Oil Production Study of the Teapot Dome Field

by

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ABSTRACT

Geographic Information Systems (GIS) is widely used in the petroleum industry and is applied across planning, production, refining and distribution. Production data from 1,317 individual wells spanning a period of 91 years between 1914 and 2005, covering 19 geographic sections, and 14 rock formations were taken from the Naval Petroleum Reserve 3 (NPR-3) or "Teapot Dome" located in state of Wyoming, USA. This paper demonstrates how GIS provides an environment to analyze oil well production data to determine which reservoir, well depth, and geographic sections produce the most oil.

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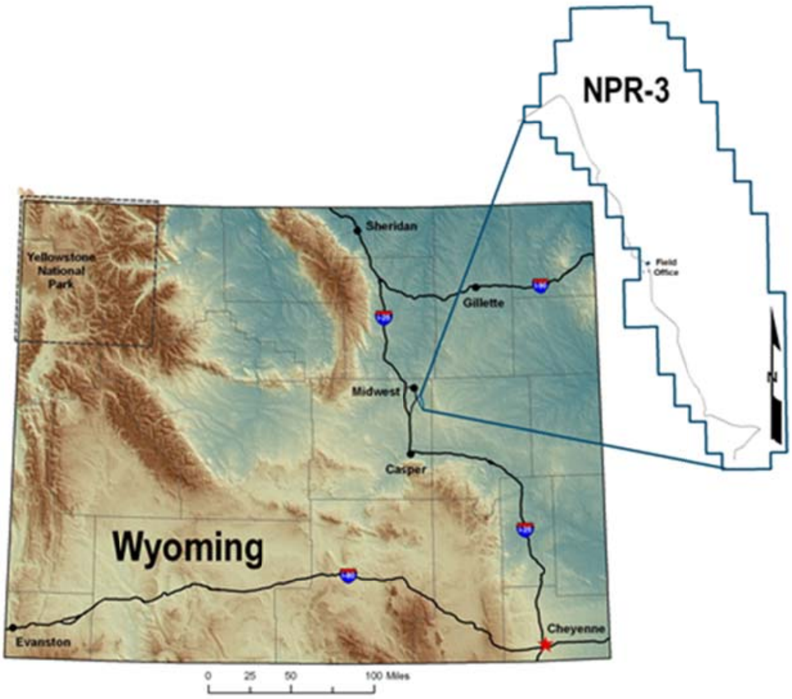
INTRODUCTION

The United States Naval Petroleum Reserve was established as a natural oil reserve where the oil would be left in the formation for the future use of the U.S. Navy. The reserve occupies public land and the subject of this study is the Naval Petroleum Reserve 3 (NPR-3) or "Teapot Dome" located in state of Wyoming in the United States of America (RMOTC n.d.).

Figure 1 – General Location of NPR-3



Source: (RMOTC n.d.)

In 1993 the Rocky Mountain Oilfield Testing Center (RMOTC) was established as a partnership between the U.S. Government's Department of Energy (DOE), the petroleum industry, and academia for the purpose of studying and field testing new technologies for drilling, production, enhanced recovery, and production cost reduction. There are currently 300 producing wells in 9 reservoirs. (RMOTC n.d.).

Figure 2 – Teapot Dome Aerial Photograph

Source: (USGS n.d.)

LITERATURE REVIEW

Introduction

Geographic Information Systems are used in a wide variety of applications in the petroleum industry. Such as “optimization of the selection of surface locations for development wells, shifting of wells, safety and security management, planning and design of pipeline routes etc.” (Shamsan and Kumar 2005) A few of the more frequent applications are discussed in the paragraphs below.

Land Acquisition

With urban encroachment on existing and newly planned oil production fields in many locations throughout the world GIS is well suited for identifying potential conflicts. In locations where land constraints for competing urban development and oil field development exist such as the Kingdom of Bahrain GIS plays a pivotal role in planning for decision makers.

> Bapco’s (Bahrain Petroleum Company) management realized that the land acquisition is going to be a very sensitive issue in the coming years, as the booming economy of Bahrain will try to corner every square foot of the land. With the dwindling free land available, the competition for acquiring land by urban development, industries, and tourism industry etc. is becoming severe (Shamsan and Kumar 2005).

Among the considerations for land acquisition decisions are the costs of drilling a horizontal well to preservation of the recreational quality, land cost assessment, land ownership (Shamsan and Kumar 2005).

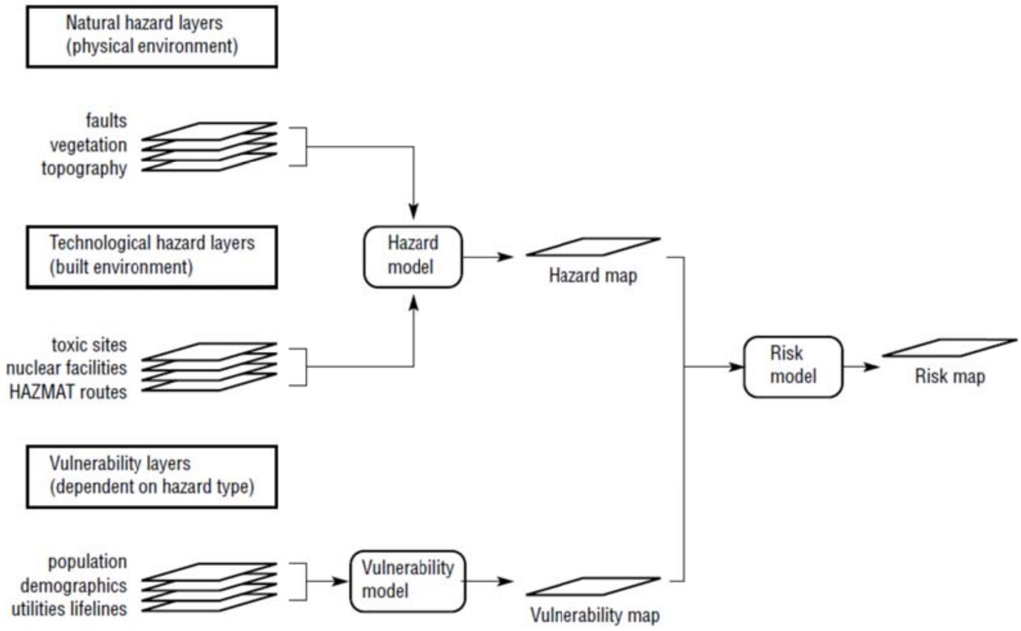
Field Development

Regular oil field performance reviews are carried out for various reservoirs and developmental strategies formulated to exploit the reserves. Well site locations are selected in advance then conveyed to the site development team to complete the civil works preparatory to mobilizing the drilling rig to location. This practice reduces the number of times the drilling rig is relocated and optimizes the rig performance reducing the overall well installation cost. Along with drilling oil wells come pipeline, access road, electrical power distribution, pump stations as well as other support facility construction (Shamsan and Kumar 2005), all of which need to be accurately documented ‘as-built’ for maintenance, optimizing routing and layout, to avoid future conflicts and facilitate project planning.

Safety & Security

Whether oil field facilities are in close proximity to densely populated areas or not, there exists a need to plan for emergency management in the case of an unplanned event. “Wind direction maps play a very important role in warning people living near oil field areas” (Shamsan and Kumar 2005) as well as directing first responders to the scene for safe entry. One active role GIS can play is analytical modeling. Hazard layers may be developed for varying spatial coincidences as well as “deterministic models of physical processes” (Cova 1996) such as locating a pipeline rupture and repairing it while mitigating the exposure to poisonous hydrogen sulfide gas (H_2S) so prevalent in oil production and refining. Cova starts with GIS hazard layers to build a hazard model. The hazard layers are grouped by type such as natural, technical, or manmade and a hazard map is the result. Vulnerability layers are then constructed based on the type of hazard identified followed by a vulnerability model resulting in a vulnerability map. A risk model is produced with the input of both the hazard and vulnerability maps. The final product of the overall process is a risk map which is then used by the emergency management team.

Figure 3 One Approach to Hazard, Vulnerability, and Risk Modeling in GIS



Source: (Cova 1996)

Well Location and Reservoir Management

GIS provides a matchless environment to analyze well production data for the purpose of locating wells and spacing for reservoir management. One such technique is presented by Gaskari and Mohaghegh (2006) wherein, using production data major and minor natural fractures are estimated for gas resivoirs. Using GIS, preliminary estimates of natural fracture trends are developed. “Then by superimposing the relusts of the preliminary estimation on reservoir quality indices developed using a fuzzy pattern reconition technique, the uncertainty associated with the initial estimation is reduced… and a locaton may be considered for drilling it there is an existing trend and also at least one stream flow network in the surrounding 160 acres (Gaskari and Mohaghegh 2006).

RESEARCH OBJECTIVE

The objective of this study is to reduce a statistically significant dataset into graphical and tabular representations to investigate oil well production of the Teapot Dome reservoir in the Naval Petroleum Reserve No. 3.

This study seeks to answer the questions of:

1. What is the overall oil production by geographic section?
2. Do deeper wells produce more oil than shallow wells?
3. Which formation is producing more oil?

RESEARCH METHODOLOGY

Introduction

This investigation studies the oil production from wells located in the Powder River Basin. A detailed study was conducted comparing the production of individual wells categorized by geographical section, well depth, and reservoir through statistical methods in order to formulate a conclusion. The methodology used to achieve this objective is broken down into the following phases:

Phase I:	Literature Review
Phase II:	Data Collection and Preparation
Phase III:	Data Analysis

Phase I: Literature Review

This phase of the investigation is to gain an in-depth knowledge of the use of geographic information systems and the oil production industry through a comprehensive study of the existing body of knowledge consisting of refereed journals, research papers, thesis, dissertations, interviews, text books and Internet sources.

Phase II: Data Collection and Preparation

Data collection is preparatory to analysis and consists of gathering information stored in various locations. The data collected will determine what analysis may be conducted to meet the research objective. This data is then prepared for analysis by assuring it is consistent and in the same format by category.

Phase III: Data Analysis

This phase describes in detail the method by which the data collected in Phase II is analyzed, coupled with the literature review leading to meaningful conclusions.

DATA ANALYSIS

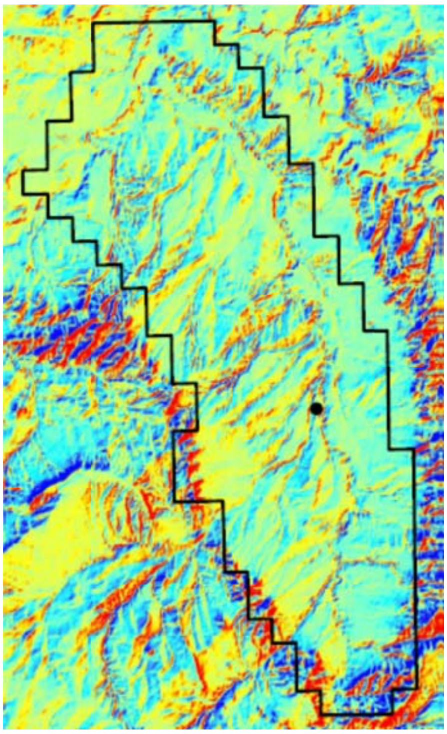
Introduction

The data to support this study was stored and downloaded from a file transfer protocol (FTP) server through access over the internet. Two primary datasets were used being; (1) well production data and (2) well attributes. The well production dataset includes the following fields: American Petroleum Institute (API) number; well number; productivity month and year; oil, water, and gas productivity volumes; days the well was productive; formation; and geographical section. The well attributes dataset contains API number, well number, Northing, Easting, well status, class, total depth, datum elevation, datum type, state, country, field, basin, lease name, ground elevation, plug-back depth, spud date, completion date, common well name, legal survey type, and location.

Data Description

Well production data for 1,317 individual wells spans a period of 91 years between 1914 and 2005 and was downloaded in four sub-sets containing 50,841; 61,677; 63,161; and 34,759 records respectively. These sub-sets were combined into a single data set with 210,438 records for analysis. Although other information exists in the overall dataset, the information considered for this study consisted of total monthly volumes produced for oil, gas, and water measured in barrels, cubic feet, and gallons respectively. The 210,438 records were summarized by well number resulting in 1,317 wells through the use of Minitab 16® statistical software. The oil field covers 19 geographic sections, and 14 rock formations. The shallowest well depth is 180 feet with the deepest being 6,864 feet below the surface. The first recorded well 1-S-10 was started in 1914 and was located in section 10 reaching a depth of 456 feet below the surface in the Shannon formation, and produced 171 barrels of oil.

Figure 4 Well 1-S-10 Location Year 1914



Statistical Analysis

The overall dataset used in this investigation consists of combining the two basic data sub-sets (1) well production data and (2) well attributes into one dataset using the well name to associate them in order to conduct the statistical analysis to meet the research objective.

Depth

The shallowest well is 180 feet, the deepest well is 6,684 feet with a median well depth of 1,004 feet below the surface. To establish the break point between shallow and deep wells the median depth is assumed. Each well is evaluated against this criterion and categorized as shallow or deep.

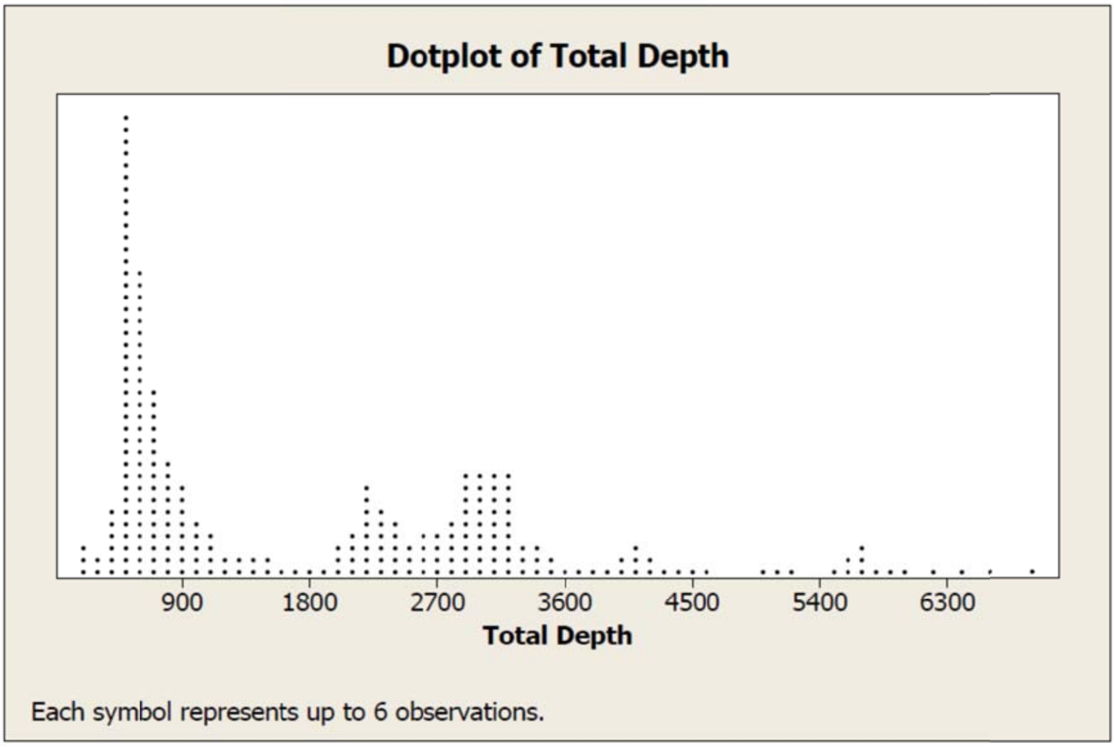
Table 1 Descriptive Statistics for Well Depth

Description	Statistic
Mean	1,728.34
Standard Error	37.57
Median	1,004.00
Mode	470.00
Standard Deviation	1,359.73
Sample Variance	1,848,857.90
Kurtosis	0.43906671
Skewness	0.98409486
Range	6,684.00
Minimum	180.00
Maximum	6,864.00
Sum	2,264,119.55

Count	1,310.00

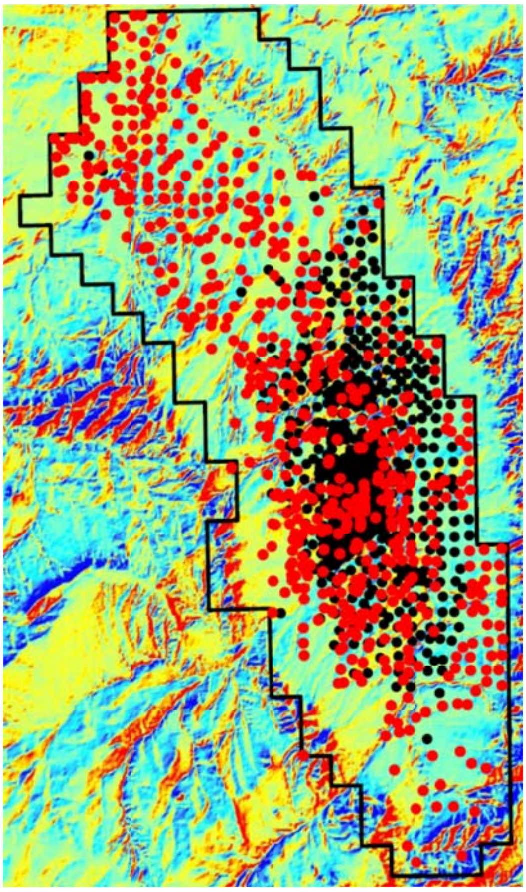
663 observations were categorized as shallow with the remaining 655 wells being categorized as deep. Shallow wells tend to be more centrally distributed around the 400-600 foot range. Whereas the deep wells tend to be less centrally distributed and take on a uniform shaped distribution around the 2,700 foot depth, with wells above 3,600 feet deep being distributed almost linier at a low frequency level.

Figure 5 Dot Plot of Well Depth



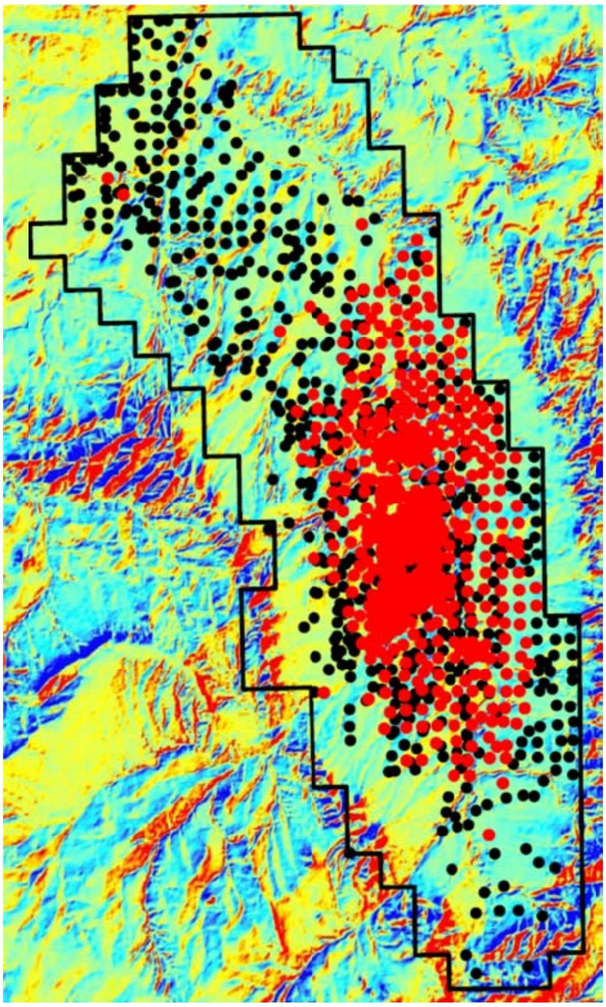
The deep wells are evenly distributed throughout the oil field as shown in Figure 6 highlighted with red symbols.

Figure 6 Deep Well Location



Shallow wells, referenced by red symbols in Figure 7, are less evenly distributed or more congregated in the central part of the oil field.

Figure 7 Shallow Well Location



Section

The total well count was summarized by section and the individual section totals were then compiled into the overall total. The oil field boundaries encompass 19 geographic sections either partial or fully as indicated in Figure 8. Spatial relationships and general location between geographic section and well density are also characterized.

Figure 8 Geographic Sections

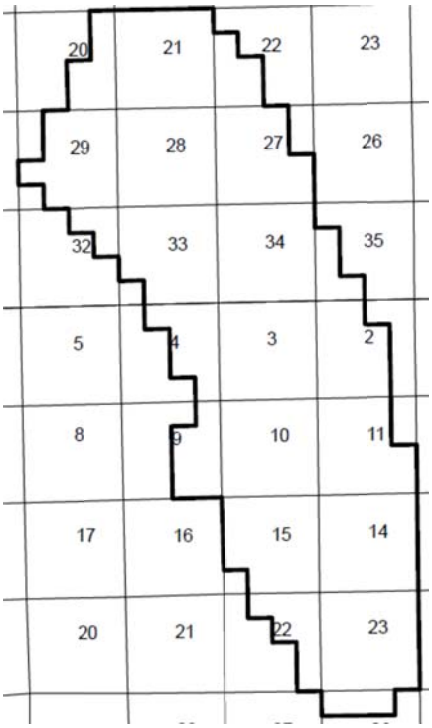
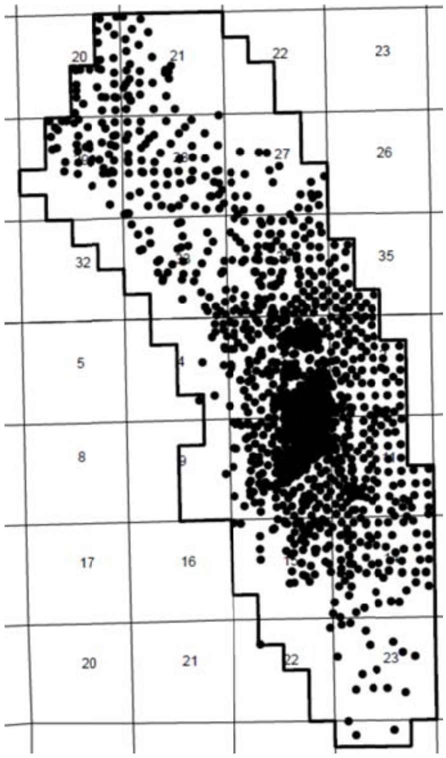


Figure 9 Well Location by Section



A percentage relative to total well count for each section number is reported in Table 2 below. The densest populations are found in sections 3 and 10 comprising 37% of the 1,317 well total. Although section 0 holds 15% of the overall well population it is dispersed over the field as depicted by the red symbols of Figure 10. The most sparsely populated section is 22 with 1 well or 0.08% of the total population which falls on the border of the field.

Table 2 Relative Distribution of Wells by Section

Section No.	Count	Relative %
0	194	14.73%

2	71	5.39%
3	265	20.12%
4	12	0.91%
10	222	16.86%
11	101	7.67%
14	66	5.01%
15	44	3.34%
20	27	2.05%
21	21	1.59%
22	1	0.08%
23	7	0.53%
26	3	0.23%
27	19	1.44%
28	57	4.33%
29	36	2.73%
33	33	2.51%
34	91	6.91%
35	47	3.57%
Total	1,317	100.00%

Figure 10 Well Location-Section 0

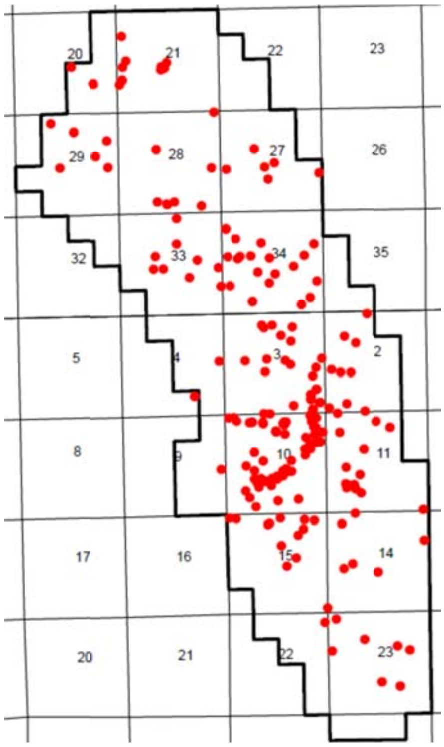


Figure 11 Well Location-Section 3

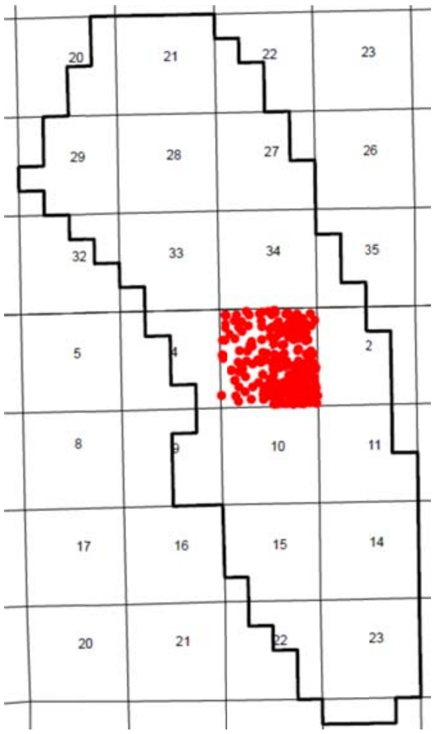
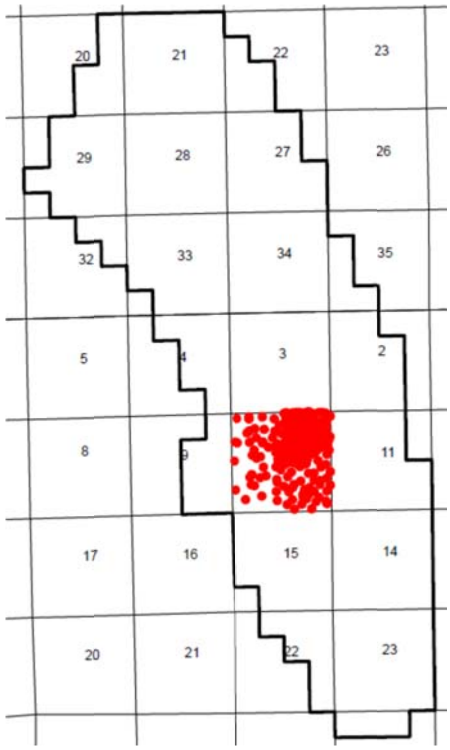


Figure 12 Well Location Section-10

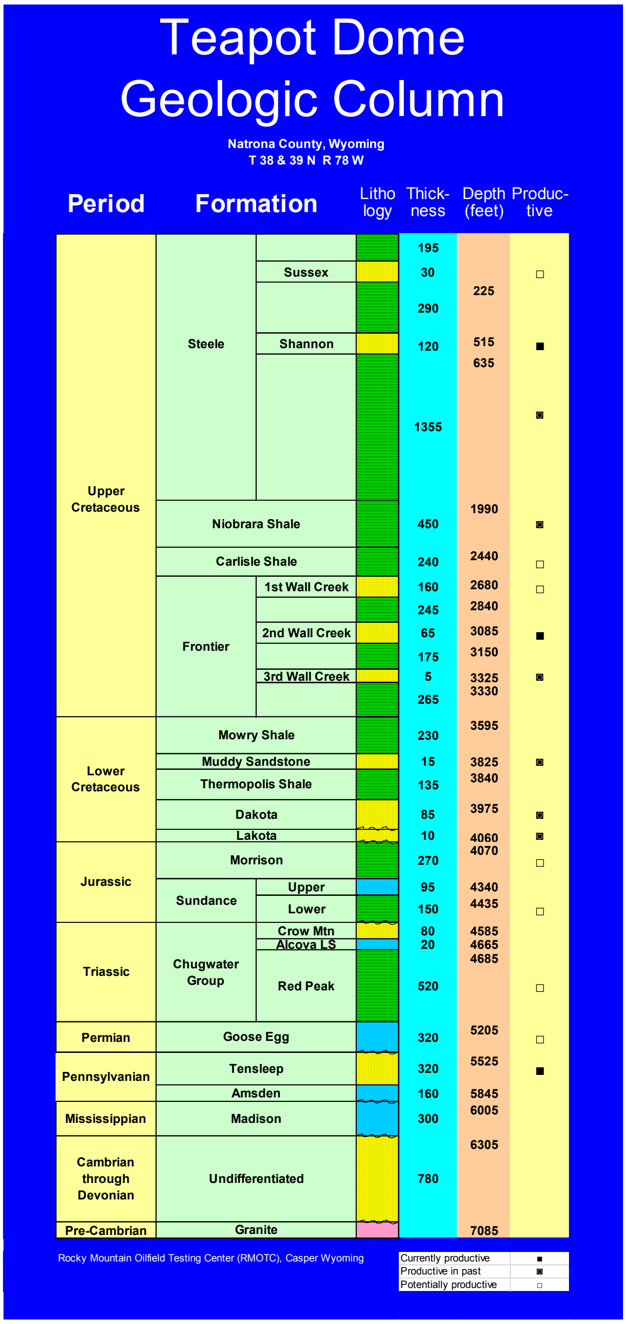


Formation

Rock formation is an informal term often used to refer to a specific group of rocks. Stratigraphy is the more formal term defined as “the study of stratified rocks with particular reference to fixing their geologic age or their continuity over unmapped areas” (Nelson and Nelson 1967). A geologic column “is a generalized map illustrating the distribution of rocks of several time units… Not all the rocks can be fitted precisely into the framework of the time classification” (Fairbridge 1975).

A geologic column helps visualize the various rock formations and puts into prospective the depth and thickness of each strata. With reference to Figure 13 one may easily see the rock formations studied in this paper to gain a better understanding of their placement in the shallow or deep category as well as the reservoir thickness.

Figure 13 Teapot Dome Geologic Column



Source: (RMOTC n.d.)

Table 3 Well Count by Formation

Formation	Wells	Relative %
0	193	14.65%
2nd Wall Creek	238	18.07%
3rd Wall Creek	4	0.30%
Crow Mountain	2	0.15%

Dakota	5	0.38%
Lakota	4	0.30%
Madison	1	0.08%
Microhole	2	0.15%
Muddy	7	0.53%
Niobrara Shale	73	5.54%
Shannon	660	50.11%
Steele Shale	108	8.20%
Tensleep	15	1.14%
Unspecified	5	0.38%
Total	1,317	100.00%

Figure 14 2nd Wall Creek Formation Wells

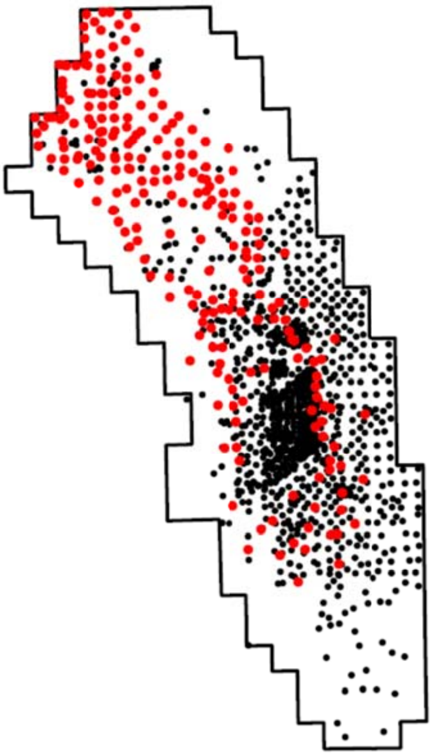
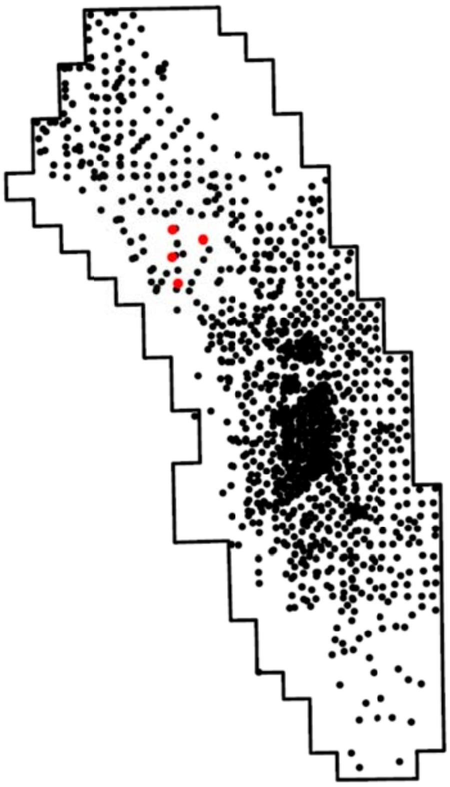


Figure 15 3rd Wall Creek Wells



QUANTITATE RESULTS

Overview

To carry out this research, data was collected from the U.S. Department of Energy Rock Mountain Oilfield Testing Center on the Teapot Dome oil field as well as other free access sources. A base map was constructed using ArcGIS® with layers depicting various natural features including rivers, roads, land sections, and fault lines as well as a layer containing the location and attributes of each oil well studied. Total oil production was analyzed by geographic section, well depth, and formation, utilizing the functionality of the ArcGIS® suite of software.

Depth

Oil production volume was summarized by well depth. A total of 7,760,700 barrels of oil were produced by the 663 shallow wells which are defined as less than 1,004 feet in depth and a total of 13,995,227 barrels of oil produced by 655 deep wells for an oil field total production of 21,755,927 barrels.

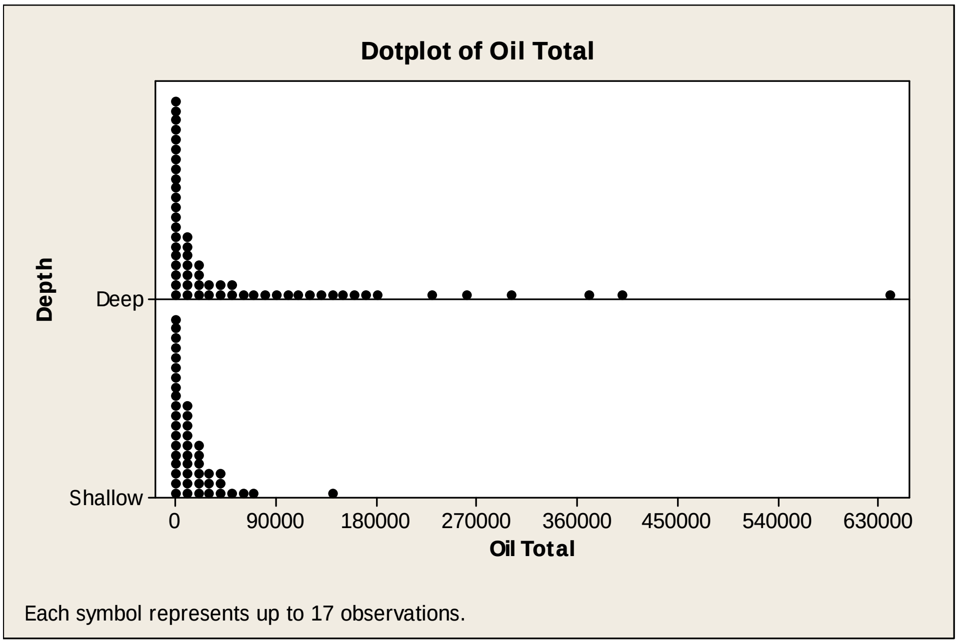
While Figure 16 indicates the majority of both shallow and deep wells individually produce less than 90,000 barrels of oil. The mean or average production for deep wells is almost double that of shallow wells. Yet the median production of deep wells is 60% that of shallow wells. With the sample sizes of both shallow and deep wells being nearly equal to each other, collectively, deep wells produce almost double that of shallow wells.

Table 4 Oil Production by Well Depth (BBL's)

Depth	Mean	Median	Sum
Deep	21,367	4,209	13,995,227
Shallow	11,723	7,150	7,760,700
		Total	21,755,927

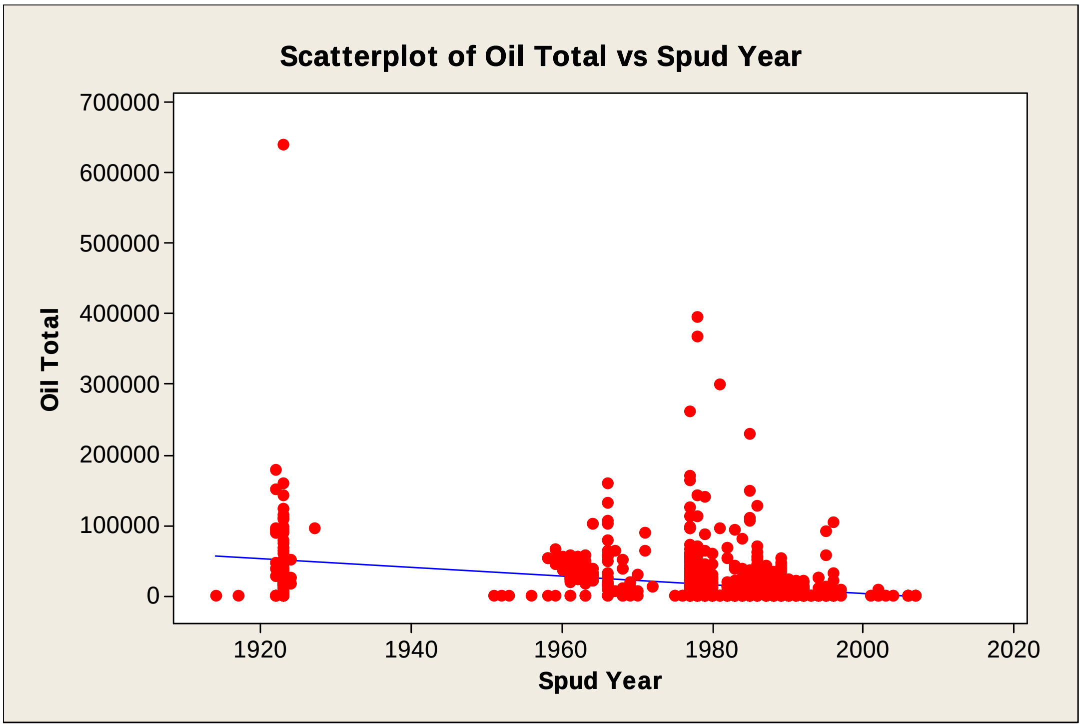
The Figure 16 exhibits similar patterns of production between the deep and shallow wells. It also shows the majority of wells (1,285 or 98%) produce less than 100,000 barrels of oil. With 31 of the remaining 32 wells producing greater than 100,000 barrels falling into the deep well category.

Figure 16 Dot Plot of Oil Production by Well Depth



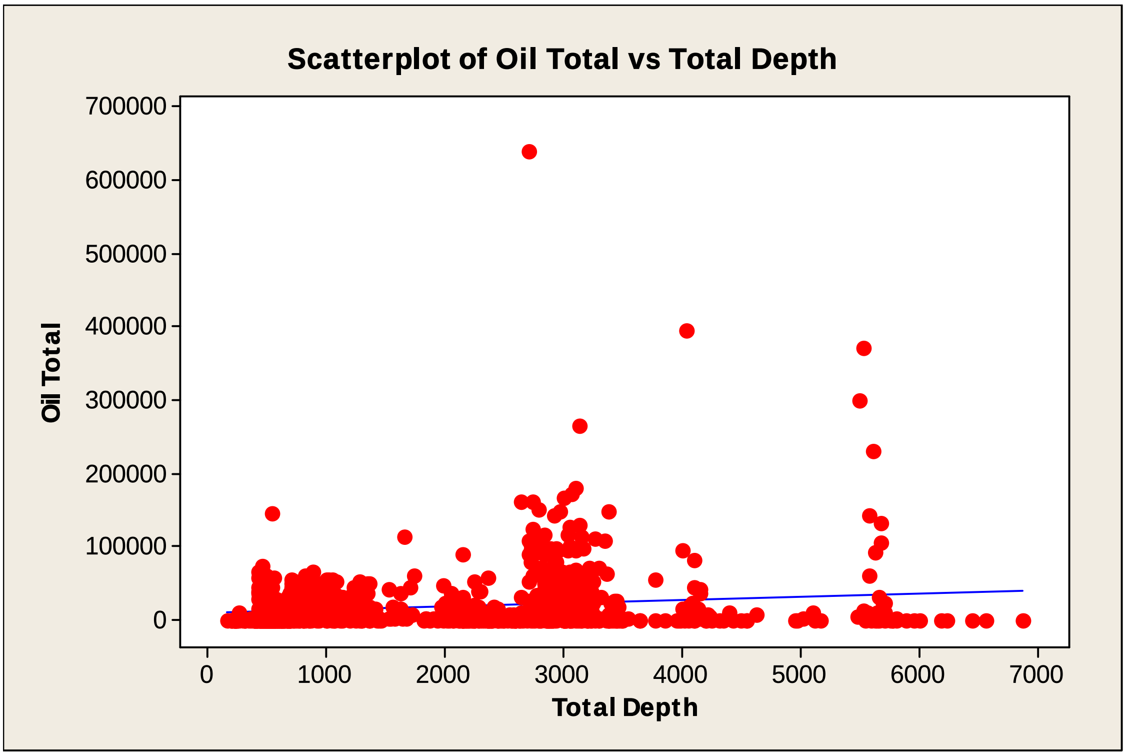
A scatterplot of total production versus year (Figure 17) reveals not only three groups of production data but missing data between 1927 and 1951 may indicate no new wells drilled during this time frame. Figure 17 also dispels the notion that some wells have been producing longer therefore skew the conclusion. However, it is noteworthy that well number 402-A-20 drilled in 1923 is the single largest producer with 639,612 barrels.

Figure 17 Scatterplot of Total Production vs. Year



A liner regression plot between well production and depth does not infer a relationship between the two attributes as indicated by the horizontal trend line shown in Figure 18.

Figure 18 Scatter Plot Total Oil Production vs. Well Depth



Section

The oil, gas, and water production for each geographical section were summarized by section number. The individual section totals were then summarized into the overall or grand total for each of three commodities separately. A percentage relative to total well production for each section number are reported in Table 5 below.

The total oil production for all sections combined is 21,755,927 barrels and is broken down into 19 sections as shown in Table 5. Sections 3, 10, and 20 are the largest producers with 14%, 21% and 11% respectively. Two percent of the total well count is located in section 20 which produces 11% of the total oil. However, section 10 overshadows all other sections with 4.6MM barrels or 21% and is the overall largest producer.

Table 5 Summary of Oil Production by Section

Section No.	Oil (BBLs)	Relative %
0	832,605	4%
2	1,454,334	7%
3	3,038,013	14%
4	80,947	0%
10	4,635,639	21%
11	2,012,716	9%
14	767,136	4%
15	457,212	2%
20	2,419,294	11%
21	473,861	2%
22	4,444	0.02%
23	39,378	0.18%
26	12,457	0.06%
27	235,988	1%
28	1,397,874	6%
29	893,824	4%
33	563,726	3%
34	1,730,931	8%
35	705,548	3%
Total	21,755,927	100.0%

Formation

The two formations which dominate the oil field production are the 2nd Wall Creek with 40.3% of the production and Shannon with 39.5% or 8,583,263 bbls. All other formations combined account for only 20.2% of the overall production. Although formation 0 has 193 wells or 14.6% of the total wells it only produces 3.83% of the total field production. While the 2nd Wall Creek formation possess 23% more wells than formation 0 at 238 wells it produces 40.3% of the field's oil. The Shannon formation has one half or 660 of the oil field's wells which is 2.8 times greater than the number of wells found in the 2nd Wall Creek formation and produces 39.5% of the oil. (Figures 20 & 21) Therefore it stands to reason the 2nd Wall Creek formation produces nearly 3 times the volume of oil per well as the Shannon formation. Although both the Shannon and 2nd Wall Creek formations produce within 1% of each other the 2nd Wall Creek has slightly more production by 188,595 bbls.

Table 6 Total Oil Production by Formation

Formation	Oil (BBL's)	Relative %
0	832,605	3.83%
2nd Wall Creek	8,770,858	40.31%
3rd Wall Creek	224,291	1.03%
Crow Mountain	10	0.00%
Dakota	41,697	0.19%
Lakota	3,157	0.01%
Madison	0	0.00%
Microhole	0	0.00%
Muddy	508,271	2.34%
Niobrara Shale	562,633	2.59%
Shannon	8,583,263	39.45%
Steele Shale	1,089,928	5.01%
Tensleep	1,139,214	5.24%
Unspecified	0	0.00%
Total	21,755,927	100.00%

Table 7 Well Count by Formation

Formation	Wells	Relative %
0	193	14.65%
2nd Wall Creek	238	18.07%
3rd Wall Creek	4	0.30%
Crow Mountain	2	0.15%
Dakota	5	0.38%
Lakota	4	0.30%
Madison	1	0.08%
Microhole	2	0.15%
Muddy	7	0.53%
Niobrara Shale	73	5.54%
Shannon	660	50.11%
Steele Shale	108	8.20%
Tensleep	15	1.14%
Unspecified	5	0.38%
Total	1317	100.00%

Figure 19 Dot Plot of Total Oil Production by Formation

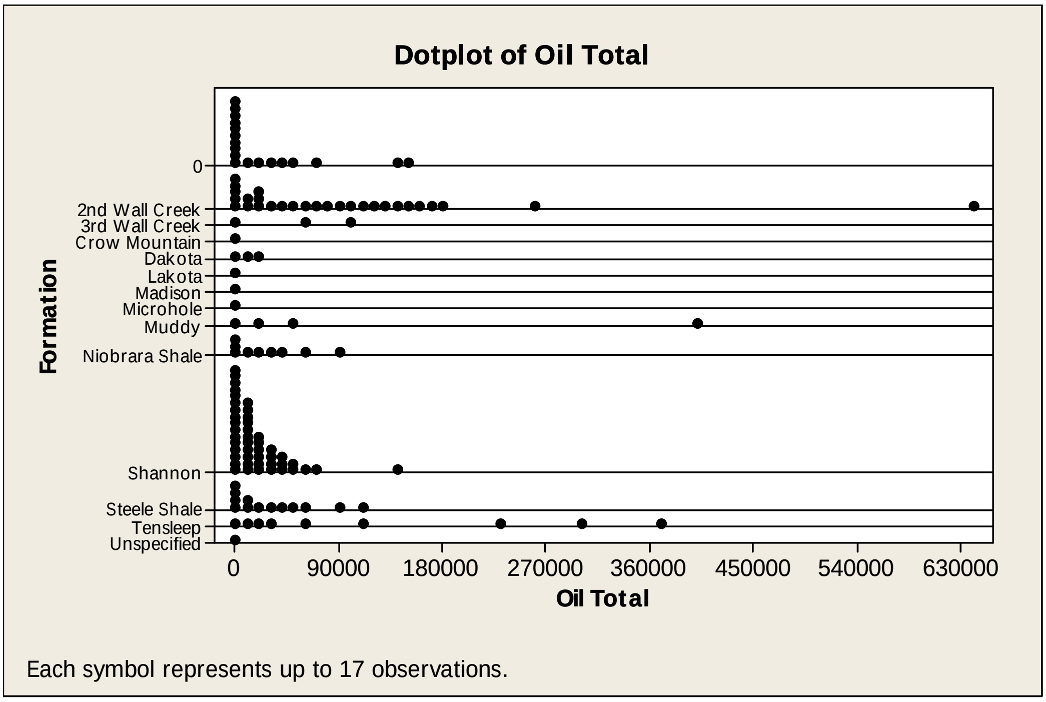


Figure 20 Oil Production by Formation

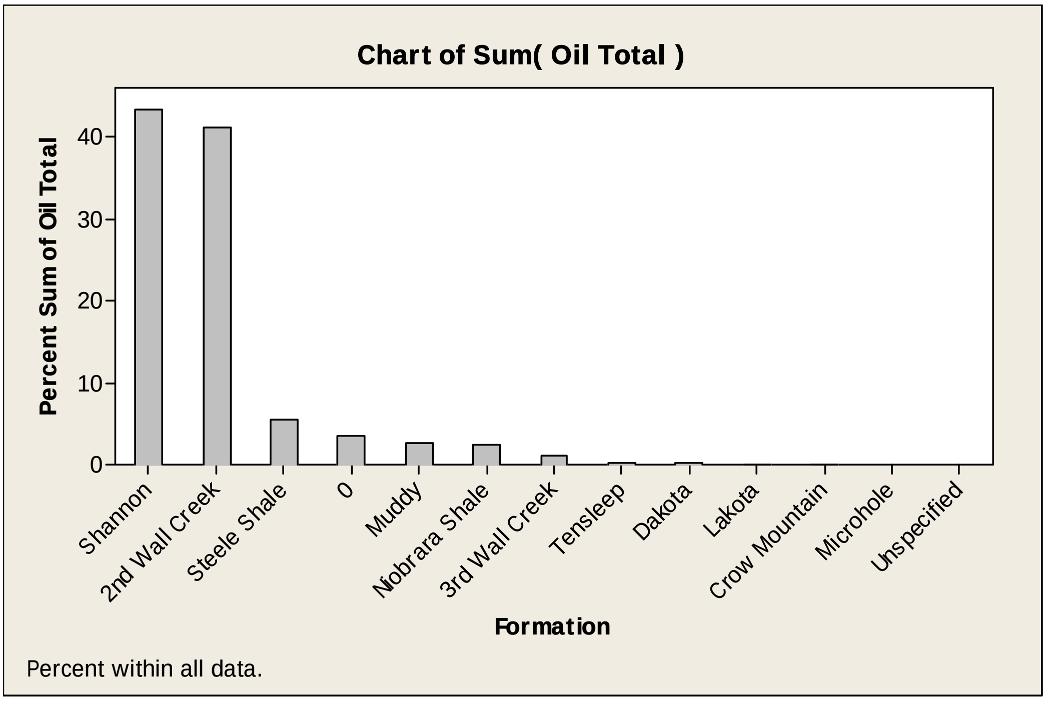
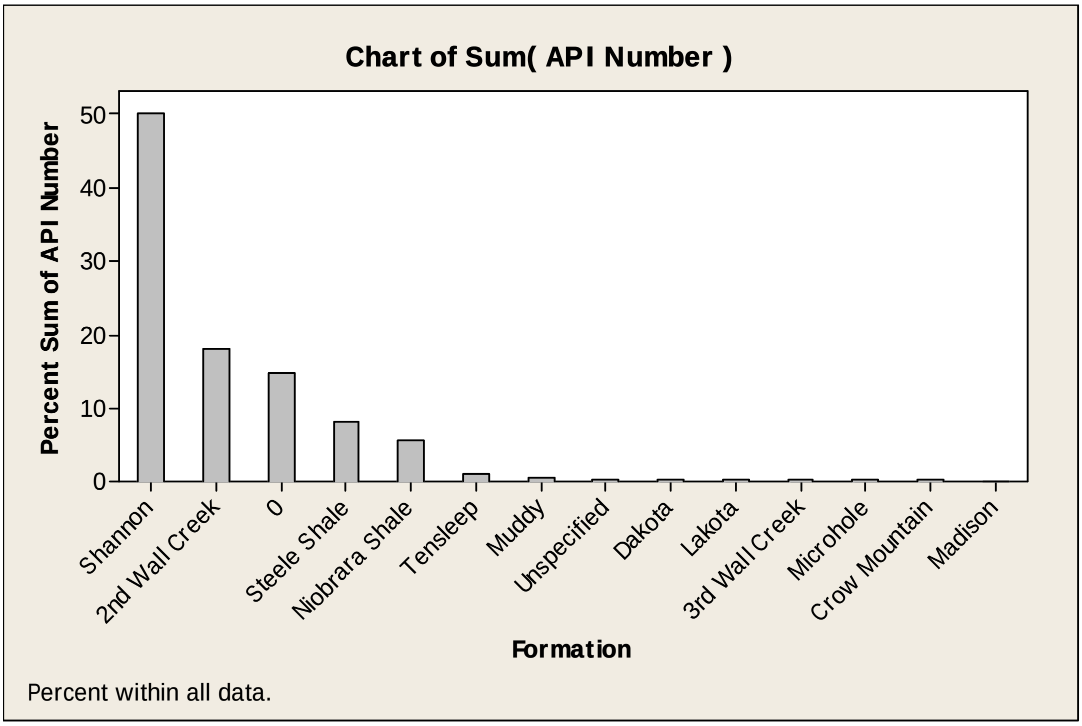


Figure 21 Well Count by Formation



CONCLUSIONS

This paper introduced the idea that GIS coupled with statistical analysis may be used to determine which reservoir, well depth, and geographic sections produce the most oil. It has been shown that GIS provides an environment to analyze oil well production data and met the research objective.

With the sample sizes of shallow and deep wells being nearly equal to each other, collectively deep wells produce almost double the volume of shallow wells.

Sections 3, 10, and 20 are the largest producers with 14%, 21% and 11% respectively. Two percent of the total well count is located in section 20 which produces 11% of the total oil. However, section 10 overshadows all other sections with 4.6MM barrels or 21% and is the overall largest producer.

Although both the Shannon and 2nd Wall Creek formations produce within 1% of each other the 2nd Wall Creek has slightly more production by 188,595 bbls.

Future Research

Using GIS to investigate the relationship between formation fracture structure and well location could lead to developing a better forecasting model for locating future wells. Another interesting study would be to investigate the environmental impact associated production wastes and ground water depletion as a result of the seemingly large volumes of water produced from these oil wells using GIS to show draw down effects. Using GIS and geostatical analysis develop a probability distribution to forecast the oil remaining in reserve and at the current rate of production and technology forecast the end of productive life for the overall reserve.

Research Limitations

The scope of this study is limited to conducting a quantitative analysis based on data gathered from one source. It is assumed all data is complete and correct. The well coordinates projections are off slightly, but not enough to alter the results of the study. It is unclear to the researcher the criterion for assigning a well to section 0 and formation 0 as no explanation was offered by RMOTC at the time of this study. Some section numbers were double assigned on the general location map however, the wells fell into the section numbers assigned inside the field boundaries.

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APPENDIX 1

Statistical Notes

Data Sensitivity

The Rocky Mountain Oilfield Testing Center (ROMTC) is an energy testing center which partners with industry and academia to test products and prove processes in a real-world environment. As a U.S. Government facility much of the RMOTC's data us non-proprietary and available to the public upon request with the intended use of scientific or academic research.

Removal of Statistical Outliers

The technique used for identifying statistical outliers is the same used to define outliers in most statistical texts. Outlying observations or outliers are numerically distant from the rest of the data and would likely distort the statistical summaries produced.

APPENDIX 2

Acknowledgements

Special recognition goes to the Rocky Mountain Oilfield Testing Center and United States Department of Energy for providing data to accomplish this study. For more information, please contact: Connie Wallace, Business Development Manager 001.307.233.4800 ext. 4846 connie.wallace@rmotc.doe.gov

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APPENDIX 3

Data Set