Minerals	1,161	50,780	51,940
Davy Crockett National Forest	161,140	228,469	389,609
Federal Oil and Gas Minerals - Total	158,490	2,045	160,535
Open to Federal Leasing	154,935	1,977	156,913
Closed to Leasing - Incorporated Place	90	67	157
Closed to Leasing - Wilderness Area	3,465	0	3,465
Non-Federal Oil and Gas Minerals	2,649	226,424	229,073
Lyndon B. Johnson National Grassland	20,102	95,306	115,408
Federal Oil and Gas Minerals - Total	19,459	481	19,940
Open to Federal Leasing	19,459	481	19,940
Non-Federal Oil and Gas Minerals	643	94,826	95,468
Sabine National Forest	161,087	293,455	454,542
Federal Oil and Gas Minerals - Total	138,586	32,194	170,781
Open to Federal Leasing	131,293	32,194	163,487
Closed to Leasing - Incorporated Place	88	0	88
Closed to Leasing - Wilderness Area	7,205	1	7,206
Non-Federal Oil and Gas Minerals	22,500	261,261	283,761
Sam Houston National Forest	163,257	332,059	495,315
Federal Oil and Gas Minerals - Total	119,782	198	119,980
Open to Federal Leasing	114,966	198	115,164
Closed to Leasing - Incorporated Place	1,104	0	1,104
Closed to Leasing - Wilderness Area	3,711	0	3,711
Non-Federal Oil and Gas Minerals	43,475	331,861	375,335
Supervisor's Office, Lufkin	12	0	12
Federal Oil and Gas Minerals - Total	12	0	12
Closed to Leasing - Incorporated Place	12	0	12
Grand Total - NFGT Proclaimed Boundary	677,685	1,243,790	1,921,476

Supplemental Table B. Well densities for development potential categories.

Development Potential Category	Well Density (Wells per 100 Square Miles)	
	Range	Value Used in RFD Calculations
Very High	Greater than 100	263.600
High	26 to 100	65.900
Medium	4 to 25	13.180
Low	Fewer than 4	3.295

These data are presented for completeness and reproducibility only. We strongly encourage planners and specialists to use the density ranges in their calculations. Oil and gas development does not occur homogeneously across large areas. The well density ranges account for this spatial variability.